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Evaluating the Low-Carbon Competitiveness of Listed Paper-Making Firms under China's Dual-Carbon Goals

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Abstract: *Drawing on the resource-based view and the core competence perspective, this paper constructs an innovative evaluation index system for the low-carbon competitiveness of listed paper-making firms. Using publicly available data for 30 listed paper-making companies from 2019 to 2021, we build a combined weighting model based on the Analytic Hierarchy Process (AHP) and the entropy weight method to obtain indicator weights and assess firms' low-carbon competitiveness. The results show that: (1) the overall level of low-carbon competitiveness among listed paper-making firms is relatively low, with large disparities across firms; (2) most leading firms lag in environmental competitiveness and have weak awareness of low-carbon management. While pursuing large-scale growth, they tend to overlook sustainable development, indicating that listed paper-making firms are still primarily driven by economic interests. Finally, the paper provides targeted policy and managerial recommendations.*

Keywords: *dual-carbon goals; low-carbon competitiveness; listed paper-making firms*

1. Introduction

In the context of a low-carbon economy, China's nationally determined contributions (NDCs) under the Paris Agreement and the specific emission-reduction measures set out in the 13th Five-Year Plan are being implemented progressively from regions to industries, and from industries to individual enterprises[1]. As claimants of natural resources and core carriers of social wealth creation, enterprises are key regulatory targets under the dual-carbon goals. Their low-carbon competitiveness is a critical factor in coordinating ecological civilization construction and achieving carbon peaking and carbon neutrality[2]. Enhancing firms' low-carbon competitiveness, controlling carbon emissions, and improving carbon performance are therefore essential for coping with environmental change, achieving sustainable development, and supporting the dual-carbon agenda.

The paper-making industry is an important basic raw-material supplier within China's secondary sector, but it is also characterized by high levels of pollution and energy consumption.[3] Accordingly, this study focuses on listed paper-making companies as the research object and adopts the theory of endogenous competitive advantage as its theoretical foundation. We construct an evaluation system for the low-carbon competitiveness of listed paper-making firms and build a combined weighting model using the entropy weight method and the Analytic Hierarchy Process (AHP) to measure their low-carbon competitiveness and propose corresponding recommendations.

2. Literature Review

Research on evaluating firms' low-carbon competitiveness is still limited, and rigorous quantitative evidence is scarce. Nina (2020) notes that, unlike traditional competitiveness assessments, recent studies incorporate "low-carbon" indicators and apply methods such as neural networks, fuzzy comprehensive evaluation, and the Analytic Hierarchy Process (AHP) to examine how the low-carbon economy affects firm competitiveness[3].

Existing indicator systems mainly follow two approaches. The subjective approach derives indicators from the literature and expert judgement, then assigns weights using AHP or principal component

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analysis. For example, Dong (2018) builds a low-carbon competitiveness index with criteria such as low-carbon production, low-carbon economy, and low-carbon technology, and subjectively weights 20 indicators[1]. Wang (2020) uses principal component analysis to construct an index focusing on low-carbon logistics environment and capability[4].

The objective approach identifies frequently mentioned influencing factors through literature retrieval, refines them into indicators, and then applies methods such as the entropy weight method and TOPSIS. Jiang and Fan (2016) propose five first-level indicators (e.g., human resources, technological level) and 23 second-level indicators, and validate them with steel enterprise data[5]. Yang (2022) adopts a combined weighting model with three first-level indicators—quota-type, emission-reduction-type, and carbon-source-type carbon assets—and 13 second-level indicators, based on railway enterprise data[6].

Only a few studies integrate qualitative and quantitative approaches. In response, this paper focuses on listed paper-making firms and, grounded in the theory of endogenous competitive advantage and the industry's carbon-emission characteristics, develops a low-carbon competitiveness evaluation system. A combined weighting model based on the entropy weight method and AHP is employed, with particular emphasis on environmental competitiveness, to measure the low-carbon competitiveness of listed paper-making firms.

3. Theoretical Framework and Research Methods

3.1 Theoretical Framework

The theory of endogenous competitive advantage, combining the resource-based view and core competence perspective, posits that internal resources and capabilities are decisive for sustaining competitive advantage, profitability, and long-term development. Choi (2020) further argues that low-carbon competitiveness should be analysed within this competitiveness logic, integrating internal resources and capabilities[7].

Existing studies mainly assess low-carbon competitiveness along human, technological, market, and managerial dimensions. This paper, in line with low-carbon and environmental requirements, additionally incorporates an environmental dimension into the framework (see Figure 1).

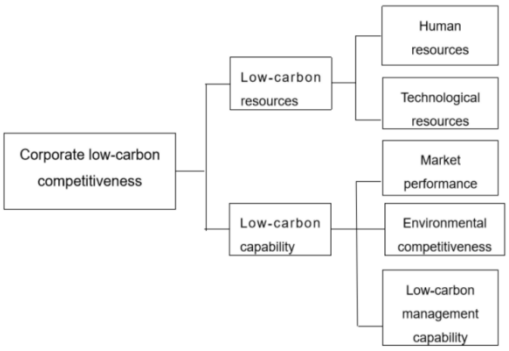

Figure 1. Theoretical framework

3.2 Research Methods

Building on prior studies, this paper adopts a combined weighting approach that integrates the Analytic Hierarchy Process (AHP) and the entropy weight method. First, AHP is used to obtain the weights of the five first-level criteria based on expert judgements[8]. Then, the entropy weight method is applied to calculate the weights of the secondary indicators under each criterion. Finally, the comprehensive weight of each indicator is derived, and the low-carbon competitiveness of listed paper-making firms is evaluated for the 30 sampled companies.

For AHP, expert scores are collected using a 1–5 scale to construct the pairwise comparison matrices at the criterion level. The eigenvectors and the maximum eigenvalue λ_{max} of each judgment matrix are then computed to derive the criterion weights. Specifically, λ_{max} is calculated as

$$\lambda_{max} \frac{1}{n} \sum_{i=1}^{n} \frac{(EW)_i}{W_i} \quad (1)$$

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where E is the judgment matrix, W is the eigenvector of weights, and nnn is the order of the matrix. The consistency index (CI) is then obtained as

$$CI=\frac{\lambda_{max}-n}{n-1} \tag{2}$$

and, given the corresponding random index (RI), the consistency ratio (CR) is computed as

$$CR=\frac{CI}{RI} \tag{3}$$

A judgment matrix is considered to have acceptable consistency when CR<0.1CR < 0.1CR<0.1. The resulting weights and consistency tests are reported in Tables 1 and 2.

Table 1. AHP results

Dimension	Eigenvector	Weight	Maximum eigenvalue	CI
Human resources	0.365	7.310%	5.137	0.034
Technological resources	1.282	25.640%		
Market performance	0.365	7.310%		
Environmental competitiveness	2.134	42.672%		
Management capability	0.853	17.069%		

Table 2. Consistency test results

Summary of consistency test results				
Maximum eigenvalue	CI	RI	CR	Consistency test result
5.137	0.034	1.120	0.031	Passed

As shown in Table 1, a 5×5 judgment matrix is constructed for the five first-level criteria and analysed using the AHP (product-sum method). The normalized eigenvector gives the weight vector W_j for the five criteria. The maximum eigenvalue of the matrix is λ_{max}=5.137, and the resulting consistency index is CI=0.034, indicating that the matrix passes the consistency test (CR<0.1).

Second, the entropy weight method is used to compute the weights of the secondary indicators under each criterion. In the first step, the original data are normalized. In the second step, the entropy value of indicator j is calculated as

$$e_j=-\frac{1}{\ln n}X_{ij}\ln X_{ij} \tag{4}$$

where X_{ij} is the normalized value of indicator j for firm i, and n is the number of firms. The information utility value is then

$$d_j=1-e_j \tag{5}$$

and the entropy weight of indicator j is

$$Q_j=\frac{d_j}{\sum_{i=1}^{n} d_j} \tag{6}$$

The resulting indicator weights are reported in Table 2.

Finally, the comprehensive weight of each indicator is obtained by combining the criterion weight and the entropy weight:

$$D_j=Q_jW_j \tag{7}$$

4. Construction of the Evaluation Index System

Based on a review of domestic and international studies and current policy requirements, this paper selects indicators according to the principles of feasibility, representativeness, comprehensiveness, and practical relevance. To enhance low-carbon competitiveness, paper-making firms can improve along five dimensions: human resources, technological resources, market performance, environmental competitiveness, and low-carbon management capability. Accordingly, an evaluation index system for the low-carbon competitiveness of listed paper-making firms is constructed along these five dimensions.

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The specific indicators are shown in Table 3.

Table 3. Indicators and weights for low-carbon competitiveness

	Primary indicator	Secondary indicator	Collection method
Low-carbon resources	X1 Human resources (0.07310) X2 Technological resources (0.25640)	X11 Proportion of technical staff (0.0534)	Annual report
		X12Proportion of employees with a bachelor's degree(0.1360)	Annual report
		X13 Dedicated department for managing carbon-related data (yes/no)(0.8106)	Annual report; social responsibility report; public sources
		X21 Number of granted patents related to energy-saving or alternative energy technologies(0.5826)	Public information / Public sources
		X22 R&D expenditure as a share of main business revenue(0.0284)	Annual report
		X23 Adoption of energy-saving equipment (yes/no)(0.1493)	Social responsibility report
		X24 Adoption of photovoltaic or biomass power generation (0.2397)	Social responsibility report
Low-carbon capability	X3 Market performance (0.07310)	X31 Earnings per share(0.5870)	Annual report
		X32 Return on equity (0.1695)	Annual report
		X33 Revenue growth rate (0.2435)	Annual report
	X4 Environmental competitiveness （0.42671）	X41 Emissions of major pollutants(0.2288)	Annual report; social responsibility report; public sources
		X42 Disclosure of carbon emissions (yes/no)(0.1492)	Annual report; social responsibility report; public sources
		X43 Greenhouse gas emissions (tCO_2)(0.0372)	Annual report
		X44 Value of carbon emission quota trading(0.2834)	Annual report
		X45 FSC-COC certification (yes/no)(0.0921)	Annual report
		X46 ISO 14001 certification (yes/no) (0.0271)	Annual report
		X47 Government low-carbon awards or honors (yes/no)(0.1822)	Annual report
	X5 Management capability (0.17069)	X51 Completeness of low-carbon enterprise institutional framework(0.2029)	Annual report; social responsibility report; public sources
		X52 Completeness of GHG emissions management system(0.1649)	Annual report; social responsibility report; public sources
		X53 Completeness of low-carbon publicity system(0.1639)	Annual report; social responsibility report; public sources
		X54 Disclosure of carbon emission reductions (yes/no)(0.2178)	Annual report; social responsibility report; public sources
		X55 Publication of a standalone environmental report (yes/no)(0.2505)	Public information

5. Empirical Analysis of Low-Carbon Competitiveness

5.1 Sample and Data

5.1.1 Sample Selection and Data Sources

The research sample consists of listed paper-making firms classified under the paper-making industry by the China Securities Regulatory Commission. Among 36 firms in this category, 30 with complete disclosure were retained after excluding those with missing information. Data for 2019–2021 are obtained from firms' annual reports, social responsibility reports, environmental reports, sustainability reports, Cninfo, and other public disclosures.

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5.1.2 Descriptive Statistics

Descriptive statistics for the main indicators are reported in Table 4.

Table 4. Descriptive statistics of main variables

Name	Minimum	Maximum	Mean	Standard deviation
Proportion of R&D staff	0.037	0.209	0.114	0.042
Proportion of employees with a bachelor's degree or above	0.025	0.444	0.115	0.077
Number of granted patents for energy-saving / alternative energy technologies (units)	0.000	3.333	0.178	0.648
R&D expenditure as a share of main business revenue	0.008	0.079	0.033	0.016
Earnings per share (RMB)	-0.099	4.615	0.584	0.860
Return on equity	-0.037	0.290	0.093	0.071
Revenue growth rate	-0.088	0.772	0.123	0.155
Emissions of major gaseous pollutants (t)	0.000	3647.725	344.600	750.285
Greenhouse gas emissions (10,000 t)	11.770	479.549	327.259	183.374
Value of carbon emission quota trading (10,000 RMB)	0.000	141.323	15.508	353.5611
Completeness of low-carbon enterprise institutional framework	0.000	3.667	0.444	0.859
Completeness of GHG emissions management system	0.000	4.333	0.789	1.218
Completeness of low-carbon publicity system	0.000	3.333	0.722	1.072

5.2 Evaluation Results

The comprehensive scores and rankings of the low-carbon competitiveness of listed paper-making firms are presented in Table 5.

Table 5. Comprehensive scores and rankings of low-carbon competitiveness

Rank	Company	Score	Rank	Company	Score
1	Shanying International	0.686	16	Meiliyun	0.347
2	Jingxing Paper	0.504	17	Shunhao Co., Ltd.	0.338
3	Xianhe Co., Ltd.	0.498	18	Global Printing	0.318
4	Yutong Technology	0.492	19	Jinghua Laser	0.315
5	Huawang Technology	0.464	20	Hengfeng Paper	0.304
6	Sun Paper	0.459	21	Yibin Paper	0.302
7	Kain Co., Ltd.	0.447	22	Meiyingsen	0.291
8	Yueyang Forest & Paper	0.445	23	Guanhao High-Tech	0.284
9	Minfeng Special Paper	0.439	24	Chenming Paper	0.283
10	Rongsheng Environmental	0.432	25	Qingshan Paper	0.281
11	Haoyue Hygiene	0.432	26	Qifeng New Materials	0.260
12	Wuzhou Special Paper	0.422	27	Xintonglian	0.252
13	Dashengda	0.409	28	Hexing Packaging	0.252
14	Zhongshun Jierou	0.356	29	ST Songyang	0.240
15	Bohui Paper	0.350	30	Huatai Co., Ltd.	0.217

Based on the calculated low-carbon competitiveness scores for 30 listed paper-making firms over 2019–2021, the overall level is low and awareness of low-carbon development remains weak. The average score is 0.371, indicating a generally low level of low-carbon competitiveness. Only 13 firms score above the mean, while 17 fall below it, meaning about 56.67% of the sample do not reach the average level. This suggests substantial room for improvement. Among the sample, Shanying International records the highest score, which is 3.16 times that of Huatai, the lowest-scoring firm. Overall scores range from approximately 0.2 to 0.7, implying considerable dispersion in low-carbon competitiveness.

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To help firms identify specific weaknesses during low-carbon transition, this study further evaluates scores at the dimensional level using the entropy-based weights of the secondary indicators. For the three dimensions with the highest weights, the top ten firms under each dimension are reported in Table 6.

Table 6. Top ten listed paper-making firms under selected secondary dimensions

Technological resources			Environmental competitiveness			Management capability		
Rank	Company	Score	Rank	Company	Score	Rank	Company	Score
1	Shanying International	0.237	1	Jingxing Paper	0.360	1	Shanying International	0.095
2	Chenming Paper	0.119	2	Kain Co., Ltd.	0.349	2	Minfeng Special Paper	0.086
3	Sun Paper	0.119	3	Wuzhou Special Paper	0.344	3	Zhongshun Jierou	0.065
4	Xianhe Co., Ltd.	0.074	4	Minfeng Special Paper	0.326	4	Jingxing Paper	0.063
5	Meiliyun	0.062	5	Huawang Technology	0.322	5	Yutong Technology	0.044
6	Jingxing Paper	0.059	6	Dashengda	0.314	6	Sun Paper	0.043
7	Rongsheng Environmental	0.054	7	Xianhe Co., Ltd.	0.310	7	Yueyang Forest & Paper	0.043
8	Yutong Technology	0.054	8	Yueyang Forest & Paper	0.298	8	Kain Co., Ltd.	0.038
9	Huawang Technology	0.054	9	Yibin Paper	0.295	9	Rongsheng Environmental	0.038
10	Yueyang Forest & Paper	0.046	10	Rongsheng Environmental	0.285	10	Xianhe Co., Ltd.	0.035

From Table 6, the average score for low-carbon technological resources is 0.037, with only 40% of firms at or above the mean and a maximum of 0.237. This indicates large disparities and substantial room to strengthen low-carbon technologies. For environmental competitiveness, the average score is 0.263, with 53.3% of firms reaching or exceeding the mean and a maximum of 0.360, suggesting a certain foundation but clear scope for further improvement. For low-carbon management capability, the average score is only 0.023, with 46.67% of firms above the mean, yet all firms score below 0.1, implying low managerial attention and weak awareness of low-carbon management.

Comparing dimensional scores with overall low-carbon competitiveness rankings, Shanying International, Chenming Paper, and Sun Paper perform relatively well in technological resources; Jingxing Paper, C&S Paper (Kain), and Wuzhou Special Paper perform better in environmental competitiveness; and Shanying International, Minfeng Special Paper, and Zhongshun Jierou score higher in management capability. Overall, the results show that listed paper-making firms still have substantial room to enhance low-carbon competitiveness and need to invest more resources and place greater emphasis on low-carbon sustainable development.

6. Discussion

6.1 Recommendations

6.1.1 Government: Issue Low-Carbon Enterprise Evaluation Guidelines

Market-oriented low-carbon policies can promote high-quality economic development. Shenzhen has issued a standardized guiding document on low-carbon enterprise evaluation, under which the government strictly supervises firms' low-carbon disclosure and evaluation, thereby encouraging them to advance low-carbon technologies and applications and supporting greener, more sustainable growth[9]. By analogy, governments should strengthen low-carbon evaluation and supervision in the manufacturing sector, give full play to their guiding role, and use market competition to accelerate low-carbon technological innovation. This not only improves firms' environmental image, but also contributes to social sustainability and the achievement of the dual-carbon goals[10].

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6.1.2 Industry Associations: Guide Leading Firms to Play a Demonstration Role

Many leading firms have not acted as role models in low-carbon development and still maintain high-carbon growth patterns. Industry associations should serve as communication bridges, encouraging leading firms to build low-carbon awareness and strengthen low-carbon management[11]. Through experience-sharing activities, associations can motivate leading firms to support small and medium-sized enterprises in low-carbon technological upgrading, open up technological resources along the value chain, and build platforms for cooperation among large, medium, and small firms. This can foster industry alliances characterized by leading-firm guidance, coordinated development across tiers, and complementary advantages[12].

6.1.3 Firms: Strengthen Low-Carbon Awareness and Governance

Enhancing and institutionalizing green values is a prerequisite for corporate green self-discipline. Firms' low-carbon awareness directly shapes low-carbon behavior. Enterprises should therefore cultivate low-carbon awareness among both managers and frontline employees, and translate awareness into concrete actions[13]. This includes improving internal systems for low-carbon governance, formulating medium- and long-term low-carbon plans, strengthening technological capability building, and increasing R&D investment[14]. Firms should also enhance carbon management and disclosure by regularly publishing carbon audit reports and proactively releasing environmental and carbon-emission information, thereby facilitating external supervision and assessment.

6.2 Limitations and Future Research

This study has several limitations. First, although the indicator system has some degree of innovation and reference value, the non-mandatory nature of carbon-related information disclosure means that some potentially important indicators cannot be included, which affects the scientific rigor and completeness of the evaluation system. Second, data collection is challenging: carbon-emission data are not fully disclosed, information disclosure is limited, and values for the same indicator may differ across data sources[15]. A small number of original data points may therefore contain minor errors, although these do not materially affect the overall evaluation results.

Future research can further deepen the analysis of listed paper-making firms. On the basis of this paper's focus on environmental competitiveness and its industry-specific evaluation system, subsequent studies may conduct field surveys and interviews to obtain first-hand data and incorporate more informative indicators—such as electricity consumption per ton of paper and carbon sink performance—into the index system, thereby improving its completeness and explanatory power[16].

7. Conclusions

This study yields three main findings.

First, the overall level of low-carbon competitiveness among listed paper-making firms is low, with large differences across firms[17]. This indicates that the cultivation of low-carbon competitiveness in the paper-making industry is still at an early stage and requires a long-term effort.Second, firms such as Shanying International, Chenming Paper, and Sun Paper possess relatively strong low-carbon technological resources but lag in environmental competitiveness. While expanding scale, they have not effectively controlled carbon emissions and have not fully played a leading role as industry front-runners. Although some leading firms (e.g., Shanying International) show stronger low-carbon awareness in management, many still pay insufficient attention to low-carbon governance and fail to balance scale expansion with sustainable development goals.Third, during data collection it is observed that many small paper-making firms do not disclose environmental information, resulting in very limited low-carbon information disclosure and weak public and governmental oversight. In contrast, some firms, such as Yutong Technology in Shenzhen, achieve high scores in low-carbon management, largely because the Shenzhen municipal government has issued a guiding technical document on low-carbon enterprise evaluation, which drives local firms to follow and implement relevant low-carbon policies[18].

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