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Research article

Research on financing and technological innovation efficiency of China's energy-saving and environmental protection enterprises

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ABSTRACT

Green, low-carbon circular economy and the development model of energy-saving and environmental protection are emerging worldwide, and the world's economies have taken the energy-saving and environmental protection industry as a strategic emerging industry to cultivate and develop. Coordinating finance and technological innovation is crucial to promoting the healthy development of Energy-Saving and Environmental Protection Enterprises (ESEPEs). According to industry classification, this paper divides 121 ESEPEs into 12 categories as research objects. Firstly, the DEA-SBM model is used to calculate financing efficiency (FE) and technological innovation efficiency (TIE). Subsequently, the changes in the two efficiencies are analyzed from the perspectives of time series, industry, and annual mean value, and the changes of the two efficiencies are analyzed from the perspectives of time series, industry, and annual average values. Secondly, through the coupling coordination degree (CCD) model, the development status of the coupling coordination between the two efficiencies is innovated expounded. Finally, the Tobit regression model is used to discuss the factors influencing CCD from the whole and industry perspectives. The results show that: (1) TIE is generally lower than FE, and FE shows a downward trend while TIE shows an upward trend. (2) CCD between the two efficiencies is Near dysfunction, and TIE restricts the development of CCD between the two efficiencies to a certain extent. (3) R&D intensity, enterprise size, and government subsidy intensity have a significant positive impact on CCD between FE and TIE of ESEPEs, while the impact of other factors is not significant.

1. Introduction

Promoting green and low-carbon development has become a global consensus. China bears a significant responsibility for energy conservation and reducing emissions. Governments are required to adopt more rigorous measures to attain their carbon peak and carbon neutrality targets [1]. In recent years, different industries and fields have conducted compelling explorations on carbon reduction measures and factors affecting carbon emissions [2–6]. Among them, ESEPE is the main body of green and low-carbon development and the critical support for achieving the goal of carbon peaking and carbon neutralization. Due to the characteristics of ESEPEs with significant investment funds, long return cycles, strong policy dependence, and low internal management and unreasonable capital structure, the vigorous development of energy saving and environmental protection industry is hindered [7]. On the other hand, government financial support is mainly used for energy-saving and environmental protection infrastructure, and the direct subsidy distribution is uneven. Equity financing and bank credit are more suitable for critical enterprises above the designated size.

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The internal and external unfavorable factors lead to the dilemma of insufficient financial capital supply in ESEPEs, which becomes the biggest obstacle to the long-term sustainable development of ESEPEs [8].

2016 and 2021 are the beginning and end of the 13th Five-Year Plan, and introducing relevant policies provides new opportunities for energy-saving and environmental protection companies [9]. In 2016, the National 13th Five-Year Plan for Scientific and Technological Innovation was issued, which set forth the goals of "actively cultivating an open and transparent capital market with healthy development," "increasing the proportion of direct financing," and developing the capital market. The 14th Five-Year Plan of the People's Republic of China's National Economic and Social Development and the Outline of 2035 vision goals pointed out that the "14th Five-Year Plan" period to encourage enterprises to increase investment in research and development, support industrial standard basic technology research and development, improve the enterprise innovation service system. Throughout history, financial capital and technological innovation have coexisted and promoted each other, and the combination of the two is not "addition" but "multiplication."

The coordinated development of finance and innovation is a crucial way to help China achieve the "double carbon" goal on schedule. Many studies have shown that science, technology, and innovation can contribute to financial development [10–13]. There is also a coupling relationship between financial capital and technological innovation. As the hub of social resource allocation, finance can provide financial support for technological innovation activities, financial tools, and institutional arrangements for avoiding and resolving innovation risks. In solving ecological problems, technological innovation can provide systematic solutions for accurate pollution control, scientific pollution control, and legal pollution control, enhance the scientific and accurate pollution control, and its innovation results will also bring returns to financial capital [14]. Therefore, when financial capital and technological innovation achieve coupling and coordinated development, it can promote energy-saving and environmental protection enterprises to explore more profound product value and play a vital role in the vigorous development of the energy-saving and environmental protection industry.

FE and TIE are essential manifestations of the level of finance and innovation. The micro meaning of FE is the ability to create value for enterprises using integrated financial resources [15]. Zeng (1993) first proposed FE and analyzed seven factors affecting FE and cost [16]; Zheng (2004) proposed that FE is a necessary condition for economic growth and the source of sustainable development of enterprises [17]. At the same time, technological innovation is an essential driving force that promotes the upgrading of industrial structures and economic growth. TIE refers to the ratio of technological innovation input to output in a certain period, an important index reflecting the ability of enterprises to allocate innovation resources [18]. In the era of Carbon peaking and neutralization, many scholars have conducted in-depth discussions on environmental protection enterprises [19–24].

Efficiency evaluation can help enterprises find problems and clarify the direction of development. The evaluation methods of FE and TIE mainly include grey correlation analysis [8], entropy method [25], and data envelopment analysis (DEA) [26–28]. Grey correlation analysis has no requirement for sample size and irregular sample size, which makes up for the regret caused by mathematical statistics. However, it is difficult to determine the optimal value of some indicators and needs to be more objective. The entropy method conforms to the mathematical law and has strict mathematical significance but often ignores the subjective intention of the decision-maker. The DEA method is a method used to measure organizational efficiency, and it can be used to evaluate the maximum output that an organization can achieve with limited resources. This method takes the input and output weights of decision-making units as variables and evaluates from the perspective that is most beneficial to decision-making units, thus avoiding determining the weights of each indicator in the sense of priority. At the same time, it does not have to determine some possible display relationship between input and output, which excludes many subjective factors, so it has strong objectivity. Charnes et al. (1978) proposed data envelopment analysis [29]. A variety of derived and unique DEA models are constantly developed and improved, which have a significant impact on theory and application [30–33].

The CCD model can be used to analyze the level of coordinated development between finance and innovation, and the coupling degree (CD) can reflect the degree of interdependence and mutual restriction between systems. The coordination degree refers to the degree of benign coupling in the coupling interaction relationship, which can reflect the quality of coordination. Many scholars have applied the CCD model to conduct empirical studies [34–37]. In studies on factors affecting CCD, scholars usually adopt the Tobit regression model [38–40], and panel threshold regression models [41–43].

Based on the above research findings, scholars mainly discuss FE and TIE of enterprises separately or study CD of FE and technological innovation level, rarely combine the two efficiencies to analyze their CCD [44,45], and rarely mention the influencing factors of CCD. Therefore, this paper refers to the DEA-SBM and the CCD models adopted by Xu and Zhao (2020) in industrial enterprises' production efficiency [46], innovation efficiency, and ecological efficiency. The Tobit regression model adopted by Zhang and Deng (2021) in the analysis of influencing factors of CCD evaluates and studies CCD of FE and TIE of energy-saving and environmental protection enterprises in China from 2016 to 2021 and its influencing factors [47]. It provides a decision-making reference for China's ESEPEs to formulate more scientific and reasonable development countermeasures. This paper aims to use DEA-SBM, CCD, and Tobit models to answer some questions such as: (1) From 2016 to 2021, how about the FE and TIE of China's ESEPEs? What are its evolution and characteristics? (2) What is CCD between FE and TIE of China's ESEPEs? (3) What are the constraints and drivers of CCD in question (2)?

Compared with previous studies, the marginal contributions of this paper are as follows: (1) From the perspective of research objects, on the one hand, most of the current studies on ESEPE focus on FE and investment efficiency without taking TIE into account, and there are few studies on CCD between the two efficiencies. On the other hand, at the research level, the existing research focuses on the division of macro-regions or the analysis of a specific industry. This paper starts from the perspective of enterprises and then classifies according to industry to explore CCD between FE and TIE of ESEPEs and its influencing factors, analyzes the influencing factors of CCD from the industry perspective to make the research more detailed and the analysis more comprehensive. (2) From the perspective of research methods, the non-angle DEA-SBM model adopted in this paper effectively overcomes the errors caused by different angles in the traditional DEA model and the shortcomings of ignoring relaxation variables in the radial model. Combined with the CCD model, the span analysis from enterprises to industries is completed. Finally, the parameters of the influencing factors are calculated from the industry level through the Tobit regression model, and the result data is more accurate.

In summary, the research framework of this paper is a systematic analysis of the development of ESEPES through the study of 12 industry categories in 121 ESEPES. The specific research framework is shown in Fig. 1.

Explanation of terms used in this paper:

Financing efficiency (FE): It is the effectiveness and efficacy achieved by the company in financing its financial activities.

Technological innovation efficiency (TIE): It refers to the input-output ratio of scientific and technological innovation behavior.

Coupling degree (CD): The degree of association, perception and dependence between a module (class) and other modules (classes), which in this paper refers to the association between financing efficiency and STI efficiency.

Coupling coordination degree (CCD): Used to describe the degree of consistency and effectiveness of interactions between parts of a system.

The rest of this paper is organized as follows. Section 2 gives the research ideas and method model. Section 3 introduces indicators and data sources. Section 4 carries out empirical analysis and discussion. Section 5 provides policy recommendations. Finally, Section 6 presents the conclusions and research gaps.

2. Method

2.1. Efficiency calculation: DEA-SBM model

DEA is used to evaluate the relative efficiency of multi-input multi-output DMU. The CCR and BCC models belong to radial models, and the efficiency measurement requires that all inputs decrease in the same proportion or all outputs increase in the same proportion. When there is excessive input or insufficient output, when there is non-zero relaxation of input or output, the improvement of relaxation is not reflected in the efficiency measurement. Therefore, radial models tend to overestimate the efficiency of DMU. At the same time, there are only two kinds of input Angle or output Angle in the CCR model and BCC model, and the DEA model of Angle will inevitably ignore a particular aspect of input or output, which will have a specific impact on the results of efficiency evaluation. According to these shortcomings, the non-radial SBM model proposed by Tone (2001) successfully solved the problem of ignoring the relaxation variables in the efficiency evaluation process of the radial model [48]. The SBM model has a non-angle model, which can measure efficiency from two perspectives of input and output. The non-angle DEA-SBM model is as follows:

$$SBM\begin{cases} \min E = \dfrac{1-\dfrac{1}{m}\sum_{i=1}^{m} s_i^- / x_{i0}}{1+\dfrac{1}{s}\sum_{r=1}^{s} s_r^+ / y_{r0}} \\ s.t. X_0 = X_j\lambda_j + S^- \\ Y_0 = Y_j\lambda_j - S^+ \\ \lambda_j \geq 0\ ,\ S^- \geq 0\ ,\ S^+ \geq 0\ ,\ j = 1, 2, \ldots, n \end{cases} \tag{1}$$

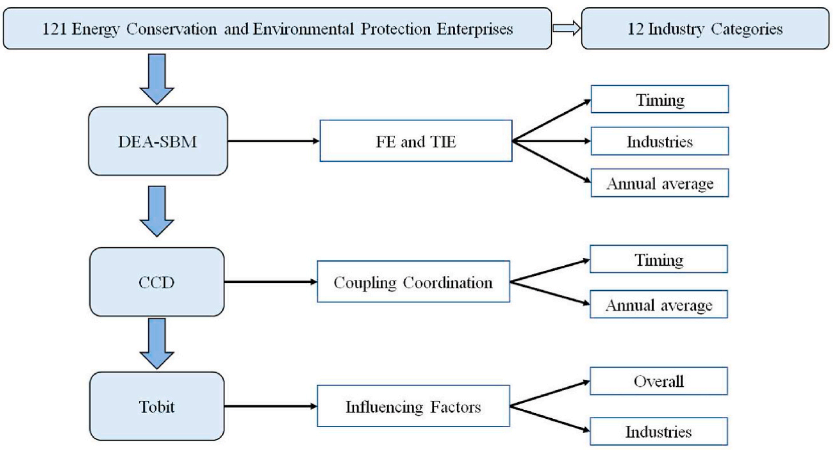

Fig. 1. Research framework.

In the formula, n represents the number of ESEPEs (DMU), X representing the input vector for each DMU, Y representing the output factor vector for each DMU, E represents the value of FE or TIE, m represents the number of input factor indicators, s represents the number of output factor indicators, s_i^- represents the relaxation variable of input factors, s_i^+ represents the slack variable of output factors, λ Represents linear combination coefficient.

2.2. Coupling relation: CCD model

According to the values of FE and TIE, CD of FE and TIE is further established:

$$C = \left\{ \frac{E_1 \times E_2}{\left[\frac{E_1+E_2}{2}\right]^2} \right\}^{\frac{1}{2}} \tag{2}$$

In the formula, E_1 is FE value for ESEPEs, E_2 is TIE value for ESEPE. In order to avoid the defects caused by CD calculation, and further evaluate the coupling and coordinated development status of FE and TIE of ESEPE, CCD model is constructed on the basis of CD:

$$\begin{aligned} T &= \alpha E_1 + \beta E_2 \\ D &= \sqrt{CT} \end{aligned} \tag{3}$$

Among them, T is a comprehensive coordination index of E_1 and E_2, $\alpha, \beta \in (0\ ,\ 1)$ is the undetermined coefficient, represents the contribution of financing and technological innovation, and $\alpha + \beta = 1$. This paper is based on Du (2023) research [14], make $\alpha = E_1/(E_1 + E_2)$, $\beta = E_2/(E_1 + E_2)$. D represents CCD between FE and TIE, and CCD types are shown in Table 1.

2.3. Influencing factors: Tobit regression model

The Tobit model was put forward by American economist James Tobin in 1958, and it was initially an econometric model used to study the demand for durable consumer goods. CCD studied in this paper belongs to left-cut data, and using the general least square method may cause bias in parameter estimation. Hence, the Tobit model based on maximum likelihood estimation is the best choice for dealing with this data type. Therefore, in order to study the influencing factors of CCD between FE and TIE of ESEPE, a Tobit regression model was established:

$$D_{it} = \beta_0 + \beta_1 RD_{it} + \beta_2 SCALE_{it} + \beta_3 PGDP_{it} + \beta_4 KF_{it} + \beta_5 GS_{it} + \beta_6 SQ_{it} + \varepsilon_{it} \tag{4}$$

In the formula, D for CCD between FE and TIE, i, t represent separately each enterprise and year, ε represents random error. The variable indicators of influencing factors are: R&D investment intensity (RD), enterprise size (SCALE), regional economic development level (PGDP), opening-up degree (KF), government subsidy intensity (GS) and financial environmental protection support intensity (SQ).

This section introduces the DEA-SBM model used in the efficiency study, the coupling coordination degree model, the Tobit regression model used in the influencing factors, the reasons for using the model, and the specific formula.

3. Index system design and data source

3.1. Index system design

The selection method of indicators is based on the principles of accessibility, rationality, and pertinence. Selection of indicators to meet two primary conditions: (1) Selected input and output indicators are positive, there can be no negative or zero, to prevent the

Table 1
Types of CCD between FE and TIE.

CD C	CD level	CCD D	type	CCD level
$0 < C \leq 0.3$	Low level coupling	0–0.09	I	Extreme disorder
		0.10–1.19	II	Serious disorder
		0.20–0.29	III	Moderate disorder
$0.3 < C \leq 0.5$	antagonism	0.30–0.39	IV	Mild disorder
		0.40–0.49	V	Near dysfunction
$0.5 < C \leq 0.8$	running-in	0.50–0.59	VI	Barely coordination
		0.60–0.69	VII	Primary coordination
		0.70–0.79	VIII	Intermediate coordination
$0.8 < C \leq 1$	High level coupling	0.80–0.89	IX	Good coordination
		0.90–0.99	X	High quality coordination

Note: FE for financing efficiency, TIE for technological innovation efficiency, CD for coupling degree, CCD for Coupling coordination degree.

measurement results from being wrong. (2) Selected input and output indicators and the sum of the decision-making unit should be less than two times to prevent the efficiency of the value of the overestimation. In this paper, the number of decision-making units is 121, and the maximum sum of the number of indicators is 6, which aligns with the premise assumptions. The indicators are selected from the perspectives of input and output and refer to the method of [7,49] to establish an evaluation index system for FE and TIE of ESEPE. The specific indicators are shown in Table 2.

(1) Evaluation indicators for FE

Starting from the perspective of financing channels, this paper selects two types of external financing, namely debt financing and equity financing, which can objectively and directly reflect the scale of integrated funds and the flow and utilization of the financing funds. Input indicators include total liabilities, cash outflows from financing activities, and owner's equity. Total liabilities reflect the scale of funds enterprises raise through operating liabilities or credit and can also measure the impact of debt capital on the FE of enterprises. Cash outflow from financing activities includes the amount of cash enterprises spend on dividend distribution, profit distribution, and other activities related to raising funds. Total owner's equity refers to the equity value owned by the enterprise owner after deducting the creditor's equity of the enterprise's assets, reflecting the scale of funds obtained by the enterprise through equity financing.

The output indicators of FE are selected from enterprises' profitability, operation ability, and growth ability, respectively, including return on equity, total asset turnover, and operating revenue. The return on equity is the ratio of the net profit after tax to the enterprise's net assets, reflecting the enterprise's ability to obtain the final return by allocating funds. The total assets turnover ratio is the percentage of the net operating income and the total assets of the enterprise in the current year, and the total assets turnover ratio can evaluate the utilization effect of the funds raised by the enterprise in research and development, production, and management activities. Operating revenue refers to the amount of capital that an enterprise obtains through normal business operations and other ways, which indicates the ability of an enterprise to obtain income through daily production and operation projects.

(2) Evaluation indicators for TIE

In the innovation process, R&D investment, capital input, and labor input are the most essential input factors. Investment indicators include R&D investment amount, R&D personnel, and proportion of R&D personnel. Among them, the amount of R&D investment refers to the cost of the enterprise in the process of new product development and new technology research. The number of R&D personnel can reflect the investment cost of human resources in technological innovation activities, and represent the investment intensity of enterprises in technological innovation activities. The proportion of R&D personnel reflects the intensity of R&D personnel input.

The final output of technological innovation is the economic benefit brought by the innovation results. Output indicators include net profit and intangible assets. Among them, net profit refers to the profit after excluding taxes and fees; Intangible assets measure enterprises' technological innovation and transformation ability.

(3) Variable indicators of influencing factors

This paper refers to the practice of Li and Zhong (2021) and analyzes the influencing factors of CCD between FE and TIE from three aspects: enterprise, government, and market [50]. Select R&D investment intensity and enterprise size at the enterprise level. Select regional economic development level and the degree of opening to the outside world at the market level. At the government level, choose government subsidy intensity and financial support for environmental protection. Specific variable indicators are shown in Table 3.

Table 2
Evaluation index system of FE and TIE of ESEPEs.

System layer	Criterion layer	Indicator layer	explain
FE	Input variable	Total liabilities	Utilization of debt financing funds
		Cash outflows from financing activities	Dividends payable + interest payable + finance expenses
		Total owners' equity	Undistributed income + paid-in capital
	Output variable	Return on equity	Net profit/net assets
		Total Asset turnover	Current year's operating revenue/average total assets
		operating revenue	Main business income + other business income
TIE	Input variables	R&D investment amount	Total investment in enterprise innovation activities
		R&D personnel	Number of R&D personnel in the enterprise
		Proportion of R&D personnel	R&D personnel as a percentage of total employees
	Output variable	Net profit	Profit after deducting taxes and fees
		intangible assets	Technological innovation and transformation capability of foreign-funded enterprises

Note: FE for financing efficiency, TIE for technological innovation efficiency.

3.2. Data sources

Due to the lack of clear industry classification standards for ESEPE in China, these enterprises are mostly scattered across various industries. This paper selects all the components of the concept of energy conservation and environmental protection in East money network. Excluding enterprises with incomplete data on individual indicators, 121 ESEPEs were selected as sample enterprises. According to the industry code in the industry classification results of listed companies in the third quarter of 2021 revised by the China Securities Regulatory Commission, 121 ESEPE are divided into 12 categories, including ecological protection and environmental governance industry, civil engineering construction industry and water production and supply industry, as the research object of this paper. The classification results are shown in Table 4. The input-output data of enterprises in this paper come from Guo Taian Database (CSMAR) and annual reports of enterprises. The variable index data of influencing factors of CCD were obtained from *China Statistical Yearbook* and *China Science and Technology Statistical Yearbook*.

4. Empirical analysis

4.1. Research on FE and TIE

4.1.1. Analyzing from a temporal perspective

The values of FE and TIE of ESEPE from 2016 to 2021 are calculated according to formula (1), as shown in Table 5.

According to Table 5, FE values of C1, C3, C4, C5, C6, C7, C9, and C11 industries decreased during fluctuations, while the other industries showed an upward trend of fluctuations. Among them, the C12 industry increased significantly, with an FE value of 0.270 in 2016 and 0.370 in 2021. The C7 industry has a large decline, the FE value in 2016 was 0.569, and in 2021, the FE value dropped to 0.267, a decrease of 53.1 %. In terms of TIE, C1, C24, C3, C4, C5, C6, C7, C8, C10, C11 and C12 industries increased in the fluctuation, and only C9 industry showed a downward trend. Among them, the C1 industry shows a straight upward trend; the value of TIE in 2016 was 0.012, and the value of TIE in 2021 rose to 0.071. The value of TIE in the C9 industry showed a downward trend in 2016–2019 and rapid growth in 2019–2021, but the overall decline was 11.2 %. In general, although the TIE value of ESEPE is smaller than the FE value, the TIE of most industries shows a significant growth trend, indicating that the development prospect of technological innovation in various industries is good.

4.1.2. From an industry perspective

Fig. 2 is drawn according to the average FE and the average TIE of each industry.

As can be seen from Fig. 2, the average FE of C1, C2, C3, C4, C5, C6, C7, C10, C11, and C12 industries is higher than the average TIE, and the average TIE of C8 and C9 industries is higher than the average FE. The average FE of computer, communication, and other electronic equipment manufacturing industry C6 is the highest, and the average TIE is the lowest. With the continuous development of high-tech, the life cycle of electronic products is gradually shortening, accelerating the replacement of electronic products. The investment income of the computer, communication, and other electronic equipment manufacturing industries in China has increased yearly, improving the average FE of this industry. However, the design and manufacturing processes of electronic industrial products are more complex and related to many technological fields. The shortage of high-skilled talents and the cognition level and ability of Chinese enterprises to protect intellectual property rights are relatively backward, resulting in the average TIE in this industry is lower than that of other industries.

The water production and supply industry C9 has the lowest average FE and the highest average TIE. Enterprises in this industry are highly decentralized. Local enterprises have low management levels and poor profitability, and a significant positive correlation exists between profitability and FE [51]. Compared with other industries, the water production and supply industry does not have high requirements for research and development investment intensity, nor does it belong to high-tech industries. With the deepening of the market-oriented reform of China's water production and supply industry and the opening of the policy, the water market has gradually developed from state-owned enterprises to state-owned enterprises, private enterprises, and foreign enterprises. The intensity of R&D investment with low requirements and the sound development trend of the water market makes the average TIE in this industry higher than in other industries.

4.1.3. From the perspective of annual mean value analysis

Fig. 3 is drawn according to the annual average of FE and TIE of ESEPEs.

Table 3
Variable index of influencing factors of CCD.

level	Measurement factors	Specific indicators	symbol
Enterprise	R&D investment intensity	R&D expenses/total assets	*RD*
	Enterprise size	Pairs of total assets of the enterprise	*SCALE*
Market	Regional economic development level	The ratio of GDP to the total number of permanent residents	*PGDP*
	Level of openness to the outside world	The proportion of total import and export to GDP	*KF*
Government	Government subsidy intensity	Government subsidy	*GS*
	Financial support for environmental protection	Financial environmental protection expenditure	*SQ*

Table 4
Classification results of 121 ESEPEs.

Serial number	Industry name	symbol
1	Chemical raw material and chemical product manufacturing industry	C1
2	General equipment manufacturing	C2
3	Special Equipment Manufacturing Industry	C3
4	automotive industry	C4
5	Electrical machinery and equipment manufacturing industry	C5
6	Computer, communication, and other electronic equipment manufacturing industry	C6
7	Instrument manufacturing industry	C7
8	Electricity, thermal production and supply industry	C8
9	Water production and supply industry	C9
10	Civil engineering and construction industry	C10
11	Ecological protection and environmental governance industry	C11
12	other	C12

This section describes the establishment of the indicator system, the explanatory notes of the specific indicators, the data sources, and the results of the classification of the research subjects.

Table 5
Value of FE and TIE of ESEPEs from 2016 to 2021.

Industry	Efficiency value	2016	2017	2018	2019	2020	2021
C1	E_1	0.400	0.403	0.320	0.232	0.252	0.284
	E_2	0.012	0.023	0.036	0.038	0.057	0.071
C2	E_1	0.250	0.266	0.317	0.227	0.317	0.287
	E_2	0.020	0.031	0.031	0.043	0.047	0.044
C3	E_1	0.368	0.269	0.291	0.268	0.268	0.253
	E_2	0.045	0.050	0.086	0.074	0.089	0.089
C4	E_1	0.438	0.492	0.394	0.283	0.264	0.360
	E_2	0.129	0.225	0.248	0.245	0.257	0.177
C5	E_1	0.414	0.368	0.349	0.334	0.374	0.310
	E_2	0.080	0.063	0.080	0.119	0.083	0.127
C6	E_1	0.548	0.393	0.573	0.477	0.307	0.475
	E_2	0.007	0.008	0.013	0.012	0.024	0.020
C7	E_1	0.569	0.564	0.542	0.420	0.376	0.267
	E_2	0.013	0.019	0.015	0.019	0.019	0.025
C8	E_1	0.204	0.244	0.191	0.169	0.123	0.212
	E_2	0.118	0.314	0.268	0.152	0.252	0.145
C9	E_1	0.116	0.143	0.203	0.084	0.092	0.066
	E_2	0.662	0.494	0.406	0.356	0.369	0.588
C10	E_1	0.203	0.259	0.156	0.262	0.292	0.282
	E_2	0.100	0.046	0.086	0.114	0.105	0.109
C11	E_1	0.216	0.215	0.179	0.212	0.146	0.195
	E_2	0.059	0.091	0.105	0.101	0.097	0.116
C12	E_1	0.270	0.328	0.282	0.323	0.270	0.370
	E_2	0.030	0.073	0.077	0.061	0.089	0.089

Note: E_1 is the value of financing efficiency, E_2 is the value of technological innovation efficiency.

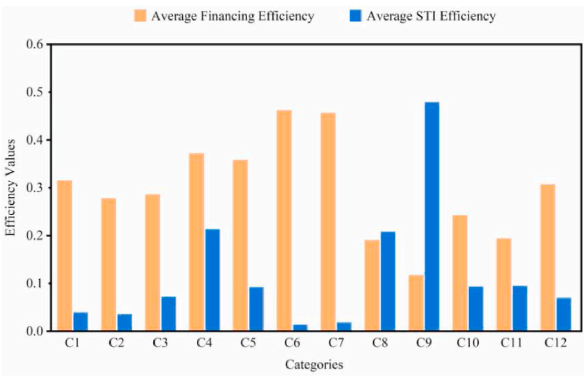

Fig. 2. Average FE and TIE of 12 industry categories.

As seen in Fig. 3, the annual mean value of FE and TIE of ESEPEs is consistent, and the annual mean value of TIE lags behind the annual mean value of FE. Specifically, from 2016 to 2021, the annual average of TIE of ESEPEs has been maintained within the range of 0.1–0.2, and the annual average of TIE in 2016 was 0.106. The annual average of TIE in 2021 was 0.133, showing an upward trend, and the increase rate is negligible. From 2016 to 2018, the average annual FE of ESEPEs was maintained in the range of 0.3–0.4, and from 2019 to 2021, it has been maintained in the range of 0.2–0.3. The average annual FE in 2016 is 0.333, and the average annual TIE in 2021 is 0.280, 1.1 times that of 2020. However, the overall trend is downward. The average annual TIE was relatively stable but slightly increased. After a brief decline from 2018 to 2019, the annual average of FE began to increase in 2020, and the growth rate was relatively large.

4.2. Research on CD and CCD

4.2.1. From a temporal perspective

According to formulas (2) and (3), CD and CCD of FE and TIE of ESEPEs from 2016 to 2021 are calculated, as shown in Table 6.

According to Table 6, the CD between FE and TIE of C9 and C10 industries decreased from 2016 to 2021 by 11 % and 4 %, respectively, while the remaining industries showed an upward trend. Among them, the C1 industry increased significantly, CD in 2016 was 0.337, and CD in 2021 rose to 0.799, an increase of 137.3 %, and CD level rose from the antagonistic stage to the running-in stage. C8 and C11 industries fluctuate more smoothly, rising by 2 % and 17.7 % from 2016 to 2021, and the CD level has been at a high coupling stage. Regarding CCD, C3, C4, C5, C7, and C9 industries showed a downward trend, while the others showed an upward trend. Among them, the C12 industry increased significantly, CCD was 0.385 in 2016, and CCD rose to 0.499 in 2021, 29.6 %. CCD of the C9 industry decreased from 0.643 to 0.489 from 2016 to 2019, the CCD level increased from 0.489 to 0.568 from 2019 to 2021, and the CCD level increased from near to barely coordinated. The reason is that the value of TIE in the C9 industry showed a downward trend in 2016–2019 and rapid growth in 2019–2021.

4.2.2. From the perspective of annual mean value analysis

Fig. 4 shows the annual mean value of CD and CCD between FE and TIE from 2016 to 2021.

As shown in Fig. 4, CD and CCD of FE and TIE of ESEPEs show a promising trend of rising from 2016 to 2021, and CCD rises slowly. The slight decline in the CCD in 2017–2019 was caused by the decline in FE of ESEPEs in 2017–2019, and it rose slowly in the rest of the years. From 2016 to 2021, the CD between the FE of ESEPEs and TIE changed from 0.6 to 0.8. According to Table 1, CD between FE and TIE has always been in the running-in stage. From 2016 to 2021, the CCD between FE of ESEPEs and TIE changed from 0.4 to 0.5. According to Table 1, CCD between FE and TIE has been Near Dysfunction, so CD between FE and TIE of ESEPEs is not optimistic. Since the TIE of ESEPEs lags behind FE, CD between them can be further enhanced by improving TIE.

4.3. Research on factors influencing CCD

In this section, the paper uses the Tobit regression model to explore the influencing factors of CCD, and the specific steps are shown in Fig. 5.

4.3.1. From a holistic perspective

According to the Tobit model, the SPSSPRO data analysis platform was used to conduct regression analysis on the influencing factors of CCD between FE and TIE of ESEPEs, the p-value in the results of the likelihood ratio test of the model is 0.000***, thus the model is valid. The analysis results are shown in Table 7.

It can be seen from Table 7 that the intensity coefficient of R&D input is positive and passes the significance test. It shows that the more R&D investment, the higher CCD between FE and TIE. For every increase of R&D investment intensity of 1 unit, CCD increases by 0.126 units, and the impact effect is weak. According to statistics, most of the R&D investment intensity of enterprises from 2016 to

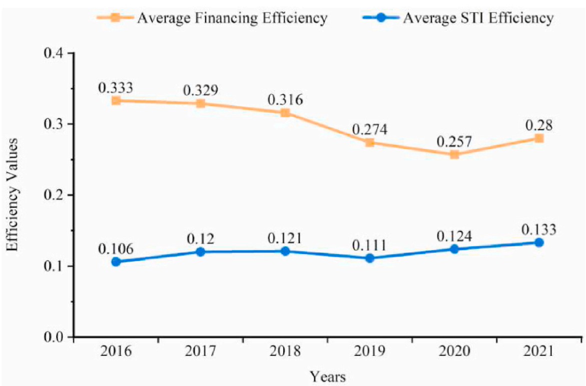

Fig. 3. Annual mean value of FE and TIE of ESEPEs from 2016 to 2021.

Table 6
CD and CCD of FE and TIE of ESEPEs from 2016 to 2021.

industry	index	The year 2016	The year 2017	The year 2018	The year 2019	The year 2020	The year 2021
C1	*C*	0.337	0.452	0.603	0.697	0.778	0.799
	D	0.362	0.416	0.419	0.378	0.409	0.439
C2	*C*	0.524	0.615	0.566	0.734	0.671	0.679
	D	0.349	0.385	0.406	0.381	0.435	0.416
C3	*C*	0.621	0.725	0.839	0.824	0.866	0.877
	D	0.455	0.413	0.452	0.432	0.440	0.429
C4	*C*	0.837	0.928	0.974	0.997	1.000	0.940
	D	0.555	0.616	0.574	0.514	0.510	0.531
C5	*C*	0.737	0.708	0.781	0.880	0.772	0.908
	D	0.515	0.478	0.483	0.494	0.498	0.483
C6	*C*	0.220	0.280	0.297	0.311	0.519	0.392
	D	0.345	0.329	0.408	0.381	0.386	0.423
C7	*C*	0.300	0.358	0.325	0.408	0.427	0.555
	D	0.408	0.442	0.414	0.405	0.391	0.370
C8	*C*	0.963	0.992	0.986	0.999	0.939	0.982
	D	0.408	0.530	0.482	0.401	0.444	0.426
C9	*C*	0.713	0.835	0.943	0.786	0.800	0.603
	D	0.643	0.589	0.565	0.489	0.501	0.568
C10	*C*	0.940	0.713	0.958	0.919	0.883	0.896
	D	0.399	0.402	0.354	0.447	0.463	0.458
C11	*C*	0.821	0.915	0.965	0.935	0.979	0.967
	D	0.387	0.403	0.383	0.406	0.352	0.400
C12	*C*	0.604	0.771	0.822	0.733	0.863	0.790
	D	0.385	0.466	0.442	0.454	0.441	0.499

Note: *C* is the degree of coupling, *D* is the degree of coupling coordination.

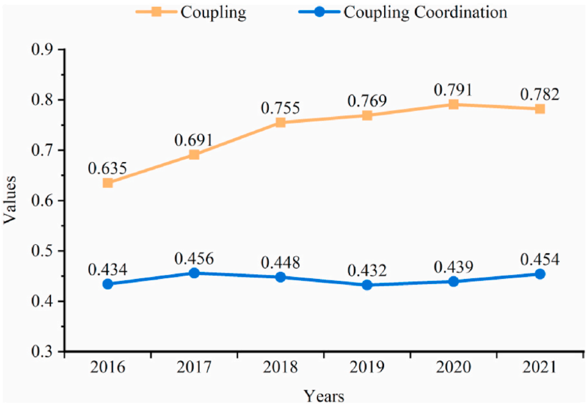

Fig. 4. Annual mean values of CD and CCD from 2016 to 2021.

2021 is below 5 %. Therefore, even if the R&D investment intensity has a promoting effect on CCD, when the R&D investment intensity is low, the effect is not apparent. Therefore, enterprises can continue to promote the development of coupling coordination between the two efficiencies by increasing research and development investment intensity.

The enterprise scale coefficient is positive and passes the significance test. It shows that the larger the enterprise's total assets, the higher the CCD between FE and TIE. For every increase of one unit of enterprise scale, CCD increases by 0.242 units. Compared with the R&D investment intensity, the impact is more significant. Large-scale enterprises have advantages in financial management, optimizing capital structure, and strengthening modern enterprise systems, which is conducive to improving the FE of enterprises. On the other hand, by attracting talent and introducing technology, large-scale enterprises can occupy market share faster to obtain more profits to bring returns to financial capital and promote CCD of FE and TIE.

There is a negative correlation between the regional economic development level and CCD. The higher the regional economic development level, the lower CCD between FE and TIE of ESEPEs. Every time the regional economic development level is increased by 1 unit, CCD is reduced by 0.032 units, indicating that the regional economic development level is an obstacle to CCD, but the effect is insignificant. This is similar to the conclusions of [52,53]. The reason may be that in recent years, economic development is mainly tilted towards infrastructure construction and improving residents' living standards. When the regional economic development level is high, the funds initially used for scientific and technological innovation modules flow to other fields. It also further shows that from 2016 to 2021, the level of regional economic development is, to a certain extent, at the cost of obstructing CCD between corporate FE

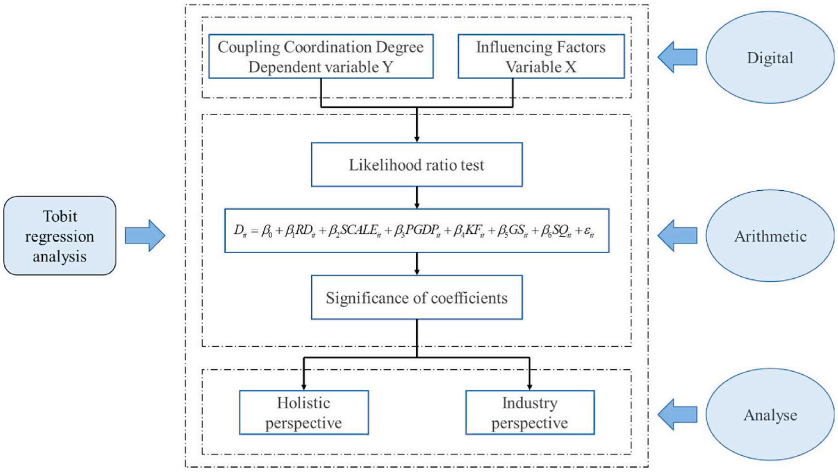

Fig. 5. Tobit regression analysis flowchart.

Table 7
Regression results of influencing factors of CCD.

indicators	coefficient	Standard error	t-value	P-value
RD	0.126	0.047	2.670	0.008***
SCALE	0.242	0.034	7.015	0.000***
PGDP	−0.032	0.033	−0.955	0.340
KF	0.033	0.032	1.048	0.295
GS	0.370	0.057	6.504	0.000***
SQ	−0.021	0.029	−0.719	0.472
c	0.233	0.020	11.883	0.000***

Note1: ***, ** and * represent significance levels of 1 %, 5 % and 10 % respectively.
Note2: RD is the intensity of R&D investment, SCALE is the size of enterprises, PGDP is the level of regional economic development, KF is the degree of openness to the outside world, GS is the intensity of government subsidies, and SQ is the strength of financial and environmental support.

and TIE.

The degree of opening to the outside world is positively correlated with CCD. The greater the degree of opening to the outside world, the higher the CCD of FE and TIE. For every increase of 1 unit of opening to the outside world, CCD increases by 0.033 units, indicating that the degree of opening to the outside world promotes the coupling and coordinated development, but the effect is insignificant. In strengthening foreign trade and attracting foreign capital, enterprises can promote their structural reform, upgrade their operation and management systems to a certain extent, and improve the CCD of enterprise FE and TIE from within enterprises.

The intensity coefficient of government subsidy is positive and passes the significance test. It shows that the greater the intensity of government subsidy, the higher CCD between FE and TIE. With every increase of 1 unit of government subsidy intensity, CCD increases by 0.370 units. From the statistical data, the intensity of government subsidies from 2016 to 2021 is not significant. However, the promotion effect on CCD is evident, indicating that the government encourages enterprises to transform significantly, and the government subsidies have been effectively played.

There is a negative correlation between the degree of fiscal environmental protection support and CCD—the greater the fiscal environmental protection support, the lower the CCD of enterprises' FE and TIE. For every increase of one fiscal environmental protection support unit, CCD will decrease by 0.021 units. Similar to the level of regional economic development, the intensity of fiscal environmental protection support has a hindering effect on CCD, and the effect is also insignificant. This shows that fiscal, environmental protection expenditure has not brought good development to ESEPE. On the contrary, due to insufficient financial support for environmental protection, vicious competition among enterprises may result in the overall decline of enterprise FE and TIE, which hinders the development of coupling and coordination between the two efficiencies. Regarding coefficient values, the intensity of government subsidies has the most significant effect on CCD, and the degree of openness to the outside world has a minor effect on CCD.

4.3.2. *From the perspective of industry analysis*

According to the Tobit model, regression analysis is carried out on the influencing factors of CCD between FE and TIE of 12 industries, respectively. At the significance level of 5 %, the regression coefficient of influencing factors is shown in Fig. 6.

As can be seen from Fig. 6, R&D investment intensity is positively correlated in C3, C4, C5, C10, C11, and C12 industries and negatively correlated in C9. The C4 coefficient value of the automobile manufacturing industry is the largest; that is, the CCD of FE and

TIE of the automobile manufacturing industry is most affected by the intensity of R&D investment. Enterprises in the automobile manufacturing industry have invested huge funds and workforce in research and development activities and gradually become an essential carrier of social and technological innovation [54]; Du's empirical research on R&D investment and innovation performance in China's automobile manufacturing industry also shows that R&D investment has a significant positive effect on innovation performance [55]. When the intensity of R&D investment increases, it can provide the fundamental guarantee for the innovation activities of enterprises, which is conducive to improving the innovation activities of enterprises and then improving CCD from the aspect of TIE. The coefficient value of C9 in the water production and supply industry is negative, indicating that the higher the R&D investment intensity in the water production and supply industry, the lower the CCD of enterprise FE and TIE. According to the analysis of Fig. 2, the average TIE in the water production and supply industry is the highest, and further increasing the intensity of R&D investment may lead to the problem of unequal resource distribution. In addition, the water production and supply industry is facing resource shortage problems and insufficient investment, and enterprises should pay more attention to improving their competitive advantages in investment [56].

Enterprise scale is positively correlated in C2, C4, and C12 industries. The larger the enterprise scale, the greater the CCD between FE and TIE. The parameter value of C12 in other industries is the largest, indicating that for most industries, the larger the enterprise scale, the higher CCD between FE and TIE. In C11 industries, the level of regional economic development is positively correlated, while in C1 and C9 industries, it is negatively correlated. Among them, CCD of ecological protection and environmental governance industry C11 increases with regional economic development level improvement. As can be seen from Fig. 2, the average TIE of the ecological protection and environmental governance industry is lower than that of FE. In regions with higher levels of regional economic development, the stronger the allocation ability of market resources and the residents' demand for green environmental protection products, the better the external development environment for environmental protection enterprises can be provided, the better the green technology innovation ability of enterprises can be promoted. Meanwhile, the difference between TIE and FE can be made up, and the CCD can be improved [57].

In the C9 industry, the degree of openness to the outside world is positively correlated. The greater the openness to the outside world, the greater the CCD between FE and TIE. In C5, C10, and C11 industries, the intensity of government subsidies is positively correlated, and the coefficient value of C5 in the electrical machinery and equipment manufacturing industry is the largest, that is, the CCD of FE and TIE in the electrical machinery and equipment manufacturing industry is the most affected by the intensity of government subsidies. The electrical machinery and equipment manufacturing industry is low frequency, high requirements, long service cycle industry, and service quality is difficult to control, resulting in frequent quality problems. Suppose the government controls and increases the intensity of government subsidies. In that case, it can also make good development guidelines for the electrical machinery and equipment manufacturing industry while alleviating the limitations of the industry itself and the problem of service disorder. In the C3 industry, fiscal environmental protection support intensity is negatively correlated. The greater the intensity of fiscal environmental protection support, the lower the CCD between enterprises' FE and TIE.

This section explains the details of the study case. It analyses the financing efficiency and scientific and technological innovation efficiency of energy-saving and environmental protection enterprises from the perspectives of time series, industry, and annual average; analyzes the coupling coordination degree from the perspectives of time series and annual average; and analyses the influencing factors of the coupling coordination degree from the perspectives of the whole and the industry.

5. Recommendations

The Energy-saving and environmental protection industry is an industry that provides technical basis and equipment guarantee for saving energy and resources, developing a circular economy, and protecting the environment. With the continuous and rapid development of China's economy and the deepening of urbanization and industrialization, the contradiction between economic development and environmental protection is becoming increasingly apparent, and the state attaches more and more importance to energy-saving and environmental protection. According to the above conclusions, the following targeted suggestions are provided for the feasible path to promote the healthy development of ESEPEs.

(1) Optimize the industrial structure, strengthen the modern enterprise system, and improve FE. In ESEPEs, the FE of most industries shows a downward trend. Therefore, at the enterprise level, we should make full use of all available funds and strengthen financial management, especially the management of accounts receivable and cash, to increase cash flow and improve the scale of internal financing. Starting from the two aspects of optimizing the capital structure and strengthening the modern enterprise system, we should give play to our industry advantages to attract investment institutions and improve FE. In terms of policy, it is necessary to establish the negative list system, power list system, and responsibility list system of enterprise investment project management, Break industrial and regional barriers, and departmental monopolies, and cut off the exciting relationship between intermediary service agencies and government departments. From the supply side, we were targeted to reduce investment and financing costs and solve investment and financing problems.

(2) Optimize the allocation of technological resources, improve innovation capacity, and promote the coordinated development between financing and technological innovation. The innovation ability of China's ESEPEs is not strong, and the energy-saving and environmental protection technology innovation system with enterprises as the main body still has room for improvement. For enterprises, technology is the constant competitiveness. Through the integration of new technologies and new industries, the formation of new models and new industries will promote the development of energy-saving and environmental protection industries. Enterprises should firmly grasp the relevant opportunities, achieve breakthroughs in key technology links, and

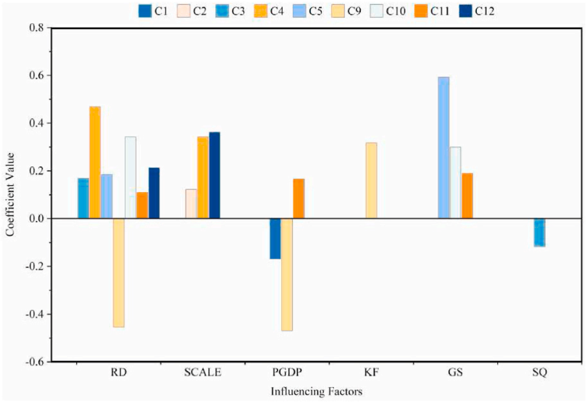

Fig. 6. Values of regression coefficients of influencing factors across industries at a 5 per cent level of significance.

eliminate dependence on imports of essential equipment as soon as possible. The government should increase the leading role of enterprises in the allocation of innovation resources and give full play to the leading role of enterprises in technological innovation decision-making, research and development investment, scientific research organization, and the transformation and application of achievements. Improve the enterprise R&D assessment system, determine uniform standards, fair competition, and other regulations, make up for the shortcomings of the system, and consider including R&D expenditures in the scope of performance assessment to incentivize and guide enterprises to invest more in R&D. Improve the incentive policy for technological innovation, truly realize open innovation, open cooperation, and open win-win, improve the social environment, and promote the balanced development between financing and technological innovation.

(3) Increase government subsidies, seize investment opportunities, and guide the healthy development of the industry. China's energy-saving and environmental protection industry has a short time, small-scale participating enterprises, low industrial concentration, and weak leading enterprises. Although many laws and regulations are related to energy-saving and environmental protection in China, the system has not been established, and the price reform of resource products and environmental protection charges have not been finalized. The government should continue to establish a "package" policy system in terms of industrial protection, talent support, fiscal and tax relief, actively regulate the development of the industry, form effective industry standards and access thresholds, increase the intensity of subsidies for ESEPEs, and form an influential guiding role. Investment institutions should rationally grasp the opportunity in different segments of the industrial chain, start to lay out start-up enterprises and more mature enterprises with high technical barriers, significant market share, and transparent profit model, vigorously support the R&D investment of enterprises, improve the independent innovation ability of enterprises, and expand the scale of enterprises.

This paper provides suggestions from enterprises, governments, investment institutions, etc. At the micro level, it broadens the financing channels of energy-saving and environmental protection enterprises, promotes enterprises' internal structural adjustment, and strengthens enterprises' ability to gather innovative resource elements, thus effectively promoting the rapid and healthy development of enterprises. At the macro level, China's ecological civilization construction has entered a critical period to promote the comprehensive green transformation of economic and social development and achieve quantitative to qualitative changes in improving ecological environment quality. Energy-saving and environmental protection enterprises are the main body of green and low-carbon development, sound enterprise financial and scientific and technological innovation system, and energy-saving and environmental protection enterprises to flourish and promote China's high-quality economic growth, which is of great practical significance.

6. Conclusions

The coordinated development of finance and innovation is a critical way to help achieve the goal of "two-carbon." In this paper, through the construction of financing efficiency and scientific and technological innovation efficiency evaluation index system, the DEA-SBM model is used to calculate the financing efficiency and scientific and technological innovation efficiency, and the coupling coordination degree model is used to calculate the level of coordinated development between the two, and the Tobit regression model is further used to analyze the influencing factors of the degree of coupling coordination. The results show that the annual mean value of FE and TIE of ESEPEs is the same, and the annual mean value of TIE lags behind the annual mean value of FE. The FE value of most industries shows a downward trend, indicating that the financing situation of various industries is not good. Although the TIE value of most industries is smaller than the FE value, the TIE value has an apparent growth trend, indicating that the development prospect of technological innovation in various industries is good. Through CCD analysis, is believed that the CD between the two efficiencies is not high. Furthermore, combined with the Tobit regression model to analyze the influencing factors, the impact of R&D investment intensity, enterprise size, and government subsidy intensity on the CCD of FE and TIE of ESEPEs is significantly positive, and the coefficient value of government subsidy intensity is the largest. It is believed that the intensity of government subsidies can be strengthened to improve the coordinated development of the two efficiencies.

Although the research has obtained considerable results, there are still some limitations: (1) This paper does not consider the potential impact of individual enterprise characteristics such as management quality, organizational culture, and strategy, which may impact financing and technological innovation efficiency. These influencing factors are included in the scope of the subsequent research. (2) At present, this study is limited to the study of ESEPEs in China, and the future study will promote the research method and extend it to other countries and industries.

Data availability statement

Data will be made available on request.

CRediT authorship contribution statement

Jingjie Li: Writing – review & editing, Writing – original draft, Validation, Supervision, Methodology, Funding acquisition, Conceptualization. **Chuanjuan Li:** Writing – original draft, Software, Formal analysis, Data curation, Conceptualization. **Yiting Qin:** Writing – review & editing, Resources, Methodology, Investigation. **Shanwei Li:** Visualization, Software, Methodology.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

[1] Z.Y. Ouyang, Z.T. Shi, M.J. Shi, D.W. Yang, R.Y. Long, H.C. Zhou, S.J. Lin, R.F. Guo, Y.J. Wang, Carbon Peaking Carbon Neutrality": Challenges and Countermeasures, vol. 5, Journal of Hebei University of Economics and Business, 2021, pp. 1–11, https://doi.org/10.14178/j.cnki.issn1007-2101.20210826.001.

[2] Y.J. Wang, Q.Q. Sun, J.J. Wu, S. Han, R.N. Zhang, S.Y. Jiang, X. Gu, Research on the low carbon development path of China's coal industry under carbon peaking & carbon neutral target: based on the RCPs-SSPs framework, Resour. Pol. 86 (2023) 104091, https://doi.org/10.1016/j.resourpol.2023.104091.

[3] R.R. Li, L.J. Li, Q. Wang, The impact of energy efficiency on carbon emissions: evidence from the transportation sector in Chinese 30 provinces, Sustain. Cities Soc. 82 (2022) 103880, https://doi.org/10.1016/j.scs.2022.103880.

[4] Q. Wang, F.Y. Zhang, R.R. Li, Revisiting the environmental kuznets curve hypothesis in 208 counties: the roles of trade openness, human capital, renewable energy and natural resource rent, Environ. Res. 216 (2023) 114637, https://doi.org/10.1016/j.envres.2022.114637.

[5] Q. Wang, F.Y. Zhang, R.R. Li, Free trade and carbon emissions revisited: the asymmetric impacts of trade diversification and trade openness, Sustain. Dev. 32 (2023) 876–901, https://doi.org/10.1002/sd.2703.

[6] Q. Wang, X.W. Wang, R.R. Li, X.T. Jiang, Reinvestigating the environmental Kuznets curve (EKC) of carbon emissions and ecological footprint in 147 countries: a matter of trade protectionism, Humanities and Social Sciences Communications 11 (2024) 160, https://doi.org/10.1057/s41599-024-02639-9.

[7] Q.Y. Liu, The Research on Financing Efficiency Evaluation and its Influencing Factors of the Green and Low-Carbon Enterprises, Hunan University, 2020, https://doi.org/10.27135/d.cnki.ghudu.2020.004228.

[8] Y. Cao, C.X. Geng, On financing efficiency of listed companies of energy saving and environmental protection industry based on grey correlation models, J. Hefei Univ. Technol. (Nat. Sci.) 30 (1) (2016) 25–34, https://doi.org/10.3969/j.issn.1008-3634.2016.01.004.

[9] H. Lei, Q.Y. Liu, Research on financing efficiency of the green low carbon enterprises based on four stage dea model, Theory Pract. Finance Econ. 41 (3) (2020) 72–78, https://doi.org/10.16339/j.cnki.hdxbcjb.2020.03.010.

[10] M. Mazzucato, M. Tancioni, R&D, patents and stock return volatility, J. Evol. Econ. 22 (4) (2012) 811–832, https://doi.org/10.1007/s00191-012-0289-x.

[11] A. Muhammad, N.M. Gatawa, H.S.B. Kebbi, Impact of information and comunication technology on banks performance:A study of slected commercial banks in Nigeria(2001-2011), Eur. Sci. J. 9 (7) (2013) 213–238. https://core.ac.uk/download/pdf/236412234.pdf.

[12] X.H. Jin, Innovation on Financing Efficiency of Enterprises Research on the Impact of Financial Technology, South China University of Technology, 2021, https://doi.org/10.27151/d.cnki.ghnlu.2021.002368.

[13] H.Y. Ye, S. Wei, Executive financial connection, financing constraints and corporate technological Innovation efficiency based on the moderating role of digital financial inclusion, Economic Forum 10 (5) (2022) 117–129. https://kns.cnki.net/kcms2/article/abstract?v=v5HVlYuqh9roTVr94Ihv8PklgQ-dEdr63HjMWelriOwz8bO6AN0iQvr4x2ueoOOTpbjtYdJIrkRVpXG_YwD_xR04KPBctTSGcxfgzMC7Kp7-IF35nKd8HK_fHnm4wzHWos4Fi0QVLR8=&uniplatform=NZKPT&language=CHS.

[14] Y.P. Du, Y.H. Luo, Research on coupling and coordination evaluation of innovation efficiency and green economy efficiency——based on data from 30 provinces and autonomous regions in China, China Collective Economy 4 (2023) 94–97. https://kns.cnki.net/kcms2/article/abstract?v=v5HVlYuqh9o4C1BQcnPGW3eaGqljEU1vQDDKFyKc3GJsd1mZwEIxZP3ET_ECAQd85lPEzEHTGxW_JDwEvTh680SHYHo_loQMgpA2nm6mgSt_X2YrVSHFEAsNa8JWdAtUZNXCevoXuVxpVJWJfhXxzQ==&uniplatform=NZKPT&language=CHS.

[15] X.L. Nie, L.Q. Huang, Theoretical analysis framework of enterprise financing efficiency, Journal of Industrial Technological Economics 26 (10) (2007) 157–159, https://doi.org/10.3969/j.issn.1004-910X.2007.10.044.

[16] K.L. Zeng, How to view direct financing and indirect financing, J. Financ. Res. 3 (1996) 35–40. https://kns.cnki.net/kcms2/article/abstract?v=v5HVlYuqh9o93LqwyZm1mQqyz_3Tyaag-lJCOrMosbC6Kokj-G_X8cKF3y06vAG1rk7r2MWIoRF4KydfaB_sJ2ee3yikjhQf8hy3TuYAYEbg6UzpDK1a_rlXY782NamYJvxHAMURcM4=&uniplatform=NZKPT&language=CHS.

[17] W.B. Zheng, On Financing Efficiency of Small and Medium-Sized Enterprise, Party School of the Central Committee of CPC, 2004. https://kns.cnki.net/kcms2/article/abstract?v=v5HVlYuqh9rCcwx8ukzT2cnsaYylYP9nnC5bOLQfZG7zVbIn8BJ2bWfD6Q23ahacUzsjrzZitkVwteOmSYXrGHTpSKEu_JHkRuyCqbeUBgcs0dEJbAZsu1LJSgO0pu3zgu0RbAuYq_NByRknPyUhpw==&uniplatform=NZKPT&language=CHS.

[18] W. Zou, J.K. Wan, Analysis and enlightenment of scientific and technological innovation efficiency in Hubei Province, Science & Technology And Economy 17 (5) (2004) 13–16, https://doi.org/10.3969/j.issn.1003-7691.2004.05.005.

[19] X. Guan, Research on the Profit Model of Environmental Protection Industry under the Background of Green Development——Take company A as an example, Southeast University, 2020, https://doi.org/10.27014/d.cnki.gdnau.2020.002525.
[20] H.J. Xiong, Capital allocation efficiency evaluation of energy conservation and environmental protection enterprises in the yangtze river delta of China, Nat. Environ. Pollut. Technol. 19 (2) (2020) 603–610, https://doi.org/10.46488/NEPT.2020.V19I02.015.
[21] Y.M. Shang, F.Q. Zhou, L. Lin, Impact of open innovation on the innovation performance of energy saving and environmental protection enterprises, Sci. Technol. Prog. Policy 38 (10) (2021) 114–122, https://doi.org/10.6049/kjjbydc.2020050140.
[22] Y. Li, L. Jiang, P.L. Yang, How to drive corporate responsible innovation? A dual perspective from internal and external drivers of environmental protection enterprises, Front. Environ. Sci. 10 (2023), https://doi.org/10.3389/FENVS.2022.1091859.
[23] Q. Ali, A. Salman, S. Parveen, Evaluating the effects of environmental management practices on environmental and financial performance of firms in Malaysia: the mediating role of ESG disclosure, Heliyon 8 (12) (2022) e12486, https://doi.org/10.1016/J.HELIYON.2022.E12486.
[24] Y. Guo, G. Bruno, D. Zhang, K. Han, Analysis of low-carbon technology innovation efficiency and its influencing factors based on triple helix theory: evidence from new energy enterprises in China, Heliyon 9 (10) (2023) e12486, https://doi.org/10.1016/J.HELIYON.2023.E20308.
[25] M.L. Xu, Research on the debt financing efficiency of s energy conservation and environmental protection company, Shenyang University, 2021, https://doi.org/10.27692/d.cnki.gsydx.2021.000366.
[26] W.X. Cao, Analysis on financing efficiency of energy conservation and environmental protection industry, Zhejiang University, 2020, https://doi.org/10.27461/d.cnki.gzjdx.2020.002156.
[27] D.Q. Li, C.L. Zhong, J.W. Hu, Environmental regulation, government support, and efficiency of green technology lnnovation :empirical research of industrial enterprises above designated size from 2009 to 2017, Journal of Jianghan University(Social Science Edition) 37 (6) (2020) 38–49+125, https://doi.org/10.16387/j.cnki.42-1867/c.2020.06.004.
[28] X.Y. Wang, Supply chain integration and green innovation efficiency of energy saving and environmental protection listed enterprises, Fuzhou University, 2020, https://doi.org/10.27022/d.cnki.gfzhu.2020.000254.
[29] A. Charnes, W.W. Cooper, E. Rhodes, Measuring the efficiency of decision making units, Eur. J. Oper. Res. 2 (6) (1978) 429–444, https://doi.org/10.1016/0377-2217(79)90229-7.
[30] University of Science and Technology vol. 12 (1996) 83–86. https://kns.cnki.net/kcms2/article/abstract?v=v5HVlYuqh9r7ViTWNQbC6Lw8XRn7P-V3sWq_CODLoiYHJBRvKQkM_kR3Hs7Q0olEqGjvUVg7jbBwHKXlunw_ezxx7hWW7Hr1Qfkkonf74fASV2dWLfrGFmPtfWz_VtBld6oNyGY7O6o=&uniplatform=NZKPT&language=CHS.
[31] R.D. Banker, W.W. Cooper, E. Grifell-Tajté, J.T. Pastor, P.W. Wilson, E. Ley, C.A.K. Lovell, Validation and generalization of DEA and its uses, Top. 2 (2) (1994) 249–314, https://doi.org/10.1007/bf02574811.
[32] Z.X. Ma, Research on the data envelopment analysis method, Syst. Eng. Electron. 24 (3) (2002) 42–46, https://doi.org/10.3321/j.issn:1001-506X.2002.03.014.
[33] X. Hou, Z.X. Ma, C.Y. Zhao, Research on models of the data envelopment analysis, Journal of Inner Mongolia University(Natural Science Edition) 41 (5) (2010) 583–593, https://doi.org/10.3969/j.issn.1000-1638.2010.05.020.
[34] A.J. Sun, Z.C. Dong, X.Y. Zhang, Coupling degree between urban economy and technical efficiencyof water use in China, Resour. Sci. 30 (3) (2008) 446–453, https://doi.org/10.3321/j.issn:1007-7588.2008.03.018.
[35] T. Tang, J. Tan, Study on coupling between city land utilization efficiency and environment, Journal of Anhui Agricultural Sciences 38 (26) (2010) 14723–14724, https://doi.org/10.13989/j.cnki.0517-6611.2010.26.201.
[36] T.T. Xie, Y.Z. Hu, Research on the coupling and coordination of green finance and ecological efficiency under the dual-carbon target, Huabei Finance 10 (12) (2022) 15–27, https://doi.org/10.3969/j.issn.1007-4392.2022.12.002.
[37] L.F. You, Q. Liu, C.R. Huang, Q. Huang, T.T. Tang, Spatiotemporal characteristics of coupled development of green finance and low-carbon economy in China: an empirical analysis based on inter-provincial panel data, Management and Administration 5 (2023) 1–13, https://doi.org/10.16517/j.cnki.cn12-1034/f.20230417.001.
[38] J.H. Feng, Q.W. Zang, Research on the coupling development and influencing factors of ecological effciency and technological innovation of heavy pollution industrial enterprises, Ecol. Econ. 36 (9) (2020) 67–71. https://kns.cnki.net/kcms2/article/abstract?v=v5HVlYuqh9pP75HD8jO2dJyCm8tTyY5fPyfCCt_7BPMILHKwB7gwmOEsMr6U_k04wFJQklmcbUSPMFXDFxm8y191yGMRW1ui3Eir3P9A4FW2FPwz7kx2a0RPsMCOvutafMGGqncnUET9hrdsEKOQ_A==&uniplatform=NZKPT&language=CHS.
[39] X.Q. Ding, Q. Wu, X.N. Liu, L.Y. Tan, J. Wang, Coupling and coordination degree of land use, high-qualityeconomic development, and carbon emissions and influencing factors in China:An empirical study of 282 prefecture-level cities, Resour. Sci. 44 (11) (2022) 2233–2246. https://kns.cnki.net/kcms2/article/abstract?v=v5HVlYuqh9opPWeMk4ey3YGEFff-oupUHbZgAVcz-2PhzXy3VbiPddt5-s40GDVjZ36FLBhc8jYuFGmXft1VoN8-39EmhU7i9XRIOxkcNQzvcp_BrWLE1NgJkflAyqFFuGKQtkybmFGQtSj1INd_-Q==&uniplatform=NZKPT&language=CHS.
[40] S.K. Bian, Study on the coupling coordination degree between innovation performance of national high-tech zones and urban innovation environment, Shenyang University of Technology, 2022, https://doi.org/10.27322/d.cnki.gsgyu.2022.000900.
[41] Q. Wang, X.C. Cheng, R.R. Li, Does the digital economy reduce carbon emissions? The role of technological innovation and trade openness, J. Clean. Prod. 447 (2023) 141298, https://doi.org/10.1016/j.jclepro.2024.141298.
[42] R.R. Li, Q. Wang, J.L. Guo, Revisiting the environmental kuznets curve (EKC) hypothesis of carbon emissions: exploring the impact of geopolitical risks, natural resource rents, corrupt governance, and energy intensity, J. Environ. Manag. 351 (2024) 119663, https://doi.org/10.1016/j.jenvman.2023.119663.
[43] Q. Wang, S.L. Hu, R.R. Li, Could information and communication technology (ICT) reduce carbon emissions? The role of trade openness and financial development, Telecommun. Pol. 48 (2024) 102699, https://doi.org/10.1016/j.telpol.2023.102699.
[44] D. Luo, Research on the coordinated development of regional logistics efficiency and innovation efficiency in China, Inner Mongolia University of Finance and Economics. https://doi.org/10.27797/d.cnki.gnmgc.2021.000219, 2021.
[45] J. Tang, C. Liu, Z.C. Feng, The study on the coupling and coordination relationship between production technology efficiency and fertilizer application efficiency, Chinese Journal of Agricultural Resources and Regional Planning 3 (2023) 1–16. https://kns.cnki.net/kcms2/article/abstract?v=v5HVlYuqh9qmuMN9cJGgQnGHxnF1Cb7hZr03VPdA5GmFbXDT13sBvqorBqoTZNCCd3aAptSGIYFpMuCjlig1Y-V6GWgTy_re-kP57DXxlWnMJYqxno1qguJ6TauLgbUrldofw6PgYMrfDoPIBvrXhg==&uniplatform=NZKPT&language=CHS.
[46] Y.N. Xu, G.H. Zhao, Production efficiency, innovation efficiency and ecological efficiency of industrial enterprises——based on the perspective of coupling coordination, Journal of Statistics 1 (5) (2020) 13–24, https://doi.org/10.19820/j.cnki.issn2096-7411.2020.05.002.
[47] A.X. Zhang, R.R. Deng, Coupling coordination degree of carbon emission efficiency and industrial structure optimization in six provinces of central China and research on its influencing factors, Ecol. Econ. 37 (3) (2021) 31–37. https://kns.cnki.net/kcms2/article/abstract?v=v5HVlYuqh9r9eWhBSKBLOrS7JeAtbrj-YTulHxaiEy3BXFwa6eOeF-fGtu5syytKaGr5W_lZNHBG1jWjauKcSeYVADijjYkuxuFn08BVAyTWaA9VEXjbvwWjjjIR8XlThRkWVtJClT5n4Ckg3pP3SA==&uniplatform=NZKPT&language=CHS.
[48] K.A. Tone, Slacks–based measure of super–efficiency in data envelopment analysis, Eur. J. Oper. Res. 130 (3) (2001) 498–509, https://doi.org/10.1016/s0377-2217(01)00324-1.
[49] F.J. Xu, X.M. Li, Deconstruction and optimization path of technological innovation efficiency of eco-agricultural enterprises: based on analysis of sample data of 35 listed agricultural investment enterprises, Journal of Liaoning University of Technology(Social Science Edition) 23 (6) (2021) 40–44, https://doi.org/10.15916/j.issn1674-327x.2021.06.009.
[50] D.Q. Li, C.L. Zhong, Study on measurement and influence factors of green technology innovation efficiency of industrial enterprises based on dea-tobit model:an example from Hubei Province, Journal of Shanghai Economic Management College 19 (6) (2021) 30–41, https://doi.org/10.19702/j.cnki.jsemc.2021.06.004.
[51] Y. Lin, H. Wang, X. Liu, Credit rating, profitability and corporate financing efficiency, Communication of Finance and Accounting 26 (2019) 21–24, https://doi.org/10.16144/j.cnki.issn1002-8072.2019.26.004.
[52] X.Y. Zhou, G.C. Zuo, Analysis on the efficiency evaluation and influencing factors of scientific and technological innovation in Hunan Province, Science Technology and Industry 22 (6) (2022) 38–42, https://doi.org/10.3969/j.issn.1671-1807.2022.06.008.

[53] Y.F. Lai, P.J. Xie, L.T. Ye, X.R. Ma, Research on the efficiency and influencing factors of science and technology innovation in China;based on the super-efficiency SBM-malmquist-tobit model, Sci. Technol. Prog. Policy 38 (13) (2021) 37–45. https://kns.cnki.net/kcms2/article/abstract?v=v5HVlYuqh9odLZ9USMptqYmGI2NsAhDgt-PEXBBrvKA4seaeilnMdnr90-TRQhs3MkXNqnBA2j-o_JfiqPSIE9CnE-5AFY5cvHNFn6nJTF_jHkX2_WL3l8NtRk2HkuRG1EdaNc7QRFd-6gTWSKAJDg==&uniplatform=NZKPT&language=CHS.

[54] J. Yao, Competence enhancement for R&D project management in the automotive manufacturing industry, Fortune Today (China Intellectual Property) 416 (3) (2023) 53–55. https://kns.cnki.net/kcms2/article/abstract?v=v5HVlYuqh9reboVtr421dfH3qYb9qY3wT1lVk-qRrhjuUKJRvcb2UQl1JeTOBZjhgtTN3wv-38ZLAWC78yXR2h-0aQN3AorEJujYvmKzRWlFN03OHJCQUgzviUF1HHYQjUu-UMiA3DZTPiBqHkwOEw==&uniplatform=NZKPT&language=CHS.

[55] R. Du, R&D investment, knowledge stock and innovation performance of China's automobile manufacturing industry, Huazhong University Of Science And Technology, 2021, https://doi.org/10.27157/d.cnki.ghzku.2021.005968.

[56] H.F. Zhao, L.Q. Xu, F.F. Mei, Analysis of investment value of listed companies in water production and supply industry, Mark. Mod. 10 (1) (2015) 128–132, https://doi.org/10.3969/j.issn.1006-3102.2015.01.087.

[57] Q. Li, Research on efficiency and influencing factors of green technology innovation in environmental protection industry, Shaanxi Normal University, 2020, https://doi.org/10.27292/d.cnki.gsxfu.2020.001159.