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Evaluating the Effectiveness of Green Transformation of Resource-Based Cities: A Case Study of Shandong Province, China

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Abstract: Resource-based cities are vulnerable to the depletion of natural resources and urgently need to undergo a green transformation to avoid the so-called "resource curse" and achieve sustainable development. At present, there is a lack of a scientific and reasonable indicator system and theoretical model to guide the evaluation of the effectiveness of green transformation of resource-based cities. To undertake a comprehensive analysis of the causality of indicators, this study employs the DPSIR (Driving Force–Pressure–State–Impact–Response) model to construct an evaluation index system for the effectiveness of green transformation of resource-based cities. The DEMATEL (Decision-Making Trial and Evaluation Laboratory) method is employed to explore the level of importance of the evaluation indicators and the causal relationships between the evaluation indicators. The VIKOR ('VlseKriterijumska Optimizacija I Kompromisno Resenje' in Serbian) method is introduced to evaluate the effectiveness of green transformation of resource-based cities. This study selects Shandong Province, a strategically important energy resource region in China, as an example. The results of the study show that the effectiveness of green transformation of resource-based cities in Shandong Province as a whole was on an upward trend from 2013 to 2021. This study categorizes the phases into rapid start-up period, adjustment and optimization period, and recovery and acceleration period. Currently, the green transformation shows remarkable effectiveness. The effectiveness of green transformation within each dimension of the DPSIR model reveals a ranking of response > pressure > driving force > state > impact. By incorporating regional characteristics, this study explores and proposes recommendations to enhance the green transformation of resource-based cities. It can not only furnish policy references for green transformation of similar resource-based cities, but also offer case study practices for different types of resource-based cities to achieve sustainable development.

Keywords: resource-based cities; green transformation; DPSIR model; DEMATEL method; VIKOR method

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1. Introduction

To meet the challenges of global climate change, tightening resource and environmental constraints, and environmental pollution [1], China proposed the "dual-carbon" strategic development goal in 2020 [2]. More than 70 percent of global energy-related carbon emissions are generated by cities [3]. Cities are the main battlefield for achieving "carbon peak and carbon neutrality" [4]. Resource-based cities are cities with mining and processing of natural resources such as minerals and forests in the region [5]. In the process of sustainable development of the global economy, these cities tend to rely excessively on a single resource-based industry [6], resulting in a highly vulnerable economy, a monolithic industrial structure, and serious damage to the ecological environment [7]. Resource-based cities have become a key area of unbalanced and inadequate economic development, which is a huge obstacle to China's economy towards high-quality development [8]. In 2021, China's State Council approved the "*14th Five-Year Plan for Promoting High-quality Development of Resource-Based Regions*", requiring that by 2025, the capacity of resource-based regions to ensure resource and energy security should be greatly improved, and by 2035, the goal of high-quality development of resource-based regions with strong resource security, a vibrant economy, a beautiful ecological environment, and people's well-being and happiness should be achieved. In the *20th CPC National Congress Report*, green transformation development is a core step towards achieving a high-quality green and low-carbon economy and society. In 2023, *China's State Council Government Work Report* further emphasized the development of a green and low-carbon economy and the promotion of a green transformation of the industrial, energy, and transportation structures. All this shows that green transformation has fully penetrated the construction of ecological civilization and high-quality development, providing strong support for the coordinated development of Chinese society. Therefore, resource-based cities, which have long been burdened with economic and environmental challenges, urgently need to embrace green transformation to keep pace with the national strategic goal and achieve their own sustainable development.

The green transformation of resource-based cities means the transformation of cities from an "extensive" growth mode highly dependent on natural resources to an "intensive" growth mode of green economic development, emphasizing "ecological priority and green priority", while taking into account economic development and seeking "adaptation points" between economic development and ecological environment to avoid the so-called "resource curse" [9]. Green transformation of resource-based cities is the main way for resource-based cities to break environmental constraints, promote high-quality economic development, and ultimately achieve sustainable development [10]. In recent years, resource-based cities have actively implemented transformation strategies, and have achieved certain transformation achievements through industrial structure adjustment and upgrading, full development of mineral resources, management of coal-mining subsidence zones, and other integrated management modes [11]. However, due to the numerous historical issues, the intricacies involved in rehabilitating ecological damage, and the limitations set by market mechanisms, it is of urgent necessity to augment the effectiveness of the transformation [12]. Shandong Province is an important strategic base of energy resources in China [13], implementing a major project to replace old and new growth drivers, and governments have attached great importance to the green transformation of resource-based cities [14]. In August 2022, China's State Council issued the "*Opinions on Supporting Shandong Province to Deepen the Conversion of Old and New Dynamic Energy and Promote Green, Low-Carbon, and High-Quality Development*". This initiative aims to assist Shandong Province in advancing the transformation from traditional energy sources to new dynamic energy forms. It explores pathways for transformation and development to further enhance regional vitality and build upon existing efforts. Additionally, this initiative positions Shandong as a pioneering zone tasked with significant responsibilities in constructing a sustainable future. Therefore, studying the effectiveness of green transformation in resource cities in Shandong Province is not only important for realizing China's "dual-carbon" goal and sustainable development, but also provides practical experience and theoretical references for similar studies around the world [15].

In recent years, the green transformation of resource-based cities has gradually become a hot topic of scholars' research, which mainly focuses on connotation characteristics, transformation effectiveness evaluation, the transformation path, and so on. Due to different research perspectives and purposes, scholars have different understandings of resource-based cities. In terms of connotation and characteristics, resource-based cities have special functions [16], and their development stages change with the development degree of regional resources [17]. Lucas categorized the development of resource-based cities into four periods: construction, development, transformation, and maturity, laying the foundation for the study of the development stages of resource-based cities [18]. Li, starting from the life cycle of resource-based cities, argued that China's resource-based cities have mainly experienced four periods: the foundation period, the development period, the crisis period, and the transformation and revitalization period [19]. It can be seen that the research of resource-based cities is gradually deepening, involving a variety of perspectives. The research on resource-based cities has gradually expanded to different levels, providing several theoretical bases for the green transformation of resource-based cities.

In terms of evaluation of transformation effectiveness, some scholars have established the index system from multiple perspectives, such as the transformation magnitude [20] and development trend [21], and comprehensively utilized both qualitative [22] and quantitative [23] methods to conduct an in-depth assessment. These methods can reveal the differences and influencing factors of transformation effectiveness in terms of the degree of transformation [24], industrial structure [25], and other aspects. Kim found that the impact of resource abundance on the economic development of different countries varies greatly, which is closely related to the degree of government intervention in the country [26]. Gonzalez developed a multi-criteria methodology that combined Material Flow Analysis (MFA), Life Cycle Assessment (LCA), and Data Envelopment Analysis (DEA) to assess the sustainability of cities [27]. Jing argued that the sustainable development of resource-based cities involves a variety of factors such as social stability, economic growth, and environmental quality [28]. Xie used a dynamic panel Generalized Moment Method (GMM) estimation method to study the impacts of technological innovation and technology introduction on the green transformation of industries in resource-based cities [29]. However, the existing research on the effectiveness evaluation of green transformation lacks theoretical support and interaction analysis among indicators. To fill the above gap, this study will take the DPSIR model as the theoretical support and combine it with the DEMATEL method to explore the importance of each evaluation index and the mutual influence. Compared with traditional evaluation methods, the VIKOR method can provide a compromise solution under a series of conflicting criteria. Therefore, the combination of the three is applicable to the evaluation study of the effectiveness of green transformation of resource-based cities.

In terms of the transformation path, the green transformation of resource-based cities needs to be realized by promoting industrial upgrading [30] and developing non-resource-based industries [31], emphasizing scientific and technological innovation [32] and resource reuse [33]. Yang believes that in the context of high-quality development, the green transformation of China's resource-based cities must implement the new development concept [34]. Childers argues that achieving a sustainability transformation will require adjustments to existing systems or even a new urban system [35]. Xing believes that it is important to promote the integration of resource-based and non-resource-based industries [36]. Liu built a system dynamics model, took Ordos City as an example, and simulated the effects of various policies under different socio-economic situations [37]. Ruan's study found that the main policies adopted by resource-based cities varied at various stages of their development [38]. However, the current research has not put forward specific suggestions for the local environment, culture, and other aspects. Therefore, this study will make up for the defects and put forward the applicable policies for the green transformation of resource-based cities.

Most of the current research has overlooked the effectiveness of green transformation of resource-based cities. This study aims to address this concern from the following aspects. Firstly, an evaluation index system for the effectiveness of green transformation of resource-based cities within Shandong Province will be established. This system will be grounded on the DPSIR model, taking into account both the prevailing circumstances of the effectiveness of green transformation of cities and the unique geographical characteristics of Shandong Province. Secondly, the DEMATEL method will be employed to analyze the causal associations between the significance level of each indicator and the multi-factor combinations of the effectiveness of green transformation of resource-based cities. Thirdly, by taking six resource-based cities in Shandong Province as samples, the VIKOR method will be utilized to evaluate the effectiveness of green transformation of resource-based cities in Shandong Province, followed by temporal sequence analysis and dimensional analysis of the obtained results. Finally, according to the urgency of transformation in each dimension and the local practices, this study will formulate a series of policy recommendations.

2. Study Area and Indicator Design

2.1. Study Area

Shandong Province is located on the east coast of China, at 34°22.9′–38°24.01′ north latitude, 114°47.5′–122°42.3′ east longitude; the specific location is shown in the left part of Figure 1. The province covers a total area of 15.79 trillion km^2 and has a warm temperate monsoon climate. With a total area of 157,900 km^2, Shandong Province has a topography dominated by plains and spanning five major water systems. For the whole year of 2023, the GDP of Shandong Province amounted to CNY 920.69 billion, an increase of 6.0% from the previous year at constant prices. By the end of 2023, Shandong Province had a resident population of 101,229,700 people. Shandong Province has discovered 147 kinds of mineral resources, accounting for 85.47% of the 173 kinds in the country, and 85 kinds of identified resource reserves, accounting for 53.46% of the 162 kinds in the country.

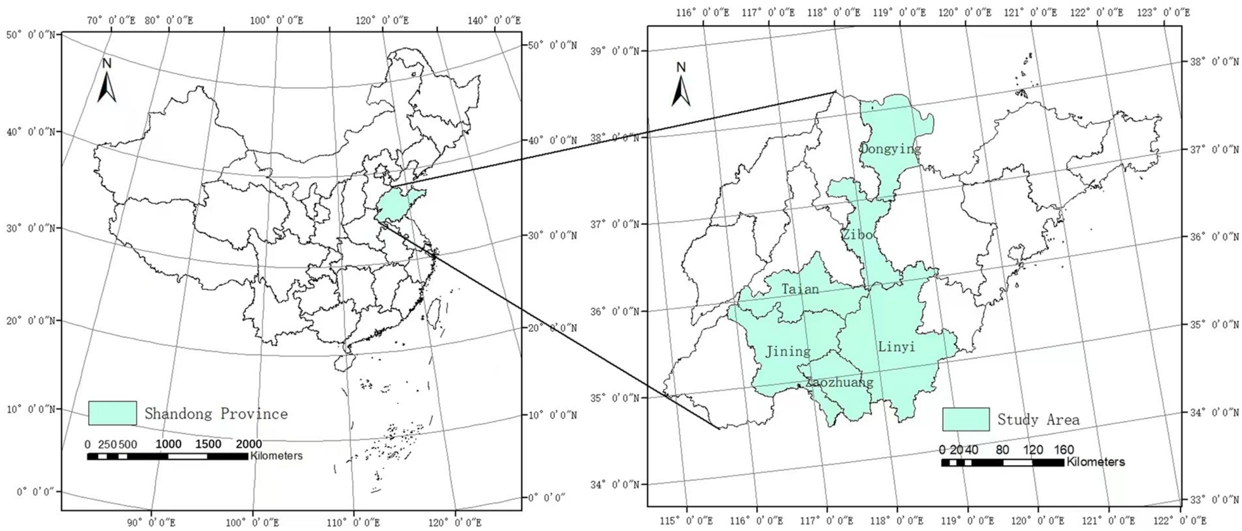

Figure 1. Study area.

As shown in the right part of Figure 1, resource-based cities in Shandong Province are primarily concentrated in the central and southwestern regions. According to the *National Sustainable Development Plan for Resource-Based Cities (2013–2020)*, Zibo, Zaozhuang, Dongying, Jining, Tai'an, and Linyi are the six resource-based prefecture-level cities in Shandong Province, comprising over one-third of the total number of prefecture-level cities. The specific details of resource-based prefectures in Shandong Province can be found in Table 1. In 2022, the combined population of resource-based cities accounted for 45.56% of the province's total population. Additionally, in 2023, the GDP of these resource-based cities made up 27.87% of the province's overall GDP.

Table 1. List of resource-based prefecture-level cities in Shandong Province.

Name	Location	Total Area	Stage of Development	Main Resource Type
Dongying	Northern Shandong Province	7900 km^2	Mature	Oil and gas type
Jining	Southwestern Shandong Province	112,000 km^2	Mature	Coal type
Tai'an	Western Shandong Province	78,000 km^2	Mature	Coal type
Zaozhuang	Southwest Shandong Province	460,000 km^2	Declining	Coal type
Zibo	Central Shandong Province	60,000 km^2	Regenerative	Coal type
Linyi	Southern Shandong Province	17,200 km^2	Regenerative	Non-metallic type

2.2. Indicator Design

In the process of green transformation of resource-based cities, various factors are intertwined. Notably, any alteration in a single factor will impact multiple aspects, such as the economic, social, and environmental ones. Based on the Pressure–State–Response (PSR) model and the Driving Force–State–Response (DSR) model, the Driving Force–Pressure–State–Impact–Response (DPSIR) framework proposed by the Organization for Economic Cooperation and Development (OECD) operates within the logical framework of sustainable development. This model effectively links social, economic, resource, environmental, and policy factors to facilitate a comprehensive analysis of the causal relationships inherent in complex systems' index systems. Furthermore, it adeptly reflects the causal connections between regional environmental issues and human activities [39]. Therefore, the DPSIR model has applicability to this study. Given this, as shown in Figure 2, with the help of the DPSIR model, this study explores the causal chain between evaluation indicators and constructs an evaluation index system of the effectiveness of green transformation of resource-based cities in Shandong Province, which embodies the causal relationship between indicators from five aspects: driving force, pressure, state, impact, and response.

Regarding the DPSIR model evaluation framework system, the evaluation indicators of the effectiveness of green transformation of resource-based cities in Shandong Province are analyzed layer by layer from top to bottom. The effectiveness of green transformation of resource-based cities in Shandong Province is taken as the first layer, that is, the target layer.

The second layer is the criterion layer, which includes five levels: driving force (D), pressure (P), state (S), impact (I), and response (R), and their combination can reflect the transformation effectiveness more comprehensively. Among them, driving force reflects the degree of socio-economic development and the corresponding patterns of consumption and forms of production, such as economic activities and industrial development. Pressure represents the state of use of land and other resources, as well as the operation and emissions of associated biological and chemical factors. State indicates the condition of the city in response to different quantities and qualities of physical and biochemical pressure phenomena in a given area and time. Impact represents influences on the city's resource environment, socio-economics, and human life that can lead to changes in environmental factors. Response refers to countermeasures taken to adapt to environmental changes and mainly encompasses governmental, institutional, group, and individual behaviors.

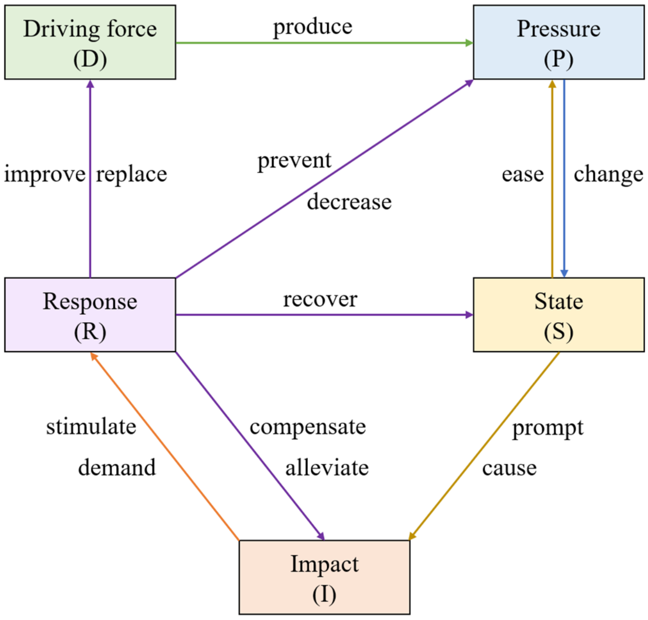

Figure 2. Evaluation index causality based on the DPSIR model.

The third layer is the sub-criterion layer. Among them, resource carrying reflects the ability of resources to support urban development, economic development focuses on the driving effect of economic factors in urban transformation, and urban construction is mainly related to the linkage between urban elements and green transformation, so this study categorizes the driving force level into three aspects: resource carrying, economic development and urban construction. Resource consumption is used to measure the degree of consumption of resources in the process of urban development, pollution emission mainly evaluates the pollution status of industrial production activities on the environment, and residents' life represents the pressure that people bring to the city in their daily life, so this study divides the pressure level into three aspects: resource consumption, pollution emission, and residents' life. Environmental quality mainly reflects the environmental condition of the city, the industrial structure measures the rationality and modernization of the city's industrial structure, and social living reflects the vitality of the city's development and the living standard of the residents from the social level, so this study divides the state level into three aspects, namely, environmental quality, industrial structure, and social life. The ecological environment focuses on the impact of urban green transformation and the natural environment, social development mainly measures the impact of urban transformation on the social level, and resource exploitation represents the efficiency of resource exploitation and the impact on the environment, so this study categorizes the impact level into three parts: ecological environment, social development, and resource exploitation. Environmental governance mainly reflects the city's ability and measures in environmental governance, technological innovation mainly focuses on the role of science and technology in urban green transformation, and green city focuses on the city's initiatives in green transportation and infrastructure development, so this study divides the response dimension into three parts: environmental quality, technological innovation, and green city.

The fourth layer is the index layer, which follows the principles of scientific rigor, comprehensiveness, and practicality. In this study, textual information is collected in three ways: literature search, policy information collection, and field research, to realize the multifaceted combination of research information and ensure that the indicators are scientific and comprehensive. Firstly, conducting textual analysis by searching and tracing the literature related to resource-based cities and green transformation yields indicators that involve various aspects such as population, economy, society, resources, and environment. Secondly, relevant materials such as policy documents, typical cases, news media reports, and other related materials about resource-based cities and green transformation are retrieved. Keywords were extracted and organized into indicators. Thirdly, field research on the current situation of green transformation of resource-based cities is conducted to gain a deeper understanding of the current transformation dilemma and to supplement the indicators. By combining the characteristics of resource-based cities in Shandong Province and the availability of various types of indicator data, a preliminary evaluation index system for the effectiveness of green transformation of resource-based cities in Shandong Province is constructed. The evaluation index system is subjective because it may be influenced by personal preference. Therefore, the expert consultation method was adopted to collect and analyze the opinions and suggestions of experts in the fields of construction and management of resource cities or academic research to improve the objectivity of the indicator system. In-depth interviews and consultations were conducted with 20 experts, including 15 researchers and 5 government personnel, who have more than 5 years of experience in urban transformation research or related work. An indicator was chosen when 16 or more experts agreed with it. After thorough interview consultation and revision, the final evaluation index system for measuring the effectiveness of green transformation of resource-based cities in Shandong Province was created and is presented in Table 2.

This index system consists of a total of 30 indicators. Among them, the positive indicators have a positive effect on the green transformation of resource-based cities in Shandong Province. That is, the larger the index value, the better the effectiveness of green transformation of cities. In contrast, the negative indicators have a negative effect on the green transformation of resource-based cities in Shandong Province. Specifically, the larger the index value of the negative indicators, the worse the effectiveness of green transformation of cities. Specific descriptive notes for each indicator are provided below:

The per capita possession of mineral resources, which refers to the ratio of the reserves of mineral resources in a region to its population, is an important factor affecting regional economic development strategies. The per capita water resource possession, obtained by dividing a region's total water resources by its population, is a key gauge of water resource abundance. The GDP growth rate is a core indicator of a region's economic growth rate and development vitality, which reflects the growth rate of regional gross domestic product in a certain period. The proportion of financial revenue to GDP reflects the government's share of regional economic distribution and its ability to control and deploy economic resources. The natural population growth rate reflects the speed of natural population growth in a region, that is, the ratio of the number of births minus the number of deaths to the total population. The urbanization level is usually measured by the proportion of the urban population to the total population and is an important indicator of the degree of economic and social development of a region.

Table 2. Evaluation indicator system of the effectiveness of green transformation of resource-based cities in Shandong Province.

Target Layer	Criterion Layer	Sub-Criterion Layer	Indicator Layer	Unit	Index Attribute
Effectiveness of Green Transformation of Resource-Based Cities in Shandong Province	Driving force (D)	Resource carrying	Per capita possession of mineral resources	Tons/person	Positive
			Per capita water resource possession	m^2/person	Positive
		Economic development	GDP growth rate	%	Positive
			Proportion of fiscal revenue to GDP	%	Positive
		Urban construction	Natural population growth rate	%	Positive
			Urbanization level	%	Positive
	Pressure (P)	Resource consumption	Energy consumption per unit of GDP	Tons of standard coal/CNY 10,000	Negative
			Electricity consumption per unit of GDP	Kilowatt-hour/ CNY 10,000	Negative
		Pollution emission	Industrial smoke (powder) dust emissions	Million tons	Negative
			Industrial wastewater emissions	Million tons	Negative
		Residents' life	Urban registered unemployment rate	%	Negative
			Per capita disposable income of urban residents	CNY	Positive
	State (S)	Environmental quality	Air quality index (AQI)	%	Negative
			City water quality index (CWQI)	%	Negative
		Industrial structure	Proportion of the secondary industry in GDP	%	Negative
			Proportion of the tertiary industry in GDP	%	Positive
		Social life	Fixed assets investment volume	Billion CNY	Positive
			Per capita total retail sales of social consumer goods	CNY	Positive

Table 2. *Cont.*

Target Layer	Criterion Layer	Sub-Criterion Layer	Indicator Layer	Unit	Index Attribute
Effectiveness of Green Transformation of Resource-Based Cities in Shandong Province	Impact (I)	Ecological environment	Green coverage rate of built district	%	Positive
			Per capita urban park area	m^2	Positive
		Social development	Urban gas penetration rate	%	Positive
			Basic medical insurance participation rate	%	Positive
		Resource exploitation	Unit construction land output rate	%	Positive
			Carbon emissions per capita	Tons of carbon dioxide/person	Negative
	Response (R)	Environmental governance	Harmless treatment rate of life waste	%	Positive
			Comprehensive utilization rate of industrial solid waste	%	Positive
		Technological innovation	Proportion of R&D internal expenditure in GDP	%	Positive
			Internet penetration rate	%	Positive
		Green city	Number of public transport vehicles per 10,000 people	Station	Positive
			Per capita urban road area	m^2	Positive

Energy consumption per unit of GDP refers to the total amount of energy consumed per unit of GDP produced in a region over a certain period, and it reflects the degree of dependence on energy for the region's economic growth and the efficiency of energy utilization. Electricity consumption per unit of GDP is a specialized measure of the amount of electricity consumed per unit of GDP, and electricity is an important form of energy for modern urban production and living. Industrial fume (powder) dust emissions, denoting the total amount of fume (powder) dust emitted into the atmosphere during industrial production, is an important indicator of air environmental pollution caused by industrial activities. Industrial wastewater emissions, representing the total amount of wastewater discharged by industrial enterprises in the production process, are a crucial factor in evaluating industrial environmental impact. The urban registered unemployment rate is the ratio of urban registered unemployed to the sum of urban employed (excluding certain special categories), inactive urban workers, various urban business and self-employed individuals, and the registered unemployed. The per capita disposable income of urban residents refers to the sum of final consumption expenditures and other non-obligatory expenditures as well as savings per capita of urban households, i.e., the income that can be used for discretionary spending by households, which reflects the residents' living standard and consumption ability.

Air Quality Index (AQI), a dimensionless index that quantitatively describes the state of air quality, is derived by monitoring the concentrations of various pollutants in the air, including SO_2, NO_2, and RSP, and then calculated according to a specific method. City Water Quality Index (CWQI) is a comprehensive assessment of the quality status of urban surface or groundwater, taking into account several factors such as the level of chemicals in the water, microbiological indicators, pH, and other factors. The proportion of the secondary industry in GDP reflects the role and contribution of industry in the regional economy. The proportion of the tertiary industry in GDP is one of the most important indicators of the degree of modernization and quality of development of regional economies. The fixed assets investment volume is a general term for the amount of work carried out by society as a whole to build and acquire fixed assets within a certain period and the costs associated with it, expressed in monetary terms, and it reflects the scale of the city's investment and construction efforts. The per capita total retail sales of consumer goods, calculated by dividing the total retail sales of consumer goods in a certain period by the average number of permanent population members in the same period, reflects the residents' average consumption level.

The green coverage rate of the built-up area refers to the ratio of the green coverage area to the total built-up area in the urban built-up area, which directly reflects the level of urban green construction and the quality of the ecological environment. The per capita urban park area refers to the average area of park green space owned by each urban resident, which is an important indicator of urban residents' enjoyment of green space and recreational environment, reflecting the effectiveness of urban planning and construction of green space. The urban gas penetration rate refers to the ratio of the number of people using gas in a city to the total population of the city, and it reflects the popularity of the use of clean energy among urban residents. The basic medical insurance participation rate refers to the proportion of people participating in basic medical insurance to the number of people who should be insured, and it reflects the degree of coverage of medical insurance for urban residents. The unit construction land output rate is the ratio of the gross regional product to the total area of construction land in a certain period, which reflects the efficiency of the utilization of construction land and the effectiveness of economic output. The carbon emissions per capita is the ratio of the total carbon dioxide emissions of a region to the total population of the region, which is a key indicator of the level of regional carbon emissions and the degree of impact on climate change.

The harmless treatment rate of life waste refers to the percentage of the amount of municipal life waste treated harmlessly to the total amount of municipal life waste generated, and it reflects the capacity and level of the city in terms of life waste treatment. The comprehensive utilization rate of industrial solid waste refers to the ratio of the comprehensive utilization of industrial solid waste to the amount of industrial solid waste generated, and it reflects the degree of recycling of solid waste by industrial enterprises. The proportion of R&D internal expenditure in GDP refers to the ratio of a region's internal expenditure on R&D activities to the region's GDP, which reflects the strength of the region's investment in science and technology innovation. Internet penetration rate refers to the ratio of the number of users accessing the Internet to the total population of a region, which reflects the level of informatization and the degree of development of the digital economy in a region. The number of public transportation vehicles per 10,000 people refers to the average number of public transportation vehicles per 10,000 residents in a city, reflecting the supply level and service capacity of urban public transportation. The per capita urban road area is the ratio of the total area of urban roads to the total population of the city, reflecting the scale of urban road construction and the convenience of travel for residents.

2.3. Data Collection

Based on data sources such as the China Statistical Yearbook, the Shandong Statistical Yearbook, and public government reports, this study collects panel data from six resource-based prefecture-level cities in Shandong Province as analysis samples. The research period selected for the analysis of the transformation spans from 2013 to 2021, due to the incomplete release or updating of some data sources after 2021. To ensure the accuracy and reliability of the research, the interpolation method was used for dealing with the missing data, aiming to reflect the transformation from 2013 to 2021 as accurately as possible. The interpolation method uses the function values of several known points in a certain interval to make an appropriate specific function, and then uses the value of this specific function as an approximation of the original function at other points in the interval to obtain an estimate of the missing data [40]. After processing the data with this method, the integrity and usability of the data were improved, which laid a solid foundation for the subsequent in-depth analysis of the transformation.

3. Methodology

3.1. DEMATEL Method

The evaluation of the effectiveness of green transformation of resource-based cities is a relatively complex systematic project, with a variety of indicators contributing to the effectiveness of the transformation. Some indicators directly contribute to the effectiveness of green transformation, while others indirectly contribute to the effectiveness of green transformation by influencing other indicators. Indicators are not independent of each other, and the degree of importance of each one has a certain degree of difference and does not have ambiguity. Therefore, this study selects the DEMATEL method to calculate the weights of indicators.

The DEMATEL method, which stands for Decision-Making Trial and Evaluation Laboratory, was initially proposed by scholars A. Gabus and E. Fontela of Battelle Laboratory in the United States. This method involves obtaining the direct influence matrix through logical relationships between elements. It further calculates the influence degree, influenced degree, center degree, and cause degree of each research factor through matrix operations. Subsequently, it determines the comprehensive influence degree of factors based on the center degree and establishes causal relationships between research factors by judging their attributes according to the cause degree [41].

3.1.1. Establish the Direct Influence Matrix

Ten experts and scholars were invited to score the mutual influence relationship between every 2 indicators of the 30 indicators in the evaluation index system of the effectiveness of green transformation of resources-based cities in Shandong Province, and the scores were used to evaluate the influence relationship between the indicators, where a_{ij} indicates the influence of indicator i on indicator j. This rating is designed with 5 levels: 0 points (no impact), 1 point (small impact), 2 points (general impact), 3 points (large impact), and 4 points (very large impact). These experts and scholars included 7 research scholars and 3 government officials, all of whom had been engaged in research or work related to the green transformation of resource-based cities for more than 5 years. The average percentage of error in the consistency test for the recovered data was found to be less than 0.05, thereby satisfying the established standard. The scoring results were then averaged to obtain a 30×30 original matrix Z.

$$Z = \begin{bmatrix} a_{11} & \cdots & a_{1j} \\ \vdots & \ddots & \vdots \\ a_{i1} & \cdots & a_{ij} \end{bmatrix} \tag{1}$$

3.1.2. Establish the Comprehensive Influence Matrix

The direct influence matrix Z is normalized to obtain the canonical influence matrix G.

$$G = \frac{Z}{\underset{1 \le i \le n}{max} \sum_{j=1}^{n} a_{ij}} \tag{2}$$

In the above Equation, $Z = (a_{ij})_{n \times n}$ is the row and the maximum value.

Then, the comprehensive influence matrix T is calculated from the canonical influence matrix G.

$$T = G(I - G)^{-1} \tag{3}$$

In the above formula, I is the identity matrix.

3.1.3. Determine the Centrality and Causality of Each Factor

(1) Calculate the degree of influence and the degree of being influenced.

To calculate the degree of influence of an evaluation indicator is to sum all the values of the indicator in the rows of the integrated impact matrix T, and the resulting set is denoted as D. To calculate the degree of influence of an evaluation indicator is to sum all the values of the evaluation indicator in the columns of the integrated impact matrix T, and the resulting set is denoted as C.

$$D = \sum_{i=1}^{n} t_{ij}, (i = 1, 2, 3, \ldots, n) \tag{4}$$

$$C = \sum_{j=1}^{n} t_{ij}, (j = 1, 2, 3, \ldots, n) \tag{5}$$

(2) Calculate the degree of centrality and the degree of cause.

Adding and summing the degree of influence and the degree of being influenced of an evaluation indicator leads to the degree of centrality of the evaluation indicator, which is denoted as M. Subtracting the degree of influence and the degree of being influenced of an evaluation indicator leads to the degree of cause of the evaluation indicator, which is denoted as N.

$$M = D_i + C_i, (i = 1, 2, 3, \ldots, n) \tag{6}$$

$$N = D_i - C_i, (i = 1, 2, 3, \ldots, n) \tag{7}$$

The degree of centrality indicates the degree of comprehensive influence of the indicator on the system. In this study, the larger the centrality degree, the higher the degree of influence of the indicator on the effectiveness of green transformation of resource-based cities in Shandong Province, and vice versa. According to the value, positive and negative can be divided into cause indicator and result indicator; when $N > 0$, the indicator is judged as a cause indicator, which means it will be easy to influence other indicators; and when $N < 0$, the indicator is judged as a result indicator, which means it will be easy to be influenced by other indicators.

3.1.4. Calculate the Weight of Each Indicator in the System

The centrality M_i of each indicator in the integrated impact matrix is normalized to finally obtain the weight W_i of each indicator.

$$W_i = \frac{M_i}{\sum M_i} \tag{8}$$

3.2. VIKOR Method

The VIKOR method (VlseKriterijumska Optimizacija I Kompromisno Resenje, which means "Multi-criteria Optimization and Compromise Solution" in Serbian) is a decision-making approach that captures the subjective preferences of the decision-maker by considering group utility value, individual regret value, and compromise evaluation value. It ranks multi-attribute alternatives and facilitates the selection of the best solution. The fundamental concept behind the VIKOR method involves initially calculating the optimal and worst solutions among all options. Subsequently, the distances between the evaluation values of different solutions and these extreme points are compared to determine the optimal solution sequentially [42]. Compared with the TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) method, the VIKOR method can effectively avoid the generation of the reverse order, and the results obtained are more reasonable [43]. Therefore, it is more readily accepted by decision-makers and is suitable for evaluating and researching the effectiveness of urban transformation.

3.2.1. Data Standardization

To reduce the influence of the difference in the quantitative scale on the evaluation index system of the effectiveness of green transformation of resource-based cities in Shandong Province, this study carries out the dimensionless processing of the constructed index system, that is, the standardization of the indexes. The corresponding standardized formulas for positive and negative indicators are as follows.

$$q_{ij} = \frac{v_{ij} - min(v_{ij})}{max(v_{ij}) - min(v_{ij})} \tag{9}$$

$$q_{ij} = \frac{max(v_{ij}) - v_{ij}}{max(v_{ij}) - min(v_{ij})} \tag{10}$$

3.2.2. Calculate Positive and Negative Ideal Solutions

The positive ideal solution (x_i^*) consists of the maximum value of each column element and the negative ideal solution (x_i^-) consists of the minimum value of each column element.

$$x_i^* = {}_j^{max} x_{ij} \tag{11}$$

$$x_i^- = {}_j^{min} x_{ij} \tag{12}$$

3.2.3. Calculate Group Utility Values and Individual Regret Values

The group utility value (S_i) can be used to measure the decision-maker's subjective tendency and preference for certain things. The individual regret value (R_i) reflects the value of loss caused by the decision-maker's wrong judgment.

$$S_i = \sum_{j=1}^{n} \omega_j \left(x_j^* - x_{ij}\right) / \left(x_j^* - x_i^-\right) \tag{13}$$

$$R_i = max\omega_j \left(x_j^* - x_{ij}\right) / \left(x_j^* - x_j^-\right) \tag{14}$$

where x_j^* is a positive ideal solution; x_j^- is a negative ideal solution; i = 1, 2, . . ., m; and j = 1, 2, . . ., n.

3.2.4. Calculation of Interest Rate Ratios for Evaluation Subjects

$$Q_i = \varepsilon(S_i - S^-)/(S^+ - S^-) + (1 - \varepsilon)(R_i - R^-)/(R^+ - R^-) \tag{15}$$

where $S^+ = \max(S_i)$, $S^- = \min(S_i)$, $R^+ = \max(R_i)$, $R^- = \min(R_i)$, ε is the compromise coefficient, and $\varepsilon \in [0, 1]$. When $\varepsilon > 0.5$, it means that the decision is based on maximizing the group's interest; when $\varepsilon < 0.5$, the decision is based on minimizing the individual's regret; and generally, $\varepsilon = 0.5$ is taken when making the decision.

3.2.5. Ranking of Evaluation Targets

The evaluation objects are ranked in ascending order according to the values of S_i, R_i, and Q_i, and the process of determining the optimal object is as follows. First, the scheme with the smallest value of Q_i is a compromise optimal object if the following two conditions are satisfied:

Condition 1: Appropriate advantages

$$Q(A(2)) - Q(A(1)) \geq 1/(m-1) \tag{16}$$

where A(1) and A(2) are the first and second evaluators in ascending order of Q value, respectively.

Condition 2: Adequate stability in decision-making

The evaluation object A(1) must also satisfy that it is optimal in ascending order of S and/or R values.

If one of the conditions is not satisfied, only a set of compromise solutions can be obtained: If condition 2 is not satisfied, the set contains A(1) and A(2); if condition 1 is not satisfied, the set contains A(1), A(2), $\cdots\cdots$, A(M), and the maximum value of M in A(M) is determined by the ratio of $Q(A(M)) - Q(A(1)) < 1/(m-1)$.

3.2.6. Calculation of the Transformation Index

The above VIKOR evaluation process ranks the evaluated objects according to the interest rate ratio Q_i, and the smaller the value of Q_i, the better the effect of the evaluated object. To facilitate the subsequent analysis of the effectiveness of the transformation, the transformation index U_R is calculated. The value of U_R is between 0 and 1, and the larger the value, the better the effectiveness of the transformation.

$$U_R = 1 - Q \tag{17}$$

4. Results and Analysis

4.1. Indicator Weights for Evaluating the Effectiveness of Green Transformation of Resource-Based Cities in Shandong Province

4.1.1. Degree of Centrality and Cause for Each Indicator

The results regarding the degree of centrality and the degree of causality for each indicator were determined and are presented in Table 3. An indicator with a degree of causality greater than 0 is classified as a cause indicator, signifying that it has a relatively significant impact on other indicators. Conversely, an indicator with a degree of causality less than 0 is regarded as a result indicator, suggesting that it is more likely to be influenced by other indicators. The top five indicators of centrality are urbanization level (F6, 4.0904), GDP growth rate (F3, 3.2951), the proportion of secondary industry in GDP (F15, 3.2853), the proportion of tertiary industry in GDP (F16, 2.9640), and the proportion of fiscal revenue to GDP (F4, 2.8206). The top five indicators in terms of causality are the proportion of fiscal revenue to GDP (F4, 0.5135), per capita ownership of mineral resources (F1, 0.4159), GDP growth rate (F3, 0.3696), internal expenditure on R&D as a share of GDP (F27, 0.3204), and urbanization level (F6, 0.2823).

Table 3. Calculation of centrality and causality for each indicator.

Indicators	Degree of Influence	Degree of Being Influenced	Centrality	Centrality Ranking	Causality	Causality Ranking
F1	1.0424	0.6266	1.6690	29	0.4159	2
F2	0.8003	0.6731	1.4735	30	0.1272	11
F3	1.8324	1.4628	3.2951	2	0.3696	3
F4	1.6671	1.1536	2.8206	5	0.5135	1
F5	1.3279	1.1012	2.4290	11	0.2267	7
F6	2.1864	1.9041	4.0904	1	0.2823	5
F7	1.0492	1.2498	2.2990	20	−0.2006	23
F8	0.9569	1.2696	2.2265	23	−0.3127	27
F9	1.0541	1.3576	2.4117	13	−0.3035	25
F10	1.0343	1.3147	2.3489	18	−0.2804	24
F11	1.1646	1.1903	2.3549	16	−0.0257	20
F12	1.3916	1.3755	2.7672	7	0.0161	17
F13	1.0136	1.7383	2.7519	8	−0.7247	30
F14	0.9156	1.5434	2.4590	10	−0.6279	29
F15	1.7502	1.5352	3.2853	3	0.2150	8
F16	1.4672	1.4969	2.9640	4	−0.0297	21
F17	1.3007	1.1923	2.4930	9	0.1084	12
F18	1.2019	1.2054	2.4073	14	−0.0035	18
F19	1.2107	1.1680	2.3787	15	0.0427	15
F20	1.1121	1.2141	2.3261	19	−0.1020	22
F21	1.0577	0.8910	1.9487	27	0.1666	9
F22	0.7434	1.0525	1.7959	28	−0.3092	26
F23	1.0143	1.0323	2.0466	25	−0.0181	19
F24	1.1750	1.6295	2.8045	6	−0.4544	28
F25	1.1500	1.0946	2.2446	21	0.0555	14
F26	1.2237	1.1960	2.4198	12	0.0277	16
F27	1.3264	1.0240	2.3504	17	0.3024	4
F28	1.0804	0.9220	2.0024	26	0.1585	10
F29	1.2491	0.9915	2.2405	22	0.2576	6
F30	1.1424	1.0359	2.1782	24	0.1065	13

According to Table 3, the centrality–causality distribution diagram of each indicator is drawn as shown in Figure 3. The farther away from the origin of the evaluation index, the larger the value of its centrality; the higher the ranking, the greater the importance; and vice versa.

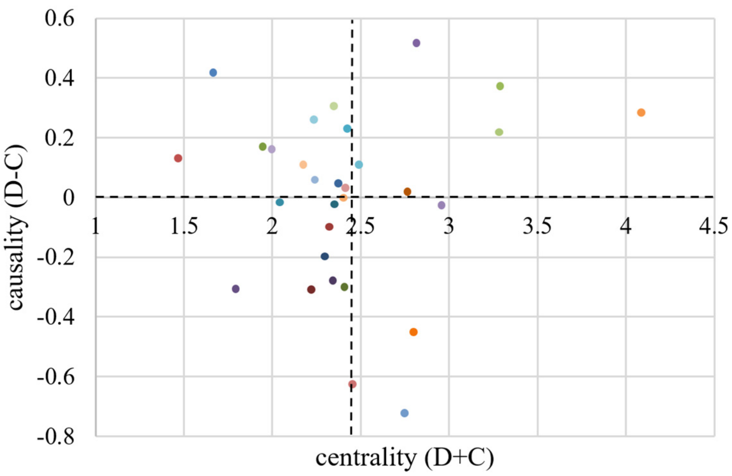

Figure 3. Distribution of centrality–causality of each indicator.

As can be seen from Figure 3, the evaluation indexes of the effectiveness of green transformation of resource-based cities in Shandong Province are aggregated into four categories. Each dot represents a corresponding indicator. The first category is the strong cause index (upper right area). It has a highly significant influence on the effectiveness of green transformation of resource-based cities in Shandong Province and exerts a greater influence on other result-based indexes. The second category is the weak cause index (upper left area). It has an important influence on the effectiveness of green transformation of resource-based cities in Shandong Province and also has a certain influence on other result-based indicators. The third category is weak result-based indicators (lower-left area). It is the result of the combined effect of other cause-based indicators and has a certain influence on the effectiveness of green transformation of resource-based cities in Shandong Province. The fourth category is strong result-based indicators (lower-right area). It is also the result of the combined effect of other cause-based indicators but has a very important influence. Given that the greater the centrality of an indicator, the more significant its importance, the strong cause indicators in the upper-right zone and the strong result indicators in the lower-right zone are the sets of indicators that need to be focused on.

4.1.2. Results of the Calculation of the Weights of the Indicators

The weight value of each indicator was calculated (as shown in Table 4). Among them, the top five are urbanization level (F6, 0.0558), GDP growth rate (F3, 0.0450), the share of secondary industry in GDP (F15, 0.0448), the ratio of tertiary industry in GDP (F16, 0.0405), and the proportion of fiscal revenue to GDP (F4, 0.0385). Among the five dimensions of driving force, pressure, state, impact, and response, the indicators with the highest weights in each dimension are urbanization level (F6, 0.2593), per capita disposable income of urban residents (F12, 0.1921), the proportion of secondary industry to GDP (F15, 0.2008), per capita carbon emissions (F24, 0.2109), and the comprehensive industrial solid waste utilization rate of industrial solid waste (F26, 0.1801).

Table 4. Weighting and ranking of indicators.

Indicators	Weights	Ranking	Intra-Group Weight	Group Ranking
F1	0.0228	29	0.1058	5
F2	0.0201	30	0.0934	6
F3	0.0450	2	0.2088	2
F4	0.0385	5	0.1788	3
F5	0.0332	11	0.1540	4
F6	0.0558	1	0.2593	1
F7	0.0314	20	0.1596	5
F8	0.0304	23	0.1545	6
F9	0.0329	13	0.1674	2
F10	0.0321	18	0.1630	4
F11	0.0321	16	0.1634	3
F12	0.0378	7	0.1921	1
F13	0.0376	8	0.1682	3
F14	0.0336	10	0.1503	5
F15	0.0448	3	0.2008	1
F16	0.0405	4	0.1812	2
F17	0.0340	9	0.1524	4
F18	0.0329	14	0.1471	6
F19	0.0325	15	0.1788	2
F20	0.0317	19	0.1749	3
F21	0.0266	27	0.1465	5
F22	0.0245	28	0.1350	6
F23	0.0279	25	0.1539	4
F24	0.0383	6	0.2109	1
F25	0.0306	21	0.1671	3
F26	0.0330	12	0.1801	1
F27	0.0321	17	0.1749	2
F28	0.0273	26	0.1490	6
F29	0.0306	22	0.1667	4
F30	0.0297	24	0.1621	5

4.2. Analysis of the Evaluation Results on the Effectiveness of Green Transformation of Resource-Based Cities in Shandong Province

4.2.1. Overall Evaluation Results of the Effectiveness of Green Transformation of Resource-Based Cities in Shandong Province

By calculating the index weights and index data obtained, the group utility value, individual regret value, and interest rate ratio of the overall effectiveness of green transformation of resource-based cities in Shandong Province from 2013 to 2021 were calculated, and finally, the green transformation index of resource-based cities in Shandong Province from 2013 to 2021 was calculated. Based on the calculated green transformation index results, the overall trend of the effectiveness of green transformation of resource-based cities in Shandong Province was calculated and is plotted in Figure 4.

As shown in Figure 4, the effectiveness of green transformation of resource-based cities in Shandong Province from 2013 to 2021 shows an overall upward trend. Among them, the speed of green transformation is faster from 2013 to 2017, the development of green transformation has a slightly stagnant trend from 2017 to 2020, and the faster transformation speed is restored from 2020 to 2021. This study defines these three phases as the rapid start-up period, the adjustment and optimization period, and the recovery acceleration period, respectively.

(1) Rapid start-up period (2013–2017)

In this phase, the green transformation index rapidly increases from 0.0472 to 0.6785, with a relatively fast growth rate. In 2013, the State Council issued the "*National Sustainable Development Plan for Resource-based Cities (2013–2020)*", which clarifies the overall idea, key tasks, and safeguard measures for the sustainable development of resource-based cities across the country. It also stipulates specific transformation requirements for all resource-based cities in Shandong Province. Subsequently, the "*Guidance Catalog for Industrial Structure Adjustment in Shandong Province (2013 Revision)*" was released in the same year, providing specific requirements for industrial structure adjustment in Shandong Province. This shows that Shandong Province has attached great importance to green transformation of resource-based cities at an early stage and has actively responded to national policies to promote industrial restructuring and ecological environmental protection.

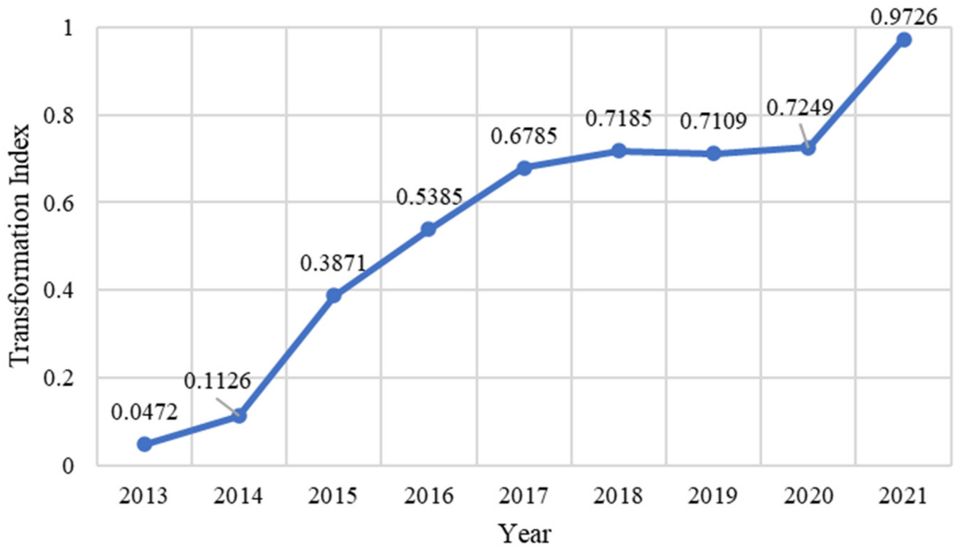

Figure 4. Overall trend of the effectiveness of green transformation of resource-based cities in Shandong Province.

(2) Adjustment and optimization period (2017–2020)

In this phase, the green transformation index is relatively stable, with a slight overall upward trend. This could be attributed to challenges in the transformation process, such as industrial restructuring and environmental protection pressures. In 2019, Shandong Province revised the "*Regulations on the Protection of the Geological Environment of Mines*" to enhance the protection and management of the geological environment in mines, aiming to prevent and minimize environmental damage caused by mining activities. However, the outbreak and continuation of the COVID-19 pandemic have also had a significant impact on this phase of green transformation. Supply chain disruptions, declining market demand, and operational difficulties have put pressure on traditional industries in resource-based cities. Lockdowns and quarantines have also limited technological innovation and regional cooperation in these cities. In response, the Shandong provincial government enhanced support for enterprises through financial and tax incentives, as well as increased investment in green industries to mitigate the economic impact of the pandemic. However, the COVID-19 pandemic has accelerated the adoption of digital and intelligent technologies. Shandong Province is seizing this opportunity to promote the digital transformation of resource-based cities, aiming to improve resource utilization efficiency and reduce environmental pollution and ecological damage through new technologies, processes, and models to sustain the green transformation of these cities.

(3) Recovery and acceleration period (2020–2021)

In this phase, the green transformation index increases rapidly from 0.7249 to 0.9726, with a significantly accelerated growth rate. In 2021, China's State Council issued the "*Guiding Opinions on Accelerating the Establishment and Improvement of a Green, Low-carbon and Circular Development Economic System*", proposing to promote the new concept of green development in various aspects such as ecological protection, environmental construction, urban development, and people's lives. The goal is to improve the level of green development and promote comprehensive green transformation of economic and social development. China's State Council also approved the "*14th Five-Year Plan for Promoting*

High-quality Development of Resource-Based Areas" in the same year, which set higher requirements for the transformation of resource-based cities. After early adjustment and optimization, resource-based cities in Shandong province have found new impetus and growth points in green transformation. They have also shown strong resilience and adaptability in facing challenges brought by the novel coronavirus pandemic. For example, during the pandemic, there was an increased demand for green products and services due to people's concerns about health and safety. Technological innovation has also driven new forms of business like telecommuting and online education while promoting digital transformation and intelligent upgrading of cities.

In summary, during the rapid start-up period, the resource-based cities in Shandong Province actively complied with national policies. They vigorously promoted industrial restructuring and ecological environmental protection, thereby attaining remarkable achievements in the realm of green transformation. In the subsequent adjustment and optimization period, Shandong Province confronted a series of challenges, including industrial restructuring difficulties, mounting environmental protection pressure, and the influence of the COVID-19 pandemic. Nevertheless, by intensifying the protection of the geological mine environment and augmenting the investment in green industries, it managed to maintain the stability of the pace of green transformation of resource-based cities. In the recovery and acceleration period, with the support of national policies and the digital development opportunities emerging from the post-pandemic era, green transformation of resource-based cities in Shandong Province was remarkably accelerated, manifesting robust resilience and adaptability.

4.2.2. Evaluation Results of the Effectiveness of Green Transformation of Resource-Based Cities in Shandong Province by Dimension

Through the specific steps of the VIKOR method, combined with the indicator weights of each indicator obtained by the DEMATEL method within the five-dimension group of driving force, pressure, state, impact, and response, the group utility values, individual regret values, and interest rate ratios of the transformation driving force, transformation pressure, transformation state, transformation impact, and transformation response of the green transformation of resource-based cities in Shandong Province from 2013 to 2021 were calculated. Finally, the transformation index of each dimension was calculated, and the results of the transformation index calculation are shown in Table 5.

Table 5. Transformation index of resource-based cities in Shandong Province for each dimension of green transformation.

Year	Driving Force Transformation Index	Pressure Transformation Index	State Transformation Index	Impact Transformation Index	Response Transformation Index
2013	0.1495	0.0424	0.0000	0.1926	0.3643
2014	0.1577	0.1099	0.2803	0.2398	0.2632
2015	0.2140	0.3359	0.4923	0.4445	0.1586
2016	0.7057	0.6991	0.5961	0.1246	0.4161
2017	0.5277	0.9428	0.9062	0.4292	0.6912
2018	0.4798	0.6315	0.7587	0.7025	0.4395
2019	0.5394	0.5086	0.9003	0.7866	0.6509
2020	0.4455	0.7051	0.8173	0.8845	0.4411
2021	0.9033	0.7728	0.9357	1.0000	0.5000

Through the calculation results in Table 5, the transformation effectiveness of each dimension of green transformation of resource-based cities in Shandong Province is analyzed as follows:

(1) Driving force transformation index

From 2013 to 2021, the driving force transformation index exhibited an overall growth trend. The period from 2013 to 2015 saw relatively flat exponential growth of the driving force transformation due to challenges and uncertainties faced in the early stages of the transformation. However, starting from 2016 and especially through 2021, there was a significant increase in the driving force transformation index. This reflects important breakthroughs in the driving force of green transformation for resource-based cities in Shandong Province. Throughout this study period, the government played a crucial role in providing a strong driving force for green transformation by introducing a series of policies such as environmental protection regulations and industrial support policies. These policies not only guided optimal resource allocation but also improved fiscal revenue and urbanization levels.

(2) Pressure transformation index

From 2013 to 2021, the pressure transformation index initially grew and then declined. In the early stages of green transformation, the index remained relatively low due to limited initial transformation challenges and uncertainties. Nevertheless, as the transformation advanced, various challenges emerged, such as resource scarcity and increased pollution. Around 2017, the pressure transformation index peaked before gradually declining, coinciding with heightened stress levels among residents, rising unemployment rates, and a decrease in per capita disposable income. Concurrently, government entities, businesses, and various sectors of society intensified their collaborative efforts to comprehensively address these challenges throughout the transformation process. Consequently, from 2019 to 2021, the pressure transformation index for resource-based cities in Shandong Province began to rise again.

(3) State transformation index

From 2013 to 2021, the state transformation index demonstrated a consistent upward trend, indicating significant progress in the green transformation of resource-based cities in Shandong Province. This progress is evident in the optimization of industrial structure, enhancement of social living conditions, and improvement in environmental quality. Throughout this period, measures such as eliminating outdated production capacity and fostering emerging industries have led to the optimization of industrial structure in resource-based cities. The emergence of new industries such as high-tech and green industries has become pivotal in urban development. Simultaneously, strengthened environmental protection measures and pollution control efforts have resulted in substantial improvements in environmental quality, particularly with regard to air- and water-quality indicators within resource-based cities in Shandong Province.

(4) Impact transformation index

From 2013 to 2021, the impact transformation index demonstrated a trend of continuous growth, although it did not consistently maintain a steady increase. The index experienced relatively slow growth between 2013 and 2015, possibly due to the delayed impact of the initial phase of the transformation. However, since 2016, particularly in 2020 and 2021, there was a significant increase in the impact transformation index. This reflects the ongoing expansion of the positive effects of green transformation on the ecological environment, social development, and resource utilization in resource-based cities within Shandong Province.

(5) Response transformation index

From 2013 to 2021, the response transformation index exhibited significant volatility. In the period from 2013 to 2015, the response transformation index was relatively high, possibly reflecting cities' positive responses to green transformation in the early stages of the process. However, in subsequent years, the response transformation index fluctuated, likely due to new challenges and issues encountered during the transformation process that impacted the speed and effectiveness of responses. Nevertheless, overall, resource-based cities in Shandong Province have maintained a positive attitude towards green transformation and have endeavored to address various challenges.

To visually demonstrate the evolving trend of the effectiveness of green transformation of resource-based cities in Shandong Province, a five-dimensional evolution trend is depicted based on existing results, as shown in Figure 5.

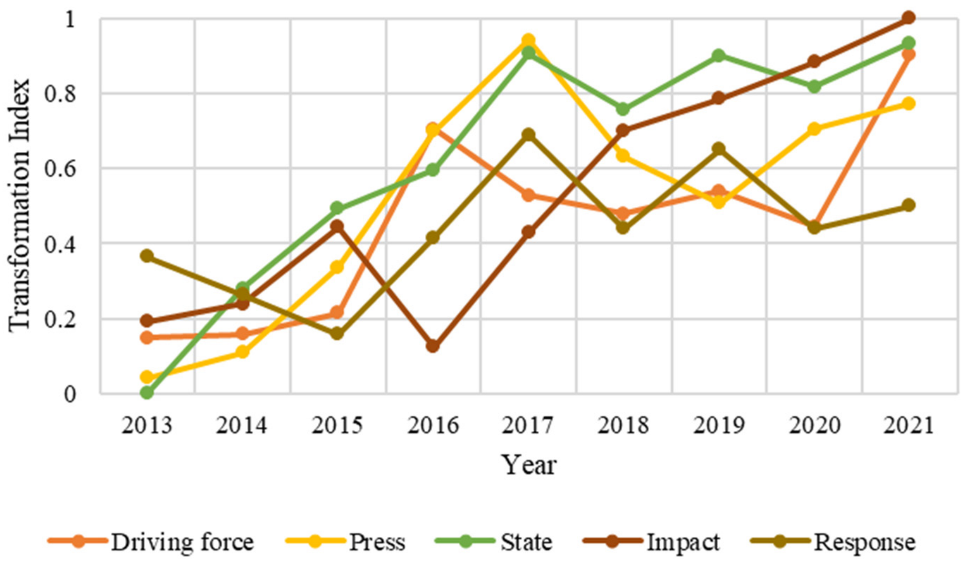

Figure 5. Five-dimensional evolution trend of the effectiveness of green transformation of resource-based cities in Shandong Province.

The overall trend of the effectiveness of green transformation within these cities is witnessed to be on the rise across all dimensions. Particularly, the state transformation index demonstrates the most remarkable alteration, whereas the response transformation index presents the least variation. It is proposed that Shandong Province augment its investment in environmental governance and scientific and technological innovation to identify novel breakthroughs in the transformation process.

5. Discussion

5.1. Implications

Based on the DPSIR model, this study constructs evaluation indexes of the effectiveness of green transformation of resource-based cities in Shandong Province from five dimensions: driving force, pressure, state, impact, and response, and evaluates the effectiveness of green transformation of resource-based cities in Shandong Province from 2013 to 2021 based on the DEMATEL and VIKOR methods. In addition, the study analyzes in depth the general trend of the effectiveness of green transformation of resource-based cities of Shandong Province during the study period and the degree of urgency to improve the effectiveness of transformation in each dimension.

The effectiveness evaluation of green transformation of resource-based cities is a relatively complex systematic project, with a variety of indicators contributing to the effectiveness of transformation. Some indicators contribute directly to the transformation effectiveness, while others contribute indirectly by influencing other indicators. The causal relationship between the indicators is uncertain; they are not independent and have some differences in mutual importance. Previous studies rarely take into account the relationship between indicators, so this study uses the DEMATEL method to determine the importance and causality of evaluation indicators. The top three most important indicators are urbanization level, GDP growth rate, and the proportion of secondary industry in GDP. Firstly, a higher level of urbanization means that cities have better conditions for infrastructure construction, industrial agglomeration, and public service provision, which is conducive to the efficient allocation of resources [44]. Secondly, rapid GDP growth can provide financial support, investment in technological research and development, and attraction of talent for the transformation, which can help to promote industrial structure upgrading and green technological innovation as well as facilitate the transformation of cities to a green economic model [45]. Thirdly, if the proportion of the secondary industry in GDP is too high, it may imply a single industrial structure, over-reliance on resource development and processing, and challenges to the sustainability of economic development [46].

The VIKOR method is used to evaluate the effectiveness of green transformation of resource-based cities in Shandong Province. The analysis reveals that the effectiveness of green transformation of resource-based cities in Shandong Province showed an upward trend during the study period. In 2013, the green transformation index was 0.0472, and it gradually increased to 0.9726 by 2021. During the same study period, other cities or provinces in China demonstrated similar overall development trends and were in comparable development stages to those in this study in terms of the evaluation of green transformation of resource-based cities (as shown in [20,24]). The government's continuous promotion of policies like green finance support and industrial restructuring guidance has effectively driven the progress of green transformation, which is of great significance for enhancing the sustainable development ability of resource-based cities [11]. This shows that China attaches great importance to the development of resource-based cities and has achieved certain results [22].

This study comparatively analyzes the green transformation of resource-based cities in Shandong Province from the five dimensions of the DPSIR model. From the results of comparing the dimensions, the effects of the state dimension and the impact dimension are not satisfactory enough. Combined with the slight stagnation in transformation effectiveness in 2017–2020 (adjustment and optimization period), it may be that COVID-19 has a greater influence on transformation effectiveness [9]. First, there is the consumption pattern [47]. Offline consumption has been severely affected. Shopping malls and other commercial places have seen a downturn. Although the shift in commerce to the online platform is beneficial for the optimization of land resources [48], a large number of physical business closures lead to an increase in unemployment. Second, there is the work style [49]. The growth of telecommuting reduces traffic pressure and aids in the transformation of office space. However, in some industries, telecommuting is not efficient. There is a mismatch between the job losses in traditional industries and the talent needs in emerging industries, which impacts the stability of employment. Third, there is the concept of living [50]. People's environmental demands for living space have increased, promoting the building of green structures and ecological areas. But this has also been accompanied by housing price fluctuations in some cities, adding to the pressure on residents to buy a home and affecting the ecological balance of urban living [51]. The interaction among these three aspects not only presents challenges and opportunities for the green transformation of resource-based cities but also has complex effects on both the green transformation and the overall development of cities around the world [52].

5.2. Limitations

This study has the following limitations:

In the selection of evaluation indexes, due to the complexity of the effectiveness of green transformation of resource-based cities in Shandong Province, only 30 indicators were selected in the construction of the evaluation index system in the study. In the future, advanced technologies such as machine learning will be used to further optimize the index system.

Since data from county-level cities are difficult to obtain, only six prefecture-level cities are considered in the study. In the future, it is of great necessity to further enhance the capacity of data acquisition and extend the research scope to county-level cities, thereby facilitating a more comprehensive exploration of the effectiveness of the green transformation of resource-based cities.

6. Conclusions and Policy Recommendations

6.1. Conclusions

Most of China's cities are resource-based cities, with significant development potential and the possibility for green and low-carbon development. Therefore, it is crucial to study the effectiveness of green transformation of resource-based cities to realize the goal of the "carbon peak". This study takes six resource-based cities in Shandong Province as the research object. The DPSIR model is utilized to construct an evaluation index system containing 30 indicators from five dimensions: driving force, pressure, state, impact, and response, and to examine the interactions and causal relationships among the indicators. Based on this framework, the effectiveness of green transformation in these cities from 2013 to 2021 is evaluated and analyzed. The study also obtains insights into the overall development trend and urgency of implementing such transformations. These are the main findings:

The centrality–causality calculation and analysis of the indicators for evaluating the effectiveness of green transformation of resource-based cities yields that the five indicators with the highest degree of importance are the level of urbanization, the GDP growth rate, the proportion of the secondary industry in GDP, the proportion of the tertiary industry in GDP, and the proportion of fiscal revenue to GDP.

From the analysis of the time-series evaluation results, it can be seen that the effectiveness of green transformation of resource-based cities in Shandong Province shows an overall upward trend, with some fluctuations in different years. During the study period, the green transformation of resource-based cities in Shandong Province experiences a rapid start-up period, an adjustment and optimization period, and a recovery and acceleration period.

The analysis of the evaluation results of the five dimensions of driving force, pressure, state, impact, and response shows that the overall trend of the five dimensions during the study period is in an upward state, but the trend of each dimension shows some fluctuation between different years. The largest numerical change is in "state" and the smallest change is in "response".

6.2. Policy Recommendations

This study examines the urgency of enhancing the effectiveness of green transformation of resource-based cities in Shandong Province. The findings indicate that the order of importance for transformation is as follows: response > pressure > driving force > state > impact. Based on the results of the study and the characteristics of regional development, the following policy recommendations can be proposed:

6.2.1. Driving Force

From the perspective of resource carrying, natural resources departments should encourage enterprises to promote resource-recycling technology and improve resource utilization efficiency and carrying capacity. The government should establish a crossregional resource allocation system, rationally allocate resources according to the needs of cities, and achieve balanced allocation of resources.

From the perspective of economic development, development and reform departments should guide enterprises to deeply integrate the industrial chain and promote the transformation of traditional industries into green ones [53]. Local governments should strengthen regional eco-economic cooperation, break the boundaries of administrative divisions, form resource-based city development alliances, and realize industrial complementarity [54].

From the perspective of urban construction, urban planning departments should scientifically plan urban space, rationally lay out functional areas, reserve ecological space, and improve urban operation efficiency and livability [55]. Urban management departments should actively introduce digital technologies, build smart city management platforms, and enhance the intelligent level of urban management.

6.2.2. Pressure

From the perspective of resource consumption, environmental protection departments should improve regulation systems of resource consumption, encourage the development of low-energy and high-value-added industries, and guide the green transformation of high-energy industries. The government needs to implement energy-saving subsidy policies, encourage enterprises and residents to use energy-saving products, and strengthen the training and publicity of energy-saving technologies.

From the perspective of pollution emission, environmental protection departments should strengthen environmental law enforcement, strictly regulate industrial pollution emissions, and increase penalties. The government should support enterprises to introduce advanced pollution control technology and equipment, improve pollution control levels, and promote cleaner industrial production [56].

From the perspective of residents' life, employment departments should carry out vocational skills training, build employment service platforms, and encourage entrepreneurship. The government should improve the social security system, raise the level of security, expand coverage, stabilize the price level, and ensure the supply of basic living materials.

6.2.3. State

From the perspective of environmental quality, environmental management departments should continue to promote the prevention and control of air pollution, strengthen the treatment of industrial pollution sources, and control vehicle exhaust and dust pollution. Environmental protection departments should strengthen water pollution control and cooperate with multiple departments to establish a sound water source protection mechanism to ensure the safety of drinking water sources [57].

From the perspective of industrial structure, economic development departments need to promote the intelligent upgrading of traditional industries, cultivate strategic emerging industries, build industrial parks, and form industrial agglomeration effects. In addition, it is necessary to vigorously develop the modern service industry, optimize the structure of the service industry, improve the quality and level of service, and meet diversified needs [58].

From the perspective of social life, relevant government departments should optimize the allocation of educational resources, improve the quality of education at all levels, and cultivate talents suitable for industrial development. Health departments should improve the medical and health service system, strengthen the construction of grassroots medical services, and improve the level of medical security. Cultural departments need to strengthen cultural construction and enrich the spiritual and cultural life of residents.

6.2.4. Impact

From the perspective of ecological environment, natural resource management departments should strictly implement the ecological protection redline system, and relevant law enforcement departments should strengthen supervision to prevent illegal development and protect important ecological areas. Ecological restoration departments should promote the restoration of ecosystems such as mines, wetlands, and forests to restore ecological functions [59].

From the perspective of social development, local governments should coordinate the allocation of urban and rural resources and improve the level of rural public services. Civil affairs departments have innovated social governance methods, strengthened community construction, and guided social organizations to participate. Market supervision departments should ensure food safety, foster multi-departmental cooperation to improve the quality of life of residents, and optimize public space.

From the perspective of resource exploitation, resource-planning departments should accurately plan resource development and formulate development strategies according to urban resource reserves. Mining management departments should optimize the layout of resource development, improve the efficiency of resource development, and strengthen development management. Resource-recycling departments should strengthen the follow-up management of resource development and promote the reuse of abandoned mines.

6.2.5. Response

From the perspective of environmental governance, financial departments should increase investment in environmental governance, establish a diversified investment mechanism, and support the construction of environmental protection projects [60]. Environmental supervision departments should improve the environmental governance and supervision mechanism, strengthen the supervision of the whole process of the project, and establish a performance evaluation system [61].

From the perspective of technological innovation, science and technology management departments should establish scientific and technological innovation platforms, introduce incentive policies for scientific and technological innovation, and improve innovation enthusiasm [62]. Talent management departments should strengthen the construction of scientific and technological talents, introduce and train high-level talents, and promote personnel exchanges and cooperation.

From the perspective of green city, construction-planning departments should promote green building standards, encourage the construction of green buildings, and improve the level of building energy conservation and environmental protection [63]. Traffic management departments should optimize the urban transportation system, prioritize the development of public transportation, and promote new-energy vehicles. Garden management departments should strengthen urban ecological construction, promote green space systems and wetland protection, and improve urban ecological stability [64].

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References

1. Ghasemi, E.; Azari, R.; Zahed, M. Carbon Neutrality in the Building Sector of the Global South-A Review of Barriers and Transformations. *Buildings* **2024**, *14*, 321. [CrossRef]
2. Wei, X.; He, Z.; Li, Y.T.; Li, X.P. Research on High-Quality Carbon Reduction Pathways for Green Buildings under the Dual Carbon Background. *Buildings* **2024**, *14*, 2082. [CrossRef]
3. Li, X.L.; Shi, Y.Y.; Li, X.; Luo, X. Impacts of Low-Carbon Pilot Policies on the Land Green Use Efficiency in Adjacent Non-Pilot Cities: An Empirical Study Based on 257 Prefecture-Level and above Cities in China. *Buildings* **2024**, *14*, 1163. [CrossRef]
4. Chen, M.J.; Wang, Q.R.; Bai, Z.K.; Shi, Z.Y.; Meng, P.; Hao, M. Green Land Use Efficiency and Influencing Factors of Resource-Based Cities in the Yellow River Basin under Carbon Emission Constraints. *Buildings* **2022**, *12*, 551. [CrossRef]
5. Yang, Y.; Cheng, D.Y.; Zhang, B.; Guan, C.H.; Cheng, X.L.; Cheng, T. Coal resource-based cities at the crossroads: Towards a sustainable urban future. *Cities* **2023**, *140*, 15. [CrossRef]
6. Tan, J.T.; Lo, K.V.; Qiu, F.D.; Liu, W.X.; Li, J.; Zhang, P.Y. Regional Economic Resilience: Resistance and Recoverability of Resource-Based Cities during Economic Crises in Northeast China. *Sustainability* **2017**, *9*, 2136. [CrossRef]
7. Li, M.X.; Liu, J.H.; Chen, Y.; Yang, Z.J. Can sustainable development strategy reduce income inequality in resource-based regions? A natural resource dependence perspective. *Resour. Policy* **2023**, *81*, 11. [CrossRef]
8. Wang, L.; Li, Z.; Xu, Z.J.; Yue, X.; Yang, L.Q.; Wang, R.J.; Chen, Y.L.; Ma, H.Q. Carbon emission scenario simulation and policy regulation in resource-based provinces based on system dynamics modeling. *J. Clean. Prod.* **2024**, *460*, 18. [CrossRef]
9. Zhu, J.H.; Wang, S.S. Evaluation and Influencing Factor Analysis of Sustainable Green Transformation Efficiency of Resource-Based Cities in Western China in the Post-COVID-19 Era. *Front. Public Health* **2022**, *10*, 13. [CrossRef]
10. Wang, Y.J.; Chen, H.; Long, R.Y.; Sun, Q.Q.; Jiang, S.Y.; Liu, B. Has the Sustainable Development Planning Policy Promoted the Green Transformation in China's Resource-based Cities. *Resour. Conserv. Recycl.* **2022**, *180*, 11. [CrossRef]
11. Zhang, J.; Yang, J.H.; Zhao, F. Do government innovation preferences enhance ecological resilience in resource-based cities?-Based on mediating effect and threshold effect perspectives. *PLoS ONE* **2024**, *19*, e0303672. [CrossRef] [PubMed]
12. Li, Y.F.; Chen, X.S.; Wan, J.Z.; Liu, H.M.; Cui, W.; Wang, Q.Q. Urban Renewal Potential of Old Urban Areas in Resource-Based Cities in Developing Countries: A Case Study of Dongsheng District, Ordos, China. *Buildings* **2024**, *14*, 3065. [CrossRef]
13. Zhang, X.; Xu, L.R.; Li, C.H. Sustainability of Water Resources in Shandong Province Based on a System Dynamics Model of Water-Economy-Society for the Lower Yellow River. *Sustainability* **2022**, *14*, 3412. [CrossRef]
14. Qu, Y.B.; Jiang, G.H.; Ma, W.Q.; Li, Z.T. How does the rural settlement transition contribute to shaping sustainable rural development? Evidence from Shandong, China. *J. Rural Stud.* **2021**, *82*, 279–293. [CrossRef]
15. She, Y.J.; Hu, C.L.; Ma, D.J.; Zhu, Y.H.; Tam, V.W.Y.; Chen, X.J. Contribution of Infrastructure to the Township's Sustainable Development in Southwest China. *Buildings* **2022**, *12*, 164. [CrossRef]
16. Yu, J.H.; Li, J.M.; Zhang, W.Z. Identification and classification of resource-based cities in China. *J. Geogr. Sci.* **2019**, *29*, 1300–1314. [CrossRef]
17. Ge, X.C.; Xu, J.; Xie, Y.; Guo, X.; Yang, D.Y. Evaluation and Dynamic Evolution of Eco-Efficiency of Resource-Based Cities-A Case Study of Typical Resource-Based Cities in China. *Sustainability* **2021**, *13*, 6802. [CrossRef]
18. Lucas, R. *Minetown, Milltown, Railtown: Life in Canadian Communities of Single Industry*; University of Toronto Press: Toronto, ON, USA, 1971.
19. Li, B.; Han, Y.K.; Wang, C.S.; Sun, W. Did civilized city policy improve energy efficiency of resource-based cities? Prefecture-level evidence from China. *Energy Policy* **2022**, *167*, 12. [CrossRef]
20. Fan, F.; Zhang, X.R. Transformation effect of resource-based cities based on PSM-DID model: An empirical analysis from China. *Environ. Impact Assess. Rev.* **2021**, *91*, 12. [CrossRef]
21. Pang, M. Planning, Transformation and Development of Resource Based Industrial Cities. *Open House Int.* **2017**, *42*, 88–92. [CrossRef]
22. Song, Y.; Yeung, G.; Zhu, D.L.; Xu, Y.; Zhang, L.X. Efficiency of urban land use in China's resource-based cities, 2000–2018. *Land Use Pol.* **2022**, *115*, 14. [CrossRef]
23. Chen, W.; Hu, C.C.; Liu, L.; Zhang, J.J.; Wang, K.; Liu, S.D. Characteristics of built-up land change in resource-based cities and their impact on land surface temperature-Taking Wu'an as an example. *Ecol. Inform.* **2022**, *68*, 12. [CrossRef]

24. Liu, B.; Wang, J.M.; Jing, Z.R.; Tang, Q. Measurement of sustainable transformation capability of resource-based cities based on fuzzy membership function: A case study of Shanxi Province, China. *Resour. Policy* **2020**, *68*, 14. [CrossRef]
25. Chen, W.; Chen, W.J.; Ning, S.Y.; Liu, E.N.; Zhou, X.; Wang, Y.A.; Zhao, M.J. Exploring the industrial land use efficiency of China's resource-based cities. *Cities* **2019**, *93*, 215–223. [CrossRef]
26. Kim, D.H.; Lin, S.C. Natural Resources and Economic Development: New Panel Evidence. *Environ. Resour. Econ.* **2017**, *66*, 363–391. [CrossRef]
27. Gonzalez-Garcia, S.; Manteiga, R.; Moreira, M.T.; Feijoo, G. Assessing the sustainability of Spanish cities considering environmental and socio-economic indicators. *J. Clean. Prod.* **2018**, *178*, 599–610. [CrossRef]
28. Jing, Z.R.; Wang, J.M. Sustainable development evaluation of the society-economy-environment in a resource-based city of China: A complex network approach. *J. Clean. Prod.* **2020**, *263*, 17. [CrossRef]
29. Xie, W.; Yan, T.; Xia, S.; Chen, F. Innovation or introduction? The impact of technological progress sources on industrial green transformation of resource-based cities in China. *Front. Energy Res.* **2020**, *8*, 598141. [CrossRef]
30. Wang, X.J. Application of Internet of Things Technology to Promote High-Quality Development of Resource-Based City Industrial Transformation and Upgrading Demonstration Areas. *Mob. Inf. Syst.* **2022**, *2022*, 14. [CrossRef]
31. Zheng, F.H.; Niu, Y. Environmental Decentralization, Resource Endowment and Urban Industrial Transformation and Upgrading: A Comparison of Resource-Based and Non-Resource-Based Cities in China. *Sustainability* **2023**, *15*, 475. [CrossRef]
32. Zhang, X.N.; Qu, M. Impact of Environmental Regulation on Scientific and Technological Competitiveness of Resource-Based Cities in China-Based on Panel Data of 33 Resource-Based Cities. *Int. J. Environ. Res. Public Health* **2020**, *17*, 9187. [CrossRef] [PubMed]
33. Yu, C.; de Jong, M.; Cheng, B.D. Getting depleted resource-based cities back on their feet again the example of Yichun in China. *J. Clean. Prod.* **2016**, *134*, 42–50. [CrossRef]
34. Yang, Y.Y.; Guo, H.X.; Chen, L.F.; Liu, X.; Gu, M.Y.; Ke, X.L. Regional analysis of the green development level differences in Chinese mineral resource-based cities. *Resour. Policy* **2019**, *61*, 261–272. [CrossRef]
35. Childers, D.L.; Pickett, S.T.A.; Grove, J.M.; Ogden, L.; Whitmer, A. Advancing urban sustainability theory and action: Challenges and opportunities. *Landsc. Urban Plan.* **2014**, *125*, 320–328. [CrossRef]
36. Xing, M.L.; Luo, F.Z.; Fang, Y.H. Research on the sustainability promotion mechanisms of industries in China's resource-based cities -- from an ecological perspective. *J. Clean. Prod.* **2021**, *315*, 15. [CrossRef]
37. Liu, X.Q.; Pei, T.; Zhou, C.H.; Du, Y.Y.; Ma, T.; Xie, C.J.; Xu, J. A systems dynamic model of a coal-based city with multiple adaptive scenarios: A case study of Ordos, China. *Sci. China-Earth Sci.* **2018**, *61*, 302–316. [CrossRef]
38. Ruan, F.L.; Yan, L.; Wang, D. The complexity for the resource-based cities in China on creating sustainable development. *Cities* **2020**, *97*, 10. [CrossRef]
39. Bai, Y.; Qin, J.M.; Liu, W.J.; Li, L.H.; Wu, Y.; Zhang, P. The DPSIR Model-Based Sustainability Assessment of Urban Water Resources: A Comparative Study of Zhuhai and Macao. *Water* **2024**, *16*, 1413. [CrossRef]
40. Fuda, C.; Hormann, K. Algorithm 1048: A C++ Class for Robust Linear Barycentric Rational Interpolation. *ACM Trans. Math. Softw.* **2024**, *50*, 17. [CrossRef]
41. Braga, I.F.B.; Ferreira, F.A.F.; Ferreira, J.J.M.; Correia, R.J.C.; Pereira, L.F.; Falcao, P.F. A DEMATEL analysis of smart city determinants. *Technol. Soc.* **2021**, *66*, 13. [CrossRef]
42. Nath, B.; Basumatary, B.; Wary, N.; Basumatary, U.R.; Basumatary, J.; Rokhum, S.L.; Azam, M.; Min, K.M.; Basumatary, S. Agricultural Waste-Based Heterogeneous Catalyst for the Production of Biodiesel: A Ranking Study via the VIKOR Method. *Int. J. Energy Res.* **2023**, *2023*, 23. [CrossRef]
43. Ma, Y.N.; Guga, S.; Xu, J.; Liu, X.P.; Tong, Z.J.; Zhang, J.Q. Assessment of Maize Drought Risk in Midwestern Jilin Province: A Comparative Analysis of TOPSIS and VIKOR Models. *Remote Sens.* **2022**, *14*, 2399. [CrossRef]
44. Kuai, P.; Li, W.; Cheng, R.H.; Cheng, G. An application of system dynamics for evaluating planning alternatives to guide a green industrial transformation in a resource-based city. *J. Clean. Prod.* **2015**, *104*, 403–412. [CrossRef]
45. Yin, Q.; Wang, Y.D.; Wan, K.D.; Wang, D.L. Evaluation of Green Transformation Efficiency in Chinese Mineral Resource-Based Cities Based on a Three-Stage DEA Method. *Sustainability* **2020**, *12*, 9455. [CrossRef]
46. Zhang, M.; Yan, T.H.; Ren, Q.Z. Does Innovative Development Drive Green Economic Growth in Resource-Based Cities? Evidence From China. *Front. Environ. Sci.* **2022**, *9*, 20. [CrossRef]
47. Sun, S.Y.; Xie, Z.; Yu, K.T.; Jiang, B.Q.; Zheng, S.W.; Pan, X.T. COVID-19 and healthcare system in China: Challenges and progression for a sustainable future. *Glob. Health* **2021**, *17*, 8. [CrossRef]
48. Sharifi, A.; Khavarian-Garmsir, A.R. The COVID-19 pandemic: Impacts on cities and major lessons for urban planning, design, and management. *Sci. Total Environ.* **2020**, *749*, 14. [CrossRef] [PubMed]
49. Haslag, P.; Weagley, D. From LA to Boise: How Migration Has Changed During the COVID-19 Pandemic. *J. Financ. Quant. Anal.* **2024**, *59*, 2068–2098. [CrossRef]

50. Gibbons, D.W.; Sandbrook, C.; Sutherland, W.J.; Akter, R.; Bradbury, R.; Broad, S.; Clements, A.; Crick, H.Q.P.; Elliott, J.; Gyeltshen, N.; et al. The relative importance of COVID-19 pandemic impacts on biodiversity conservation globally. *Conserv. Biol.* **2022**, *36*, 14. [CrossRef] [PubMed]
51. Wilson, B.; Neale, C.; Roe, J. Urban green space access, social cohesion, and mental health outcomes before and during COVID-19. *Cities* **2024**, *152*, 14. [CrossRef]
52. Nigam, R.; Tripathi, G.; Priya, T.; Luis, A.J.; Vaz, E.; Kumar, S.; Shakya, A.; Damásio, B.; Kotha, M. Did COVID-19 lockdown positively affect the urban environment and UN- Sustainable Development Goals? *PLoS ONE* **2022**, *17*, e0274621. [CrossRef] [PubMed]
53. Li, Q.; Guo, Q.; Zhou, M.; Xia, Q.; Quan, M.Q. Analysis on the Mechanism and Influencing Factors of the Coordinated Development of Economy and Environment in China's Resource-Based Cities. *Sustainability* **2022**, *14*, 2929. [CrossRef]
54. Yu, Y.G.; Xu, Z.N.; Shen, P.Y.; Zhang, L.N.; Ni, T.H. Efficiency Evaluation and Influencing Factors of Green Innovation in Chinese Resource-Based Cities: Based on SBM-Undesirable and Spatial Durbin Model. *Int. J. Environ. Res. Public Health* **2022**, *19*, 13772. [CrossRef] [PubMed]
55. Wu, J.; Bai, Z.K. Spatial and temporal changes of the ecological footprint of China's resource-based cities in the process of urbanization. *Resour. Policy* **2022**, *75*, 12. [CrossRef]
56. Meng, Y.X.; Liu, L.; Wang, J.L.; Ran, Q.Y.; Yang, X.D.; Shen, J.L. Assessing the Impact of the National Sustainable Development Planning of Resource-Based Cities Policy on Pollution Emission Intensity: Evidence from 270 Prefecture-Level Cities in China. *Sustainability* **2021**, *13*, 7293. [CrossRef]
57. Yin, Q.; Wang, Y.D.; Xu, Z.H.; Wan, K.D.; Wang, D.L. Factors influencing green transformation efficiency in China's mineral resource-based cities: Method analysis based on IPAT-E and PLS-SEM. *J. Clean. Prod.* **2022**, *330*, 18. [CrossRef]
58. Lu, H.Y.; Liu, M.; Song, W.J. Place-based policies, government intervention, and regional innovation: Evidence from China's Resource-Exhausted City program. *Resour. Policy* **2022**, *75*, 21. [CrossRef]
59. Luo, L.F.; Liu, P.Y.; Zhu, F.J.; Sun, Y.P.; Liu, L.N. Policy objective bias and institutional quality improvement: Sustainable development of resource-based cities. *Resour. Policy* **2022**, *78*, 10. [CrossRef]
60. Neale, C.; Austin, M.M.K.; Roe, J.; Converse, B.A. Making people aware of eco-innovations can decrease climate despair. *Clim. Chang.* **2023**, *176*, 21. [CrossRef]
61. Zhang, H.T.; Sun, X.M.; Bi, C.F.; Ahmad, M.; Wang, J. Can sustainable development policy reduce carbon emissions? Empirical evidence from resource-based cities in China. *Sci. Total Environ.* **2022**, *838*, 13. [CrossRef] [PubMed]
62. Zhang, Y.X.; Cui, M.Z. Determining the innovation efficiency of resource-based cities using a relational network dea model: Evidence from China. *Extr. Ind. Soc.* **2020**, *7*, 1557–1566. [CrossRef]
63. Roe, J.; Mondschein, A.; Neale, C.; Barnes, L.; Boukhechba, M.; Lopez, S. The Urban Built Environment, Walking and Mental Health Outcomes Among Older Adults: A Pilot Study. *Front. Public Health* **2020**, *8*, 15. [CrossRef]
64. Beatley, T. Planning for biophilic cities: From theory to practice. *Plan. Theory Pract.* **2016**, *17*, 295–300.