1 Indicator system

Table 1 Low-Carbon Transition Performance Assessment Indicator System

Guideline	Indicator	Indicator properties
Transition progress (C1)	Share of thermal power capacity (C11) Renewable energy growth rate (C12) The carbon emission factor of power supply (C13) Carbon productivity (C14)	Quantitative
Financial support (C2)	Earnings per share (C21) Total asset turnover ratio (C22) EVA elasticity to power generation (C23) Operating cash flow per share (C24)	Quantitative
Technology investment (C3)	R&D investment intensity (C31) Coal consumption intensity of power supply (C32)	Quantitative
Governance(C4)	Clarity of low-carbon commitment (C41) Completeness of Social Responsibility Report (C42) Implementation of low-carbon systems/policies (C43) Establishment of strategy committee (C44)	Qualitative

(1) Transition progress (C1)

The transition progress is a direct manifestation of the low-carbon transformation performance of thermal power listed companies, that is, the overall effectiveness of low-carbon governance implemented by listed companies during the “13th Five-Year Plan” period, including the change of power generation structure and the environmental performance of energy conservation and emission reduction. Low-carbon transition requires enterprises to optimize the power supply structure, vigorously develop clean and low-carbon electricity, reduce new investment in thermal power, increase the proportion of renewable energy, improve the level of environmental governance and reduce carbon emissions.

Therefore, share of thermal power capacity (C11) and renewable energy growth rate (C12) are set to measure the low-carbon power structure of listed companies, and the carbon emission factor (C13) and carbon productivity (C14) of electricity are set to evaluate the carbon emission reduction work of listed companies. The carbon emission factor (C13) indicates the carbon dioxide emissions per kilowatt-hour of on-grid electricity produced by thermal power units, and the carbon productivity (C14) refers to the revenue value generated by each unit of carbon used, and the increase in carbon productivity means creating more value with fewer carbon-based fossil resources.

The calculation formula of the carbon emission factor is as follows:

$$EF = E / W \tag{1}$$

EF: the carbon emission factor;

E: the carbon emission of the thermal power listed company in 2020;

W: the total power generation of the thermal power listed company in 2020.

The calculation formula of carbon productivity is as follows:

$$PR = R / E \tag{2}$$

PR: carbon productivity;

R: the main business income of the listed thermal power company in 2020;

E: the carbon emissions of the listed thermal power company in 2020.

(2) Financial support (C2)

Financial support is an important foundation for the low-carbon transition of thermal power listed companies, which is the financial guarantee to support the company's low-carbon transition, reflecting the company's ability to create value, and the financial benefits of listed companies can intuitively reflect the smooth transition of the company. Referring to the current Implementation Rules for Comprehensive Performance Evaluation of Central Enterprises issued by the State-owned Assets Supervision and Administration Commission (SASAC), and taking into account the characteristics of listed companies, we select financial indicators that can measure the financial performance of low-carbon transformation of listed thermal power companies.

Earnings per share (C21) reflects the level of earnings realized by common shareholders, which is the final result of the company's profitability and reflects the company's market performance. For investors, earnings per share is a comprehensive concept that can more appropriately account for the increase or decrease in earnings. Earnings per share is a financial indicator that is relatively comparable between listed companies of different sizes in different industries and is widely cited in performance comparisons between listed companies.

Total asset turnover ratio (C22): The ratio of the net sales revenue to the average total assets of an enterprise in a certain period, which can measure the ratio between the scale of asset investment and the sales level, and reflect the operating capacity of the listed company. The higher the index, the higher the utilization efficiency of the company's assets, reflecting the operating efficiency of the low-carbon transition of thermal power listed companies.

The main business of a thermal power listed company is power generation, and the power generation volume can measure the potential of the company's power generation business to create economic value, and the economic value added (EVA) can evaluate the company's ability to effectively use capital and create value for shareholders, and provide better performance evaluation standards. In this study, EVA elasticity to power generation (C23) was specially selected as an evaluation indicator, which can directly reflect the operation of power generation companies, show whether the growth of power generation volume can drive the simultaneous improvement of economic value added, and also reflect the social responsibility of power supply.

EVA elasticity to power generation is as follows:

$$E' = \frac{\Delta Y / Y}{\Delta X / X} \tag{3}$$

E' : EVA elasticity to power generation;

$\Delta Y / Y$: rate of change in power generation of thermal power listed companies during the 13th Five-Year Plan period;

$\Delta X / X$: rate of change in EVA of thermal power listed companies.

Cash flow is usually used as an indicator of internally available funds in investment modeling, and in this research, operating cash flow per share (C24) is selected to measure the amount of cash inflow from the operation of thermal power listed companies in the process of low-carbon transition from a dynamic perspective. Operating cash flow per share is the most substantial financial indicator; if the earnings per share or undistributed profit per share is high but the cash flow is unsatisfactory, it means that the listed company doesn't have enough cash to guarantee the dividend payout.

(3) Technology investment (C3)

Low-carbon technology is not only a continuous driving force for low-carbon economic development, but also a decisive factor in CO_2 emission reduction. Technological innovation helps thermal power listed companies in low-carbon transformation, which is an important driving force for low-carbon transition.

R&D investment intensity (C31), which refers to the ratio of R&D investment to operating revenue, reflects the importance that thermal power listed companies place on low-carbon technologies.

Coal consumption intensity of power supply (C32) refers to the average amount of standard coal consumed by a thermal power unit for each unit of kWh of electricity supplied, reflecting the level of energy consumption per unit of product produced by a thermal power listed company.

(4) Governance (C4)

Governance covers the low-carbon transition target planning as well as the development direction proposed by thermal power listed companies, which provides the core concept for low-carbon transition and is also the cornerstone for the fulfillment of the company's social responsibility, reflecting the listed company's ambition and social performance in low-carbon transition.

Low-carbon commitment (C41) refers to the specific implementation goals and action plans of thermal power listed companies considering national policies, their development conditions, and development orientation, the clarity of which reflects the determination of thermal companies to transition to low-carbon.

Low-carbon implementation (C42) reflects the implementation strength of specific measures of thermal power companies and the role of implementation measures on transition performance.

Corporate Social Responsibility (C43) is part of corporate value creation, and the fulfillment of corporate social responsibility can earn the company a good social reputation, enhance the competitiveness of the company, and promote the sustainable development of the company.

A Strategy Committee (C44) aims to research and make recommendations on the company's long-term development strategy and major investment decisions. The establishment of a Strategy Committee can improve the decision-making procedures for major matters, enhance the quality and efficiency of decision-making, and realize the company's goal of high-quality and steady operation.

2 Indicator data collection

(1) Quantitative data collection based on annual reports

It is mandatory for listed companies to release annual reports as per legal obligations. Annual reports mainly disclose the listed companies' operating conditions and financial information, and the data of quantitative indicators selected for this study are obtained from the annual reports of thermal power listed companies, which are obtained from the official websites of the companies and the Juchao Information Network.

For the data that can be directly obtained from the company's annual reports, including R&D investment intensity and coal consumption of power supply, the corresponding indicators directly adopt the data disclosed in the annual reports; for the data of the indicators that cannot be directly obtained, the data of the relevant formulas are collected and organized according to the calculation

formula, such as the total liabilities, the total assets, the operating revenues, the cash flow, the power generation, the installed capacity, etc., and the data that have been sorted out are calculated.

(2) Qualitative data collection based on text extraction

① Textual analysis

Drawing on existing literature, this study uses text analysis to quantitatively evaluate the qualitative indicators of thermal power listed companies in terms of governance. First, the annual reports, social responsibility reports, and sustainable development reports of selected thermal power listed companies were downloaded in bulk from the information dissemination network, and the files were converted into TXT format, and then keywords were extracted using Python for the associated words involved in the low-carbon transition commitment, low-carbon action plan and low-carbon implementation initiatives to generate a visualized word cloud map. Secondly, the manual reading method is used to read the annual reports and social responsibility reports of thermal power listed companies, search for low-carbon transition-related statements, integrate and sort out relevant information, and tag keywords. Finally, based on the word cloud and the key information extracted manually, we analyzed the clarity of the low-carbon commitments, the completeness of the social responsibility report, and the implementation of low-carbon development of the thermal power listed companies during the 13th Five-Year Plan period, and give scores to the selected indicators, to evaluate the governance provided by the companies in the process of transition, and further explore the company's low-carbon transition performance in terms of governance.

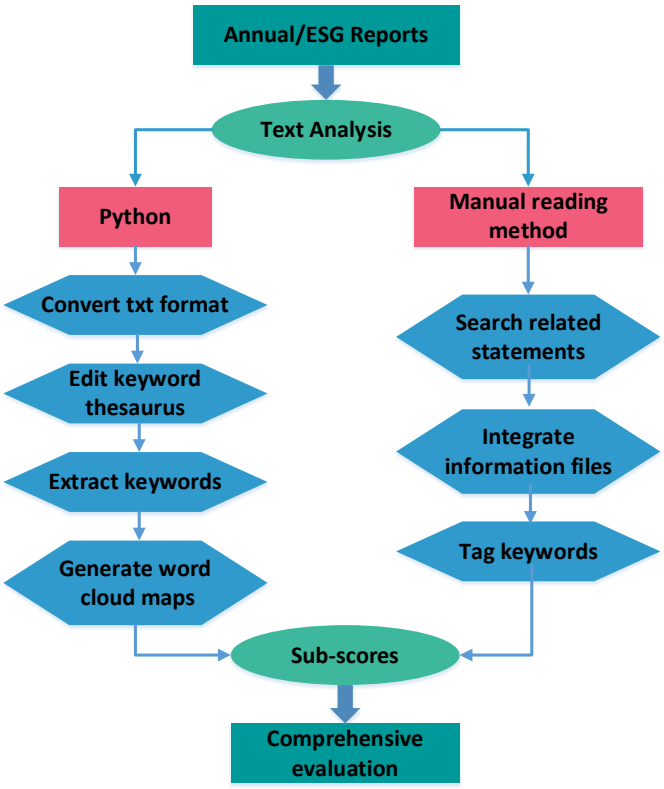

Figure 1 Qualitative data collection process

② Governance evaluation

The evaluation basis of the governance indicators selected in this study mainly includes three

dimensions, namely, the clarity of the low-carbon commitment, the completeness of the social responsibility report, and the implementation of low-carbon development. The details of the scores for these three dimensions are given as shown in Table 2, which are scored by the expert scoring method.

Table 2 Scoring rules for governance indicators

Evaluation dimension	Issue	Indicator	Indicator rules	Score	Total
Clarity of low-carbon commitment	Change in energy structure	Coal power transition	Retirement/shutdown/life extension	1	16
			Ultra-low emission retrofit	1	
			Flexibility modification/CCS/CCUS	1	
			High-parameter, high-efficiency, large-capacity coal power	1	
			Combined heat and power (CHP)	1	
		Developing clean energy	Wind/solar/hydro /nuclear/biomass	5	
	Business model innovation	New business areas	Hydrogen	1	
			Energy storage	1	
			Integrated energy	1	
			Distributed energy	1	
	Low-carbon development drivers	Technology retrofits and innovation		1	
		Energy saving and emission reduction plans		1	
Completeness of Social Responsibility Report	Transparency	Information availability	Publication of independent reports	1	21
			Reporting references	1	
		Completeness	Disclosure standards index table is available	1	
			Scope of disclosure	1	

			consistent with financial reporting		
		Balanced	Standardize the disclosure of information on penalties	1	
		Substantive	Substantive issue disclosure and analysis	1	
		Quantitative comparability	Provide a 3-year key quantitative performance table	1	
			Disclosure of the calculation methodology of key quantitative performance metrics	1	
		Reliability	Uses third-party certification	1	
			Board responsibility for ESG governance	1	
		Annual report disclosure	Environmental penalty disclosure	1	
			Excess emissions disclosure	1	
			Carbon emissions disclosure	1	
			Poverty eradication and rural revitalization	1	
			Social responsibility disclosure	1	
		Exchange disclosure rating	Exchange disclosure rating	1	
	Climate change response disclosure index	Identification of transition risks	Identification of transition risks	1	
			Policy and legal risk	1	
			Technology risk	1	
			Market risk	1	
			Reputation risk	1	
Implementation	Change in	Coal power	Retirement/shutdown/life	1	16

of low-carbon policies	energy structure	transition	extension	
			Ultra-low emission retrofit	1
			Flexibility modification /CCS/CCUS	1
			High-parameter, high-efficiency, large-capacity coal power	1
			Combined heat and power (CHP)	1
		Developing clean energy	Wind/solar/hydro /nuclear/biomass	5
	Business model innovation	New business areas	Hydrogen	1
			Energy storage	1
			Integrated energy	1
			Distributed energy	1
	Low-carbon development drivers	Effectiveness of technology retrofits and innovation		1
		Effectiveness of energy saving and emission reduction plans		1

*Note: The clarity of low-carbon commitment includes three topics: energy structure change, business model innovation, and low-carbon development dynamics, while the indicators include clean utilization of coal power, development of clean energy, new business models, technological retrofits and innovation, as well as energy conservation and emission reduction plans. The main ways of clean utilization of coal power include retirement, shutdown, life extension, ultra-low emission retrofit, flexibility retrofit, CCS or CCUS retrofit, and the development of high-parameter, high-efficiency, and large-capacity coal power. Clean energy includes wind power, solar power, hydropower, nuclear power, and biomass, and the new business areas mainly refer to hydrogen energy, energy storage, distributed energy, integrated energy, etc.

The main ways to develop clean coal power and clean energy, as well as the new business areas mentioned above, are set as the keywords and criteria for scoring points, and “technological innovation”, “energy saving and emission reduction” and their related terms are also set as

keywords, and points will be given to those who mention related initiatives and terms in conjunction with the disclosed data. Since there is no preference given to the type of clean energy developed, so long as a listed company develops one or more types of clean energy such as wind, solar, hydro, nuclear, biomass, etc., it is regarded as a company concerned with the development of clean energy. As such, the item is scored in parallel, and a full score of 5 points is given to the item for the sake of uniformity, while the full score of all other items are 1 point. The retirement, shutdown, and life extension scores are assigned by combining the data of coal power units belonging to each listed thermal power company with relevant keywords. The scoring rules for the implementation of low-carbon development are the same, and the relevant data are compared with the low-carbon commitment data, and the specific scoring rules and standards are shown in Table 3.

Table 3 Detailed scoring criteria for indicator evaluation

Indicator rules	Scoring criteria	Score
Clarity of low-carbon commitment		
Retirement/shutdown/life extension	Mentions retirement/shutdown/life extension, including early retirement of units (during the 13th Five-Year Plan period)	1
	Mentions normal decommissioning of units, though no mention of early retirement/shutdown (during the 13th Five-Year Plan period)	0.8
	Keywords are mentioned, but the number or capacity of decommissioned units is not mentioned	0.5
Ultra-low emission retrofit	Mentions specific data on ultra-low emission retrofit units	1
	General references to ultra-low emission retrofit	0.5
	No mention of ultra-low emission retrofit	0
Flexibility retrofit /CCS/CCUS	Mentions specific data on flexibility retrofit /CCS/CCUS	1
	General references to flexibility retrofit/CCS/CCUS	0.5
	No mention of flexibility retrofit /CCS/CCUS	0
High-parameter, high-efficiency, large-capacity coal power	Mentions specific data on the development of high-parameter, high-efficiency, large-capacity coal power	1
	General references to high-parameter, high-efficiency, large-capacity coal power	0.5
	No mention of high-parameter, high-efficiency, large-capacity coal power	0
Combined heat and power (CHP)	Mentions specific data on combined heat and power	1
	General references to combined heat and power	0.5

	No mention of combined heat and power	0
Wind/solar/ hydro /nuclear/biomass	Mentions specific data on wind/solar/ hydro /nuclear/biomass	5
	General references to wind/solar/ hydro /nuclear/biomass	2.5
	No relevant information on the development of clean energy is mentioned	0
New business areas (hydrogen/ stored energy/ integrated energy/ distributed energy)	Mentions specific development data on the development of new business areas	1
	General references to new business areas	0.5
	New business areas are not mentioned	0
Technological innovation/energy conservation and emission reduction	Mentions specific data on technological innovation/energy conservation and emission reduction	1
	General references to technological innovation/energy conservation and emission reduction	0.5
	No mention of technological innovation/energy conservation and emission reduction	0
Implementation of low-carbon systems/policies		
Retirement/shutdown/life extension	Mentions retirement/shutdown/life extension and early retirement of units (during the 13th Five-Year Plan period)	1
	Mentions normal decommissioning of units, though no mention of early retirement/shutdown (during the 13th Five-Year Plan period)	0.8
	There are units that have reached the end of their lifetime that have not been retired (during the 13th Five-Year Plan period)	0.5
Ultra-low emission retrofit	Completed ultra-low emission retrofit target, and gives specific data	1
	Gives ultra-low emission retrofit data but did not meet the target	0.8
	General references to ultra-low emission retrofit	0.5
	Ultra-low emission retrofit was not mentioned	0
Flexibility modification	Completed flexibility retrofit/CCS/CCUS target, and gives	1

/CCS/CCUS	specific data	
	Gives flexibility retrofit /CCS/CCUS data but did not meet the target	0.8
	General references to flexibility retrofit /CCS/CCUS	0.5
	Flexibility retrofit/CCS/CCUS was not mentioned	0
High-parameter, high-efficiency, large-capacity coal power	Completed high-parameter, high-efficiency, large-capacity coal power target, and gives specific data	1
	Gives high-parameter, high-efficiency, large-capacity coal power data but did not meet the target	0.8
	General references to high-parameter, high-efficiency, large-capacity coal power	0.5
	High-parameter, high-efficiency, large-capacity coal power is not mentioned	0
Combined heat and power (CHP)	Completed combined heat and power target, and gives specific data	1
	Gives combined heat and power data but did not meet the target	0.8
	General references to combined heat and power	0.5
	Combined heat and power is not mentioned	0
Wind/solar/ hydro /nuclear/biomass	Completed wind/solar/ hydro /nuclear/biomass target, and gives specific data	5
	Give wind/solar/ hydro /nuclear/biomass data but did not meet the target	4
	General references to wind/solar/ hydro /nuclear/biomass	2.5
	No relevant information on the development of clean energy is mentioned	0
New business area (hydrogen/ stored energy/ integrated energy/ distributed energy)	Completed new business area target, and gives specific data	1
	Gives new business area data but did not meet the target	0.8
	General references to new business area	0.5
	New business area is not mentioned	0
Technological innovation/energy conservation and	Completed technological innovation/energy conservation and emission reduction target, and gives specific data	1
	Gives technological innovation/energy conservation and	0.8

emission reduction	emission reduction data but did not meet the target	
	General references to technological innovation/energy conservation and emission reduction	0.5
	Technological innovation/energy conservation and emission reduction is not mentioned	0

The assessment of the completeness of the social responsibility report includes whether a stand-alone social responsibility report or sustainability report is issued and whether the information disclosed in the report is adequate. The report refers to the ESG environmental performance evaluation index provided by Qingyue Data, and selects the transparency and climate change response disclosure index as the topic of the completeness of the social responsibility report, integrating its existing evaluation results and relevant data, with each indicator of "Completeness of Social Responsibility Report" in the above table corresponding to 1 point, and disclosure of relevant information given an extra point.

3 Evaluation grading

The evaluation grading is divided into 5 levels: ★★★★★, ★★★★½ , ★★★★, ★★★½ and ★★★. An arithmetic progression is established with a tolerance (d) calculated as (max-min)/5. Each term of the arithmetic progression serves as the minimum value for the classification of each level. The low carbon transition index (LCTI), transition progress(C1), financial support (C2), technology investment (C3) and governance(C4), which within the two intervals is rated in the corresponding grade, and the specific evaluation grades are divided as follows:

Term	Basis of division	Grade
a_1=max		
min		
d=(max-min)/5		
a_2= a_1-d	a_2< LCTI/C1/C2/C3/C4 ≤a_1	★★★★★
a_3= a_2-d	a_3< LCTI/C1/C2/C3/C4 ≤a_2	★★★★½
a_4= a_3-d	a_4< LCTI/C1/C2/C3/C4 ≤a_3	★★★★
a_5= a_4-d	a_5< LCTI/C1/C2/C3/C4 ≤a_4	★★★½
a_6= a_5-d	a_6≤ LCTI/C1/C2/C3/C4 ≤a_5	★★★