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Eco-City Problems: Industry–City–Ecology, Urbanization Development Assessment in Resource-Exhausted Cities

Xin Li [1,2,†] and Xinyu Zhuang [3,*,†]

[1] School of Tourism and Geography Science, Qingdao University, Qingdao 266071, China
[2] Advanced Institute of Culture & Tourism, Qingdao University, Qingdao 266071, China
[3] College of Quality & Standardization, Qingdao University, Qingdao 266071, China
* Correspondence: xinyu@qdu.edu.cn
† These authors contributed to the work equally and should be regarded as co-first authors.

Abstract: Not one single event affected as much of the world as the present period of warming is now doing. Due to the global energy crisis, climate warming and other issues, low-carbon eco-cities have become the general trend. In the context of this study, we aim to solve problems of resource-exhausted cities, which are in urgent need for green transformation. The selection of research objects is mostly based on representative regions (eastern, middle. and western regions) in China, which will lead to significant regional characteristics in eco-city planning. On the basis of the index selection, construction of the evaluation index system and calculation on the coordinated development degree of industrial structure and urbanization, we explore the coordination relationship between industrial transformation and urbanization level with the time span of three-time nodes (2005, 2010, 2015), which were also the speed-up of industrialization and urbanization in China. Results indicate that the transformation and upgrading of the current regional industrial structure is lagging behind, and the internal power of industrial upgrading is insufficient, which limits the ecological development of resource-exhausted cities. It can also be found that the coordinated development index of urbanization and industrial structure is too low. The main implications of this study state that resource-exhausted cities are still in the state of being on the verge of imbalance and still have a wide development space based on the division standard. Furthermore, compared to the rationalization industrial structure, this study indicates the contributive rate of industrial structure supererogation to the overall level of urbanization is bigger. Countermeasures about the urban environment from the ecology stratification plane and how the cities achieve the urban form of sustainable development as a complex organism are also proposed. Scientific analysis and discussion on resource-cities by studying and solving related problems on the eco-city's construction has vital significance to urbanization and sustainable development, which can reflect the relationship between industry, city, and ecology.

Keywords: green transformation; urbanization development; evaluation model; urban sustainability; eco-city

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1. Introduction

An eco-city is one with coordinated development of society, economy. and eco-environment, and the eco-city construction has been widely carried out around the world since the concept of the ecological city was proposed by the MAB Program (Man and Biosphere Program) in the 1970s (UNESCO, 1971) [1–3]. Since the 1990s, many scientists, politicians, and sociologists have proposed a low-carbon ecological development direction [4], which makes the mode of urban development face the choice of transformation [5]. There is no doubt that the direction of the transformation of most cities is to develop eco-cities, so urban transformation is quite imminent [6,7].

An eco-city is a highly-developed economy, a prosperous society, great living, and a virtuous ecological cycle. The urban environment and human settlements are clean, beautiful, comfortable, and safe, which is conducive to improving the stability of a coordinated

and sustainable artificial complex ecosystem [8,9]. Taking a comprehensive view of eco-city construction, it can be roughly summarized into six types of eco-cities, namely, landscape leisure cities, green industrial cities, resource-saving cities, environment-friendly cities, circular economy cities, and green consumption cities [10,11]. In this study, we focused on the green transformation of resource-exhausted cities, which aims to transform the ways of eco-cities. The basic elements of urban green transformation are the industrial structure and urbanization development. The adjustment of the industrial structure and development of the urbanization level are the core in the process of social and economic development [12,13].

The upgrading of industrial structure and the development of urbanization influence each other. On one hand, the upgrade and transformation of the industrial structure constantly promote the improvement on the level of industry and significantly improve the degree of industrial agglomeration [14,15]. Meanwhile, the upgrade and adjustment of the industrial structure can promote the development of urban infrastructure and the urban tertiary industry [16]. On the other hand, the acceleration of the urbanization process will greatly stimulate the development of the tertiary industry, and more capital will flow to the tertiary industry in the urbanization process [17], which will promote the progress of the financial industry, education industry, Internet industry, and other tertiary industries, and will also provide the market demand for the transformation and upgrade of the urban industrial structure [18]. It can be seen that the high-quality coordination between the development of urban industrial structure and the level of urbanization has important value for the urban transformation and development. Therefore, in the period when coal resource-exhausted cities are now at the critical moment of industrial structure transformation and upgrade, it is particularly important to explore the synergy between the industrial structure and urbanization level of coal resource-exhausted cities, which can better promote the rational allocation of resources and urban transformation.

Urban problems can be regulated by ecological construction, which is a cause of concern of academia, the government, and managers [19,20]. The two concepts of industrial structure changes and urbanization have always been the focus of academic research, and the interaction between them are also of concern. As early as 1954, W.A. Lewis [21] established mathematical models to prove that the process of urbanization will inevitably lead to the labor force beginning to transfer to urban areas. After analyzing the urbanization data of developing countries in the world, Japanese scholar Reeitsu Kojima (1996) pointed out that the industrialization level of developing countries in Latin America lags behind their urbanization process, while the development of developing countries in Asia is basically synchronous. Y. Murata demonstrated the impact mechanism between industrial structure changes and urbanization by using the quantitative regression method, and considered that there was indeed an interactive relationship between them [22]. Chen et al. [23] studied the interaction between the industrial structure and the urbanization process of Fujian Province and built a spatial model to demonstrate it. Wang Junsheng et al. [24] regarded the coordinated development of urbanization and industrial structure as a system from the perspective of system science by taking Shaanxi Province as an example, and they quantitatively analyzed the coordinated development level. Huang Xiaojun et al. [25] used SPSS analysis to conduct regression analysis on the interaction between industrial structure changes and urbanization in Northeast China in the past 10 years. Tong Xinhua discussed the dynamic relationship between population urbanization and industrial structure in Jilin Province and used the time series data from 1952 to 2013 to conduct econometric analysis. The results indicate that population urbanization played a greater role in driving the tertiary industry than secondary industry [26].

In practice, since the 1990s, during the accelerated process of urbanization, the eco-city has become a research hotspot and focus problem. However, the construction and planning of ecological cities in some countries is far from international standards, and the construction effect is limited. There are many problems in the planning and construction of ecological cities (i.e., the weakness of planning and management of an eco-city), and

there are even less mechanisms for public participation in the construction of eco-cities, the evaluation index system on eco-city lacks dynamic reflection, which has seriously restricted the development process of an eco-city.

The existing literature reviews play a great role in helping us to understand the relationship between the industrial structure and urbanization, but there are still gaps that remain to be explored. First, the selection of research objects is mostly based on one province or country, and studies on different and representative regions in a country as research objects is relatively lacking, which will lead to the incomplete realization of the significant regional differences in eco-city planning, the selection and valuation of evaluation indices for eco-city construction will also lack regional characteristics, and the formulation and implementation of ecological planning are disconnected. Second, the previous evaluation index system lacks dynamics that fails to reflect the organic relationship among the environment, economy, and society. Third, most of them have focused on the interaction mechanism, dynamic relationship, and development modes, while studies focused on the coordination degree between the industry and urbanization are few. Moreover, almost all of the previous research studies have proposed countermeasures regarding the urban environment from ecology stratification, but ignored how urban space can achieve urban sustainable development as a complex organism through coordinated development.

Because of the above reasons, the related problems on the construction of an eco-city have been studied. The purposes of this study were to explore problems and solutions of regions with different characteristics in the process of green transformation and green development, demonstrate the effect of unreasonable industrial structure on the optimization of industrial structure, and provide a case reference for urban green transformation and ecological city construction. Meanwhile, what are the barriers to eco-city development, how to accelerate the ecological development of cities, how to establish a bridge between green transformation, and the sustainability of eco-city development to maintain urban sustainability are also the main research objectives in this study.

Hence, in the context of ecological development and green transformation, this study takes coal-resource-exhausted cities as the research objectives to explore the coordination relationship between industrial transformation and urbanization level. On the basis of the interactive mechanism between the industrial structure and urbanization of coal-resource-exhausted cities, this study constructed the evaluation index system of the industrial structure development and urbanization level of coal-resource-exhausted cities by taking nine representative coal-resource-exhausted cities in the eastern region, middle region, and western region of China as the research objects, calculates the coordinated development degree of industrial structure and urbanization level from 2005 to 2015, and puts forward policy recommendations for the green transformation and ecological development of resource-exhausted cities, according to the empirical analysis results. The rest of this paper is organized as follows. Section 1 presents the introduction and research background. Section 2 reviews the theoretical basis and discusses the interaction between the industrial structure and urbanization in building the eco-city. Section 3 describes the methods and construction principles of the comprehensive evaluation index system of industrial structure and urbanization. We construct the comprehensive evaluation index system, calculate, and analyze the coordinated development degree of industrial structure and urbanization based on the case study in Section 4, while the main findings and discussion of this study are detailed in Section 5. Conclusions including the enlightenment and policy recommendations are summarized in Section 6.

2. Theoretical Basis

2.1. Eco-City

The word "ecology" in eco-city actually includes three aspects: ecological industry, ecological environment, and ecological culture. Eco-city construction is no longer just environmental protection and ecological construction, which covers environmental pollution prevention and control, ecological protection and construction, ecological industry devel-

opment (including ecological industry, ecological agriculture, and ecotourism), human settlement environment construction, ecological culture, etc. This is exactly the requirement of a sustainable development strategy [27,28].

As a reflection and sublation of the traditional urbanization, "eco-city" embodies the integration and coordination of industrialization, urbanization, and modern civilization, is a great innovation for mankind to consciously overcome the "urban disease", and move from gray civilization to green civilization. It essentially adapts to urban sustainable development [29], which marks the transformation of the city from the traditional economic growth mode to the compound development mode of the organic integration of economy, society and ecology [30,31]. It also reflects the transformation from traditional humanism to rational humanism in the concept of urban development [32].

The standards for the construction of eco-cities should be determined from three aspects: social ecology, economic ecology, and natural ecology. The principle of social ecology is to put people first and create a free, equal, just, and stable social environment; the principle of economic ecology is to protect and rationally use all natural resources and energy, improve the regeneration and utilization of resources, and adopt the development model of sustainable production, consumption, transportation, and residential areas; the principle of natural ecology is to give priority to the natural ecology and protect it to the maximum extent, so that development and construction activities can be kept within the carrying capacity allowed by the natural environment, and on the other hand, reduce the negative impact on the natural environment [33].

The sustainability of an eco-city is a new concept based on the human's deeper understanding of the relationship between man and nature. It is a new social relationship of coordinated development of society, economy, and nature based on the ecological principles. It is also a new way of production and life that effectively uses environmental resources to achieve sustainable development [34]. The eco-city is designed to establish an efficient, harmonious, healthy, and sustainable human settlement environment, which is the environmental ecological performance of urban sustainable development, representing its application in urban development [35]. Urban sustainable development is a process in which a city constantly pursues its inherent natural potential to realize the process of sustainability. Its purpose is to establish a garden city based on living capacity. In order to achieve sustainable development, cities must make rational use of their own resources and use environmental and ecological rules to solve urban environmental problems, which are the basic problems faced by urban sustainable development.

2.2. Theories of Industrial Structure Upgrading

The transformation and upgrade of industrial structure mean that the changes of industrial structure move from hindering economic development to promoting economic development, and finally achieves the rationalization and supererogation of the industrial structure. The rationalization of the industrial structure needs to adapt to the current economic development situation, while the industrial structure supererogation focuses on the rationalization of economic situation of the industrial structure transformation. There are several theoretical basis on industrial structure upgrading (Table 1).

(1) Kuznets Theory

Kuznets theory, also known as Kuznets curve, was proposed by the American economist Kuznets in 1955. The Kuznets curve shows that at the beginning of the economic development process, especially when the national income per capita rises from the lowest to the middle level, the income distribution situation tends to deteriorate first, then gradually improves with the economic development, and finally reaches a relatively fair income distribution situation in an inverted U shape.

Based on the analysis of changes in the proportions of three major industries, Kuznets believes that the industrial structure will gradually reduce the proportion of the first industry with the development of the economy, and the proportion of the secondary industry will obviously increase in the early stage and then gradually decrease. The tertiary industry will gradually and steadily rise [36].

(2) Petty–Clark Law

The Petty–Clark law is an economic term, which is the law of industrial structure evolution. With the improvement in the national income per capita, the labor force shifts from the first industry to the secondary industry; when the national income per capita is further increased, the labor force will shift to the tertiary industry [37].

(3) Gradient Transfer Theory

Gradient transfer theory originates from the product lifecycle theory of industrial production proposed by Vernon [38]. According to the product lifecycle theory, all sectors of industry and products are in different development stages of the lifecycle [39] (i.e., experiencing four stages of innovation, development, maturity, and decline). Since then, Wells and Hirsch have verified the theory, enriched, and developed it. When this theory is introduced into regional economics, the gradient transfer theory of regional economic development is produced.

According to gradient transfer theory, the development of the industrial structure is controlled by the leading industries. With the continuous development of economy, the production gradually shifts from high gradient areas to low gradient areas. In other words, developed countries begin to transform and upgrade the industrial structure first, and then promote the transformation and upgrading of the industrial structure of developing countries through the transfer of leading industries. The development of a regional economy depends on the status of the industrial structure, which in turn depends on the regional economic sectors, especially the stage of its leading industries in the industrial lifecycle. According to the theory, innovation activities are the decisive factor that determine the gradient level of regional development, and most of them occur in high gradient areas. With the changes in lifecycle stages, production activities gradually shift from high gradient areas to low gradient areas, and this gradient transfer process is mainly expanded through multi-level urban systems. Similar to gradient transfer theory is the flying geese paradigm proposed by Japanese scholar Kaname Akamatsu. Subsequently, Japanese scholars such as Yamazawa have extended and applied it to explain the process of the international division of labor, changes in industrial results, and successive economic development of Asian countries with East Asia as the center [40]. On the issue of international transfer according to comparative advantages, the theory of the flying geese paradigm is similar to Vernon's theory of lifecycle.

2.3. Urbanization Theory

Urbanization theory can be divided into the behavioral school, structural school, post-modernism school, etc. Among them, the behavioral school analyzes human activities, explores the role of human activities in the process of urban formation, and links the research of urbanization with sociology. The structural school regards the process of urbanization as a social choice in the process of social and economic development, rather than being determined by individuals. The post-modernism school aims to highlight the synergy of cities, social humanities, and ecological environment [41,42].

Table 1. Interpretation and extension of the industrial structure and urbanization theory.

Theory	Time	Researcher	Main Point	Conclusion
Theory of industrial structure upgrading	1930 1955	Simon Smith Kuznets	Kuznets Theory [36]	The Kuznets curve proposes the income distribution changes with the process of economic development. The industrial structure will gradually have an influence on the proportions of three major industries.
	1932	Kaname Akamatsu	Flying Geese Paradigm [40]	Similar to the gradient transfer theory is the flying geese paradigm proposed by Japanese scholar Kaname Akamatsu. Subsequently, Japanese scholars such as Yamazawa have extended and applied it to explain the process of the international division of labor, changes in industrial results, and successive economic development of Asian countries with East Asia as the center.
	1955	William Petty Colin Clark	Petty–Clark Law [37]	Clarke believes that with the development of the economy, the industrial structure will continue the process of transferring from the primary industry to the secondary industry and gradually transferring from the secondary industry to the tertiary industry.
	1966	Raymond Vernon Wells and Hirsch, etc.	Product lifecycle theory Gradient transfer theory [38]	Gradient transfer theory originates from the product lifecycle theory of industrial production proposed by Vernon. Wells and Hirsch verified the theory, and enriched and developed it, which emphasized international investment and international trade in the product lifecycle.
	1960–1975	G. Krumme R. Hayor	Gradient transfer theory of regional economic development [9]	When this theory is introduced into regional economics, the gradient transfer theory of regional economic development is produced, which considers that the development of the regional economy depends on the industrial structure, while innovation activity is the decisive factor that determines the gradient level of regional development.
Urbanization theory		——	Urban theoretical models: [43] Single-center city model, Multi-center city model, Spatial mismatch theory, Suburb urbanization theory	Urbanization theory can be divided into the classical school, ecological school, neoclassical school, behavioral school, structural school, new Weber school, post-modernism school, etc.
	1933 1940	Walter Christaller August Lösch	Theory of Regional Urban Agglomeration: [44] Theory of central places, Theory of urban field, Theory of interaction between cities	The Central Place Theory is the product of the combination of geography and economics. The basic feature is that every place has the opportunity to accept a central place under the ideal state. The urban field is the result of the late urbanization development. According to the theory of interaction between cities, when the attraction between cities is greater than the repulsion, the two cities will be closely linked to attract more people and resources and strengthen the scale of cities.

The theoretical models of cities proposed by scholars can be divided into the following types: single-center city model, multi-center city model, spatial mismatch theory, and suburb urbanization theory. The single-center city model refers to only one center in the city, so the radiation from the center to the outside is formed, the rent is reduced, and the

commercial function is declined. A multi-center city model refers to a city with multiple centers, which is more conducive to urban expansion and is convenient for the daily life of people. The spatial mismatch theory refers to the mismatch between the geographical location of the population residence and the work unit, which makes it difficult for the employees to find a suitable job near their home, and also makes it difficult for the units with remote geographical location to recruit job seekers. The suburban urbanization theory is a form of expression that runs counter to urbanization, which usually occurs in the later stage of urbanization. In the later stage of urbanization, various urban problems such as traffic congestion and serious pollution will gradually increase, while with the increase in employment opportunities in the suburbs, the improvement in infrastructure construction and the continuous improvement in traffic conditions, it will gradually shift to the suburbs [43]. Moreover, the theory of regional urban agglomeration mainly has three major theoretical viewpoints: the theory of central place, theory of urban field, and theory of interaction between cities [44] (Table 1).

3. Methods

3.1. Data Source and Construction Principles

3.1.1. Selection of Study Regions

In the document GF [2013] No. 45 issued by the State Council on 12 November 2013, a total of 67 resource declining cities were summarized including 24 cities at or above the prefecture level. Meanwhile, coal-resource-exhausted cities were selected from the list of coal-resource-exhausted cities published in 2008, 2009, and 2011 with the division of three representative regions in the eastern region, the middle region, and the western region of China. Three representative cities in each region are selected as the research objects. Specifically, the eastern region includes Zaozhuang City in Shandong Province, Liaoyuan City in Liaoning Province, and Hegang City in Heilongjiang Province; the middle region includes Huaibei City of Anhui Province, Jiaozuo City of Henan Province, and Xinyu City of Jiangxi Province; the western region includes Lanzhou City of Gansu Province, Tongchuan City of Shaanxi Province, and Shizuishan City of Ningxia Hui Autonomous Region (Figure 1). The China Statistical Yearbook from 2005 to 2015 was selected as the data source. In order to ensure the feasibility of the calculation process, the study used the missing value replacement method to supplement some missing data.

The reason why we selected the object cities based on the list of coal-resource-exhausted cities published in 2008, 2009, and 2011 is as follows. In 2008, 2009, and 2011, the National Development and Reform Commission defined 69 resource-exhausted cities as well as nine counties (cities, banners and districts) in the Da and Xiao Xing'an Mountains. Among them, there are 36 coal-resource-exhausted cities, and Fuxin (coal), Yichun (forest and industry), Liaoyuan (coal), Baishan (forest and industry), and Panjin (petroleum) are among the first pilot cities for green transformation. As of 2013, the State Council issued the National Sustainable Development Plan for Resource-based Cities (2013–2020) (GF [2013] No. 45, hereinafter referred to as the "Plan"). There are 262 resource-based cities within the planning scope in China, accounting for 39.6% of the total number of cities in China (661 cities). Among them, there are prefecture-level administrative regions (including prefecture-level cities, regions, autonomous prefectures, leagues, etc.) and 188 county-level cities due to the influence of its geographical location, resource-based cities are less open than coastal cities and the economic development is also slower, hence, it is particularly difficult to transform for resource-based cities.

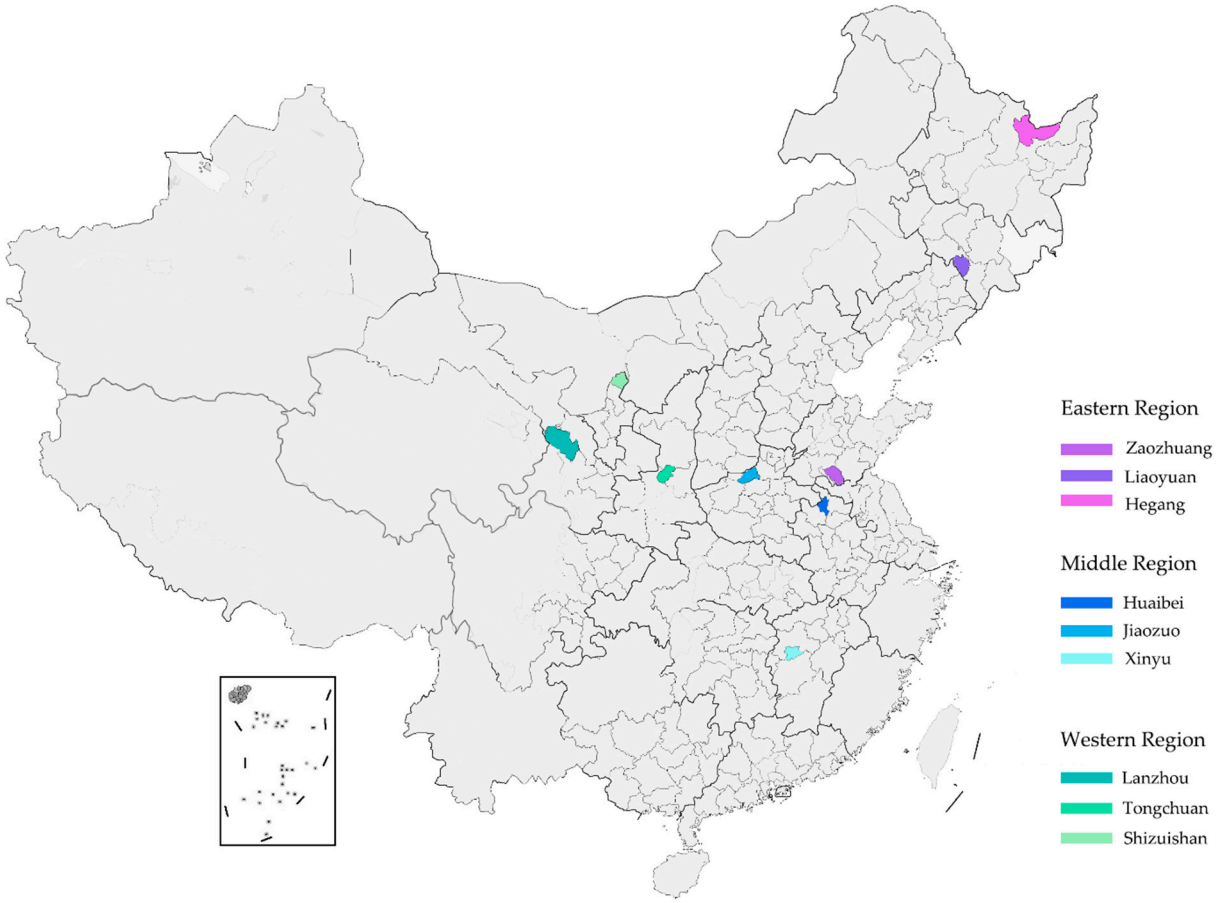

Figure 1. Location and distribution of the object cities. Source: Author self-painting.

In the Plan, according to the urban development and non-renewable resources, resource-based cities are divided into four types: growth type, mature type, decline type, and regeneration type. Specifically, declining resource-based cities refer to those cities whose mineral resources have been rapidly developed and the development capacity has declined or dried up. Furthermore, 67 declining resource-based cities were designated, accounting for nearly 40% of the total number of resource-based cities. The 67 cities were exactly from 69 resource-exhausted cities defined in three batches in 2008, 2009, and 2011. Panjin City and Xiaoyi City, formerly affiliated to resource-exhausted cities, have become renewable cities. Since the list of resource-exhausted cities have not been updated, this study selected nine coal-resource-exhausted cities in the eastern, middle, and western regions of China as the research objects according to the list of resource-exhausted cities published by the National Development and Reform Commission in three batches in 2008, 2009, and 2011 and the Plan issued by the State Council on 12 November 2013.

3.1.2. Construction Principles of Comprehensive Evaluation Index System of Industrial Structure and Urbanization

The design of a comprehensive index system of industrial structure and the urbanization of coal-resource-exhausted cities should follow certain principles and evaluate the industrial structure, urbanization level, and quality of coal-resource-exhausted cities on the premise of fully considering the development characteristics of coal-resource-exhausted cities objectively, scientifically, and comprehensively. The construction process of the industrial structure and urbanization comprehensive index system of coal-resource-exhausted cities in this study mainly follow the following principles:

(1) Systematic Principle

This principle requires us to be logical in setting each index. Each subsystem is composed of a group of indices. Each indicator is independent of each other and keeps contact with each other. The whole index system is progressive and inseparable from the macro level to the micro level.

(2) Consistency Principle

The purpose of establishing the comprehensive evaluation index system of industrial structure and urbanization is to objectively and fairly evaluate the development status of urban industrial structure and urbanization level. The constructed index system must be able to meet the purpose of constructing the evaluation index system and maintain consistency.

(3) Typicality Principle

In the construction process, we should ensure that the evaluation indices are representative and can reflect the development level of the industrial structure and urbanization of coal-resource-exhausted cities as accurately as possible.

(4) Feasibility Principle

The selection of indicators must be available, operable, comparable, and quantifiable. The development level of the industrial structure and the urbanization development level of coal-resource-exhausted cities should be unified in calculation measurement and calculation method, with simple and clear indices and not too complicated.

(5) Simplicity and Scientificity Principle

The design of each index must be based on the principle of scientificity, and can objectively and truly reflect the industrial structure and urbanization level of coal-resource-exhausted cities.

3.2. Research Procedure

In order to better understand the research procedure, a diagram of the research process is provided as follows (Figure 2).

3.3. Index Selection and Index Weight

3.3.1. Index Selection for the Comprehensive Evaluation Index System of Industrial Structure and Urbanization

The coordinated development of industrial structure and urbanization is a complex system involving all aspects of cities. In order to explore the relationship, this study separated the whole system into two subsystems, namely, the comprehensive evaluation index system of industrial structure and the comprehensive evaluation index system of the urbanization level of coal-resource-exhausted cities. The two subsystems have their own criteria layer and index layer.

(1) Index Selection for Comprehensive Evaluation Index System of Industrial Structure

According to a previous description of connotation and relevant theoretical basis of the industrial structure, based on current studies and the actual characteristics of coal-resource-exhausted cities, this study defines the selection of indices of a comprehensive evaluation index system of the industrial structure at three criteria levels of output value, rationality, and employment structure, and based on this, constructed three criteria levels and eight index levels for the comprehensive evaluation index system of the industrial structure of coal-resource-exhausted cities. Table 2 presents the details.

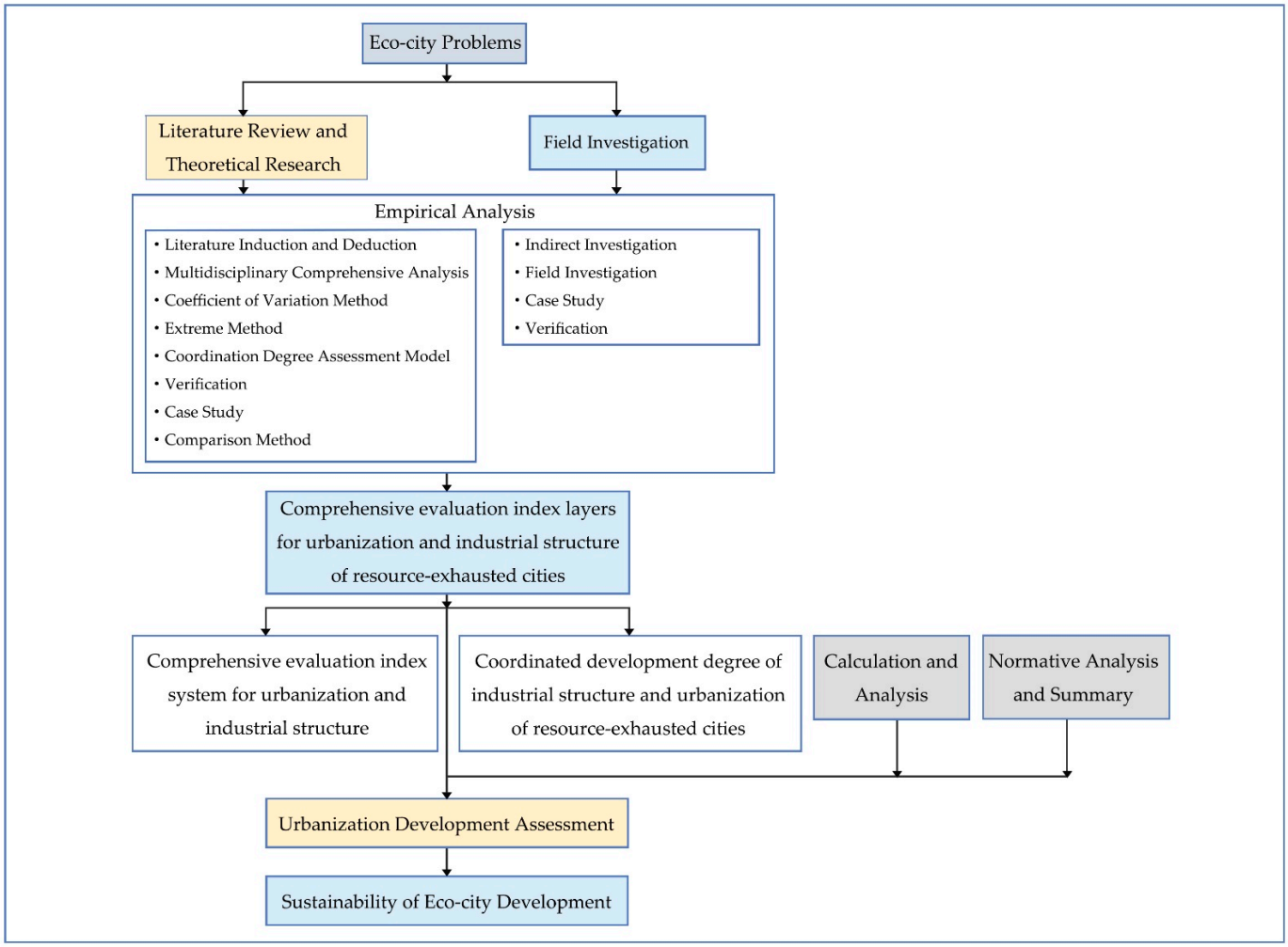

Figure 2. Diagram of the research process. Source: Author self-painting.

Table 2. Comprehensive evaluation index system of the industrial structure of coal-resource-exhausted cities.

Target Subsystem	Rule Layer	Index Layer	Unit	Index Property
Comprehensive evaluation index system of urbanization	Output value	Proportion of first industry in GRP	%	Negative
		Proportion of secondary industry in GRP	%	Positive
		Proportion of tertiary industry in GRP	%	Positive
	Rationalization	Comprehensive utilization rate of industrial solid waste	%	Positive
		Water resources per capita	ton	Positive
	Employment structure	Proportion of employees in first industry	%	Negative
		Proportion of employees in secondary industry	%	Positive
		Proportion of employees in tertiary industry	%	Positive

(2) Index Selection for Comprehensive Evaluation Index System of Urbanization

The evaluation system of urbanization is a very complex system. Based on the existing studies and combined with the actual characteristics of coal-resource-exhausted cities, this study defines the selection range of indicators for the comprehensive evaluation index system of urbanization in the following four scopes: population development level,

economic development level, social and living quality, and resource and environment, and a comprehensive evaluation index system for urbanization of coal-resource-exhausted cities was constructed, which included four standard layers of population development level, economic development level, social and living quality, resource and environment, and a total of 12 index layers. The secondary indices selected in this study, the index layer, have the following characteristics:

First, the consistency between the second-level indices and the first-level indices. The selection of second-level indices needs to be based on the requirements of the first-level indices (the criteria layer), which can reflect the purpose of the first-level indices and is closely related to the content of the first-level indices.

Second, Tthe pertinence of second-level indices to specific cities. Coal-resource-based cities have their unique urban structure and judgment criteria. Therefore, the pertinence of specific city types is a critical factor for selecting the second-level indices, so that the indices can more effectively reflect the actual situation of cities.

Third, the operability of data collection of the index samples. Second-level indices are the most specific index levels in this study and they need to be weighted by objective methods. Therefore, the selection of second-level indices must be supported by corresponding sample data.

Moreover, the proportional treatment of second-level indices. When acquiring sample data, there are often various unit forms, which cannot be directly compared. Therefore, in the preliminary processing of the data, the sample data are scaled to convert into a proportional form to partially eliminate the impact of the data unit and city scale. Hence, due to the above characteristics, the index layer of this study can convey the purpose of the standard layer according to the specific situation of coal-resource-exhausted cities, and provide operable sample data for the objective weighting of indices (Table 3).

Table 3. Comprehensive evaluation index system of urbanization of coal-resource-exhausted cities.

Target Subsystem	Rule Layer	Index Layer	Unit	Index Property
Comprehensive evaluation index system of urbanization	Population development level	Population density	per km^2	Positive
		Natural growth rate of population	‰	Positive
	Economic development level	GRP per capita	CNY	Positive
		Retail sales of consumer goods per capita	CNY	Positive
		GDP growth rate	%	Positive
	Social development & life quality	Books in public libraries per 100 people	volume	Positive
		Number of buses per 10,000 people	vehicle	Positive
		Road area per capita	m^2	Positive
		Number of doctors per 10,000 people	person	Positive
	Resources & environment	Green coverage rate of built-up area	%	Positive
		Harmless treatment rate of domestic garbage	%	Positive
		Centralized processing rate of sewage treatment plant	%	Positive

3.3.2. Determination of Index Weight

The index weighting is a key in the process of constructing the index system. By comparing the expert scoring method, the linear weighted combination method, coefficient of the variation method, principal component method, entropy method, analytic hierarchy process, etc., we believe that the coefficient of variation method was more suitable for this study. The weight of each index in the coefficient of variation method is determined by the degree of variation of each object data. The greater the degree of variation of the index, the greater the impact of the index.

(1) Dimensionless Data Processing

When using the coefficient of variation method, the original data first need to go through dimensionless processing. Through this means, we can effectively ensure the stability of the data. Meanwhile, in the process of calculation, the differences between positive and negative indices need to be calculated to ensure the accuracy. Only the proportion of the first industry in GRP and the proportion of employees in the first industry were negative indices, and the other indices were positive.

Since there are differences in the index units of the selected evaluation indices, the data have a dimension effect and the expressiveness of each data is different, thus, the selected data should be dimensionless. The commonly used dimensionless processing methods mainly include standardization and extremum. However, since the data after standardization can only reflect the impact of various indices, and cannot reflect the differences in the degree of variation among indices, compared with the extremum processing method, it is not suitable for dimensionless processing among multiple variables. Therefore, we selected the extremum method for the dimensionless processing of data. According to Equation (1), it is used for the dimensionless processing of positive indices, and Equation (2) is used for the dimensionless processing of negative indices.

$$X_{ij} = \frac{(x_{ij} - \min x_i)}{(\max x_i - \min x_i)} \tag{1}$$

$$X_{ij} = \frac{(\max x_i - x_{ij})}{(\max x_i - \min x_i)} \tag{2}$$

where X_{ij} represents the dimensionless data j of the index i; x_{ij} represents the original data j of index i; $\min x_i$ represents the minimum value of the index i; $\max x_i$ represents the maximum value of index i.

(2) Determination of Index Weight by Coefficient of Variation Method

The weight of each index in the coefficient of variation method is determined by the degree of variation of each object data. The greater the degree of variation of the indicator, the greater the impact of the indicator. The formula of coefficient of variation method is shown in Equations (3) and (4),

$$W_i = \frac{Vi}{\sum_{i=1}^{n} V\mathrm{i}} \tag{3}$$

$$V_i = \frac{\sigma i}{\overline{Xi}} \tag{4}$$

where i is the index, $i = 1, 2, 3, \ldots, n$; W_i is the weight of the index i; V_i is the coefficient of variation of the index i; σ_i is the standard deviation of the index i; and $\overline{Xi}$ is the average value of all values of the index i.

Tables 4 and 5 show the industrial structures and urbanization index system of coal-resource-exhausted cities after calculation.

Table 4. Comprehensive evaluation index system of industrial structure of coal-resource-exhausted cities after empowerment.

Target Subsystem	Rule Layer	Index Layer	Unit	Index Property (%)
Comprehensive evaluation index system of urbanization	Output value	Proportion of first industry in GRP	%	0.0324
		Proportion of secondary industry in GRP	%	0.0246
		Proportion of tertiary industry in GRP	%	0.0504
	Rationalization	Comprehensive utilization rate of industrial solid waste	%	0.0326
		Water resources per capita	ton	0.0559
	Employment structure	Proportion of employees in first industry	%	0.0108
		Proportion of employees in secondary industry	%	0.0445
		Proportion of employees in tertiary industry	%	0.0362

Table 5. Comprehensive evaluation index system of urbanization of coal-resource-exhausted cities after empowerment.

Target Subsystem	Rule Layer	Index Layer	Unit	Index Property (%)
Comprehensive evaluation index system of urbanization	Population development level	Population density	per km^2	0.0656
		Natural growth rate of population	‰	0.0200
	Economic development level	GRP per capita	CNY	0.0525
		Retail sales of consumer goods per capita	CNY	0.0644
		GDP growth rate	%	0.0196
	Social development & life quality	Books in public libraries per 100 people	volume	0.0679
		Number of buses per 10,000 people	vehicle	0.0449
		Road area per capita	m^2	0.0404
		Number of doctors per 10,000 people	person	0.0482
	Resources & environment	Green coverage rate of built-up area	%	0.2302
		Harmless treatment rate of domestic garbage	%	0.0323
		Centralized processing rate of sewage-treatment plant	%	0.0267

With regard to the choice of index layers from the point of view of its relationship with the scopes, considering that a social indicator, by definition, quantitatively translates an abstract social concept and informs something about a certain aspect of social reality, the quality of social life is an intuitive reflection of the level of urbanization. The improvement in the quality of social life will be reflected in education, medical infrastructure, and other aspects (i.e., "books in public libraries per 100 people" and "number of doctors per 10,000 people", respectively, reflect the importance and investment of urban development in improving the level of public education and medical care. "The number of buses per 10,000 people" reflects the improvement in public transportation in the process of urban development, which are key indicators to measure the level of urbanization.

4. Results

4.1. Calculation and Analysis on Coordinated Development Degree of Industrial Structure and Urbanization

4.1.1. Calculation on Industrial Structure and Urbanization Development Level of Nine Cities

After the specific index weights, the urbanization and industrial structure development level of nine cities were calculated. The specific model calculation Equations (5) and (6) are as follows;

$$Y_1 = \sum_{i=1}^{m} W_i X_i \quad (5)$$

$$Y_2 = \sum_{i=1}^{n} W_i X_i \quad (6)$$

where Y_1 is the index of urbanization development, which has a total of m indices; Y_2 is the index of industrial structure development, which has a total of n indices; W_i is the weight of index i; and X_i is the value of the index i after standardization.

The industrial structure development level and urbanization development level of nine cities in 11 years were calculated by substituting the data into the equation. Tables 6 and 7 show the details.

Table 6. Comprehensive score of the industrial structure of coal-resource-exhausted cities from 2005 to 2015.

Region	City	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Eastern region	Zaozhuang	0.115	0.113	0.116	0.114	0.114	0.116	0.121	0.123	0.122	0.127	0.127
	Liaoyuan	0.131	0.133	0.120	0.150	0.160	0.156	0.160	0.161	0.164	0.156	0.158
	Hegang	0.108	0.137	0.133	0.132	0.128	0.128	0.128	0.120	0.126	0.124	0.117
Middle region	Huaibei	0.153	0.147	0.138	0.136	0.137	0.142	0.137	0.141	0.140	0.144	0.146
	Jiaozuo	0.148	0.148	0.146	0.147	0.159	0.158	0.151	0.137	0.137	0.143	0.149
	Xinyu	0.106	0.116	0.112	0.104	0.117	0.129	0.135	0.136	0.143	0.139	0.141
Western region	Lanzhou	0.172	0.172	0.175	0.164	0.166	0.169	0.180	0.178	0.175	0.179	0.185
	Tongchuan	0.099	0.100	0.099	0.096	0.115	0.112	0.116	0.121	0.124	0.124	0.126
	Shizuishan	0.139	0.155	0.148	0.148	0.131	0.124	0.126	0.136	0.142	0.149	0.145

Table 7. Comprehensive score of urbanization of coal-resource-exhausted cities from 2005 to 2015.

Region	City	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Eastern region	Zaozhuang	0.098	0.120	0.132	0.143	0.150	0.374	0.132	0.156	0.141	0.183	0.198
	Liaoyuan	0.175	0.202	0.199	0.208	0.233	0.337	0.222	0.222	0.225	0.226	0.256
	Hegang	0.075	0.087	0.101	0.105	0.103	0.206	0.135	0.130	0.121	0.133	0.137
Middle region	Huaibei	0.171	0.153	0.174	0.181	0.163	0.325	0.208	0.219	0.217	0.227	0.221
	Jiaozuo	0.187	0.178	0.193	0.180	0.211	0.420	0.236	0.233	0.234	0.243	0.234
	Xinyu	0.072	0.109	0.104	0.147	0.155	0.307	0.199	0.209	0.207	0.215	0.219
Western region	Lanzhou	0.182	0.238	0.252	0.259	0.267	0.523	0.302	0.333	0.251	0.264	0.297
	Tongchuan	0.086	0.086	0.082	0.077	0.085	0.191	0.142	0.152	0.163	0.171	0.174
	Shizuishan	0.086	0.106	0.137	0.167	0.193	0.337	0.183	0.188	0.208	0.247	0.266

From Table 6, we can clearly see that the comprehensive score of the industrial structure of the coal-resource-exhausted cities is growing slowly, and some cities even have a downward trend. Compared with the urbanization process, the industrial structure of the coal-resource-exhausted cities in China is growing too slowly, which also proves that the transformation and upgrading of the regional industrial structure is lagging behind, and the internal power of industrial upgrading is insufficient. This restricts the development of the industrial structure of coal-resource-exhausted cities and economic transformation.

It can be seen from Table 7 that from 2005 to 2015, the urbanization development level of nine major cities showed an overall upward trend. Among them, the urbanization development level of resource-exhausted cities in the western region increased rapidly (i.e., the urbanization score of Shizuishan City in the western region in 2005 was 0.086, and the score had risen to 0.266 in 2015). The urbanization score of Xinyu City in the central region in 2005 was 0.072 and 0.219 in 2015. On the whole, the urbanization rate of the central and western regions was higher than that of the resource-exhausted cities in the eastern region.

4.1.2. Calculation on Coordinated Development Degree of Industrial Structure and Urbanization

There is an interactive relationship between the industrial structure and urbanization. The transformation and upgrading of the industrial structure can promote the urbanization process to a certain extent. Only the urbanization progresses smoothly, the adjustment and upgrading of the urban industrial structure can be more effectively promoted. These two aspects complement each other. Only when the two develop in a coordinated way, the economic development and transformation can be more successful. Therefore, the urban industrial structure and urbanization should not only be coordinated, but also be coordinated at a high level, that is, they need to develop in a coordinated manner, rather than stagnate in a coordinated manner. The measurement of coordinated development includes two aspects: the degree of coordination and development. The degree of coordination reflects the coordination between the two, while the development degree reflects the development height of the whole system.

First, we calculated the coordination degree of industrial structure and urbanization of nine cities. Maximizing the comprehensive benefits is an important basis for the calculation of coordination degree. This study uses the equations to calculate the coordination degree of nine cities. The specific calculation Equation (7) is as follows:

$$C = \frac{Y_1^2 Y_2^2}{(Y_1 + Y_2)^4} \tag{7}$$

where C is the coordination degree, which is the urbanization development index Y_1 and the industrial structure development index Y_2. The degree of coordination C is a value greater than 0 but less than 1. The closer the value is to 1, the better the degree of coordination. The closer it is to 0, the worse the degree of coordination. Table 8 shows the values of the coordination degree, Table 9 shows the criteria and type of coordination development degree separately.

Table 8. Value of the coordination degree.

Region	City	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Eastern region	Zaozhuang	0.987	0.998	0.992	0.975	0.963	0.522	0.996	0.972	0.990	0.936	0.907
	Liaoyuan	0.959	0.917	0.881	0.948	0.932	0.749	0.948	0.950	0.951	0.934	0.891
	Hegang	0.936	0.903	0.963	0.974	0.977	0.894	0.999	0.997	0.999	0.998	0.988
Middle region	Huaibei	0.994	0.999	0.974	0.960	0.985	0.716	0.917	0.908	0.909	0.902	0.918
	Jiaozuo	0.973	0.983	0.962	0.980	0.961	0.631	0.906	0.870	0.868	0.870	0.904
	Xinyu	0.928	0.998	0.997	0.942	0.961	0.694	0.928	0.912	0.934	0.910	0.908
Western region	Lanzhou	0.998	0.949	0.936	0.902	0.894	0.545	0.876	0.824	0.937	0.928	0.895
	Tongchuan	0.990	0.989	0.982	0.976	0.956	0.869	0.980	0.974	0.963	0.950	0.949
	Shizuishan	0.892	0.931	0.997	0.993	0.928	0.619	0.933	0.949	0.930	0.881	0.834

Table 9. Discrimination interval and the type of coordination development degree.

Discrimination Interval	**0–0.100**	**0.101–0.200**	**0.201–0.300**	**0.301–0.400**	**0.401–0.500**
Dysregulation type	Extreme disorder	Severe disorder	Severe disorder	Low disorder	Near disorder
Discrimination interval	0.501–0.600	0.601–0.700	0.701–0.800	0.801–0.900	0.901–1
Coordination type	Reluctantly coordination	Primary coordination	Coordination	Good coordination	High quality coordination

On the basis of calculating the coordination degree, as above-mentioned, the coordination degree is only a part of the coordination development. Therefore, this study will calculate the coordination development degree in combination with the comprehensive development degree. Equations (8) and (9) are for the specific calculation process:

$$Ti = \alpha Y_1 i + \beta Y_2 i \tag{8}$$

$$D = \sqrt{CT} \tag{9}$$

where D is the degree of coordinated development; C is the degree of coordination; T is the degree of comprehensive development; α and β are the coefficients of industrialization and urbanization of coal-resource-exhausted cities. We consider that the two are equally important, $\alpha = \beta = 0.5$, thus, the annual coordinated development degree of each city can be calculated, which is greater than 0 but less than 1, where 0 is completely uncoordinated, and 1 is fully coordinated.

According to Equations (7)–(9), we calculated the indices of industrialization and urbanization coordinated development of nine coal-resource-exhausted cities from 2005 to 2015. Table 10 presents the calculation results.

By comparing the numerical tables of the coordination degree (Table 8) and coordination development degree (Table 10), we found a very interesting phenomenon, that is, the industrial structure and urbanization of nine resource-exhausted cities were very well-coordinated, but the coordinated development of these cities was lower, and they were basically in a state of imbalance.

Table 10. Value of the coordination development degree.

Region	City	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Eastern region	Zaozhuang	0.324	0.341	0.351	0.354	0.357	0.358	0.355	0.368	0.361	0.381	0.384
	Liaoyuan	0.383	0.392	0.375	0.412	0.428	0.430	0.426	0.427	0.430	0.422	0.429
	Hegang	0.293	0.318	0.336	0.340	0.336	0.386	0.362	0.353	0.351	0.358	0.354
Middle region	Huaibei	0.401	0.387	0.390	0.390	0.384	0.409	0.398	0.404	0.403	0.409	0.410
	Jiaozuo	0.404	0.400	0.404	0.400	0.422	0.427	0.419	0.401	0.401	0.410	0.416
	Xinyu	0.287	0.335	0.328	0.344	0.362	0.389	0.394	0.397	0.404	0.401	0.404
Western region	Lanzhou	0.420	0.441	0.447	0.437	0.440	0.434	0.459	0.459	0.447	0.453	0.464
	Tongchuan	0.303	0.303	0.298	0.291	0.309	0.363	0.356	0.365	0.372	0.374	0.377
	Shizuishan	0.317	0.349	0.377	0.395	0.388	0.378	0.380	0.392	0.403	0.418	0.414

5. Discussion

By comparing the numerical tables of coordination degree and the coordinated development degree, the analysis results and findings can be drawn as follows:

First, according to Tables 6 and 7, it was found that the comprehensive score of the industrial structure of coal-resource-exhausted cities is growing slowly, and some cities even show a downward trend. Compared with the urbanization process, the industrial structure of coal-resource-exhausted cities in China is growing slowly; furthermore, in terms of the growth rate of urbanization development, the urbanization growth rate of the middle and western regions is significantly higher than that of the resource-exhausted cities in the eastern region. These two findings indicate that the transformation and upgrading of the current regional industrial structure is lagging behind, and the internal power of industrial upgrading is insufficient, which restricts the industrial structure development of coal-resource-exhausted cities. Meanwhile, it can be seen from the data that the national strategy for the great development of the western region has actively driven the urbanization process of the middle and western regions, and provides a powerful boost for the future economic transformation and development.

Second, in Table 8, it can be found that the coordination between the urbanization and industrial structure of nine coal-resource-exhausted cities during 11 years from 2005 to 2015 was close to 1, which indicates that the provinces in the eastern region, middle region, and western region of China have made certain achievements in the optimization and adjustment of the industrial structure for resource-exhausted cities in recent years. While maintaining stable economic development, all cities are actively exploring ways to optimize and upgrade the industrial structure.

Third, from Table 10, it was found that unlike the high coordination between urbanization and industrial structure, the coordinated development index of urbanization and industrial structure was too low. According to the division standard in Table 9, these nine coal-resource-exhausted cities are still in the state of being on the verge of imbalance and still have a wide development space. The reason for this situation is that the industrial structure is still very backward, so that it cannot quickly meet the needs of the new economic development situation. Although the data value in the table are low, we cannot ignore that the nine cities have made some progress in coordinated development during the past 11 years, especially Xinyu City, which increased from 0.287 in 2005 to 0.404 in 2015. It is believed that urbanization and industrialization of resource-exhausted cities in China will surely achieve coordinated development at a high level in the future.

In addition, through field investigation and survey on the research objectives, some barriers to eco-city development can be summarized as follows:

(1) Indefinite positioning on the ecological city. The urban construction has ignored the original direction and regional characteristics [45] of what kind of city is the ideal eco-

city, which is particularly important for the correct positioning of urban construction. The concept of urban construction, functional orientation, urban planning, ecological protection, coordinated development, etc. need to be guided by definite concepts and policies.

(2) Unbalanced development of economy and ecological city. The neglect of ecological development has resulted in the economic prosperity at the expense of the natural environment and green land [46]. The proportion of urban hard landscape and soft landscape is seriously uncoordinated, and the ability of environmental self-purification is also declining, which restricts the healthy development of ecological cities.

(3) Incomplete specific index system and evaluation criteria. The construction of an eco-city needs a specific index system and measurement standards to guide the construction direction. The specific index system for eco-city construction is incomplete. Due to the rapid development of ecological cities, whether the existing index system meets the needs of construction is also a puzzling problem.

(4) Weak awareness of eco-city construction. People are involved in the weak consciousness of the sustainable development of eco-cities, who should actively participate in building an ecological environment including green communities and the classification standards of domestic waste, etc.

6. Conclusions

6.1. Enlightenment

After the empirical results, through the construction of the urbanization evaluation index system and industrial structure evaluation index system, the coordinated development degree of the industrial structure and urbanization of nine coal-resource-exhausted cities in the east region, middle region, and west region was analyzed. Several conclusions on coordinated development degree of industrial structure and urbanization of coal-resource-exhausted cities can be drawn.

First, from the perspective of current development situation, the coordinated development degree of urban industrial structure and urbanization process of coal-resource-exhausted cities in the east, middle, and west regions of China was lower, which is caused by unreasonable industrial structures. Hence, promoting the optimization and upgrading of industrial structure can greatly promote the urbanization process and the economic transformation of resource-exhausted cities.

Second, from the perspective of dynamic trends, the coordinated development degree of coal-resource-exhausted cities has improved during 11 years from 2005 to 2015, and it is in an increasing trend, which indicates that a series of national policies to promote the economic transformation of resource-based cities have achieved a certain achievement in recent years.

Third, from the perspective of development diversity, the upgrading speed of industrial structures of coal-resource-exhausted cities lags behind the urbanization development process. Thus, promoting the coordinated development of urbanization and industrial structure is an important means to promote economic transformation and development. It needs to take the industrial structure transformation and upgrading as the driving force and the urbanization process as the means to promote the coordinated development [47], finally accelerating the economic transformation and upgrading of coal-resource-exhausted cities.

6.2. Policy Recommendations

First, scientific planning of an eco-city is required by coordinating the industrial planning and urban development planning and fully considering the opportunities and challenges [48]. The government needs to formulate and implement eco-city construction policies and concept, strengthen the ecological environment protection awareness, provide adequate financial support, innovate the urban three-dimensional greening system landscape to strengthen the ecological function, and scientifically plan the eco-city construction.

The urbanization development speed of resource-exhausted cities is far higher than the speed of industrial transformation development. In this way, there will be extreme imbalance, and the industrial structure will become a shackle to urban development. Hence, striving to overcome the excessive dependence of resource-based cities on resources, actively exploring new ways of industrial transformation [49], making use of the advantages of resources, vigorously developing the tertiary industry [50], and revitalizing the economy [51] are necessary for urban development. Moreover, by attaching importance to the development of pillar industries, resource-exhausted cities should take the development of pillar industries as an important link in changing the mode of urban development and promoting the ecological development of cities.

Second, we need to improve the evaluation index system of an eco-city. The construction goal of an eco-city has a strong sense of diversification including the comprehensive combination of social, economic, demographic, environmental, and other factors [52]. Therefore, it is necessary to break down the overall goal into sub-goals according to the specific stages, improve the evaluation index system of eco-city construction, and thus evaluate the speed and change trend of urban ecology, ecological capacity, and coordination. In addition, the construction and improvement of the evaluation index system of eco-city construction need specific indicators and weights that are consistent with the characteristics of different regions. For indicators that cannot be determined by using the discrimination information to implement the weights, the expert analysis method can be used to scientifically determine the weights to strengthen the rationality and scientificity of the comprehensive evaluation results of ecological cities and provide reliable and scientific reference for the construction of eco-cities.

Third, we need to develop green transformation and ecological environment protection. The resource-based cities inevitably have serious problems left over by the ecological environment. By promoting the coordinated development of industry and ecological environment, an industry–city–ecology mode of sustainable development can be continued. In order to accelerate the ecological development of cities, we should pay attention to strengthen the environmental protection and give full play to the role of the government in the process of urbanization [53,54]. While ensuring stable and rapid economic development, we should also realize the sustainability of ecological development and urbanization [55].

An eco-city is a historical product of human social development, and is closely correlated with global energy crisis, ecological environment pollution, and urban ecological problems, etc. An eco-city is regarded as a blueprint to achieve sustainable development [56]. Compactness, low-carbon, economy, and harmony should be the basic goals of the development of eco-cities [57]. In the future, more efficient management on planning eco-cities, further expansion of the pilots of ecological new towns, innovation on the construction of the eco-city system, and mechanism should be implemented so that a good environment suitable for the development of an eco-city can be created.

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