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APPLICATION OF DECISION TREE AND RELATIVE PROXIMITY TO EVALUATION OF SUSTAINABLE DEVELOPMENT CAPACITIES OF LISTED ELECTRIC POWER COMPANIES

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Abstract. In a complex market environment with fierce competition, maintaining their current market positions is an important issue for electric power companies. Sustainable development not only requires them to pay attention to their current operating efficiencies but also to actively participate in environmental and social responsibilities to maintain their competitive advantages. This paper proposes a model for evaluating the sustainable development capacities of power companies. Firstly, the preliminary evaluation indicator system is constructed with the seven dimensions of production safety, public relations and social welfare, shareholder rights protection, environmental sustainability, employee rights protection, scientific research innovation ability, and financial status. Then, specific financial indicators are selected by CART to avoid indicator redundancies and the final evaluation indicator system is constructed. Finally, the relative proximity calculated by the TOPSIS method is applied to evaluate the sustainable development capacities. An empirical study of 18 listed electric power companies is conducted to verify the evaluation model. The results show that the performances of these companies in production safety and environmental sustainability are generally satisfactory, but the overall performances in public relations and social welfare, employee rights protection, and scientific research innovation ability are relatively poor, so these dimensions should be strengthened.

Keywords: sustainable development, listed electric power companies, sustainability indicators, feature selection, CART decision tree, relative proximity.

JEL Classification: M41, C83, L20.

Introduction

For long-term survival and sustainable development, enterprises must not only achieve short-term business goals by improving operating efficiency but must also actively assume environmental and social responsibilities to flourish in competitive and expanding busi-

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ness environments (Buchholz et al., 2020). Listed electric power companies include power supply companies, power generation companies, power construction companies, and power equipment manufacturing companies. Compared with companies in other industries, power companies face more risks of environmental pollution, equipment accidents, and personnel accidents. Such risks influence their sustainable development. As suppliers of energy and important participants in social services, listed electric power companies must undertake responsibilities for the economy, environment, and society while pursuing operating efficiency. They must balance their corporate economic profits and social responsibilities. Such a balance is the only way to realize both their own sustainable development (Peñalvo-López et al., 2019) and the sustainable development and efficient operation of the national power industry.

Evaluations of the sustainable development capacities of listed electric power companies are of far-reaching significance to themselves, their investors (Bunget et al., 2020), and their countries (Popović et al., 2019), because such evaluations would help these companies to optimize their internal structures and achieve longer-term economic growth, their investors to select those companies with longer-term and more reliable incomes, and their countries to achieve higher-quality and sustainable development of their ecologies and economies. Such evaluations must consider economic, environmental, social, and governance factors. Current research on the evaluation of corporate sustainability has focused on corporate social responsibility but has failed to consider operating efficiency (Casarejos et al., 2016) and incorporate feature selection. Hence, the current evaluation indicator system is too complex and optimization cannot be realized.

This paper proposes an evaluation system for the sustainable development capacities of listed electric power companies. It has been constructed with the seven dimensions of production safety, public relations and social welfare, shareholder rights protection, environmental sustainability, employee rights protection, scientific research innovation ability, and financial status. Multiple dimensions allow for a more comprehensive, concise, and efficient system that can assist investors in making reasonable investment decisions, promote higher-efficiency and higher-quality company operations, and develop national environments and economies sustainably. The relative proximity, which is calculated by the technique for order preference by similarity to an ideal solution (TOPSIS), is used for evaluation and a decision tree is used to select specific financial indicators for a more optimized system.

The structure of this paper is as follows. The first section discusses the literature on the evaluation indicators of sustainable development and comprehensive evaluation methods. The second section introduces our evaluation model, which is based on CART decision tree and relative proximity. The next section discusses 18 listed electric power companies and the evaluation results. Finally, the conclusions and limitations of our study, as well as directions for future research, are presented.

1. Literature review

1.1. System of sustainable development evaluation indicators

Sustainable development can be considered as a strategy for enterprises to balance economic profits, environmental and social responsibilities, and other interests. Economic, environmental, social, and governance factors need to be considered. There are many studies on the evaluation of corporate sustainable development capacity and the construction of evaluation indicator systems.

For ordinary enterprises, sustainable development indicator systems have been constructed with the three dimensions of economy, environment, and society. Jiang et al. (2018) proposed such a three-dimensional assessment model that used principal component analysis to evaluate sustainable corporate performance. Engida et al. (2018) discussed and evaluated a method based on a combination of principal component analysis and data envelopment analysis for developing a composite indicator of corporate sustainability, whose basic indicators were environment, society, and governance. Mainali and Silveira (2015) constructed an energy technology sustainability indicator system with the five dimensions of technology, economy, society, environment, and management institutions. The system also considered energy availability, capital investments and carbon dioxide emissions. Dočekalová and Kocmanová (2016) proposed a complex performance indicator (CPI) model that integrated a company's environmental, social, economic, and corporate governance performance.

There is also some research on the sustainability evaluation of power industry. Wang et al. (2021) evaluated and analyzed the sustainability of five power generation subsectors comprehensively considering economic, environmental, technological, and social dimensions. Saraswat and Digalwar (2021) constructed an indicator system from economic, technical, environmental, social, political, and flexible factors for the sustainability evaluation of energy sources in India. Sarangi et al. (2019) established evaluation indexes from three aspects: economy, environment, and society, and equal weight was set to economic, environmental, and social indexes to assess the sustainability of India's power systems. Liu and Chen (2017) established a fuzzy comprehensive evaluation indicator system from six dimensions: power generation, transmission, transformation, distribution, power consumption, and dispatch. Despite the wealth of research on corporate sustainability evaluation, only a few studies of listed electric power companies are available.

1.2. Comprehensive evaluation methods

Comprehensive evaluation includes qualitative and quantitative methods. Quantitative evaluation methods include the analytic hierarchy process, fuzzy comprehensive evaluation, gray relational analysis, and methods based on goal planning, such as TOPSIS and data envelopment analysis (DEA).

Fuzzy comprehensive evaluation, grey relational analysis, and the TOPSIS method are widely used for comprehensive evaluations of certain performance aspects of enterprises. Liu (2014) used an improved DEA to establish a corporate environmental performance evaluation index system. Tseng et al. (2019) combined factor analysis with the fuzzy comprehensive evaluation method to evaluate the sustainable development performance of enterprises. Aras et al. (2018) applied content analysis, the entropy method, and the TOPSIS method to evaluate sustainable performance.

For power companies, comprehensive evaluation has always been an important research tool. Researchers have applied a variety of comprehensive evaluation methods to the evaluation of them. Niu et al. (2018) constructed a three-level indicator system, then improved the TOPSIS method to evaluate the operational efficiencies of power enterprises. Liu et al. (2019) established an index system with the dimensions of technical performance and economic benefits, then applied the information entropy and fuzzy analysis methods to evaluate the investment benefit of the distribution network. Wang et al. (2014) established a demand-side response resource value index system, used the entropy method to calculate its overall weight, and applied the TOPSIS method with improved gray correlation to evaluate the value of a demand-side response resource at a specific location. Li et al. (2012) applied the TOPSIS and gray correlation degree methods to establish an investment benefit evaluation model.

The entropy method is widely used in comprehensive evaluations as an objective method for weight determinations for indicator systems (Wang et al., 2014). Proximity is an index reflecting the degree of closeness between fuzzy sets. Compared with the weighted arithmetic average method, proximity can more directly reflect the position of the object in the overall evaluation. Compared with absolute proximity, relative proximity considers both the optimal solution and the worst solution, thus reflecting the situation of the object more accurately (Li et al., 2013). The current study combines the entropy method and relative proximity calculated by the TOPSIS method to evaluate the sustainable development capacities of listed electric power companies.

1.3. Feature selection

Feature selection is the process of selecting the most effective features from massive features to reduce the dimensionality of the feature space and improve prediction performance, reduce calculation times, and avoid the limitations of dimensionality. There are three types of feature selection methods: filtering, wrapper, and hybrid (Yao et al., 2012). The filtering method has nothing to do with the subsequent learning algorithm and directly selects features according to the statistical performance of all training data. Based on mutual information, Peng et al. (2005) proposed minimal-redundancy-maximal-relevance criterion (mRMR) for first-order incremental feature selection at very low cost.

The wrapper method uses feature selection as part of the model training process and model training accuracy to evaluate feature subsets with small deviations. Ciabattoni et al. (2015) proposed a univariate filter method based on the Bayes error rate for feature selection in fault detection. Srivastava et al. (2019) proposed a novel feature selection method based on a price prediction decision tree. This method used genetic algorithms and decision tree classifiers to obtain the smallest number of features for the best prediction accuracy.

Among the commonly used algorithms for wrapper feature selection, decision trees are classified according to tree structures, which are easy to understand and have high interpretability. Compared with ID3 and C4.5, a classification and regression tree (CART) can process continuous values with higher processing efficiency and accuracy. The rules are easier to understand because binary trees are used for classification. CART is suitable for feature selection, but few studies have used them in the construction of evaluation indicator systems. The relevant research are combed from three dimensions, and detail information is shown in Table 1.

Table 1. Literature reviewd

About	Author	Content	Year
Sustainable development evaluation indicators	Mainali, Silveira	Constructed an energy technology sustainability indicator system incorporating technology, economy, society, environment, and management institutions	2015
	Liu, Chen	Established an evaluation indicator system for power grids incorporating power generation, transmission, transformation, distribution, power consumption, and dispatch	2017
	Engida et al.	Developed a composite indicator of corporate sustainability including environment, society, and governance	2018
	Wang et al.	Evaluated the sustainability of five power generation subsectors comprehensively considering economic, environmental, technological, and social dimensions	2021
Evaluation methods	Li et al.	Applied the TOPSIS and gray correlation degree methods to establish an investment benefit evaluation model	2012
	Aras et al.	Applied content analysis, the entropy method, and the TOPSIS method to evaluate sustainable performance	2018
	Liu et al.	Established an index system based on the information entropy and fuzzy analysis methods	2019
	Tseng et al.	Combined factor analysis with the fuzzy comprehensive evaluation method to evaluate sustainable development performance of enterprises	2019
Feature selection	Peng et al.	Proposed minimal-redundancy-maximal-relevance criterion (mRMR) for feature selection	2005
	Ciabattoni et al.	Proposed a univariate filter method based on the Bayes error rate for feature selection in fault detection	2015
	Srivastava et al.	Proposed a novel feature selection method based on a price prediction decision tree	2019

It can be found that there have been some research attempts for the sustainability evaluation of power industry, but few studies are aimed at listed electric power companies. In addition, most studies subjectively select the important financial indicators from a large number of financial indicators, and do not use a more objective way to select them. Based on these problems, the CART decision tree is adopted to select the financial indicators, and the sustainability evaluation model for the listed electric power companies is constructed.

2. Evaluation approach

As shown in Figure 1, an evaluation model based on CART decision tree and relative proximity is constructed. Firstly, the preliminary evaluation indicator system is constructed with seven dimensions. Then, the CART is used to select financial indicators for avoiding redundancy and the final evaluation indicator system is constructed. Finally, the relative proximity is calculated by the TOPSIS method and applies to evaluate the sustainable development capacities of the listed electric power companies. In the indicator construction stage, the appropriate financial indicators are selected through feature selection, which can select the indicators that are truly important to sustainable development. The indicators of the other six dimensions are selected on the basis of the suggestions of some related studies and authoritative reports. These indicators cover many aspects of power companies.

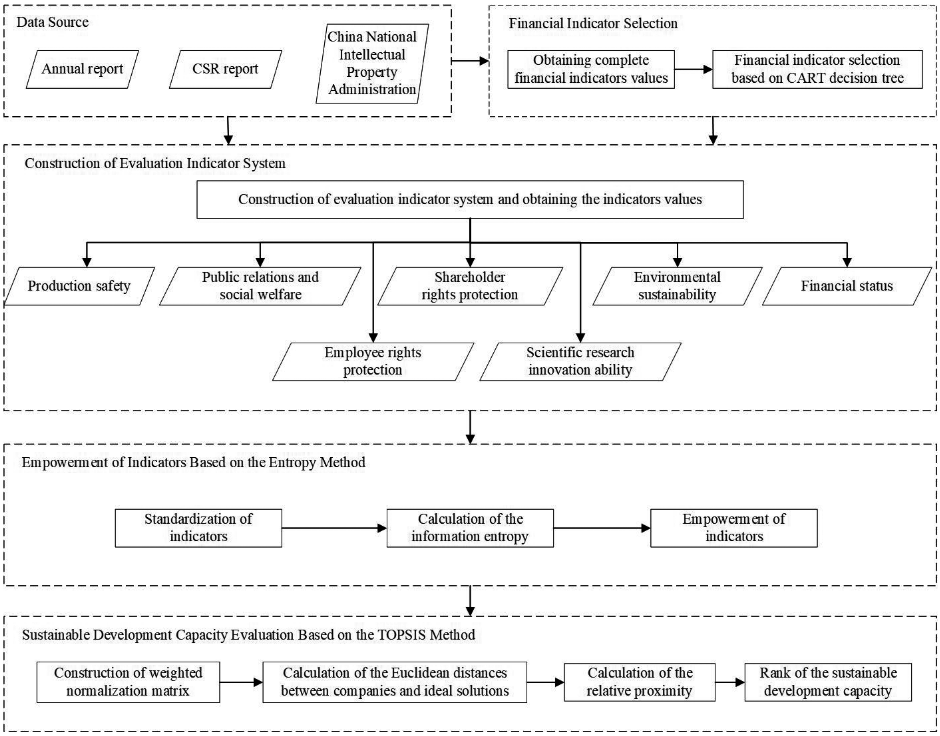

Figure 1. Evaluation model of sustainable development capacities of listed electric power companies based on CART decision tree and relative proximity

2.1. Construction of evaluation indicator system for sustainable development capacities of listed electric power companies

Using the basic principles of the indicator system and the actual operating conditions of the listed electric power companies, a two-level comprehensive evaluation indicator system is constructed with the seven dimensions, which are explained in detail in the following sections.

2.1.1. Production safety

Poor occupational safety and health performance can impact on corporate reputation and lead to competitive disadvantage through impairing a company's status in the eyes of its stakeholders (Smallman & John, 2001). The production processes of electric power companies are complex and systemation. Safety incidents have a bad impact on its businesses. Thus, this paper takes production safety as an influential factor in the sustainable development of companies and describes the four features of the production safety status of an enterprise.

Work-related accidents: occurring suddenly during operations,they threaten the safety and health of personnel, damage equipment and facilities, cause economic losses. The two types of such accidents are major work-related accidents and general work-related accidents.

Equipment-related accidents: cause direct economic losses that exceed the regulations and abnormal damages that result in the suspension or reduction of the operational efficiencies of industrial equipment and facilities. The two types of such accidents are major equipment-related accidents and general equipment-related accidents.

Pollution-related accidents: the environment is damaged because of economic or social activities and behaviors that violate environmental regulations or because of unexpected factors. This study uses the number of pollution-related accidents.

Casualties: the numbers of injuries and fatalities caused by all the abovementioned types of accidents during the operation of an enterprise.

2.1.2. Public relations and social welfare

A company's external environment has a direct or an indirect impact on its development. An excellent company must have a good sense of responsibility and actively participate in social welfare to acquire a good corporate image, build good relations with the public, and obtain continuous momentum for sustainable development. Social welfare participation and tax status are used to measure a company's performance in corporate social responsibility.

Social welfare participation: according to some research, corporate donations not only help investors to form a positive view of the enterprise (Brammer & Millington, 2005), but also have a positive impact on the value of the enterprise (Hategan & Curea-Pitorac, 2017; Houqe et al., 2021). Active participation can improve a company's public image and sustainable development. This study uses the targeted poverty alleviation amount and the number of registered persons lifted out of poverty as indicators of social welfare participation. The former is used to measure the actual investments made by companies in public welfare activities, whereas the latter is used to measure the actual achievements of these activities.

Tax status: income tax ratio, i.e., the ratio of income tax to total profit, is used to reflect a company's tax status. A higher ratio indicates the stronger willingness of a company to pay its taxes and fulfill its social responsibilities, thus reflecting a better sustainable development capacity.

2.1.3. Shareholder rights protection

Shareholder relationships are important to an enterprise as good relationships can win the understanding, trust, and support of existing and potential investors, as well as create a more favorable investment environment, stabilize the existing shareholder team, and attract more investors. Such conditions can promote the sustainable development of a company. Shareholder rights include the right to know, participate in decisions, and vote.

Right to know: information disclosure is an important basis for investors to judge a company's intrinsic value and make investment decisions, thus helping to decrease the information asymmetry between managers and investors, reduce the risks undertaken by investors when predicting the company's future earnings, enhance their confidence in the company, and promote the company's sustainable development.

Decision-making and voting rights. Brown et al. (2011) believed that adverse selection, moral hazards, and moral corruption were important to corporate stakeholders. General shareholder meetings can guarantee their rights to participate in corporate decision-making, improve corporate governance, and promote sustainable development. Another important institution of a company, the board of directors, is also important to the levels of corporate governance and sustainable development.

2.1.4. Environmental sustainability

With the rapid development of the economy, environmental pollution has been attracting more attention. To maintain the sustainable development of the environment, the Chinese government has promulgated a series of ecological and environmental protection policies, implemented clear environmental protection regulations, and strengthened the monitoring of pollution emissions. Hence, reducing such emissions through technical means is the top priority of electric companies. Pollutant emissions are used as an important indicator to reflect the environmental sustainability of enterprises.

Pollutant emissions: the amount of pollutant emissions can be used to measure the degree of damage caused by business operations to the environment. Following Dočekalov and Kocmanová (2016), this study uses emissions of soot, SO2, and NOx to measure pollutant gas emissions and reflect the environmental sustainability of listed electric power companies.

2.1.5. Employee rights protection

Employee rights refers to various legal rights and interests that include the rights to labor remuneration, social insurance and welfare, vocational skills training, and personal protection in the workplace. Such protection can fully mobilize the enthusiasm, creativity, and joint efforts of its employees to realize corporate objectives and provide internal guarantees for its sustainable development. According to the research of Staniškienė and Stankevičiūtė (2018), employee equal opportunities, employee development, health and safety are important for social sustainability evaluation of an organisation. Thus, salaries and benefits, labor security, and humanistic care are used to measure this dimension.

Salaries and benefits: indicated by average monthly employee salary and the number of trainees. The average monthly employee salary is calculated by the ratio of the company's total salary expenditures to the number of employees.

Labor security: measured by labor contract and social insurance coverage rates. The former refers to the proportion of a company's employees who have signed labor contracts, whereas the latter refers to the proportion with social insurance.

Humanistic care: the spiritual and material support provided by a company to its employees. Such support can enhance the employees' sense of belonging, improve their cohesion, create a good corporate culture, and help achieve sustainable development. The availability of a consolation fund for needy employees is used to reflect this dimension.

2.1.6. Scientific research innovation ability

Scientific research innovation ability refers comprehensively to an enterprise's capacity for invention and innovation in a certain field. Innovation is the main driving factor for the sustainable development of an enterprise. For electric power companies, scientific innovation is extremely important to accomplish low-pollution, low-consumption, and high-value-added production, thus achieving sustainable development. This dimension is measured by the following four aspects.

R&D investments: as per Xiao et al. (2020) on the evaluation of an enterprise's innovation ability, R&D investments are important to scientific research innovation ability. The proportion of R&D investments out of the total operating expenditure is selected to measure the investment intensity of the enterprise innovation activity.

Applied Patents: as an organic entity composed of sets of resources, an enterprise can maintain its competitive advantage for a long period of time if it owns or controls special resources that are difficult to imitate (Wernerfelt, 1984). Patents are special resources and key elements for innovation capacity. The annual number of applied patents of an enterprise is used to measure its capacity for innovation.

Granted patents: the annual number of patents granted reflects an enterprise's ability to create patents and maintain sustainable development.

Patent quality: According to the relevant provisions in China, patents can be divided into utility model patents, design patents, and invention patents. With higher scientific and technological contents and values, the last requires lengthier review processes, so they are more difficult to grant. The proportion of invention patents in total patents granted in the current year is used to measure the quality of an enterprise's patents.

2.1.7. Financial status

A company's financial status is the most important manifestation of its operating conditions, as it reflects its operating status, future sustainable development capabilities, and resilience in the face of emergencies. Wang et al. (2021) included average profit, average debt ratio and average total assets in the sustainability assessment. In addition, research shows that there is a virtuous circle between sustainable practice and financial status. A good financial situation can engage in more sustainable development practices and earn a good reputation for the enterprise (Martínez-Ferrero & Frías-Aceituno, 2015). Since there are numerous financial indicators and the importance of them for sustainable development is unclear, we have incorporated the complete financial indicators into the consideration of the preliminary indicator system. In the next section 2.2, CART is used to select financial indicator to construct final evaluation indicator system.

2.2. Financial indicator selection based on CART decision tree

2.2.1. Complete financial indicators

This study obtains 18 financial indicators that are used as the input data: return on assets (ROA), return on equity (ROE), operating profit ratio, operating net profit rate, sales expense rate, management expense rate, ratio of net cash to net profit, inventory turnover ratio, flow ratio, quick ratio, asset-liability ratio, equity ratio, ratio of current liabilities to total assets, ratio of long-term liabilities to total assets, ratio of cash flow to total assets, price-earnings ratio, price to book ratio, and dividend ratio.

2.2.2. Label determination

The investable value of an enterprise can reflect its actual value to a certain extent, but it can also reflect the degree of the confidence of external investors in the enterprise's sustainable development capacity to a certain extent. The value of a commodity is the basis of its price, which, in turn, is the manifestation of its value. The price fluctuates around the value. Therefore, this study uses the stock price to reflect an enterprise's value. An annual increase in the stock price can reflect the confidence of the investors in the company's development and investable value.

Both the financial and non-financial information disclosed by listed companies are closely related to their stock prices and often serve as signals, which are important bases on which many stakeholders make decisions. In turn, investment activities affect the stock prices. To figure out what financial indicator have higher information value, many studies have focused on the correlation between the stock prices and corporate financial indicators (Feltham & Ohlson, 1995; Zhang et al., 2017), but most research applied the methods of correlation analysis and regression. This paper uses CART decision tree to select the financial indicators that can best reflect the investable values and sustainable development capacities of companies.

The annual increases in stock prices used in this study are the differences between the prices in the years 2019 and 2018. After the annual increases are calculated, the companies are ranked by the amounts of increases in descending order. The top one-third of companies with investable values are labeled with "1", whereas those with no investable value are labeled with "0". These labels are used as classifiers for the financial indicator selection.

2.2.3. Financial indicator selection

The CART decision tree is a binary tree splitting algorithm executed in two stages: generation and pruning. In the generation stage, the decision tree should be as large as possible. CART builds nodes from top to bottom and takes the Gini coefficient as the criterion for the selection of the attribute at each node. This attribute is a splitting attribute used to make the training sets in the child nodes as pure as possible. In the pruning stage, the pruning criterion is used in the originally generated decision tree to prune the tree model and the best tree is selected according to the prediction performance of the test set.

The Gini coefficient is explained as follows. For a data sample set D, the number is |D|. There are K categories and the number of the k-th category is $|C_k|$, so the Gini coefficient of sample D is:

$$Gini(D) = 1 - \sum_{k=1}^{K} \left(\frac{|C_k|}{|D|} \right)^2. \quad (1)$$

According to a certain value of feature A, D is divided into |D1| and |D2|. Under the condition of feature A, the Gini coefficient of sample D is:

$$Gini(D, A) = \frac{|D1|}{|D|} Gini(D1) + \frac{|D2|}{|D|} Gini(D2). \quad (2)$$

The complete financial data mentioned in Section 2.2.1 are used as the input data, the investable value is used as a label, a CART decision tree is used to select the financial indicators, the result of the financial indicator selection is used as the financial indicator part of the sustainability evaluation indicator system, and the financial data of 18 listed electric power companies in 2018 are used as the samples, of which 14 and 4 are used as train and test sets, respectively. The final generated decision tree is shown in Figure 2.

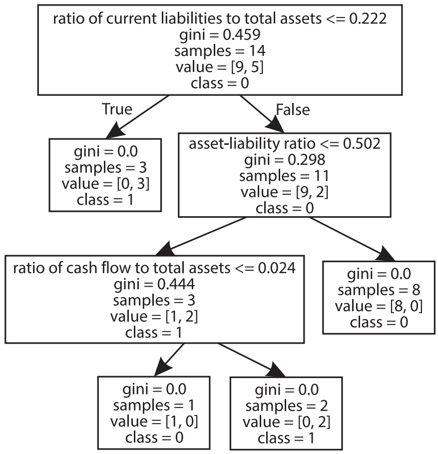

Figure 2. Financial indicator selection by CART decision tree

Asset-liability ratio, the ratio of cash flow to total assets, and the ratio of current liabilities to total assets are used to classify if the companies has investment values in the train set. The accuracy rate, recall rate, and F-value of the test set are all 100%. The classification effect is the best, so these three indicators are used as the final financial indicators for the sustainability evaluation. After financial indicator selection, final evaluation indicator system is constructed including 7 primary and 27 secondary indicators as shown in Table 2.

Table 2. Evaluation indicator system for sustainable development capacities of listed electric power companies

Primary indicators	Secondary indicators	Descriptions	Direction
Production safety	Number of major work-related accidents	Deaths of more than 10 people or direct economic losses of more than 50 million yuan	Negative
	Number of general work-related accidents	Deaths of fewer than 3 people or direct economic losses of less than 10 million yuan	Negative
	Number of major equipment-related accidents	Direct economic losses of more than 50 million yuan	Negative
	Number of general equipment-related accidents	Direct economic losses of less than 10 million yuan	Negative
	Number of pollution-related accidents	Pollution of air, water, etc.	Negative
	Number of casualties	Injuries and fatalities caused by all types of accidents.	Negative

End of Table 2

Primary indicators	Secondary indicators	Descriptions	Direction
Public relations and social welfare	Targeted poverty alleviation amount	Total amount used to help targeted poor people	Positive
	Annual number of registered persons lifted out of poverty	Annual number of people lifted of poverty	Positive
	Ratio of income tax to total profits	Percentage of income tax out of total profits	Positive
Shareholder rights protection	Annual number of public information disclosures	Annual reports, quarterly reports, temporary announcements, etc.	Positive
	Annual number of general shareholder meetings	Number of shareholder meetings held per year	Positive
	Annual number of board meetings	Number of board meetings held per year	Positive
Environ-mental sustain-ability	Annual emissions of soot	Annual amount of soot discharged	Negative
	Annual emissions of SO_2	Annual amount of SO_2 discharged	Negative
	Annual emissions of NO_x	Annual amount of NO_x discharged	Negative
Employee rights protection	Average monthly employee salary	Average monthly employee salary, including basic wages and bonuses	Positive
	Annual number of trainees	Number of employees participating in safety, vocational, and related training activities per year	Positive
	Labor contract coverage rate	Ratio of number of employees with labor contracts to total number of employees	Positive
	Social insurance coverage rate	Ratio of number of employees with insurance coverage to total number of employees	Positive
	Consolation fund for needy employees	Total amount of money given to needy employees	Positive
Scientific research innovation ability	Proportion of R&D investment	Ratio of R&D investment to total operating cost	Positive
	Annual number of applied patents	Number of patents applied this year	Positive
	Annual number of granted patents	Number of patents granted this year	Positive
	Patent quality	The proportion of invention patents in total patents granted this year	Positive
Financial status	Asset-liability ratio	Percentage of total liabilities out of total assets	Negative
	Ratio of cash flow to total assets	Percentage of cash flow out of total assets	Positive
	Ratio of current liabilities to total assets	Percentage of current liabilities out of total assets	Negative

2.3. Comprehensive evaluation of sustainable development capacities of electric power companies by relative proximity

2.3.1. Empowerment of sustainable development capacity evaluation indicators by entropy method

After the indicator system for the evaluation of sustainable development capacities is constructed, the entropy method is used to determine the weights of the evaluation indicators. The empowerment process of the evaluation indicators by the entropy method is:

1. Construction of evaluation matrix

$$X = \begin{bmatrix} x_{11} & \cdots & x_{1n} \\ \cdots & \cdots & \cdots \\ x_{m1} & \cdots & x_{mn} \end{bmatrix}, \tag{3}$$

where x_{mn} represents the value of the n-th indicator of the m-th power company.

2. Standardization of indicators

Different indicators have different indicator directions. For positive and negative indicators, larger and smaller values, respectively, indicate the greater ability of a company for sustainable development. Hence, different methods should be adopted for different indicators to standardize the latter. The specific standardization methods are:

For positive indicators, set $$b_{ij} = \frac{x_{ij} - \min(x_j)}{\max(x_j) - \min(x_j)}; \tag{4}$$

For negative indicators, set $$b_{ij} = \frac{\max(x_j) - x_{ij}}{\max(x_j) - \min(x_j)}. \tag{5}$$

3. Calculation of the information entropy of each evaluation indicator

$$H_j = -\frac{1}{\ln \mathrm{m}} \sum_{i=1}^{i=m} f_{ij} \ln f_{ij}; \tag{6}$$

$$f_{ij} = \frac{\mathrm{b}_{ij}}{\sum_{i=1}^{i=m} \mathrm{b}_{ij}}, \tag{7}$$

where H_j is the information entropy.

4. Empowerment of evaluation indicators

$$w_j = \frac{1 - H_j}{\sum_{j=1}^{j=n} (1 - H_j)}, \tag{8}$$

where w_j is the weight of the j-th evaluation indicator.

2.3.2. Comprehensive evaluation of sustainable development capacity by relative proximity calculated by TOPSIS method

Commonly used in multi-objective decision analysis, relative proximity is the ratio of the distance between the evaluation object and the worst solution, and the sum of the distance between the evaluation object and the best and worst solution. The TOPSIS method is used to calculate the relative proximity.

1. Construction of weighted normalization matrix

$$r_{ij} = w_j \cdot b_{ij}, \tag{9}$$

where w_j is the weight of the *j*-th evaluation indicator and r_{ij} is the normalized value of the *j*-th indicator of the *i*-th power company.

2. Determination of the absolute positive and negative ideal solutions

The raw data of each indicator have been standardized to a number between 0 and 1. The closer an indicator's value is to 1, the stronger is the company's capacity for sustainable development. The absolute positive or negative ideal solution is for all indicators' values to be at their maximum or minimum, respectively:

$$\mathrm{r}^+ = \max(\{r_{\mathrm{ij}} \mid i = 1,2,\cdots,m\}, j = 1,2,\cdots,n); \tag{10}$$

$$\mathrm{r}^- = \min(\{r_{\mathrm{ij}} \mid i = 1,2,\cdots,m\}, j = 1,2,\cdots,n), \tag{11}$$

where r^+ and r^- are the absolute positive and negative ideal solutions, respectively.

3. Calculation of the Euclidean distances between sustainable development capacity and the absolute ideal solutions

$$D^+ = \sqrt{\sum_{j=1}^{n} (\mathrm{r}^+ - r_{ij})^2}\ ; \tag{12}$$

$$D^- = \sqrt{\sum_{j=1}^{n} (\mathrm{r}^- - r_{ij})^2}\ , \tag{13}$$

where D^+ and D^- are the distances for the positive and negative solutions, respectively.

4. Calculation of the relative proximity of the sustainable development capacity:

$$S_i = \frac{D^-}{D^+ + D^-}, \tag{14}$$

where S_i is the relative proximity of the sustainable development capacity.

5. Ranking of the sustainable development capacities of listed electric power companies

The value of the relative proximity is the score of the sustainable development capacity. The ranking is based on the value of S_i. The larger the value, the higher is the sustainable development capacity.

3. Results and discussion

This study selects 18 listed electric power companies as samples to evaluate their sustainable development capacities. Sample enterprises includes Power Construction Corporation of China, HUANENG Power Intl Inc, Huadian Power International Co., Ltd, Hubei Energy Group Co., Ltd, etc, all of which plays an important role in ensuring people's livelihood and promoting economic development. This paper uses the content analysis method to read and analyze the annual report, social responsibility report and other documents of the 18 sample enterprises in 2018, and manually extracts the relevant index data. At the same time, the patent data of the sample enterprises are obtained from the China National Intellectual Property Administration through retrieval.

3.1. Empowerment of sustainable development capacity evaluation indicators based on entropy method

1. Construction of standardized judgment matrix

Since the values of the indicators are objective data, the distribution is scattered. To ensure the validity of the indicator weighting results by the entropy method, the values of the indicators need to be standardized by Eqs (4) and (5). The standardized judgment matrix is:

$$\begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 & \dots & 0.7417 \\ 1 & 1 & 1 & 1 & 1 & 1 & \dots & 0.7836 \\ 1 & 0.8571 & 1 & 1 & 1 & 0.8667 & \dots & 0.5589 \\ 1 & 1 & 1 & 1 & 1 & 1 & \dots & 0.4551 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \dots & \vdots \\ 1 & 1 & 1 & 1 & 1 & 1 & \dots & 0.9436 \end{bmatrix}.$$

2. Calculation of the information entropy of each evaluation indicator

The information entropy of each indicator is calculated by Eqs (6) and (7): H = (1.0000, 0.9800, 1.0000, 0.9802, 0.9802, 0.9800, 0.6586, 0.6725, 0.9378, 0.9387, 0.8953, 0.8936, 0.9664, 0.9677, 0.9623, 0.9436, 1.0000, 0.6662, 1.0000, 0.6708, 0.3617, 0.5176, 0.5035, 0.8059, 0.9396, 0.9441, 0.9656).

3. Empowerment of sustainable development capacity indicator

Eq. (8) is used for indicator weighting: w = (0.0000, 0.0052, 0.0000, 0.0051, 0.0051, 0.0052, 0.0883, 0.0847, 0.0161, 0.0158, 0.0271, 0.0275, 0.0087, 0.0084, 0.0097, 0.0146, 0.0000, 0.0863, 0.0000, 0.0851, 0.1650,0.1247, 0.1284,0.0502, 0.0156, 0.0145, 0.0089).

3.2. Comprehensive evaluation of sustainable development capacity by relative proximity

1. The Euclidean distances between the sustainable development capacities and absolute ideal solutions are calculated by Eqs (12) and (13) for the positive and negative solutions, respectively: D^+ = (0.2944, 0.2956, 0.2543, 0.2952, 0.2746, 0.3004, 0.2692, 0.2866,

0.2447,0.2997,0.2944, 0.1014, 0.2676, 0.3020, 0.2440, 0.3019, 0.2998, 0.3043); D^- = (0.0364, 0.0454, 0.1189, 0.0514, 0.0524, 0.0296, 0.0720, 0.0582, 0.1051, 0.0313, 0.0375, 0.2494, 0.1042, 0.0385, 0.1741, 0.0327, 0.0353,0.0289).

2. The relative proximities of the sustainable development capacities are calculated by Eq. (14): S = (0.1100, 0.1331, 0.3185, 0.1482, 0.1602, 0.0897, 0.2109, 0.1688, 0.3004, 0.0945, 0.1130, 0.7109, 0.2803, 0.1131, 0.4163, 0.0977, 0.1052, 0.0868).

3. These relative proximities are regarded as an overall evaluation result containing the seven dimensions. The companies are ranked by relative proximity in descending order, as shown in Table 3.

4. By the same method, the relative proximities of seven dimensions are calculated, as shown in Table 3.

Table 3. Evaluations of sustainable development capacities of 18 listed electric power companies

Listed electric power company	Overall result (seven dimensions)	Production safety	Public relations and social welfare	Shareholder rights protection	Environmental sustainability	Employee rights protection	Scientific research innovation ability	Financial status
A	0.7109	0.4974	0.9582	0.4331	0.9650	0.6269	0.7058	0.1617
B	0.4163	1.0000	0.0039	0.3914	0.9988	0.1047	0.4929	0.6201
C	0.3185	0.9047	0.3951	0.3419	0.1122	0.6967	0.1484	0.3582
D	0.3004	1.0000	0.2076	0.4304	0.0410	0.6003	0.2330	0.3531
E	0.2803	0.9516	0.1622	0.2250	0.6566	0.7261	0.0633	0.4003
F	0.2109	1.0000	0.4014	0.3020	0.7336	0.2277	0.1136	0.4217
G	0.1688	0.6356	0.2016	0.8726	0.8802	0.0893	0.0936	0.4902
H	0.1602	1.0000	0.0998	0.6585	0.9704	0.0850	0.1341	0.4652
I	0.1482	1.0000	0.0563	0.4130	0.9438	0.1107	0.1458	0.3300
J	0.1331	1.0000	0.2757	0.2722	0.9672	0.0393	0.0000	0.4254
K	0.1131	1.0000	0.0839	0.6565	0.9988	0.0558	0.0000	0.4300
L	0.1130	1.0000	0.0139	0.6421	0.8647	0.0760	0.0539	0.3989
M	0.1100	1.0000	0.1194	0.4261	0.9950	0.0889	0.0341	0.5064
N	0.1052	1.0000	0.1188	0.3212	1.0000	0.0358	0.0013	0.8731
O	0.0977	1.0000	0.0825	0.4592	0.9672	0.0211	0.0000	0.4959
P	0.0945	0.6299	0.1426	0.1923	0.9700	0.0638	0.0003	0.5462
Q	0.0897	1.0000	0.0000	0.0000	0.9215	0.0192	0.0836	0.3056
R	0.0868	1.0000	0.1100	0.1443	1.0000	0.0428	0.0000	0.5739

3.3. Analysis of the evaluation results for the sustainable development capacities of listed electric power companies

The analysis of the evaluation results is helpful not only for a systematic understanding of the sustainable development capacities of listed electric power companies but also for an understanding of the seven dimensions by providing a means for companies to compare themselves to each other, clarify their advantages and disadvantages, and continuously adjust business strategies and policies, maintain their advantages and overcome their disadvantages, and form healthy development trends. Table 4 shows the distribution of the evaluation scores of the sustainable development capacities by dimension.

Table 4. Distribution of evaluation scores by dimension

Dimension	Minimum	Maximum	Range	Average	Median	Variance	Skewness	Kurtosis
Production safety	0.4974	1.0000	0.5026	0.9233	1.0000	0.0252	–1.9960	2.6877
Public relations and social welfare	0.0000	0.9582	0.9582	0.1907	0.1191	0.0503	2.6095	8.1596
Shareholder rights protection	0.0000	0.8726	0.8726	0.3990	0.4022	0.0445	0.4074	0.4358
Environmental sustainability	0.0410	1.0000	0.9590	0.8326	0.9661	0.0847	–2.2529	4.2064
Employee rights protection	0.0192	0.7261	0.7068	0.2061	0.0869	0.0657	1.3825	0.1335
Scientific research innovation ability	0.0000	0.7058	0.7058	0.1280	0.0735	0.0352	2.2895	5.2501
Financial status	0.1617	0.8731	0.7114	0.4531	0.4277	0.0225	0.9711	3.0576

Production safety: the distribution of the evaluation scores is left-skewed, narrow, and concentrated. The overall performance of the companies is relatively good, but the secondary indicators of this dimension are less discriminative. The worst performer is A, which has experienced multiple work-related accidents and casualties, so it must pay more attention to this dimension.

Public relations and social welfare: right-skewed, wide, and relatively dispersed. The overall performance in this dimension is poor and the secondary indicators of this dimension are discriminative. The best performer is A, which is a responsible company that invested heavily in targeted poverty alleviation and helped the largest number of poor people in 2018. Probably due to its insufficient funds, Q is the worst performer and must pay more attention to this dimension.

Shareholder rights protection: right-skewed, wide. The overall performance is average and the secondary indicators have greater degrees of discrimination. The best performer is G, which disclosed many announcements and annual reports in 2018, whereas the worst performer is Q, which should disclose public information more often.

Environmental sustainability: left-skewed, wide and highly dispersed. The overall scores of this dimension are relatively high, but the performances are quite disparate. Most companies perform well but a very small number perform poorly. D is the worst performer with rather high levels of pollutant emissions, so it must reduce emissions by technological innovation and other methods while emphasizing pollution prevention. The "Report of Market Prospective and Investment Strategy Planning on China Environmental Protection In Electric Power Industry (2018–2023)" published by the Forward Business Information Co., Ltd., disclosed that the installation of desulfurization and denitrification equipment in the power environmental protection industry had ushered in rapid development since 2016. The development of flue gas desulfurization and dust removal was relatively mature. The proportion of new energy continues to increase and the power environmental protection industry is developing well.

Employee rights protection: right-skewed, relatively narrow, and dispersed. The overall performance is poor and there are no outstanding companies. The protection of employee rights should be strengthened. E is the best performer because it pays special attention to cultivating the abilities of its employees and protecting their rights to personal development.

Scientific research innovation ability: right-skewed, relatively narrow, and highly concentrated. The overall performance is poor, so this dimension should be improved. A performed the best with sufficient investments and the most granted patents in 2018, but there is still room for improvement. Many electric power companies have no R&D investments or granted patents. There are significant differences between the enterprises. The "Chinese Enterprise Innovation Capability Evaluation Report 2017" and the "2018 Chinese Enterprise Innovation Development Report" pointed out that the distribution of patents among enterprises was extremely unbalanced. Most companies had small numbers of granted patents and new energy companies had low levels of innovation.

Financial status: right-skewed, relatively narrow, and highly concentrated. The overall scores are average and the performances are similar. B performs the best, whereas A performs the worst.

In summary, the performances of the listed electric power companies in production safety and environmental sustainability are generally good, but the performances of a few companies seriously deviate from the normal in environmental sustainability. The overall performances in public relations and social welfare, employee rights protection, and scientific research innovation ability are relatively poor, so these dimensions should be strengthened. There are companies with relatively outstanding performances in public relations but none in scientific research and innovation. Our evaluation result is consistent with the published reports. Our proposed method has proved feasible for evaluating the sustainable development capacities of listed electric power companies.

Conclusions

This study proposes a model to evaluate the sustainable development capacities of listed electric power companies. 18 sample enterprises are selected as a case to verify the model's validity and practicability.

From the perspective of the design of the assessment model, compared with other studies, in the indicator construction stage, this study integrates financial indicators and non-financial indicators to build a complete sustainable development indicator system for listed electric power companies. The selection of financial indicators is based on future annual increases in stock prices, which is more consistent with the theme of sustainable development. In the overall evaluation stage, this study is based on the entropy TOPSIS method for the evaluation objective. The method has been evaluated on the basis of the actual data distribution, which is relatively objective and convenient for calculation.

From the perspective of the evaluation results, there are some differences in the overall performance of listed electric power companies in different dimensions. The overall performances in production safety and environmental sustainability are generally good, but in public relations and social welfare, employee rights protection, and scientific research innovation are relatively poor. According to that, power companies should take targeted measures, enhance employee care, actively fulfill social responsibilities and continuously invest in scientific research in the process of operation. Only in this way can electric power enterprises obtain sustainable competitiveness. For the country, we can pay more attention to the disadvantages and improve the sustainable development capacities of listed electric power companies as a whole.

This study can assist investors in making more reasonable investment decisions and encourage power companies to make their operations more efficient while promoting sustainable economic and environmental development. However, this study does have some limitations. Because the data are not readily available, the sample size of the listed electric companies is inadequate. Directions for future studies should use a larger sample for the application of this indicator system to evaluations of sustainable development capacities.

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Author contributions

All authors have contributed equally in this work.

Disclosure statement

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