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Original Research

Evaluation and Obstacle Factors of the Green Development Level of Mature Resource-Based Cities Based on Entropy Weight TOPSIS Model: A Case Study of Daqing City in China

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Abstract

Daqing City is one of the important resource-based cities in China, a city born and prospered by oil. Resource-based cities are cities formed due to the massive exploitation of natural resources, and their rough economic growth methods have caused damage to both the resources and ecological environment of resource-based cities, which must undergo green transformation and development for the sake of economic development. Exploring the status quo of green development in Daqing can not only strengthen the theoretical and empirical research related to green development, but also provide new ways for the green development of other resource cities. Based on the current research situation in Daqing, this paper constructs a green development index system and evaluates and analyzes the level of green development and the obstacle factors in Daqing in the middle of 2011-2021, by using the entropy weight TOPSIS model and obstacle degree model. The results of the study show that: (1) the comprehensive evaluation index of green development increased from 0.375 in 2011 to 0.566 in 2021, and there is still much room for improvement in the level of green development in Daqing. (2) The economic greenness, internal growth mechanism, and industrial greenness of Daqing have been improved to different degrees, and the environmental greenness has been reduced to some extent. (3) The main obstacle factors restricting the level of green development in Daqing are urbanization rate, urban registered unemployment rate, number of university students per 10,000 people, and per capita general public budget income. Based on the evaluation results and analyses, it is recommended that the government promote green economic development, strengthen environmental and ecological governance, and improve the social security system.

Keywords: Daqing, green development level, entropy weight TOPSIS, obstacle model

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Introduction

Amidst the backdrop of persistently ascending global economic activity and a burgeoning population, the exploitation and utilization of resources have emerged as the cornerstones propelling both economic and social progress [1, 2]. Resource-rich cities, boasting their distinctive endowment advantages and sturdy economic foundations, play a pivotal role within regional and national economies [3]. Nevertheless, the intensification of resource exploitation has concurrently amplified environmental concerns and ecological stress, rendering the quest for green development and the optimization of resource utilization efficiency imperative challenges that urgently demand resolution [4].

Mature resource cities, as the stable stage of resource city development, not only have strong resource security capacity and a high economic and social development level, but they are also the key links of China's energy resource security system [5]. At this stage, both resource extraction and economic growth in the city have reached a peak and remained stable, and industrial expansion has also tended to slow down [6]. In order to promote the sustainable development of these cities, the National Development and Reform Commission and other departments jointly issued the "14th Five-Year Plan" to support the high-quality development of demonstration zones for the transformation and upgrading of industries in old industrial cities and resource cities", with a special emphasis on mature resource cities such as Daqing and other mature resource cities, and stressing the importance of technological innovation, industry chain extension, and the cultivation of new industries as a means to promote the manufacturing industry. emerging industry cultivation as a means to promote green transformation of the manufacturing industry and diversification of industrial structure [7]. As a typical mature resource-based city in Heilongjiang Province, Daqing's development history fully demonstrates the characteristics of resource-based cities. Relying on rich mineral resources, Daqing has achieved rapid economic growth. However, with the rapid development of traditional industries, problems such as a slowing down of the economic growth rate, a single industrial structure, and over-dependence on resources have gradually appeared, while environmental problems have become increasingly serious, causing a great impact on the ecological balance.

With the rapid development of the global economy and the continuous expansion of the population scale, the sustainable development of resource-based cities has gradually received widespread attention. Especially in the context of the current emphasis on green development and ecological protection, the study of the green development level of mature resource cities and its influencing factors is particularly important. Scholars at home and abroad have conducted a large number of studies on this topic, and the following is a review of the relevant studies. In foreign countries, scholars have explored the sustainable development of resource-based cities earlier. With the introduction of the concept of green development, more and more studies have begun to focus on the green development level of mature resource cities. These studies are mainly carried out from various perspectives, such as theoretical frameworks, evaluation methods, and influencing factors. In terms of theoretical framework, foreign scholars have constructed a variety of evaluation models for assessing the green development level of resource-based cities. These models not only take into account factors such as resource utilization efficiency and environmental protection, but also combine the socio-economic development situation, providing a theoretical basis for comprehensively evaluating the green development of resource cities. In terms of evaluation methods, foreign studies tend to use a combination of quantitative analysis and model construction. For example, the TOPSIS method [3, 8, 9] and Data Envelopment Analysis (DEA) [10, 11] are used to quantitatively assess the green development level of resource-based cities. At the same time, it also focuses on the use of spatial econometrics [11-14] and other methods to explore the spatial distribution characteristics and influencing factors of green development [15-17]. In their research on influencing factors, foreign scholars have paid attention to various aspects such as the level of economic development [18], industrial structure [19], technological innovation [20], environmental regulation [21], and so on. They believe that these factors not only affect the green development level of resource cities, but are also closely related to their sustainable development capability. Domestic research on the green development level of mature resource cities and their influencing factors has grown rapidly in recent years. On the basis of foreign studies, domestic scholars have carried out in-depth exploration by combining national conditions and the characteristics of resource cities. At the theoretical level, scholars have put forward the concept of green development in line with reality and constructed a multi-dimensional evaluation index system including resource use, environmental protection, socio-economics, policy systems, etc., which provides the theoretical basis and tools for the comprehensive evaluation of the green development of resource cities. In terms of methodology, scholars have continuously optimized the evaluation model, such as Wang Shuying et al., who constructed an evaluation index system for the green development level of the central region by using the WSR methodology [22], Ding Zhaogang et al., who put forward a comprehensive evaluation index system of the "three green forces" [23], and Peng Dinghong et al., who used the DPSIR framework and the hesitation fuzzy set to evaluate the green development of resource-oriented cities [24]. Meanwhile, scholars have deeply analyzed the status quo and challenges of green development in typical cities such as Daqing through case studies and put forward countermeasures [25, 26]. These studies not only deepen the understanding of the law of green development in mature resource cities, but also provide theoretical support and practical guidance for promoting their sustainable development.

Although significant progress has been made in recent years in domestic and international research on the level of green development in mature resource cities and the factors influencing it, there are still some shortcomings. Firstly, although existing studies have been more comprehensive in the construction of the evaluation index system, most of them still focus on the traditional aspects of resource utilization and environmental protection and are not deep enough in the consideration of multi-dimensional factors such as socio-economic, policy, and institutional factors. In particular, there is a lack of systematic research and discussion on the impact mechanisms of the policy and institutional environment on green development. Second, in the selection of evaluation methods, although a variety of methods have been applied to the assessment of the level of green development, all methods have their limitations, and a single assessment method may be difficult to comprehensively and accurately reflect the state of green development in resource-based cities. Therefore, there is a need to explore more scientific and reasonable, comprehensive evaluation methods to more accurately assess the green development level of resource cities. In addition, existing studies are mostly macro-level in case selection, lacking in-depth analyses of specific cities. Especially for representative mature resource-based cities, such as Daqing, the status quo, problems, and challenges of their green development need more attention and research. Through in-depth profiling of the green development of these cities, it can provide useful lessons and references for other similar cities. In view of the shortcomings of existing studies, this paper aims to conduct an in-depth study on the green development level of mature resource cities and their influencing factors based on the entropy-weighted TOPSIS model and empirically analyze the city of Daqing, China, as an example.

Given that the existing studies are still insufficient in the evaluation of the green development of resource cities, especially in the comprehensiveness of evaluation indexes and the scientificity of evaluation methods, there needs to be improvement, and this paper aims to construct a set of more comprehensive and systematic evaluation index systems and introduce the entropy-weighted TOPSIS model as the evaluation method. The indicator system will comprehensively consider multi-dimensional factors such as resource utilization, environmental protection, socio-economics, policy systems, etc., in order to accurately reflect the green development status of resource-based cities. The use of the entropy weight TOPSIS model will combine the entropy weight theory to objectively assign values to the indicator weights and conduct comprehensive evaluation through the TOPSIS method, so as to overcome the limitations of a single evaluation method and improve the accuracy and scientificity of the evaluation. Taking Daqing as an example, this paper will quantitatively assess its green development level by collecting exhaustive data and information and deeply analyzing its influencing factors. Through comparative analyses and in-depth case studies, this paper aims to reveal the intrinsic laws and mechanisms of Daqing's green development and then propose targeted countermeasures. These countermeasures will not only help promote the sustainable development of Daqing, but will also provide useful references and lessons for other mature resource cities.

Materials and Methods

Study Area and Data Sources

Study Area

Daqing, situated in the heart of the Songnen Plain in western Heilongjiang Province, enjoys a strategically advantageous geographic location and a well-integrated transportation infrastructure, historically serving as a pivotal hub for northeastern, northern, and eastern China (Fig.1). As the economic, cultural, scientific, technological, and transportation center of western Heilongjiang, it connects the inland areas with the coastal regions and drives regional and national socioeconomic development. Recognized as an exemplary city abundant in resources, Daqing's substantial oil and gas reserves have propelled rapid economic growth and societal progress, with its internationally renowned petrochemical industry significantly bolstering China's energy security and economic foundation. However, alongside resource exploitation come multifaceted challenges: resource depletion, overreliance on certain sectors of industry, and environmental pollution, collectively posing risks to sustainable development. In response, Daqing has embarked on a transformative journey by pursuing green transformation and sustainability through industrial restructuring, nurturing emerging industries, and implementing environmental protection measures [27]. Demographically,Daqing has experienced favorable adjustments, including population stability despite a slight decrease, accelerated urbanization reflected in a higher urban population ratio, and an increasingly educated populace enhancing its human capital for comprehensive growth. Economically, the city has adopted a dual approach: transforming and upgrading industries while leveraging its industrial strengths. The cultivation of innovative sectors such as digital intelligence, contemporary biology creative design, renewable energy, and advanced materials has progressively diversified and refined its economic structure [28]. Concurrently, Daqing has intensified global engagement by attracting foreign investment and adopting cutting-edge technologies to accelerate growth and integration. Aligned with the national ecological civilization agenda, Daqing has embraced green development by implementing comprehensive eco-policies. Through stringent environmental management remediation of high-energy intensity and high-emission entities and ecological restoration initiatives, the city has significantly improved environmental quality, affirming its dedication to a sustainable and eco-responsible developmental trajectory.

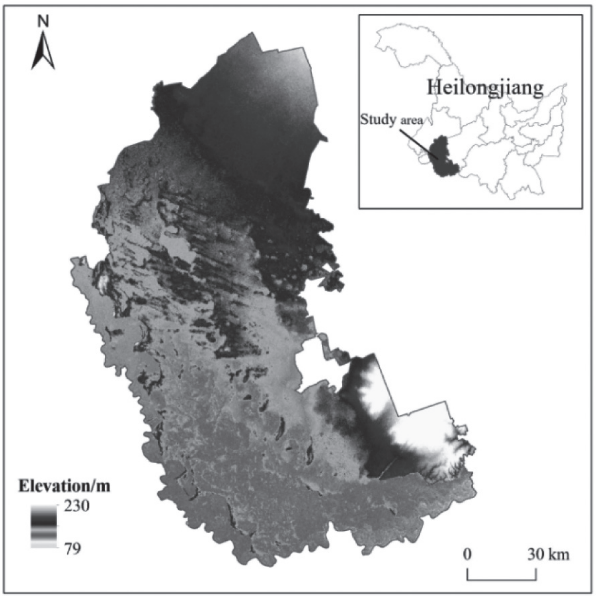

Fig. 1. Location of Daqing in Heilongjiang

Data Sources

This paper takes Daqing as the study area and selects 2011 to 2021 as the study period, and the raw data used are mainly from the Heilongjiang Statistical Yearbook, the Daqing Statistical Yearbook, and the Daqing National Economic and Social Development Statistical Bulletin. In order to ensure the completeness and accuracy of the data, for some of the data that do exist, this paper adopts the mean value interpolation method to make up for them, so as to ensure the scientificity and reliability of the study.

Research Methods

Indicator System

This research establishes an evaluation framework for Daqing's green development, anchored in principles of purpose, systemic coherence, legal conformity, and operational feasibility. Reflecting Daqing's unique context and regional development aspirations, the framework is tiered into four strata: guiding principles, factorial components, and specific metrics, encompassing 4 guiding principles, 11 factorial components, and 32 meticulous performance indicators. This layered schema holistically mirrors the nuances of Daqing's green development landscape. A detailed articulation of the tailored indicators is provided in Table 1.

In terms of economic greenness, the economy is the foundation of urban development, and a green economy is the key to achieving sustainable development. By measuring the level of economic development, it is possible to assess the impact of the city on resources and the environment in the process of economic growth, as well as the degree of optimization of the economic structure [29]. The dynamics of economic growth reflect the vigor and potential of a city's economic development. By examining indicators such as fixed asset investment, foreign investment, and total retail sales of consumer goods, it is possible to understand the drivers of the city's economic growth and whether the economy is overly dependent on resource development [30]. The degree of sophistication of the social security system is directly related to the quality of life of residents and social stability. A sound social security system can help alleviate social conflicts, promote social harmony,

Table 1. Daqing Green Development Indicator System

Target layer	Criterion layer	Element level	Index level/units	Property	Variable
Level of green development in Daqing	Economic greenness	Level of economic development	GDP per capita (million yuan/person)	+	X1
			Urbanization rate (%)	+	X2
			Per capita general public budget income (yuan/person)	+	X3
			GDP growth rate (%)	+	X4
		Economic growth dynamics	Fixed Asset Investment in GDP (%)	+	X5
			Actual utilization of foreign investment (USD million)	+	X6
			Total retail sales of consumer goods (yuan)	+	X7
		Social security	Urban registered unemployment rate (%)	-	X8
			Share of social security subsidies in general public budget expenditure (%)	+	X9
			Number of hospital beds per 10,000 people (per 10,000 people)	+	X10
	Environmental greenness	Pollution control	Sewage treatment rate (%)	+	X11
			Solid waste utilization rate (%)	+	X12
		Pollution emission	Industrial sulfur dioxide emissions (tonnes)	-	X13

Level of green development in Daqing	Environmental greenness	Pollution emission	Industrial wastewater emissions (tonnes)	-	X14
			Industrial smoke (powder) and dust emissions (tonnes)	-	X15
		Environmental quality	Proportion of good air quality days (%)	+	X16
			Green coverage rate of built-up areas (%)	+	X17
			Park green space per capita (m2/person)	+	X18
		Green life	Public transport vehicles per 10,000 people (units/ 10,000 people)	+	X19
			Gas penetration rate (%)	+	X20
			Public toilets per 10,000 people (seats)	+	X21
	Internal growth mechanism	Innovation	Internal Expenditure on R&D Funds as a Share of GDP (%)	+	X22
			Patent grants for inventions per 10,000 people (items/ 10,000 people)	+	X23
		Talent cultivation	Share of education expenditure in public financial budget expenditure (%)	+	X24
			Share of science and technology expenditure in public financial budget expenditure (%)	+	X25
			Number of university students per 10,000 people (persons/ten thousand)	+	X26
	Industry greenness	Industrial transformation	Share of tertiary industry in GDP (%)	+	X27
			Share of secondary industry in GDP (%)	-	X28
			Total amount of imports and exports (USD million)	+	X29
		Low-carbon development	Energy consumption per unit of GDP (tonnes of standard coal / million yuan)	-	X30
			Electricity Consumption per Unit of GDP/ (kW-h/million yuan)	-	X31
			Industrial carbon emission intensity (tonnes)	-	X32

and provide a favorable social environment for green development [2, 31].

In terms of environmental greenness, pollution control is an important aspect of environmental protection and is directly related to the improvement of urban environmental quality. Indicators such as the sewage treatment rate and solid waste utilization rate can be used to assess the efforts and effectiveness of cities in reducing pollution and protecting the environment. The control of pollution emissions is an important indicator of the effectiveness of urban environmental protection. The reduction of industrial sulfur dioxide, wastewater, and soot emissions helps to improve the air quality and water environment and enhance the overall environmental quality of the city [32]. Environmental quality is a visual indicator for evaluating the level of green development in a city. Indicators such as the proportion of good air quality days, green coverage rate, and green space per capita in parks can intuitively reflect the livability of the urban environment and the results of ecological construction. The promotion of a green lifestyle is an important way to achieve sustainable development. Indicators such as the number of public transport vehicles, the gas penetration rate, and the number of public toilets can reflect the living habits of urban residents and the level of urban infrastructure construction and have a positive effect on promoting green consumption and reducing environmental pollution [33].

In terms of internal growth mechanisms, innovation is the core driving force for the sustainable development of cities, and indicators such as the proportion of internal expenditure on R&D and the number of invention patents granted can reflect the scientific and technological innovation capacity and innovation environment of cities, which play an important role in promoting the upgrading of industries and the optimization of economic structure [34]. Talent is an important resource for urban development. Indicators such as the proportion of expenditure on education, the proportion of expenditure on science and technology, and the number of university students can reflect the city's investment in and attention to the cultivation of talents, which is of great significance in enhancing the overall human capital and competitiveness of the city [35].

In terms of industrial greenness, industrial transformation serves as a pivotal factor for resource-oriented cities to embark on a green development trajectory. By analyzing the proportion of tertiary and secondary industries within the GDP, along with the aggregate volume of imports and exports, we can gain insights into the direction of the city's industrial restructuring and the extent of its economic openness [36]. Low-carbon development remains a universal challenge globally. Metrics such as energy consumption per unit of GDP and the magnitude of industrial carbon emissions serve as indicators, reflecting the city's dedication and progress in mitigating greenhouse gas emissions and fostering a low-carbon economy [37].

Entropy Weight-TOPSIS Model

TOPSIS is a widely used multi-objective decision analysis and evaluation method, the core of which lies in the assessment by comparing the distance between the evaluation object and the optimal solution and the worst solution. The method has been deeply applied in the fields of urban green development and high-quality development in new urbanization [1, 3]. The main calculation steps of entropy weight TOSIS are as follows:

(1) Normalized data. The data indicators were normalized according to the extreme variance method. The calculation method is as follows:
Positive indicators:

$$X_{ij}' = (X_{ij} - X_{imin})/(X_{imax} - X_{imin}) \quad (1)$$

Negative indicator:

$$X_{ij}' = (X_{imax} - X_{ij})/(X_{imax} - X_{imin}) \quad (2)$$

(2) Construct the weighted normalization matrix. Using the evaluation index weight vector $w = [w_1, w_2, \ldots, w_{30}]^T$ and each indicator value b_{ij} construct the normalization matrix C:

$$C = [c_{ij}]_{n\times m} = w_j \times b_{ij} \quad (3)$$

(3) Construct positive and negative ideal solution vectors. Construct positive and negative ideal solution vectors from the maximum and minimum values in the obtained weighted normalized $[c_{ij}]_{n\times m}$ where: positive ideal solution vector $c_j^+ = \max c_{ij}$, negative ideal solution vector $c_j^- = \min c_{ij}$.

(4) Calculate the positive and negative ideal distances. Combine the weights of the indicators to find the Euclidean distance from each evaluation unit to the positive and negative ideal solutions:

$$D_i^+ = \sqrt{\sum_{j=1}^{n} (c_{ij} - c_j^+)^2} \quad (4)$$

$$D_i^- = \sqrt{\sum_{j=1}^{n} (c_{ij} - c_j^-)^2} \quad (5)$$

(5) Calculate the comprehensive evaluation index. The proximity of the evaluation object to the optimal program is obtained by calculation with the following formula:

$$S_i = \frac{D_i^-}{(D_i^+ + D_i^-)} \quad (6)$$

In this formula, the closer the S_i value is to 1, the closer the level of development is to the optimal scenario, the further away it is from the worst scenario, and the better the overall coherence between the indicators.

Obstacle Degree Model

In order to deeply explore the comprehensive impact of various factors on the whole system and accurately identify the main obstacle factors affecting the development of a specific city, this study adopts the obstacle degree model for systematic diagnosis and analysis [38]. As a scientific and efficient tool, the obstacle degree model can effectively quantify the obstacle degree of each factor in the system, so as to provide powerful decision support for policymakers. The specific calculation formula for the obstacle degree model is as follows:

$$O_{ij} = \frac{(1-X_{ij}) \times W_i \times 100\%}{\sum_{i=1}^{m} (1-X_{ij}) \times W_i} \quad (7)$$

In the formula, O_{ij} is the obstacle degree of the index to the green development level j in the year; W_i is the weight of the i indicator.

On the basis of an in-depth analysis of the degree of influence of each single factor on the green development of each city, this paper further explores the combined influence of each subsystem on the degree of barriers to urban green development. Its calculation formula is as follows:

$$U_i = \sum O_{ij} \quad (8)$$

In the formula: is the obstacle degree of the total goal.

Results and Analysis

Comprehensive Green Evaluation Results

In this study, the entropy weight TOPSIS model was used to analyze the data of Daqing from 2011 to 2021 in depth, so as to derive the specific status of the comprehensive level of green development. As shown in Fig. 2, the comprehensive level of green development in Daqing shows an obvious improvement trend during this decade, with its comprehensive index steadily increasing from 0.375 in 2011 to 0.566 in 2021, and this significant upward trend indicates that Daqing has made positive progress in green development. In order to build a pattern of green and high-quality development, Daqing has actively implemented policy guidance targeting a number of directions, including the economy, environment, industry, and development. However, during the study period, Daqing's green development composite index

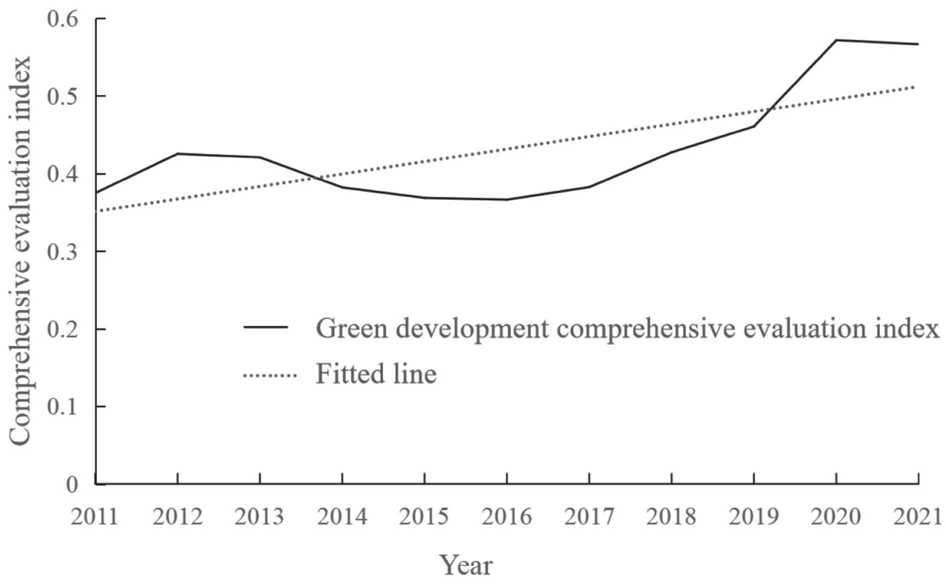

Fig. 2. Comprehensive evaluation index of green development in Daqing City from 2011 to 2021

also showed some volatility, while the performance status of the subsystems also differed from each other.

Subsystem Green Development Calculation Results

In order to evaluate the effectiveness of Daqing's green transformation more comprehensively, this paper further analyzes the evaluation results in depth from the four dimensions of economic greenness, environmental greenness, internal growth mechanisms, and industrial greenness. The calculation results are shown in Table 2.

(1) Economic Greenness: Daqing's trajectory in economic greenness registers a consistent upward trend from 2011, with the index ascending from 0.281 to a peak of 0.611 in 2020, despite a minor post-2020 adjustment. This decade-long improvement reflects the city's ongoing refinement of green industrial policies and robust support for emerging sectors in clean energy, environmental technology, and the digital economy. Through policy incentives, fiscal stimuli, and a supportive business environment, Daqing fosters innovation and industrial transformation, nurturing a greener economic fabric. Reinforced by the establishment of a green finance infrastructure and enhancements to carbon trading mechanisms, the city steadily progresses towards a high-quality, eco-friendly economic model, all while maintaining stability.

(2) Environmental Greenness: Notwithstanding a temporary decline in the environmental greenness index from 2011 to 2014, Daqing witnessed a rebound from 2015 onwards, characterized by variable yet cumulative improvements. This reversal manifests the city's adherence to national green development strategies, implementing comprehensive environmental

Table 2. Indices of subsystems of the level of green development in Daqing from 2011 to 2021

Year	Economic greenness	Environmental greenness	Internal growth mechanism	Industry greenness
2011	0.281	0.585	0.276	0.433
2012	0.335	0.530	0.466	0.458
2013	0.328	0.539	0.481	0.454
2014	0.302	0.457	0.391	0.482
2015	0.231	0.510	0.376	0.556
2016	0.248	0.511	0.341	0.516
2017	0.296	0.465	0.324	0.587
2018	0.335	0.556	0.388	0.572
2019	0.348	0.540	0.546	0.618
2020	0.611	0.542	0.513	0.558
2021	0.574	0.549	0.568	0.569

conservation policies such as the "30 Measures for Enhanced Air Pollution Control," which significantly reduced emissions and improved air quality. The clarification of departmental responsibilities for ecological protection through the "Responsibility Inventory" fosters a cooperative governance model. Additionally, initiatives like afforestation, wetland conservation, and water purification have significantly enhanced the ecological landscape.

(3) Internal Growth Mechanisms: As a pivotal indicator of economic growth's inherent strength and efficiency, this mechanism experienced peaks in 2012 and 2019, reaching 0.466 and 0.546, respectively, signaling robust growth potential in those years. Despite higher volatility until 2018, stability has prevailed since 2019, a trend attributed to Daqing's investments in innovation and talent cultivation. Policies like the "Talent Recruitment Plan" and "New Era Talent Development Strategy" have fortified the talent pipeline and innovation capacity, translating into economic growth mode transformations and enhanced growth quality and efficiency.

(4) Industrial Greenness: Reflecting the environmental sensitivity of industrial activities, this indicator initially fluctuated in Daqing from 2011 to 2017, but since 2018, it has notably improved, peaking at 0.558 in 2020. This shift denotes a heightened focus on environmental protection and sustainability in Daqing's industrial sector. The city has pursued the transformation and upgrading of traditional industries alongside the cultivation of new green industries. By developing clean energy, adopting energy-efficient technologies, and promoting green transformation in traditional sectors, Daqing has enhanced industrial green development efficiency. Furthermore, fostering green agriculture and eco-tourism contributes to a greener industrial landscape, underpinning the city's sustainable development aspirations.

Identification of Barriers to Green Development Levels

Analysis of the Barriers to Individual Indicators

Given the multitude of variables implicated in the study, this paper narrows the focus to the top five prevailing impediments for meticulous examination. Table 3 illuminates: (1) Economically, Daqing encounters a persistent challenge in its urbanization rate, evident from 2011 to 2021, underscoring the formidable hurdles in urbanization processes. Moreover, recurrent obstacles such as per capita public budget revenue, total retail sales of consumer goods, and GDP growth accentuate the necessity for continued efforts in economic restructuring, fiscal revenue stability, and fostering consumption-led growth. (2) Regarding environmental aspects, industrial sulfur dioxide emissions and solid waste utilization efficiency emerge as salient barriers, spotlighting environmental pressures from industrial activity and the imperative to enhance waste management and resource recycling. (3) In the social sphere, recurrent obstacles include education expenditure, urban unemployment rates, and the share of science and technology spending in the public budget, highlighting inadequacies in investments and outcomes in education, job markets, and innovation. Daqing must escalate its commitments in these realms, optimizing resource distribution to attain a more equitable and enduring development trajectory.

Analysis of the Barriers to Individual Indicators

According to the results of the analysis of the degree of obstacles for each indicator, it is possible to obtain changes in the degree of obstacles for each subsystem (Fig. 3).

(1) Economic greenness: from 2011 to 2015, economic greenness showed a fluctuating trend, with a peak of 0.458 in 2015, but then declining in 2016. However,

Table 3. Major impediments to green development in Daqing and the extent of such impediments

Year	1	2	3	4	5
2011	X2(13.69%)	X8(7.82%)	X26(6.4%)	X3(5.88%)	X23(5.35%)
2012	X2(15.07%)	X8(7.1%)	X26(6.69%)	X3(5.67%)	X23(5.66%)
2013	X2(15.07%)	X8(9.32%)	X26(7.66%)	X3(5.42%)	X23(5.37%)
2014	X2(13.45%)	X8(8.72%)	X26(6.86%)	X13(5.7%)	X3(4.87%)
2015	X2(14.29%)	X8(8.92%)	X3(6.44%)	X26(6.01%)	X13(5.83%)
2016	X2(13.74%)	X8(7.29%)	X3(6.23%)	X13(5.27%)	X26(5.08%)
2017	X2(13.82%)	X8(7.45%)	X25(6.57%)	X12(5.93%)	X24(5.15%)
2018	X2(15.49%)	X25(6.92%)	X8(6.54%)	X12(6.1%)	X24(5.88%)
2019	X2(16.72%)	X12(7.07%)	X24(7.07%)	X7(6.57%)	X7(6.57%)
2020	X24(9.46%)	X12(8.95%)	X7(8.77%)	X1(8.38%)	X4(7.88%)
2021	X2(11.03%)	X12(10.61%)	X24(0.38%)	X7(8.54%)	X1(7.85%)

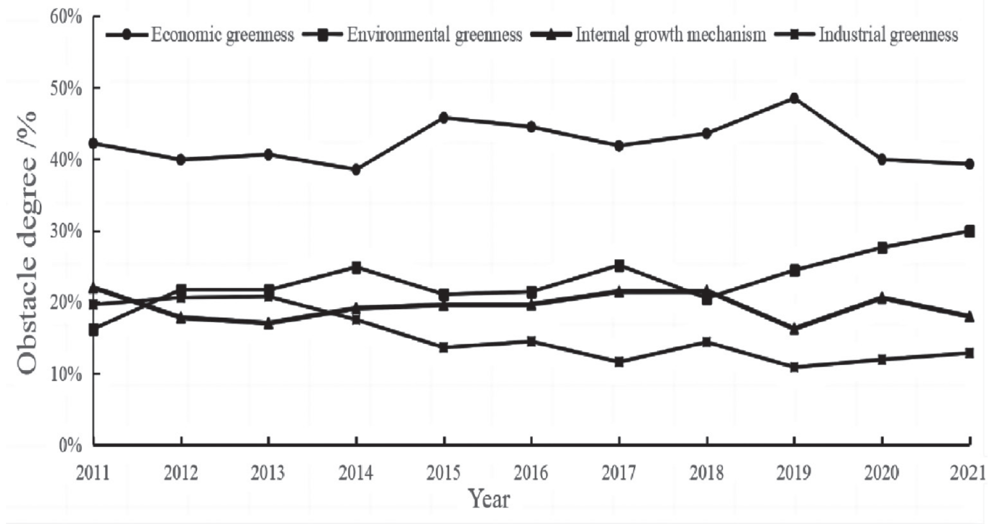

Fig. 3. Diagnosis of barrier factors of the subsystem of the green development level in Daqing

economic greenness picked up again to 0.485 by 2019, followed by a gradual decline. Overall, the greenness of the economy has increased over the decade, albeit with fluctuations in the process. This trend reflects Daqing's emphasis on education and science and technology in recent years, which has promoted the deep integration of industry, academia, and research through the development of pillar industries such as new materials, bio-medicine, and modern agriculture, as well as the support of emerging industries such as speciality tourism and e-commerce, thus fostering new points of economic growth and realizing the improvement of quality and efficiency in economic development. However, the support still needs to be further strengthened to further enhance the effect of economic greenness.

(2) Environmental greenness: between 2011 and 2014, environmental greenness showed fluctuations, with the highest value of 0.249 reached in 2014. However, there was a brief increase thereafter until 2017, but overall environmental greenness has not been significantly improved. This trend suggests that Daqing's efforts in environmental governance and ecological restoration are limited and still need to be strengthened relative to economic greenness and internal growth mechanisms. In particular, there is still room for further improvement in optimizing the natural environment, coordinating greening settings, vegetation restoration, and the management of mountains, rivers, and lakes. In addition, as the secondary industry still dominates the economy, the scale of energy extraction is large, and straw burning still exists in agriculture, leading to a rapid accumulation of pollutants such as carbon dioxide and sulfur dioxide emissions, further increasing the environmental pressure on Daqing.

(3) Internal Growth Mechanism: Internal Growth Mechanism fluctuated little between 2011 and 2013, but declined in 2014. However, the internal growth mechanism reached a maximum value of 0.214 by 2017 and then declined, but overall showed that the intrinsic dynamics and efficiency of economic growth increased significantly after 2013. This is attributed to Daqing's focus on research and development investment funding and the protection of innovations. At the societal level, Daqing has endeavored to build a consensus on values, foster the spirit of innovation, and respect intellectual property rights, thus reducing barriers to internal growth mechanisms.

(4) Industry greenness: industry greenness declined between 2011 and 2012, but rose year by year from 2013 to reach a maximum value of 0.109 in 2019, with slight fluctuations thereafter. This trend reflects that Daqing has significantly increased its emphasis on environmental friendliness and sustainable development of industries in recent years. By focusing on creating an excellent ecology for the green development of industries and building a modern industrial system, Daqing continues to nurture and grow new technologies, new products, new business forms, and new modes while improving the institutional mechanism and supporting policy systems to promote the green development of industries, promoting the optimal allocation of various types of elemental resources, and continuing to promote the optimization and upgrading of the industrial structure, so as to build a modern industrial system.

Conclusions

This paper evaluates and analyzes the level of green development and obstacle factors in Daqing from 2011 to 2021 based on the entropy weight TOPSIS model and the obstacle degree model. The following conclusions are drawn: (1) From an overall perspective, the level of green development in Daqing fluctuates greatly from 2011 to 2021, and its comprehensive evaluation index of green development increases from 0.375 in 2011 to 0.566 in 2021. There is still a lot of room for improvement in the level of green development in Daqing. (2) From each sub-system, Daqing's economic greenness, internal growth mechanism, and industrial greenness have been improved to varying degrees, but environmental greenness has been reduced to a certain extent. (3) In terms of obstacle factors, the main obstacle factor to green development in Daqing is economic greenness, followed by environmental greenness. In terms of individual factors, the main obstacle factors constraining the level of green development in Daqing are the urbanization rate, the urban registered unemployment rate, the number of university students per 10,000 people, and the per capita income from the general public budget.

Based on the results of the measurement and analysis, the following recommendations are made for the green development of Daqing: (1) The Daqing Municipal Government is impelled to escalate its commitment to cultivating a green economy, refining the policy framework for eco-industries, and incentivizing technological innovation and enterprise upgrades, thereby accelerating the transformation of traditional sectors toward sustainability. Strategies pivot on augmenting eco-investments, streamlining financing channels, and enhancing project oversight through rigorous evaluations. Additionally, efforts should target affordable housing provisions, establish a cost-benefit equilibrium in urbanization, and elevate urbanization rates. Tax relief implementations are envisaged to stimulate household consumption, harnessing consumer activity as a driver for advancing a verdant economic model. (2) The emphasis on environmental governance and the construction of an ecologically civilized city necessitates the local government of Daqing to refine green development regulations, integrate waste disposal permits within environmental oversight mechanisms, enforce stringent emission norms, and optimize social security frameworks for resource-based cities. This approach bolsters regional green development levels. Elevating the science and technology investment ratio, focusing on researcher cultivation, attracting high-tech enterprises, and facilitating technological leaps to enhance waste treatment efficiency and resource utilization constitute a pivotal pathway toward the realization of an eco-civilized Daqing. (3) To ensure stable social development, Daqing must actively court foreign investments, fueling economic growth, job creation, and reinforcing employment policies. Enhancing the workforce's quality and promoting resident employment is vital. Downwardly adjusting the social security contributions of enterprises, instituting unemployment subsidies, and refining the social security system is imperative. Elevating educational expenditures, strengthening talent cultivation with a focus on science and technology, and bolstering infrastructure for scientific personnel fortify the innovation talent pool, underpinning the transition between old and new growth drivers. Promoting scientific events and enhancing students' scientific literacy further contribute to a robust foundation for sustainable progress.

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Conflict of Interest

The authors declare no conflict of interest.

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