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Construction and Application of Regional Carbon Performance Evaluation Index System: The Case of Chinese Provinces

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Abstract: As global warming becomes increasingly severe, reducing carbon emissions and promoting low-carbon development has become an international consensus. Against this backdrop, evaluating regional carbon performance helps better understand the carbon emission status, emission reduction capabilities, and low-carbon development levels, providing a scientific basis for formulating targeted carbon emission reduction policies. This study constructed a "5E" regional carbon performance evaluation index system from five dimensions: economy, effectiveness, efficiency, environmentality, and equity. Then, this study evaluated and analyzed the carbon performance of 30 provinces in China from 2008 to 2021 using the entropy weight TOPSIS method. The research results indicated that (1) during the sample period, China's carbon performance ranged from 0.416 to 0.504, exhibiting a steady upward trend; the highest score among the first-level indicators was Effectiveness, while the lowest was Economy; (2) in terms of carbon performance among China's three major regions, it showed a decreasing pattern from east to west, with the growth potential of the central and western regions being greater than that of the eastern region; (3) in 2033, the carbon performance of China in the eastern region, the central region, and the western region will reach 0.602, 0.612, 0.613, and 0.582, respectively. A carbon performance evaluation carries significant practical and strategic implications. Our study can provide a reference for policymakers to assess carbon emission performance and improve carbon management efficiency and decision-making levels.

Keywords: global warming; regional carbon performance; "5E"; entropy weight TOPSIS

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1. Introduction

Sustainable development is the development that can meet the needs of the present without compromising the ability of future generations to meet their own needs. Sustainable development study calls for an interdisciplinary research framework that pays attention not only to political, economic, and institutional factors [1,2], but also to ecological and environmental factors. Climate change has become a global issue, and reducing carbon emissions is crucial to mitigate the greenhouse effect and achieve sustainable development. China has experienced rapid economic growth in the past few decades, significantly increasing in carbon dioxide emissions. Since 2007, China's total carbon emissions have surpassed those of the United States, making it the world's largest carbon dioxide emitter and accounting for nearly one-third of the global total. China's energy is primarily coal-based, and the relatively low coal conversion efficiency brings a low energy efficiency. Currently, China's comprehensive energy utilization efficiency is approximately 39.1%, and the overall efficiency of the energy system is approximately 14.3%, representing a significant gap compared to developed countries [3]. Severe losses and waste in energy mining, processing, conversion, storage, transportation, and terminal utilization exacerbate China's carbon emission problem. Against accelerated urbanization and industrialization, balancing economic growth with environmental protection and reducing carbon dioxide emissions is still a big challenge for China.

To reduce carbon emissions, the Chinese government has implemented a series of measures. These include promoting the establishment of the carbon market actively, enhancing the development of low-carbon, zero-carbon, and negative-carbon technologies, and advancing the transformation of industrial energy-saving and carbon-reduction technologies. In terms of legislation, the Chinese government has continuously improved its climate laws, strengthened greenhouse gas emission statistics and accounting practices, and established greenhouse gas emission reporting systems. Additionally, China encourages the adoption of clean energy substitution technologies, renewable energy substitution technologies, and new energy technologies to reduce fossil energy consumption and carbon emissions. Through measures such as afforestation, forestland restoration, and high-yield forest management, the carbon sequestration capacity of terrestrial ecosystems is increased. Although these measures have yielded specific results, China's carbon emission reduction efforts still require an improvement. In the short term, China cannot entirely shift away from its fossil fuel-based energy structure, and there are also challenges in areas such as industrial structure transformation and low-carbon technology development. It is also crucial to note that China is vast, and there are significant variations in resource endowments, economic development levels, and carbon emission statuses among various provinces. Therefore, when formulating and implementing carbon emission reduction policies, it is imperative to thoroughly consider these disparities to ensure the fairness and efficacy of the policies.

Climate change induced by greenhouse gas emissions has emerged as one of the most significant global challenges, and enhancing regional carbon performance represents a pivotal approach to reduce regional carbon emissions. A carbon performance evaluation is essential in clarifying a region's carbon performance, helping the government understand the overall carbon emission situation, and providing support for formulating and adjusting carbon emission reduction policies. Firstly, a carbon performance evaluation aids in objectively and comprehensively assessing the performance of local governments in low-carbon economic management. By evaluating metrics, such as regional carbon emission scales, carbon emission intensities, and carbon reduction measures, a clear understanding of progress towards low-carbon targets can be gained, thereby providing decision-making support for policymakers. Secondly, a carbon performance evaluation offers specific directions for improvement to local governments. Through assessment, regions can identify the primary sources and influencing factors of carbon emissions, subsequently developing more targeted emission reduction strategies and measures. This leads to optimized resource allocation and improved energy utilization efficiency. Finally, a carbon performance evaluation contributes to promoting regional sustainable development. In the process of a carbon performance evaluation, local governments will further recognize the importance of low-carbon development and gradually transition towards a low-carbon, green, and circular economic development model through the implementation of carbon emission reduction measures and participation in carbon trading.

The carbon performance evaluation indicator system serves to measure a region's carbon emissions status, objectively assessing whether economic and social development are geared toward reducing carbon emissions. There is yet to be a unified evaluation indicator system for measuring regional carbon performance internationally, and this applies to China as well. Consequently, the primary aim of our study was to establish a scientific, comprehensive, and operable regional carbon emission performance evaluation index system and to validate its effectiveness and practicability through empirical analysis. To accomplish this, we firstly comprehensively considered the characteristics and influencing factors of regional carbon emission performance and constructed a multi-dimensional evaluation system. Secondly, we needed to select appropriate evaluation methods and determine the weight of each indicator to ensure the objectivity and fairness of the evaluation results. Finally, we needed to conduct an empirical analysis to test the feasibility of this indicator system.

We intended to expand the traditional "3E" model to "5E" in order to establish a regional carbon performance evaluation index system that encompasses economy, efficiency, effectiveness, environmentality, and equity. We planned to employ the entropy weight TOPSIS method to assess the carbon performance of 30 provinces in China from 2008 to 2021. It is our aspiration that this study will provide a rational and viable framework for regional carbon performance evaluation, provide data support for the development of carbon reduction strategies, and ultimately contribute to regional low-carbon and sustainable development.

The subsequent structure of this article is outlined as follows: Section 2 presents a literature review, exploring the existing research and theories related to regional carbon performance evaluation; Section 3 focuses on the construction of the regional carbon performance evaluation index system, encompassing the guiding principles of construction, selection of indicators, and the evaluation methods employed; Section 4 conducts an empirical analysis based on 30 provinces in China, including data sources, evaluation results obtained, and potential improvement strategies; Section 5 provides conclusions, discussions, and the recommendations for policy and practice; and Section 6 acknowledges the limitations of the study and outlines directions for future research.

2. Literature Review

The development of a regional carbon performance evaluation index system should be preceded by a thorough examination of the factors that influence carbon emissions. Studying these factors is crucial both theoretically and practically in addressing climate change, refining energy policies, and promoting low-carbon development. Scholars have long delved into the variables that affect carbon emissions, positing that technology, the level of economic development, and population are the primary factors influencing carbon emissions [4]. Kaya first introduced Kaya's identity in the IPCC's working report, decomposing the determinants of carbon emissions into CO_2 emissions per unit of energy consumption, energy intensity, per capita GDP, and population [5]. Dietz and Rosa expanded the IPAT equation by incorporating random factors, resulting in the STIRPAT model [6]. York et al. observed that taking the logarithm of all variables in the STIRPAT model facilitates the analysis of the effects of population size, affluence, and technological progress on environmental pressure [7]. Beyond these factors, researchers have also investigated the impact of urbanization rates [8,9], foreign trade [10,11], transportation [12], and foreign direct investment (FDI) [13,14] on carbon emissions.

The significant number of factors influencing carbon emissions underscores the importance of rigor in constructing a regional carbon performance evaluation index system. As a crucial decision-making tool for governments in shaping development plans and policies, this index system must exhibit both sensitivity and effectiveness. Carefully analyzing and evaluating the strengths and weaknesses of carbon performance indicators and continuously refining and enhancing the index system can guide long-term and sustainable low-carbon development. According to existing research, studies on the carbon performance evaluation system encompass various aspects, including construction principles, evaluation indicators, evaluation methods, and the application of evaluation results.

The focus on research regarding the construction principles and framework of a carbon performance evaluation system is indeed on establishing a rational and practical system that can accurately assess carbon emissions and their associated impacts. Scholars have emphasized several key principles in building such system, including scientificity, systematization, and operability. In addition to these principles, scholars have proposed various evaluation frameworks and indicator systems to operationalize the construction of a carbon performance evaluation system [15,16]. Some of the classic evaluation frameworks include the Balanced Scorecard [17], the "3E" model [18], and the DRS model [19]. The indicator systems typically include multiple aspects such as carbon emissions [20], carbon emission reduction measures [21], and carbon information disclosure to comprehensively reflect the carbon performance of an enterprise or region [22].

The core of the carbon performance evaluation system lies indeed in the selection and quantification of appropriate evaluation indicators. Existing research has conducted an in-depth analysis of the characteristics and influencing factors of carbon emissions across diverse enterprises, industries, and regions, identifying representative evaluation indicators, and exploring methodologies for quantify these indicators. These indicators comprise not only direct metrics such as the carbon emission scale [23], carbon emission intensity, [24] and carbon productivity [25], but also indirect metrics such as energy consumption, energy utilization efficiency [26], and the advancement of low-carbon technologies, all aimed at reflecting the carbon performance level of the evaluation object in a more comprehensive manner [27].

Scholars have explored various methods suitable for carbon performance evaluation, such as fuzzy comprehensive evaluation [28], analytic hierarchy process [29], grey relational analysis [30], and data envelopment analysis [31]. Each of these methods possesses its unique characteristics, and the selection of an appropriate evaluation method should be based on specific circumstances. Additionally, some studies have combined practical application cases to conduct empirical analyses and verifications of the evaluation systems and methods, aiming to test their effectiveness and practicality. For instance, Wang et al. selected the DEA (Data Envelopment Analysis) model with undesired outputs to assess the carbon emission performance of 28 provinces in China from 1996 to 2007. They further analyzed the influencing factors of regional carbon performance using the convergence theory [32].

The application of carbon performance evaluation results is primarily reflected in the two key aspects. Firstly, it involves conducting a comprehensive analysis of the carbon performance of the evaluated entity to identify its strengths and weaknesses in this area. Secondly, it entails proposing solutions to address the identified shortcomings and challenges. For instance, Ye et al. employed the Balanced Scorecard approach to establish a regional carbon performance evaluation system and conducted a case study utilizing data from Jiangsu Province. They proposed specific strategies to enhance the carbon performance in terms of market-oriented reforms, industrial transformation and upgrading, the development of low-carbon technology, and the cultivation of low-carbon awareness [20]. Similarly, Wang et al. evaluated and assessed the carbon performance of Shandong province, offering development countermeasures tailored to the specific circumstances of various cities and prefectures within the province [33].

Overall, the existing studies have conducted extensive and in-depth discussions on the construction principles and frameworks of carbon performance evaluation, the selection of evaluation indicators, evaluation methods, and the application of evaluation results. They have yielded fruitful research findings, laying a solid theoretical foundation for our study. However, several aspects of the current research could be improved. Firstly, regarding evaluation objects, most studies focus on micro-enterprises, overlooking regional and national carbon performance. Secondly, in terms of evaluation frameworks, while the widely adopted “3E” analysis framework effectively captures the interplay between the economy, energy, and the environment, it disregards the efficiency and equity issues crucial to low-carbon development. Thirdly, with respect to evaluation indicators, most studies prioritize direct indicators like carbon emission scale, intensity, and efficiency, while neglecting indirect indicators such as energy utilization and the emission control effect. Additionally, qualitative indicators often pose challenges in quantification. Fourthly, in terms of evaluation methods, most scholars rely on the DEA model with undesirable outputs to measure efficiency. However, this approach may not be suitable for comprehensive indicator systems. Furthermore, fuzzy comprehensive evaluation and analytic hierarchy processes may introduce subjectivity in weighting. To address these shortcomings, this study took macro regions as the evaluation object, expanding the traditional “3E” model to a “5E” model that incorporates efficiency and equity. Based on this framework, a regional carbon performance evaluation indicator system was developed. Subsequently, the entropy weight TOPSIS method was employed to assess the carbon emission performance of 30 provinces in China from 2008 to 2021, validating the system’s effectiveness and practicality. Our research aims to contribute to the advancement of a scientific and standardized carbon performance evaluation system, providing decision support and practical guidance for local governments in implementing carbon emission reduction policies.

3. Construction of Regional Carbon Performance Evaluation Index System

3.1. Construction Principles

When constructing the regional carbon performance evaluation index system, it was necessary to take into account certain principles, which are outlined below.

3.1.1. Scientific Principle

The carbon performance evaluation index system should be grounded in scientific data and methodologies, adhering to a unified evaluation standard, thereby ensuring the objectivity and precision of the evaluation outcomes. This necessitates the utilization of accurate and reliable data, a rigorous and standardized evaluation process, as well as the employment of well-tested evaluation methods.

3.1.2. Comprehensive Principle

To ensure its comprehensiveness, the carbon performance evaluation system should consider all carbon emission activities within the region, encompassing economic factors, efficiency, profitability, environmental impact, and equity. This approach aids in identifying the region’s performance across various aspects and provides a comprehensive reference for formulating carbon emission reduction policies.

3.1.3. Comparability Principle

The carbon performance evaluation index system must be comparable, implying that the carbon performance of various regions can be contrasted to discern their respective positions and identify any disparities. This requires the adoption of universally applicable evaluation indicators and methods, thus enabling the referencing of the evaluation results across different regions.

3.1.4. Practicality Principle

The carbon performance evaluation index system should be practical, implying that the evaluation results can furnish policymakers with tangible carbon emission reduction suggestions and decision support, thereby assisting the region in achieving its established emission reduction targets. Therefore, during the design process of the carbon performance evaluation index system, it is imperative to take into full consideration the actual situation and specific needs of the region, ensuring that the evaluation results are targeted and relevant.

3.1.5. Operability and Quantifiability Principles

The carbon performance evaluation index system must be operable and quantifiable, which implies that evaluation indicators should be quantified through calculations to the greatest extent possible, ensuring that the results can be effectively applied to practical operations. This requires the selection of evaluation indicators that possess straightforward calculation methods and readily accessible data sources, thereby enabling policymakers to formulate specific emission reduction targets and implement corresponding measures.

3.2. Indicator Selection

With the escalating constraints of the global climate environment, promoting low-carbon economic development, enhancing the comparability of carbon performance evaluation results among diverse regions, ensuring fairness in the process and outcomes of regional low-carbon transformation, and comprehensively reflecting the status of local governments’ low-carbon development have become significant aspects of carbon performance evaluation research at this juncture. Based on the “3E” model, this article proposes a regional carbon performance evaluation index system encompassing five dimensions:

economy, efficiency, effectiveness, environmentality, and equity, which constitutes the "5E" framework. Subsequently, we will elaborate on the meaning of each "E" and the selection of specific indicators.

3.2.1. Economy Dimension

Economy, in the context of carbon performance evaluation, pertains to the measurement of low-carbon economic inputs and outputs. Utilizing specific criteria, scores are ascribed to the evaluation objects to gauge whether the region's low-carbon investments adhere to established standards. In the process of low-carbon development, the economy primarily endeavors to strike a balance between environmental protection and economic development. This requires regions to achieve effective cost containment, optimize benefits, and foster long-term sustainable development while implementing carbon reduction measures and carbon-related initiatives.

When selecting specific indicators, we considered the inputs and outputs in reference to existing research [34]. In terms of economic inputs, we took into account the financial investment for carbon management practices, encompassing five indicators: the ratio of completed investment in industrial pollution control to GDP, the ratio of investment in urban environmental infrastructure construction to GDP, the ratio of local fiscal expenditure on environmental protection to GDP, the ratio of completed investment in waste gas treatment projects to GDP, and the ratio of government subsidies for environmental protection to GDP. The input of personnel is primarily reflected in the indicator of the number of employees in urban environmental industries. The input of materials is reflected in the indicator of the number of industrial waste gas treatment facilities per unit of GDP.

Regarding output indicators, since industrial production is a significant source of carbon emissions, there is a direct correlation between industrial value added and carbon emissions. The economic benefits generated by most carbon-related activities can be captured through the ratio of industrial value added to GDP. Furthermore, the payment of pollution discharge fees can, to a certain extent, reflect the environmental protection behaviors and outcomes of enterprises. By raising the collection standards for pollution discharge fees, the government can convey stronger environmental protection signals and guide enterprises and all sectors of society to devote greater attention to environmental protection efforts [35]. Therefore, we also included the indicator of the ratio of pollution discharge fees to GDP. Additionally, we utilized the number of green patent applications per capita to reflect the development of low-carbon technology in a region.

3.2.2. Efficiency Dimension

Efficiency is primarily utilized to assess carbon-containing energy consumption efficiency and allocation efficiency. The utilization efficiency of carbon-based energy primarily pertains to the ratio between the effective energy extracted from carbon-containing energy (such as coal, oil, natural gas, etc.) and the total energy input during the energy utilization process. This efficiency metric encapsulates the energy conversion and losses incurred during the utilization process, thereby serving as a crucial indicator for evaluating the overall energy utilization level.

In selecting specific indicators, we considered the following three aspects: Firstly, with regard to energy efficiency, we employed total energy consumption to reflect the scale of energy use in a region. Energy consumption is closely correlated with carbon emissions, and total energy consumption directly mirrors the overall energy demand for economic and social activities. To measure energy utilization efficiency, we utilized energy consumption per unit of GDP, representing the amount of energy required for each unit of economic output. A lower energy consumption per unit of GDP signifies higher energy utilization efficiency, which is conducive to energy conservation and emission reduction. Additionally, we employed carbon emissions per unit of energy consumption to reflect the carbon emission efficiency in energy conversion and utilization. For a given energy input, a lower carbon emission per unit of energy consumption indicates higher carbon emission efficiency in the energy use process, resulting in a less negative impact on the environment.

Secondly, in terms of energy structure, we utilized the proportion of coal consumption to represent the degree of coal dependence in the energy consumption mix. Coal, being a highly polluting and emission-intensive energy source, generates numerous pollutants such as sulfur dioxide, nitrogen oxides, and dust during combustion, causing significant impacts on the environment and human health. Consequently, a higher proportion of coal consumption translates to a more severe environmental pollution problem. Moreover, coal possesses relatively low energy efficiency, low conversion efficiency, and significant waste during use compared to other energy sources. Therefore, a high proportion of coal consumption signifies low energy utilization efficiency [36].

Thirdly, regarding carbon productivity, we adopted GDP per unit of carbon dioxide emissions as an indicator to reflect the economic output generated by each unit of carbon dioxide emissions. An increased carbon productivity signifies that more GDP can be generated under the same carbon emissions, or more social wealth can be produced with less material and energy consumption. This reflects the efficiency relationship between economic development and carbon emissions and serves as one of the crucial indicators for evaluating energy utilization efficiency [37].

3.2.3. Effectiveness Dimension

Effectiveness is primarily employed to assess the impacts of carbon reduction in a region, which are intimately tied to economic performance and efficiency. Sufficient economic investment and effective energy utilization are prerequisites for achieving reasonable emission control and reduction outcomes. More specifically, effectiveness is manifested in the actual reduction of carbon emission scale and intensity, as well as improvement in air quality, thereby highlighting the effects of carbon reduction measures and their beneficial impact on the environment.

In selecting specific indicators, we have taken into account the reduction effect of carbon dioxide emissions alongside the reduction effect of other polluting gases. The former is primarily reflected by intuitive indicators, including carbon dioxide emissions, carbon dioxide intensity, per capita carbon dioxide emissions, and the reduction rate of carbon dioxide emissions. On the other hand, the latter primarily gauges the efficacy of air pollution control through metrics such as sulfur dioxide, nitrogen oxide, and dust emissions, their respective intensities, and their reduction rates. This approach ensures a comprehensive evaluation of both carbon dioxide reduction and overall air pollution mitigation efforts.

3.2.4. Environmentality Dimension

Environmentality is primarily used to evaluate the direct or indirect environmental effects of low-carbon governance and energy consumption reduction efforts. Evaluating the environmental impact of carbon-related activities can clarify whether a region has fulfilled its environmental protection responsibilities and identify potential directions for further improvement. Environmentality focuses on a region’s environmental outcomes during the low-carbon transformation process and how the adoption of effective carbon management strategies can reduce carbon emissions and mitigate their negative environmental impacts, ultimately achieving harmonious coexistence between humans and nature.

We selected the following indicators to assess environmental performance: the first is the comprehensive utilization rate of general industrial solid waste. This indicator reflects the extent to which industrial solid waste is comprehensively utilized; specifically, the efficiency of converting waste into resources or energy. An improved comprehensive utilization rate of industrial solid waste aids in reducing waste emissions and mitigating negative environmental impacts [38]. The second is the harmless treatment rate of domestic waste. This indicator measures the extent to which domestic waste is disposed of safely, and an increase in the safe disposal rate can mitigate the harmful impact of waste on the environment. The third is the forest coverage rate. Forests are integral to the Earth's ecosystem, playing crucial roles in maintaining ecological balance, regulating climate, and protecting biodiversity. It reflects the state of forest resources in a country or region and serves as one of the key indicators for evaluating the quality of the ecological environment [39]. The fourth is the urban green area ratio. Urban green areas are an integral part of the urban ecosystem, playing a crucial role in enhancing urban environmental quality, mitigating the urban heat island effect, and improving residents' quality of life. The fifth is environmental emergencies. Although environmental emergencies (such as natural disasters and pollution events) are not direct indicators of carbon emissions, their destruction and environmental impact often result in increased carbon emissions [40]. Including environmental emergencies as one of the environmentality indicators for carbon emission performance raises awareness of the impact of environmental changes on carbon emissions and promotes the adoption of more effective response measures.

3.2.5. Equity Dimension

Equity is mainly used to evaluate the fairness and equality of different entities in undertaking emission reduction responsibilities, enjoying the benefits of emission reduction outcomes, and allocating related resources during carbon emission reduction and low-carbon development efforts. Equity manifests not only within a generation but also across generations, encompassing the fair allocation of carbon emission reduction responsibilities and outcomes, as well as the fair and equitable distribution of resources.

In selecting equity indicators, we opted for the following indicators. The first is the per capita disposable income of residents, which primarily reflects the economic benefits derived from carbon-related activities at the resident level. A higher per capita disposable income indicates that residents possess greater economic resources to enhance their quality of life, including adopting more environmentally friendly lifestyles, such as purchasing energy-efficient appliances and utilizing green transportation, thereby indirectly reducing carbon emissions.

The second indicator is the per capita forest area and per capita green area, which mainly reflect the distribution of green resources among residents. Forests and green spaces offer residents recreational areas, enhancing their sense of well-being and environmental awareness.

The third indicator is environmental satisfaction, which reflects residents' comfort and satisfaction with their environment as well as the efforts and achievements of local governments in environmental governance [41].

The fourth indicator is corporate environmental governance. As one of the major sources of carbon emissions, corporate environmental governance is pivotal in reducing emissions. Incorporating corporate environmental governance as an equity indicator for carbon performance evaluation can motivate companies to adopt more environmentally sustainable production methods, minimize pollution emissions, and improve resource utilization efficiency [42].

The fifth indicator is environmental information disclosure. Environmental information disclosure serves as a crucial means to safeguard the public's environmental rights and interests. Through disclosing environmental information, the public gains insights into local environmental quality, pollution source emissions, and other relevant details, thus enhancing public environmental awareness and participation [43]. This, in turn, prompts governments and enterprises to fulfill their environmental responsibilities and drive the development of low-carbon initiatives more actively.

3.2.6. Final Indicators

Combining the actual situation of low-carbon development in various provinces in China under the dual carbon goals, we initially constructed a regional carbon performance evaluation index system. We selected indicators and categorized them into five indicator dimensions: economy, efficiency, effectiveness, environmentality, and equity. This approach resulted in formation of a regional carbon performance evaluation index system based on the "5E" model. Table 1 explicitly demonstrates these evaluation indicators and their respective quantification methods.

Table 1. Regional carbon performance evaluation index system.

Objective Level	First-Level Indicator	Second-Level Indicator	Unit
Regional Carbon Performance Evaluation Index System	Economy	Ratio of completed investment in industrial pollution control to GDP	%
		Ratio of investment in urban environmental infrastructure construction to GDP	%
		Ratio of local fiscal expenditure on environmental protection to GDP	%
		Ratio of completed investment in waste gas treatment projects to GDP	%
		Ratio of government subsidies for environmental protection to GDP	%
		Employees in urban areas of the environmental industry	People
		Number of industrial waste gas treatment facilities per unit of GDP	sets/CNY 100 million
		Per capita green patent applications	files/10,000 people
		Ratio of sewage fee income to GDP	%
		Ratio of industrial added value to GDP	%
	Efficiency	Total energy consumption	10,000 tons of standard coal
		Energy consumption per unit of GDP	tons of standard coal/CNY 10,000
		Carbon dioxide emissions per unit of energy consumption	tons/tons of standard coal
		Proportion of coal consumption in energy consumption	%
		GDP per unit of carbon dioxide emissions	CNY/ton
	Effectiveness	Carbon dioxide emissions	1,000,000 tons
		CO_2 emission per unit of GDP	ton/10,000 yuan
		Carbon dioxide emissions per capita	ton
		Reduction rate of carbon dioxide emissions	%
		Sulfur dioxide emissions	10,000 tons
		SO_2 emission per unit of GDP	ton/CNY 100,000,000
		Reduction rate of sulfur dioxide emissions	%
		Nitrogen oxide emissions	10,000 tons
		Nitrogen oxide emissions per unit of GDP	ton/CNY 100,000,000
		Nitrogen oxide emission reduction rate	%
		Smoke (powder) emission	10,000 tons
		Smoke (powder) emission per unit GDP	ton/CNY 100,000,000
		Decrease rate of smoke (powder) emission	%
	Environmentality	Comprehensive utilization rate of general industrial solid waste	%
		Harmless treatment rate of domestic waste	%
		Forest coverage	%
		Urban green area	10,000 hectares
		environmental emergencies	times
	Equity	Per capita disposable income of all residents	CNY
		Per capita forest area	hectares/10,000 people
		Per capita green area	hectares/10,000 people
		Environmental satisfaction	-
		Corporate environmental governance	-
		Environmental information disclosure	-

Specifically, we elaborate on the calculation methods for the following four indicators:

(1) Total energy consumption. According to the China Provincial Energy Inventory published by the China Emission Accounts and Datasets (CEADs), energy consumption comprises raw coal, cleaned coal, other washed coal, briquette, coke, coke oven gas, other gas, other coking products, crude oil, gasoline, kerosene, diesel oil, fuel oil, LPG, refinery gas, other petroleum products, natural gas, heat, electricity, and other forms of energy. The total energy consumption is calculated using the standard coal-conversion coefficient from the China Energy Statistical Yearbook.

(2) Environmental satisfaction. The calculation process is as follows: Based on evaluations of respondents' views on the government's environmental work from the China Social Survey (CSS), we assigned numerical values to these evaluations, with 4 indicating "very good", 3 indicating "relatively good", 2 indicating "not so good", and 1 indicating "very poor". The average value of all samples within the same province serves as the environmental satisfaction index.

(3) Corporate environmental governance. The calculation process is as follows: CSMAR has released environmental governance data for listed companies, including exhaust gas emission reduction, wastewater emission reduction, dust and soot control, solid waste utilization and disposal, noise control, light pollution control, radiation control, and the implementation of cleaner production. Each governance item is assigned a score, with 0 for no description, 1 for qualitative description, and 2 for quantitative description. The scores for each item are summed to obtain a company-level environmental governance index. The average of the scores for samples within the same registered province is taken as the corporate environmental governance index for that province.

(4) Environmental information disclosure. The calculation process is as follows: CSMAR has released environmental management information for listed companies, encompassing environmental protection concepts, goals, management systems, education and training, special environmental actions, incident emergency response mechanisms, environmental protection honors or awards, and the "three simultaneities" system. If a listed company has disclosed relevant information, it is assigned a value of 1; otherwise, it is assigned a value of 0. The scores for each item are summed to obtain a company-level environmental information disclosure index. The average of the scores for samples within the same registered province is taken as the environmental information disclosure index for that province.

3.3. Evaluation Method

3.3.1. Introduction to Entropy Weight TOPSIS

The entropy weight TOPSIS method is a multi-objective optimization decision analysis approach that integrates the principles of entropy weight method and TOPSIS method [44]. It comprehensively considers the impact of multiple evaluation indicators, determines the weight of each indicator using the entropy weight method, avoids the influence of subjective judgment, and thereby enhances the comprehensiveness and objectivity of the evaluation results. Additionally, the TOPSIS method assesses the merits and demerits by calculating the distance between the implementation plan and the optimal plan as well as the worst plan, which further elevates the accuracy of the evaluation outcomes [45]. Furthermore, this method has relatively low requirements for data. It does not necessitate making specific assumptions or conducting complex statistical analysis on the data. Provided the weights of each attribute and the data for each decision-making plan are provided, the analysis can proceed. This method exhibits strong flexibility and convenience. In summary, the entropy weight TOPSIS method boasts the advantages of objectivity, accuracy, comprehensiveness, low data requirements, intuitive understanding, and a wide application scope. It has been extensively applied in fields such as economy, environment, management, and others [46].

In the multi-index evaluation model, determining the weight of evaluation indicators is a pivotal issue. The weight signifies the level of importance of an index within the evaluation system and has a direct bearing on the evaluation results. The entropy weight method solely utilizes data, employing entropy as a measure of information and reflecting the amount of information furnished by a particular index through the calculation of its information entropy [47]. When the information entropy of a given index is smaller, it suggests that the degree of variation within that index is greater and the volume of information provided is more significant, thus leading to a greater weight [48]. As it relies solely on data and is devoid of human intervention, it ensures a certain degree of objectivity in weight determination [49].

3.3.2. Calculation Steps

Regional carbon performance involves multiple facets of carbon activities, necessitating a combined evaluation method to accurately measure such comprehensive indicators. Therefore, this article employed the entropy weight TOPSIS method to assess regional carbon performance. Firstly, a standardized process was conducted. Since the indicator system established in this article comprises various indicators (positive or negative) that impact carbon performance in different ways, and their data dimensions vary, it was imperative to standardize these indicators. This standardization process is outlined in formula (1). Secondly, the entropy weight method was utilized to assign weights to each indicator. Unlike traditional subjective assignment methods, the entropy weight method objectively determines weights based on the information entropy reflected in the data, thereby minimizing the influence of subjective factors on the weight allocation. Finally, the TOPSIS method was employed to compare the relative distances of each indicator from the optimal and worst schemes, yielding measurements of carbon performance in various regions [50]. The specific steps involved in this process are outlined below.

(1) Standardize the indicators.

$$Y_{ij} = \begin{cases} \frac{X_{ij} - \min\left(X_{ij}\right)}{\max\left(X_{ij}\right) - \min\left(X_{ij}\right)}, If\ X_{ij} \text{ is a positive indicator} \\ \frac{\max\left(X_{ij}\right) - X_{ij}}{\max\left(X_{ij}\right) - \min\left(X_{ij}\right)}, If\ X_{ij} \text{ is a negative indicator} \end{cases} \tag{1}$$

where j denotes a measure index and i denotes a region; X_{ij} and Y_{ij} denote the original measure index and the normalized measure index, respectively; and $\min\left(X_{ij}\right)$ and $\max\left(X_{ij}\right)$ denote the minimum and maximum values of X_{ij}, respectively.

(2) Calculate the information entropy E_j and weight W_j of Y_{ij}.

$$E_j = \ln \frac{1}{n} \sum_{i=1}^{n} \left\{ \left(Y_{ij} / \sum_{i=1}^{n} Y_{ij} \right) \ln \left(Y_{ij} / \sum_{i=1}^{n} Y_{ij} \right) \right\} \tag{2}$$

$$W_j = \left(1 - E_j\right) / \sum_{j=1}^{m} \left(1 - E_j\right) \tag{3}$$

(3) Construct weighted matrix R.

$$R = \left(r_{ij}\right)_{n*m} \tag{4}$$

where $r_{ij} = W_j * Y_{ij}$

(4) Determine the best scheme Q_j^+ and the worst scheme Q_j^- according to the weighted matrix R.

$$Q_j^+ = \left(\max r_{i1}, \max r_{i2}, \ldots, \max r_{im}\right) Q_j^- = \left(\min r_{i1}, \min r_{i2}, \ldots, \min r_{im}\right) \tag{5}$$

(5) Calculate the Euclidean distances d_i^+ and d_i^- of each measure scheme to the best scheme Q_j^+ and the worst scheme Q_j^-.

$$\begin{aligned} d_i^+ &= \sqrt{\sum_{j=1}^{m} \left(Q_j^+ - r_{ij}\right)^2} \\ d_i^- &= \sqrt{\sum_{j=1}^{m} \left(Q_j^- - r_{ij}\right)^2} \end{aligned} \tag{6}$$

(6) Computing the relative approximation Z_i of ideal scheme and measure scheme.

$$Z_i = \frac{d_i^-}{d_i^+ + d_i^-} \tag{7}$$

where Z_i is between 0 to 1, and the larger the Z_i value, the better the carbon performance of region i.

4. Empirical Analysis Based on 30 Provinces in China

4.1. Data Source

Due to the severe lack of data in Tibet, Hong Kong, Macao, and Taiwan, we selected 30 provinces in China from 2008 to 2021 as the evaluation subjects. We integrated the constructed carbon performance evaluation index system and utilized the entropy weight TOPSIS method to conduct a carbon performance evaluation. The data sources are described as follows: government environmental protection subsidies, pollution charges income, and the number of green patent applications were obtained from the CNRDS database [51]. Energy consumption, coal consumption, and carbon dioxide emissions were sourced from the provincial energy inventory and provincial carbon emissions inventory in the China Emission Accounts and Datasets (CEADs) established by Tsinghua University [52]. CEADs is a platform dedicated to collecting, compiling, and publishing carbon emission data from various industries and regions in China. CEADs adopts internationally recognized carbon emission statistical standards, thus ensuring the comparability and consistency of the data. Additionally, the data from CEADs originate from multiple data sources and channels, which have undergone rigorous analysis and verification, thereby guaranteeing their accuracy and credibility. The coefficients for converting various types of energy into standard coal refer to the "China Energy Statistical Yearbook" [53]. Environmental satisfaction was obtained from the Chinese Social Survey (CSS), a large-scale continuous sampling survey project launched nationwide by the Institute of Sociology of the Chinese Academy of Social Sciences in 2005, covering areas such as employment, psychology, and the environment. This article assigned values based on the respondents' answers to environmental issues and took the average of samples from the same province to obtain the environmental satisfaction of residents in that area [54]. Data on corporate environmental governance and environmental information disclosure were obtained from the CSMAR database [55]. This article quantified the environmental governance behavior and environmental information disclosure of listed companies and took the average of companies registered in the same province to determine the level of corporate environmental governance and the degree of environmental information disclosure in that area. Data on investment in urban environmental infrastructure construction and the comprehensive utilization rate of general industrial solid waste were sourced from the "China Environmental Yearbook" [51]. The remaining data were obtained from the "China Statistical Year book" [56].

4.2. Evaluation Results

Table 2 presents the carbon performance of 30 provinces in China from 2008 to 2021. The analysis of Table 2 yields the following key insights: (1) Numerically, the peek carbon performance is observed in Beijing in 2018, reaching 0.586, whereas the lowest is in Hebei in 2011, with a value of 0.308. The average carbon performance stands at 0.459, accompanied by a standard deviation of 0.055. Generally, the carbon performance levels across various regions of China are not notably high, indicating a certain distance from the optimal scenario. (2) Regarding the trends in carbon performance, all 30 provinces have witnessed varying degrees of improvement from 2008 to 2021, with an average growth rate of 21.569%. Notably, Guizhou, Henan, and Hebei have the highest growth rates, increasing by 41.257%, 38.202%, and 32.059%, respectively. Conversely, Ningxia, Guangxi, and Heilongjiang show the slowest growth rates, increasing by 9.635%, 9.766%, and 11.894%, respectively. Against the backdrop of intensifying climate crises, various regions in China have successively implemented a series of carbon emission reduction policies, actively promoting the implementation of carbon emission reduction measures. Consequently, carbon performance has improved to varying degrees in all regions, thereby achieving certain carbon governance goals.

Table 2. Carbon performance evaluation results of 30 provinces in China from 2008 to 2021.

Province/Year	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Beijing	0.497	0.509	0.503	0.510	0.529	0.548	0.567	0.565	0.576	0.583	0.586	0.577	0.556	0.575
Tianjin	0.446	0.445	0.447	0.446	0.449	0.454	0.469	0.473	0.480	0.482	0.488	0.504	0.498	0.505
Hebei	0.340	0.350	0.333	0.308	0.320	0.332	0.343	0.363	0.383	0.412	0.411	0.427	0.433	0.449
Shanxi	0.361	0.374	0.374	0.356	0.400	0.405	0.411	0.402	0.412	0.433	0.434	0.436	0.421	0.445
Inner Mongolia	0.356	0.381	0.392	0.401	0.427	0.429	0.443	0.443	0.447	0.447	0.439	0.443	0.428	0.449
Liaoning	0.391	0.401	0.397	0.404	0.424	0.419	0.412	0.415	0.443	0.447	0.450	0.452	0.449	0.476
Jilin	0.412	0.429	0.443	0.425	0.445	0.466	0.458	0.461	0.465	0.465	0.478	0.494	0.496	0.509
Heilongjiang	0.454	0.459	0.472	0.456	0.467	0.475	0.464	0.467	0.474	0.470	0.490	0.487	0.499	0.508
Shanghai	0.436	0.447	0.451	0.450	0.458	0.464	0.477	0.481	0.490	0.502	0.505	0.516	0.516	0.530
Jiangsu	0.393	0.410	0.404	0.404	0.409	0.418	0.417	0.426	0.423	0.438	0.448	0.449	0.462	0.476
Zhejiang	0.500	0.508	0.514	0.519	0.533	0.527	0.531	0.535	0.558	0.555	0.567	0.577	0.577	0.582
Anhui	0.401	0.412	0.416	0.418	0.432	0.443	0.441	0.453	0.451	0.473	0.477	0.490	0.485	0.510
Fujian	0.504	0.517	0.519	0.521	0.541	0.539	0.542	0.534	0.538	0.545	0.549	0.550	0.554	0.574
Jiangxi	0.452	0.469	0.479	0.484	0.498	0.496	0.498	0.508	0.494	0.517	0.536	0.547	0.538	0.546
Shandong	0.377	0.387	0.383	0.370	0.379	0.398	0.399	0.401	0.418	0.432	0.440	0.454	0.458	0.467
Henan	0.356	0.373	0.372	0.373	0.399	0.409	0.405	0.417	0.436	0.450	0.460	0.470	0.481	0.492
Hubei	0.403	0.424	0.423	0.421	0.427	0.445	0.450	0.449	0.470	0.475	0.491	0.494	0.487	0.495
Hunan	0.425	0.440	0.445	0.442	0.449	0.455	0.461	0.460	0.467	0.472	0.487	0.493	0.503	0.524
Guangdong	0.465	0.478	0.492	0.486	0.490	0.492	0.499	0.508	0.512	0.524	0.534	0.535	0.541	0.553
Guangxi	0.471	0.490	0.490	0.489	0.496	0.504	0.505	0.518	0.499	0.505	0.514	0.514	0.509	0.517
Hainan	0.497	0.502	0.501	0.485	0.503	0.507	0.511	0.525	0.536	0.530	0.535	0.538	0.544	0.565
Chongqing	0.424	0.443	0.446	0.467	0.463	0.472	0.483	0.489	0.498	0.501	0.513	0.521	0.524	0.538
Sichuan	0.410	0.409	0.413	0.421	0.420	0.423	0.433	0.436	0.449	0.458	0.476	0.478	0.476	0.497
Guizhou	0.366	0.380	0.406	0.395	0.413	0.415	0.435	0.450	0.445	0.460	0.481	0.496	0.498	0.517
Yunnan	0.448	0.457	0.480	0.472	0.487	0.485	0.504	0.524	0.516	0.522	0.530	0.537	0.530	0.540
Shaanxi	0.403	0.431	0.435	0.439	0.445	0.442	0.445	0.451	0.471	0.466	0.474	0.490	0.490	0.504
Gansu	0.353	0.353	0.362	0.364	0.379	0.390	0.394	0.397	0.401	0.419	0.425	0.428	0.436	0.448
Qinghai	0.399	0.423	0.425	0.441	0.437	0.453	0.449	0.456	0.470	0.465	0.472	0.492	0.499	0.486
Ningxia	0.384	0.386	0.373	0.369	0.404	0.406	0.412	0.411	0.409	0.403	0.405	0.415	0.415	0.421
Xinjiang	0.361	0.363	0.370	0.390	0.381	0.374	0.378	0.389	0.385	0.396	0.401	0.413	0.400	0.414
Average	0.416	0.428	0.432	0.431	0.443	0.450	0.455	0.460	0.467	0.475	0.483	0.491	0.490	0.504

4.3. Overall Analysis and Improvement Strategies

Figure 1 demonstrates the overall level of carbon performance in China from 2008 to 2021. Based on Figure 1, the following conclusions can be drawn: (1) In terms of carbon performance, China's peek carbon performance was recorded at 0.504 in 2021, whereas the lowest point was 0.416 in 2008, averaging at 0.459 over the entire period. During the sample period, China's carbon performance shows a tendency towards gradual increase, with brief declines noted in 2011 and 2021, while the remaining years exhibits positive growth. (2) In regard to growth rates, the most significant growth occurred in 2009, achieving 2.924%, while the slowest positive growth was recorded in 2010, standing at 0.856%. Growth rates in 2009, 2012, and 2021 remained above 2.5%. Negative growth is observed in 2011 and 2020, with respective changes of −0.262% and −0.095%. The remaining years displays growth, with variations ranging from 1% to 2%.

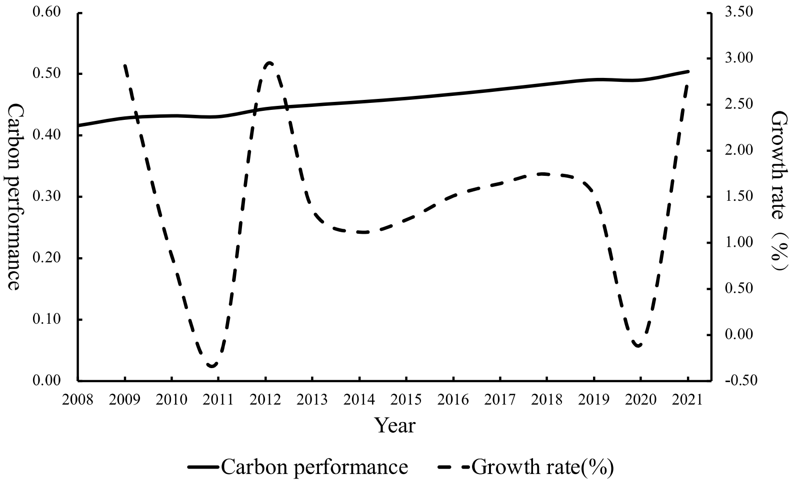

Figure 1. China's carbon performance and its growth rate from 2008 to 2021.

Figure 2 presents the evaluation results of the five sub-dimensions comprising China's carbon performance. The analysis reveals the following key insights: (1) Over the sample period, the Economy sub-dimension declined from 0.296 to 0.227, representing the sole indicator exhibiting a downward trend. This trend can be attributed to the slow growth in government economic investment in areas such as industrial pollution control and environmental infrastructure construction, despite the rapid economic development. The rapid expansion of the industrial sector has contributed to economic growth but also exacerbated environmental pressures, thereby resulting in a decline in the Economy's contribution to carbon performance. Conversely, Efficiency increases from 0.498 to 0.609, with a growth rate of 22.36%. Effectiveness grows from 0.643 to 0.750, achieving a growth rate of 16.59%. Environmentality rises from 0.442 to 0.509, representing a 15.05% increase. Lastly, Equity shows the most significant increase, from 0.224 to 0.487, with a growth rate of 116.84%. (2) In comparing the first-level indicators, Effectiveness attained the highest score, followed by Efficiency. Environmentality ranked third, while Equity and Economy had relatively lower scores.

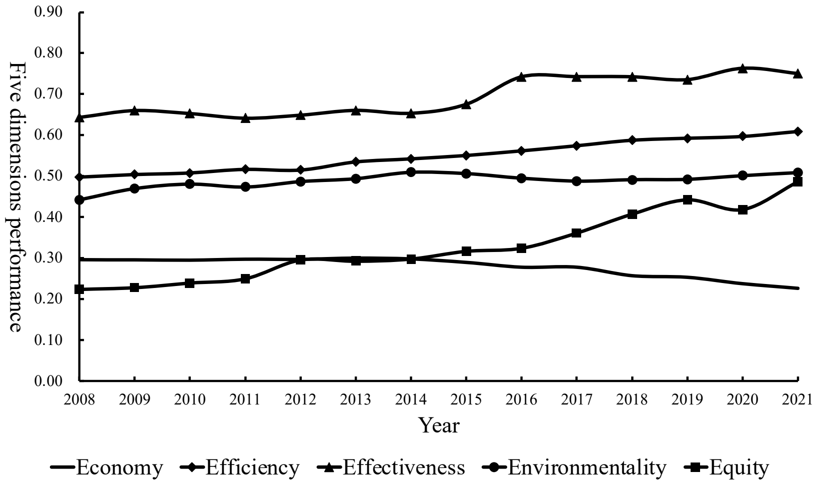

Figure 2. Five dimensions score of China's carbon performance from 2008 to 2021.

China's carbon performance ranged from 0.416 to 0.504, indicating a relatively low level. This implies that China's current carbon emission reduction policies and measures still require significant improvements. Based on the indicator system developed in this study, the following recommendations are made to enhance carbon performance:

Firstly, regarding the economy of carbon performance, it is recommended to foster technological advancements by intensifying research and innovation in pivotal areas such as clean energy, energy efficiency improvements, and carbon capture. This approach can facilitate carbon emission reductions and economic efficiency gains. The government can introduce pertinent policies, including financial subsidies, tax incentives, and loan support, to encourage enterprises to adopt low-carbon technologies and equipment, thereby promoting the development of the green industry. Additionally, establishing market mechanisms, such as carbon trading markets and green bonds, can direct capital towards low-carbon projects, reducing the costs of low-carbon technologies and motivating enterprises to actively reduce carbon emissions. Furthermore, this approach promotes the transformation of traditional high-carbon industries towards a low-carbon and circular direction. It also encourages the development of green manufacturing, green buildings, and green transportation, ultimately fostering a low-carbon and circular economic development model.

Secondly, in terms of the efficiency of carbon performance, energy conservation can be enhanced by popularizing energy-saving technologies and equipment, optimizing the energy structure, and reducing energy consumption intensity to achieve efficient energy utilization. It is essential to strengthen the monitoring and statistics of energy consumption, formulate and enforce energy conservation standards and energy efficiency labeling systems, and foster a positive societal atmosphere for energy conservation and emission reduction. Strict energy efficiency standards and energy conservation regulations should be formulated, and penalties or restrictions should be imposed on enterprises that fail to adhere to these standards. Additionally, financial subsidies, tax incentives, and other incentive policies should be provided to encourage enterprises to adopt energy-saving technologies and equipment. Furthermore, investment in energy efficiency improvement projects should be increased to promote the development of related industries.

Thirdly, regarding the effectiveness of carbon performance, the government should introduce stricter carbon emission standards and environmental protection regulations, strictly limiting and regulating high-carbon industries and emission sources. Simultaneously, implementing a carbon emission trading system can leverage market mechanisms to promote carbon emission reductions. Additionally, the government can provide financial subsidies, tax incentives, and other incentive policies to encourage enterprises to actively adopt carbon emission reduction measures. Increase investment in research and development of critical technologies, such as clean energy, energy efficiency improvement, carbon capture, and storage, to foster technological innovation and the transformation of research results into practical applications. By enhancing technological levels, carbon emissions can be effectively reduced, and emission reduction efficiency can be improved. Furthermore, promote the development of industrial structures towards a low-carbon and circular direction, restrict the expansion of high-carbon industries, and encourage the development of green industries.

Fourthly, in terms of the environmentality of carbon performance, adopting more energy-efficient equipment and technologies can minimize energy consumption and reduce carbon emissions. For instance, high-efficiency and energy-saving building materials and systems can be utilized in the construction sector. In the transportation sector, promoting the use of public transportation and non-motorized vehicles can reduce the reliance on private cars. Forests are one of the most significant carbon sinks on Earth, and by protecting existing forests, restoring degraded forest land, and undertaking afforestation initiatives, carbon sequestration capacity can be enhanced, thereby assisting in the absorption of carbon dioxide from the atmosphere.

Lastly, in terms of the equity of carbon performance, strengthening education and promotion on carbon emissions and climate change can raise public awareness and engagement in environmental protection. The government should formulate fair, transparent, and sustainable carbon emission reduction policies to ensure that all stakeholders, including individuals from different regions, industries, and income levels, can equitably share the responsibility for emission reductions. A full consultation with all parties should be conducted during the policy-making process to guarantee the fairness and rationality of the policies. The fair distribution of resources should be ensured in the process of carbon emission reductions. For example, the allocation of carbon emission rights should be based on fair principles to avoid certain regions or industries receiving a disproportionately large or small quota. Simultaneously, the allocation of carbon emission reduction technologies and funds should also be equitable, enabling all regions and industries to effectively implement emission reduction measures. To enhance public awareness of carbon emission reduction and carbon performance, as well as to strengthen public support and participation in carbon emission reduction policies, various methods can be employed. Through propaganda, education, training, and other initiatives, knowledge of carbon emission reduction can be disseminated widely, thereby improving public awareness and engagement in environmental protection.

4.4. Local Analysis and Improvement Strategies

Due to geographical location, natural conditions, historical evolution, and policy preferences, there are significant differences in economic development levels, social progress, and cultural characteristics among the eastern, central, and western regions of China. Therefore, we divided the 30 provinces into eastern, central, and western regions for local analysis. According to the classification of the National Bureau of Statistics of China, the eastern region includes Beijing, Tianjin, Hebei, Liaoning, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, and Hainan. The central region includes Shanxi, Jilin, Heilongjiang, Anhui, Jiangxi, Henan, Hubei, and Hunan. The western region includes Inner Mongolia, Guangxi, Chongqing, Sichuan, Guizhou, Yunnan, Shaanxi, Gansu, Qinghai, Ningxia, and Xinjiang.

Figure 3 demonstrates the carbon performance and its growth rate in China's eastern region from 2008 to 2021. The following observations can be made: (1) With regard to the carbon performance in the eastern region, the maximum value was 0.523 in 2021, and the minimum value was 0.441 in 2008, with an average of 0.477. During the sample period, the carbon performance in the eastern region shows a fluctuating upward trend, with declines only in 2010 and 2011, while positive growth is observed in all other years. (2) In terms of the growth rate in the eastern region, the average annual growth rate during the sample period was 1.333%. The fastest growth rate was 2.935% in 2021, while the slowest growth rate was 0.161% in 2020. The growth rates in 2009, 2012, 2016, and 2021 all remained above 2%. Conversely, negative growth is observed in 2010 and 2011, with changes of −0.202% and −0.829%, respectively. The growth rates in the remaining years ranged from 0.161% to 1.197%.

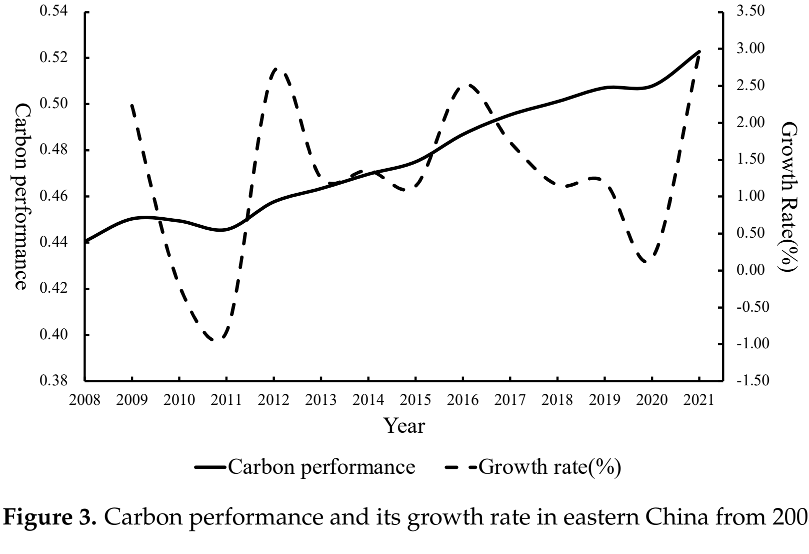

Figure 3. Carbon performance and its growth rate in eastern China from 2008 to 2021.

Figure 4 illustrates the carbon performance and its growth rate in China's central region from 2008 to 2021. Based on the analysis Figure 4, the following conclusions can be drawn: (1) Regarding the carbon performance in the central region, the lowest carbon performance score was 0.408 in 2008, while the highest was 0.504 in 2021. The average score during the sample period was 0.454. Overall, a cyclic fluctuation trend of "rise–fall" is observed, with increases in all years except for 2011, 2014, and 2020, which showed declines. (2) In terms of the growth rate in the central region, the average annual growth rate during the sample period was 1.644%. The largest increase occurred in 2012, with a growth rate of 4.207%, while the largest decline was in 2011, with a growth rate of −1.431%. Among the remaining years, the growth rates in 2009 and 2020 exceeded 3%, while the growth rates in 2013, 2017, and 2018 hovered around 2%. The growth rates in 2014 and 2020 were negative, at −0.167% and −0.026%, respectively. The growth rates in the remaining years ranged from 0.808% to 1.505%.

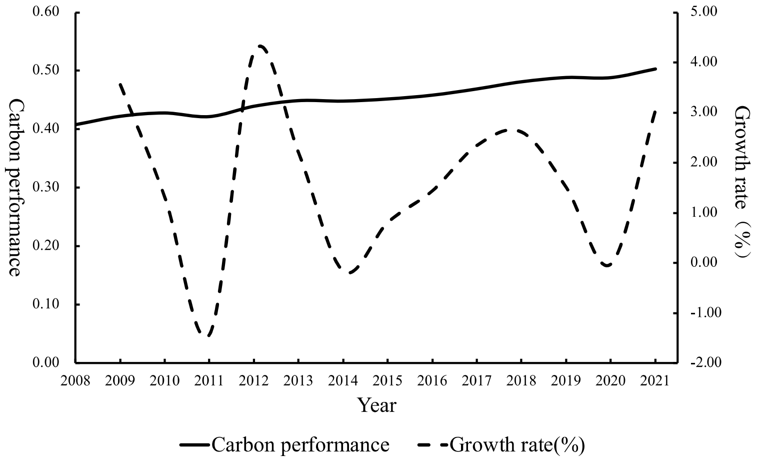

Figure 4. Carbon performance and growth rate in central China from 2008 to 2021.

Figure 5 demonstrates the carbon performance and its growth rate in China's western region. The analysis reveals the following: (1) In terms of carbon performance in the western region, it rose from a minimum of 0.398 in 2008 to a maximum of 0.485 in 2021, with a mean value of 0.444. Overall, there was a trend of slow upward development, with positive growth observed in all years except for a slight decline in 2020. (2) As for the growth rate in the western region, the average annual growth rate was 1.536%. Except for a growth rate of −0.421% in 2020, all other years showed positive growth. Among these years, the smallest growth was recorded in 2016, with only 0.524%, while the largest growth occurred in 2009, reaching 3.223%. The growth rates in other years ranged from 0.863% to 2.421%.

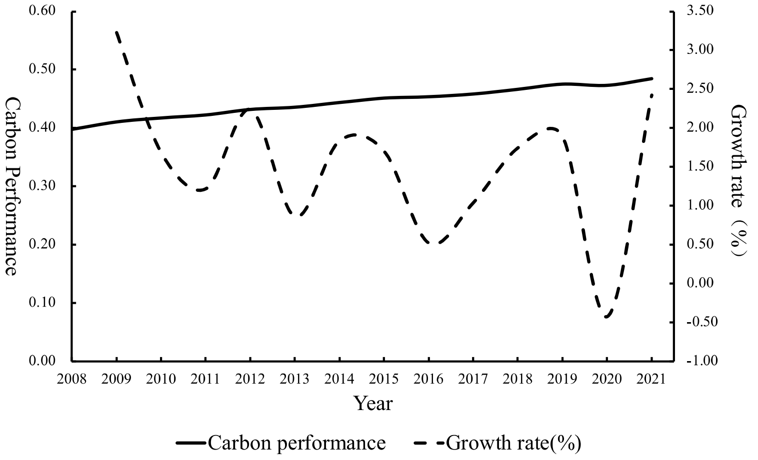

Figure 5. Carbon performance and growth rate in western China from 2008 to 2021.

Overall, the carbon performance of China's three major regions exhibited a decreasing trend from the east to the west. Conversely, the average growth rates of carbon performance in the central and western regions exceeded those in the eastern region. Based on the evaluation results of carbon performance in the three regions, we propose the following policy recommendations.

The eastern region, with its advanced economy and high level of urbanization, has a substantial energy demand. Therefore, this region should prioritize optimizing and improving its energy consumption structure and efficiency. Firstly, it should actively introduce and promote clean energy sources, such as solar and wind energy, to mitigate its reliance on fossil fuels. Secondly, through technological innovation and industrial upgrading, this region should improve its energy utilization efficiency and reduce its carbon emissions per unit of output. Finally, the eastern region can leverage its economic prowess to increase investment in research and development of carbon emission reduction technologies, thereby promoting the innovation and application of low-carbon technologies.

The central region, which is in a period of economic growth with a robust industrial base, also encounters significant carbon emission pressure. While enhancing carbon performance, the central region must strike a balance between economic development and carbon emission reduction. On the one hand, it should promote the optimization and upgrading of the industrial structure, fostering low-carbon and environmentally friendly industries, and diminishing the proportion of high-carbon industries. On the other hand, it should reduce its carbon emission intensity by improving its energy utilization efficiency and encouraging energy-saving technologies and equipment. Additionally, the central region can strengthen collaboration with the eastern region to adopt advanced carbon emission reduction technologies and experiences, fostering coordinated regional development.

The western region, boasting vast territory and rich resources but relatively low economic development, should harness its resource and geographical advantages to foster green and low-carbon development. It should enhance the carbon sequestration capacity of its ecosystems through ecological protection and restoration efforts. Moreover, the western region can leverage national strategies, such as the "Belt and Road" initiative, to strengthen cooperation with neighboring countries and jointly promote the construction of a green Silk Road.

In a word, China's eastern, central, and western regions must devise strategies tailored to their respective characteristics to improve their carbon performance. At the same time, it is necessary to fortify support in policy guidance, technological innovation, and public participation to create a conducive environment for the society to jointly promote carbon emission reductions.

4.5. Predictions

We utilized the ARIMA model to forecast the carbon performance of the country's national level, as well as its eastern, central, and western regions, spanning from 2022 to 2033. The results are depicted in Figure 6. The following observations can be made: (1) By 2033, the predicted value of the national carbon performance stands at 0.602, indicating that it is still in the upper-middle stage. Our calculations suggest that approximately 20 years of effort would be required to achieve a score of 0.7, which is expected around 2044. (2) The predicted carbon performance in 2033 is 0.612 for the eastern region, 0.613 for the central region, and 0.582 for the western region. It is anticipated that the gap between the eastern and central regions will continue to diminish, whereas the carbon performance of the western region remains behind both the eastern and central regions.

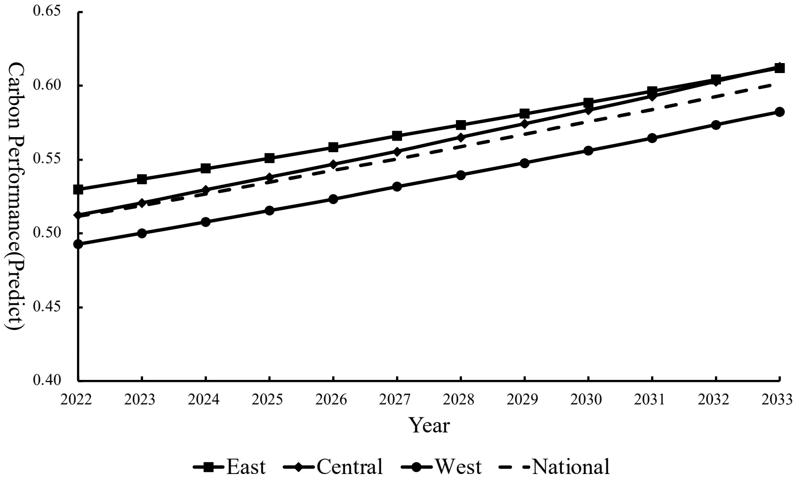

Figure 6. Predictions of carbon performance from 2022 to 2033.

5. Conclusions and Discussion

5.1. Conclusions

The evaluation of regional carbon performance is a process that assesses and analyzes a specific region's performance and effectiveness in low-carbon development. It serves as a crucial means to evaluate the effectiveness of low-carbon development within a region, thereby holding significant value in advancing sustainable development and addressing global climate change challenges. Drawing upon the "3E" evaluation framework, this study established a "5E" regional carbon performance evaluation index system that includes five dimensions of economy, efficiency, effectiveness, environmentality, and equity, encompassing 39 indicators. The entropy weight TOPSIS method was employed as the evaluation approach, incorporating specific data from 30 provinces in China spanning 2008 to 2021 to conduct carbon performance evaluations.

The evaluation results indicate that (1) China's overall carbon performance ranges from 0.416 to 0.504, showing a gradual upward trend during the sample period. (2) During the sample period, Effectiveness scored the highest among the first-level indicators, whereas Economy scored the lowest. Apart from Economy, the scores of the other four dimensions exhibited varying degrees of growth. (3) Regionally, carbon performance exhibits a spatial pattern of gradual decline from east to west, while the growth rate of carbon performance follows a descending trend from central to western to eastern regions. Based on the evaluation results, this paper proposes comprehensive improvement strategies that consider the economy, efficiency, effectiveness, environmentality, and equity of carbon performance, and suggests tailored carbon performance improvement paths that are aligned with the development characteristics of the eastern, central, and western regions. (4) Our prediction indicates that in 2033, the carbon performance of the whole country, the eastern region, the central region, and the western region will reach 0.602, 0.612, 0.613, and 0.582, respectively.

5.2. Discussion

In the context of global climate change responses, reducing greenhouse gas emissions and promoting a low-carbon economic and social transformation have become a consensus among the international community. The evaluation of regional carbon performance holds significant importance in facilitating the formulation of carbon emission reduction policies, understanding the patterns of carbon performance changes, promoting low-carbon development, and enhancing international competitiveness. The regional carbon performance evaluation index system constructed in our study can provide decision-making references for users to choose the appropriate evaluation system scientifically and objectively, thus possessing crucial theoretical significance and application value.

The theoretical contributions of this paper are threefold. Firstly, it enriches the theoretical framework of carbon performance evaluation. Traditional carbon performance evaluation often concentrates solely on economic and environmental indicators, overlooking aspects of efficiency and equity. This study introduced a regional carbon performance evaluation index system grounded in the "5E" framework, thereby enhancing the theoretical framework of carbon performance evaluation and guiding its evolution towards a more comprehensive and scientific trajectory.

Secondly, it advances the understanding of low-carbon development theory. The development of a regional carbon performance evaluation index system necessitates profound research into the theory of low-carbon development, encompassing its underlying causes, impact mechanisms, and reduction strategies. This research thus fosters a deeper understanding of low-carbon development theory and provides theoretical underpinnings for the formulation of more scientifically sound and reasonable low-carbon policies.

Thirdly, it enhances the theory of regional sustainable development. Carbon performance is a pivotal indicator of a region's sustainable development capabilities. The establishment of a regional carbon performance evaluation index system takes into account carbon emissions, regional economic development, environmental protection, and other pertinent factors, thereby refining the theoretical framework and fostering the harmonious development of the economy, society, and the environment.

5.3. Recommendations for Management Practice

Both regional carbon emission performance evaluations and Sustainable Development Goals (SDGs) are committed to achieving sustainable environmental development. The former focuses on the actual situation of regional carbon emissions, while the latter provides a global guiding framework and specific targets. Through a regional carbon emission performance evaluation, we can identify which policies and measures have significantly reduced carbon emissions, thereby promoting these successful experiences to other regions. Meanwhile, the SDGs guide regional carbon emission performance evaluations, making the evaluation more targeted. Based on the research conclusions of this paper, the following suggestions are proposed:

Firstly, establish standardized and unified carbon performance evaluation criteria and methods. Formulate nationally uniform carbon performance evaluation standards, clarifying the evaluation scope, indicators, and methods to ensure the fairness and comparability of evaluation results. Encourage various regions to develop more targeted carbon performance evaluation rules based on their unique characteristics to better reflect actual situations and reduce carbon emissions.

Secondly, strengthen the utilization and disclosure of carbon performance evaluation results. Regularly publish regional carbon performance evaluation results to enhance public attention and oversight of carbon performance. Incorporate carbon performance evaluation results into government performance evaluation systems as an important basis for policy formulation and decision-making. Provide supervision and guidance to enterprises and regions with poorer carbon performance evaluation results, assisting them in developing carbon emission reduction plans and measures to improve their carbon performance levels.

Thirdly, enhance international exchanges and cooperation on carbon performance evaluation systems. Learn from internationally advanced carbon performance evaluation methods and experiences to continuously improve China's carbon performance evaluation system. Strengthen cooperation and alignment with international carbon markets to promote the internationalization and standardization of China's carbon performance evaluation system.

In summary, by establishing scientific, comprehensive, and operable carbon performance evaluation criteria and methods, integrating with other policies, enhancing the utilization and disclosure of results, establishing incentive mechanisms, strengthening international exchanges and cooperation, and intensifying supervision and law enforcement efforts, we can effectively promote the improvement and development of the carbon performance evaluation system, providing strong support for China's low-carbon transformation and sustainable development.

6. Limitations

Although this article has made a valuable attempt to construct a regional carbon performance evaluation index system, there are still some limitations. On the one hand, although this study selected 39 indicators from five dimensions (economy, efficiency, effect, environmental impact, and equity) to establish the regional carbon performance evaluation index system, it remains a challenge to address the issue of potentially incomplete evaluation indicators. Given the operability of the index system and the availability of data, a relatively large number of quantitative indicators were selected, which led to insufficient consideration of factors such as the implementation of low-carbon policies, the degree of low-carbon promotion, and residents' awareness of low-carbon development. On the other hand, there are difficulties in data collection. Currently, China's carbon emissions and energy data are not abundant, and some data are severely missing. Differences in statistical standards and detailed categories across different regions have posed considerable challenges in data collection. Future research directions include the following aspects:

Firstly, the refinement and enhancement of the carbon performance evaluation index system. The current carbon performance evaluation system may still harbor limitations, such as the suboptimal design of indicators and challenges in data acquisition. Therefore, future research should aim to improve and optimize the index system to bolster the accuracy and practicality of the evaluation. For example, the incorporation of more qualitative indicators could facilitate a more comprehensive reflection of a region's carbon performance level.

Secondly, comparative analyses across regions and industries. Current research tends to focus narrowly on carbon performance evaluation within a single region or industry, overlooking inter-regional and inter-industry comparisons. Future research should broaden its scope and conduct comparative studies across regions and industries to identify both differences and similarities in carbon performance, thereby laying the foundation for formulating more tailored policies.

Thirdly, improvements in data collection and processing methodologies. Regional carbon performance evaluation relies heavily on data, yet existing data collection and processing methods may be inadequate. Future research should explore more sophisticated data collection and processing techniques to elevate data accuracy and reliability, thus providing stronger data support for carbon performance evaluation.

In conclusion, future research avenues in regional carbon performance evaluation are multifaceted and intricate, necessitating interdisciplinary and cross-sectoral collaboration and communication to foster continuous development and refinement in this field.

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References

1. Manioudis, M.; Meramveliotakis, G. Broad strokes towards a grand theory in the analysis of sustainable development: A return to the classical political economy. *New Political Econ.* **2022**, *5*, 866–878. [CrossRef]
2. Meramveliotakis, G.; Manioudis, M. History, knowledge, and sustainable economic development: The contribution of John Stuart Mill's grand stage theory. *Sustainability* **2021**, *3*, 1468. [CrossRef]
3. Wang, Q.Y. *2021 Energy Data*; Green Innovation and Development Center: Beijing, China, 2022.
4. Ehrlich, P.R.; Holdren, J.P. Impact of population Growth. *Science* **1971**, *171*, 1212–1217. [CrossRef]
5. Kaya, Y. *Impact of Carbon Dioxide Emission Control on GNP Growth: Interpretation of Proposed Scenarios*; Intergovernmental Panel on Climate Change/Response Strategies Working Group: Paris, France, 1989.
6. Dietz, T.; Rosa, E.A. Rethinking the environmental impacts of population affluence and technology. *Hum. Ecol. Rev.* **1994**, *1*, 277–300.
7. York, R.; Rosa, E.A.; Dietz, T. STIRPAT, IPAT and impact: Analytic tools for unpacking the driving forces of environmental impacts. *Ecol. Econ.* **2003**, *3*, 351–365. [CrossRef]
8. Brantley, L. Impact of population, age structure, and urbanization on carbon emissions energy consumption: Evidence from macro-level, cross-country analyses. *Popul. Environ.* **2014**, *3*, 286–304.
9. Ali, H.S.; Abul-Rahim, A.S.; Ribadu, M.B. Urbanization and carbon dioxide emissions in Singapore: Evidence from the ARDL approach. *Environ. Sci. Pollut. Res.* **2017**, *2*, 1967–1974. [CrossRef]
10. Kohler, M. CO2 emissions, energy consumption, income and foreign trade: A South African perspective. *Energy Policy* **2013**, *12*, 1042–1050. [CrossRef]
11. Pham, D.T.T.; Nguyen, H.T. Effects of trade openness on environmental quality: Evidence from developing countries. *J. Appl. Econ.* **2024**, *1*, 2339610. [CrossRef]
12. Manel, D. Using the LMDI decomposition approach to analyze the influencing factors of carbon emissions in Tunisian transportation sector. *Int. J. Energy Econ. Policy* **2018**, *7*, 22–28.
13. Azam, M.; Raza, A. Does foreign direct investment limit trade-adjusted carbon emissions: Fresh evidence from global data. *Environ. Sci. Pollut. Res.* **2022**, *25*, 37827–37841. [CrossRef] [PubMed]
14. Yu, X.J.; Kuruppuarachchi, D.; Kumarasinghe, S. Financial development, FDI, and CO2 emissions: Does carbon pricing matter? *Appl. Econ.* **2024**, *25*, 2959–2974. [CrossRef]
15. Wang, S. Research on carbon emission performance evaluation system of industrial enterprises. *Sci. Technol. Econ.* **2013**, *26*, 101–105.
16. Zhang, Y.L.; Liu, Q. Construction and calculation of enterprise carbon performance index system. *Stat. Decis.-Mak.* **2020**, *36*, 166–169.
17. Wang, A.H.; Li, S.S. Construction of enterprise low carbon audit DRS model evaluation index system. *Audit Econ. Res.* **2016**, *31*, 42–51.
18. Lu, X.L.; Zhao, N. Performance evaluation of urban low-carbon government based on balanced scorecard—Taking 11 cities in Hebei province as examples. *Friends Account.* **2018**, *2*, 112–116.
19. Liu, H.J.; Qian, L.C.; Guo, L.X. Coordinated promotion of pollution reduction and carbon reduction and China's 3E performance. *Financ. Res.* **2022**, *48*, 4–17.
20. Ye, Z.Y.; Wang, G.; Zhang, Y.Y. Exploring the regional carbon performance evaluation system—Taking Jiangsu province as an example. *China Mark.* **2016**, *30*, 170–175.
21. Yang, J.A.; Tang, L.; Mi, Z.F. Carbon emissions performance in logistics at the city level. *J. Clean. Prod.* **2019**, *231*, 1258–1266. [CrossRef]
22. Xu, L.P.; Jian, X.Y. Construction of enterprise carbon performance evaluation index system based on "3E" triangle model under the "double carbon" goal. *Value Eng.* **2023**, *42*, 1–3.
23. Tol, R.S.; Pacala, S.W.; Socolow, R.H. Understanding long-term energy use and carbon dioxide emissions in the USA. *J. Policy Model.* **2009**, *31*, 425–445. [CrossRef]
24. He, Y.; Tang, Q.L.; Wang, K.T. Carbon performance and financial performance. *Account. Res.* **2017**, *2*, 76–82.
25. Li, Z.P.; Hu, Y.F. Can environmental subsidies improve corporate carbon performance—Based on empirical analysis of a-share listed companies. *J. Dalian Univ. Technol. (Soc. Sci. Ed.)* **2024**, *45*, 33–41.
26. Zhang, F.; Qi, Y. Research on the performance evaluation index system construction and countermeasure of low-carbon economic development in China. *IOP Conf. Ser. Earth Environ. Sci.* **2020**, *440*, 042058. [CrossRef]
27. Zhang, C.P.; Yue, W.J.; Tan, D.M. Carbon performance evaluation system and practice analysis for the sustainable enterprises. *Sustain. Dev.* **2022**, *31*, 292–306. [CrossRef]
28. Kuosmanen, T.; Kortelainen, M. Measuring eco-efficiency of production with data envelopment analysis. *J. Ind. Ecol.* **2005**, *9*, 59–72. [CrossRef]
29. Zhou, P.; Ang, B.W.; Han, J.Y. Total factor carbon emission performance: A Malmquist index analysis. *Energy Econ.* **2010**, *32*, 194–201. [CrossRef]

30. Asavava-llobh, N.; Gronberg, T.J.; Jansen, D.W. Introducing a new DEA methodology for environmental inputs. *Appl. Econ. Lett.* **2013**, *20*, 1592–1595. [CrossRef]
31. Yu, J.T.; Zhang, J.Y. Research on low-carbon supply chain performance evaluation based on AHP-DEA. *Econ. Syst. Reform* **2015**, *5*, 44–51.
32. Wang, Q.W.; Zhou, P.; Zhou, D.Q. Dynamic changes, regional differences and influencing factors of my country's carbon dioxide emission performance. *China Ind. Econ.* **2010**, *1*, 45–54.
33. Wang, X.; Gai, M.; Wang, S. Regional carbon emission performance evaluation in Shandong province. *Resour. Dev. Mark.* **2017**, *33*, 150–155.
34. Yang, Q.L.; Liu, J. Exploration on the construction of carbon performance evaluation index system for Chinese enterprises under the 'dual carbon' target. *Financ. Account.* **2022**, *3*, 57–60.
35. Chen, S.Y.; Zhang, J.P.; Liu, Z.L. Environmental regulation, financing constraints, and enterprise pollution reduction: Evidence from the adjustment of pollutant discharge fees. *J. Financ. Res.* **2021**, *9*, 51–71.
36. Cui, W.; Man, Y.C.; Yang, R.L. Regional economic growth, energy consumption structure, and 'carbon neutrality' in China. *Consum. Econ.* **2023**, *5*, 51–64.
37. Wang, X.; Li, Y.X.; Xu, H.W. Regional differences in carbon productivity development and driving factors: An empirical study of 21 cities at the prefecture level in Guangdong province. *Environ. Sci. Res.* **2023**, *10*, 2022–2030.
38. Sun, J.; Geng, C.L.; Zhang, Z.T. Current status of industrial solid waste resource comprehensive utilization technology. *Mater. Rep.* **2012**, *11*, 105–109.
39. Zheng, Y.; Li, S.; Kanran, T. Impact of forest coverage rate and other air pollutants and meteorological factors on PM2.5: A case study of 13 cities (districts) in winter in Heilongjiang province. *J. Northeast For. Univ.* **2020**, *4*, 64–70.
40. Yu, G.H.; Chen, T.R.; Zhou, P.C. Research on the early warning index system and model of environmental mass incidents in China. *J. Intell.* **2013**, *7*, 13–18.
41. Tang, B.; Cheng, T.; Peng, Y. Government trust, government responsibility, and public environmental satisfaction: An analysis based on the 2019 China social conditions comprehensive survey. *Econ. Geogr.* **2023**, *7*, 161–169.
42. Jiao, J.; Miao, S.; Zhang, Z.W. Political connections, corporate environmental governance investment, and corporate performance: An empirical study based on Chinese private enterprises. *Technol. Econ.* **2018**, *6*, 130–139.
43. Zhang, Y.; Huang, Q.Z.; Li, D.D. A Configurational analysis of enterprise environmental information disclosure and low-carbon production behaviors from the perspective of stakeholders. *Soft Sci.* **2024**, *1*, 1–10.
44. Chen, P.Y. Effects of the entropy weight on TOPSIS. *Expert Syst. Appl.* **2021**, *168*, 114186. [CrossRef]
45. Zhu, J.; Sun, H.P.; Liu, N.Y.; Zhou, D.Q.; Taghizadeh-Hesary, F. Measuring carbon market transaction efficiency in the power industry: An entropy-weighted TOPSIS approach. *Entropy* **2020**, *9*, 973. [CrossRef] [PubMed]
46. Wang, Y.; Zhao, H.; Duan, F.; Wang, Y. Initial provincial allocation and equity evaluation of China's carbon emission rights—Based on the improved TOPSIS method. *Sustainability* **2018**, *10*, 982. [CrossRef]
47. He, S.Q.; Song, D.Z.; Mitri, H.; He, X.Q.; Chen, J.Q.; Li, Z.L.; Xue, Y.R.; Chen, T. Integrated rockburst early warning model based on fuzzy comprehensive evaluation method. *Int. J. Rock Mech. Min. Sci.* **2021**, *142*, 104767. [CrossRef]
48. Xu, X. A note on the subjective and objective integrated approach to determine attribute weights. *Eur. J. Oper. Res.* **2004**, *2*, 530–532. [CrossRef]
49. Yu, L.P.; Zheng, K. Comparison and consideration of different objective weighting methods in journal evaluation. *J. Mod. Inf.* **2021**, *12*, 121–130.
50. Wei, M.; Li, S.H. Research on the measurement of high-quality development level of China's economy in the new era. *J. Quant. Tech. Econ.* **2018**, *11*, 3–20.
51. Chinese Research Data Services Platform. Available online: https://www.cnrds.com (accessed on 20 May 2024).
52. Carbon Emission Accounts and Datasets. Available online: https://www.ceads.net (accessed on 20 May 2024).
53. Chinese Social Quality Data Archive. Available online: http://csqr.cass.cn (accessed on 20 May 2024).
54. Department of Energy Statistics, National Bureau of Statistics. *China Energy Statistical Yearbook*; China Statistics Press: Beijing, China, 2022.
55. Department of Ecological Environment, National Bureau of Statistics. *China Environment Statistical Yearbook*; China Statistics Press: Beijing, China, 2022.
56. National Bureau of Statistics. *China Statistical Yearbook*; China Statistics Press: Beijing, China, 2022.