Eco Cities (2022) Volume 3 Issue 2, *10 pages*.
doi: 10.54517/ec.v3i2.1842

Asia Pacific
Academy of Science Pte. Ltd.

REVIEW ARTICLE

Research progress of ecocity evaluation

Xuefeng Yang*, Yi Zhou

Zhejiang University of Finance & Economic, Hangzhou 310018, Zhejiang, China. E-mail: future1698@126.com

ABSTRACT

Building an ecological city is the main way to implement the "five in one" overall layout and important content to promote the construction of ecological civilization. The establishment of an ecocity evaluation system is particularly necessary for the construction of ecocity. This paper comprehensively combs the research literature on ecocity evaluation, analyzes the relevant literature from three aspects: evaluation method, evaluation dimension, and evaluation index system, and puts forward suggestions on the existing ecocity evaluation methods.

Keywords: ecocity; evaluation index system; comprehensive evaluation method

1. Introduction

In ancient China, *Guanzi* put forward the idea of building a city that integrates heaven and man, conforms to nature, and embodies the urban idea of harmonious coexistence between man and nature. Since the concept of "ecocity" was first put forward by UNESCO in the 1970s, China has also actively participated in research on ecocities from different aspects. In 1984, the famous Chinese ecologist Ma proposed to establish a social economic ecological composite ecosystem[1]. This idea was adopted and further expanded by many scholars, which played a great role in promoting the research and development of ecological cities in China.

In addition, ecocities are also receiving increasing attention from countries and governments. In his speech at the 13th National People's Congress, Xi Jinping pointed out that we should take greater efforts and more concrete measures to promote the construction of ecological civilization, accelerate the formation of green production methods and lifestyles, focus on solving outstanding environmental problems, and make our country bluer. The mountains are greener, the water is clearer, and the environment is more beautiful, so the idea that green water and green mountains are invaluable assets is more fully demonstrated in the land of the motherland. The report of the 19th National Congress emphasized that the main social contradiction in the new era has been transformed into The contradiction between the people's need for a better life and the unbalanced and inadequate development fully shows that the people's pursuit of an ecological environment and life has become the main goal of ecological city construction. The "Thirteenth Five-Year Plan" outline is also clear. It is proposed to promote green buildings, popularize green transportation, promote distributed energy, shallow geothermal, and other new energy supply systems, accelerate the promotion of public green space and forest areas, and build several demonstration green

ARTICLE INFO
Received: June 10, 2022 | Accepted: July 15, 2022 | Available online: August 1, 2022

CITATION
Yang X, Zhou Y. Research progress of eco city evaluation. Eco Cities 2022; 3(2): 10 pages.

cities, ecological garden cities, and forest cities. With the development of a series of green and low-carbon actions, many cities have begun to incorporate the construction of ecological cities into urban planning, and are gradually implementing them. Based on the durability of urban management and the necessity of the government's response, how to evaluate the ecological construction of the city and establish a standard evaluation system has become the primary problem that the ecological city urgently needs to face. Therefore, it is very important to construct a scientific and reasonable ecocity evaluation index for the construction of ecocity.

This paper comprehensively analyzes the research of scholars on ecocity evaluation index systems in recent years, combs the academic research literature on ecocity evaluation from three aspects: evaluation method, evaluation dimension, and evaluation index system, compares and analyzes the evaluation method, evaluation content, and evaluation index, and puts forward some suggestions to improve the index system. It is hoped to provide a scientific basis for urban builders and managers to create an ecological city.

2. Evaluation method of ecocity

There are many studies on ecocity evaluation methods in the existing literature, such as the expert scoring method (Delphi), the analytic hierarchy process (AHP), the principal component analysis method, the factor decomposition method, etc. The research method of the ecocity evaluation system is mainly reflected in two stages: index selection and index weight calculation. Through literature review, we can divide the index selection methods into model analysis method and non-model analysis method. The calculation of index weight can be divided into subjective assignment method and objective assignment method. As shown in **Figure 1**, different evaluation methods can be selected at different stages of establishing the index system.

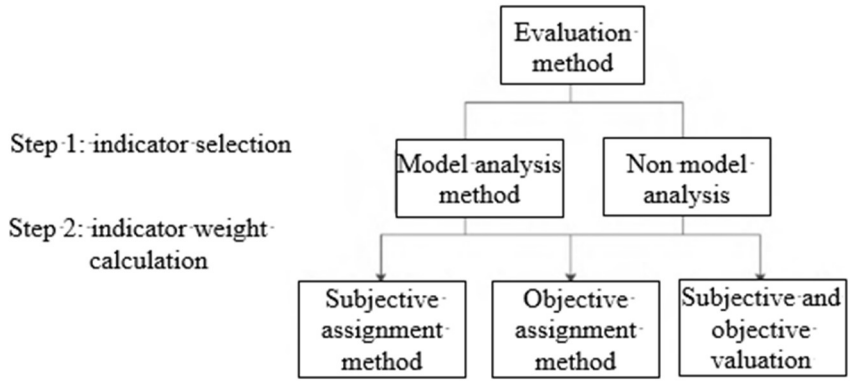

Figure 1. Schematic diagram of selection of ecological city evaluation method.

2.1. Index selection method

Model analysis

The model analysis method uses the existing theoretical framework model to reflect the attributes and characteristics of ecocity evaluation indicators. For example, Gao studied the construction of Zhengzhou ecological city based on the PSR (pressure state response) model[2]. Shao and Ju[3], Zhu *et al*.[4] established the basic framework of a low-carbon city index system according to the DPSIR model. The DPSIR model is a conceptual model of an environmental assessment index system widely used in environmental systems. It reflects the environmental assessment content through five aspects: driving forces, pressure, state, impact, and responses. Yi *et al*.[5] proposed an extended model of DPIGA, "Driving-Pressure-Impact-Govern-Achievement", based on the DPSIR model, to establish a suitable China eco-city index system at the current stage of development. Both the DPIGA model and the DPIGA

model reveal the impact of the ecological environment on human health and the social economy. In comparison, the DPIGA model focuses more on the embodiment of government functions and the final effect of the city and is more suitable for the construction of comprehensive evaluation indicators for ecological cities. The model analysis method is based on systematic knowledge subject background and mature empirical experience, and is highly persuasive.

Non model analysis

The non model analysis method refers to a method that does not directly use the model framework to construct the index system when selecting the index. The common non model analysis method is mainly the expert scoring method, and some scholars establish the ecocity index system according to the ecocity theory system proposed by authoritative researchers at home and abroad or the relevant index system issued by research institutions. Generally speaking, non-model analysis is still very common in the research and application of scholars. For example, Chinese ecologist Ma first put forward the theory of "social economic natural composite ecosystem," and in 1987, Soviet ecologist Yanitsky believed that ecocity is an ideal city model, emphasizing the full integration of technology and nature, giving full play to human creativity and productivity, and realizing the ideal model of efficient recycling of material, energy, and information. Huang *et al*.[6] established an urban green evaluation index system including urban construction, environmental friendliness, and economic development based on these two theories and the specific actual situation of Guangzhou. Zhang and Luo[7] synthesized the evaluation index system of ecocity construction at home and abroad and the evaluation index system of Wuhan according to the actual statistical data of Wuhan. Another example is Zhu *et al*.[8], who take the low-carbon ecocity index database as the basic index to build a dynamic index system from different dimensions. The non-model analysis method has high flexibility and can freely adjust the index system accordingly in order to be better applicable to the construction of local ecological cities, but it also has a certain degree of human subjectivity.

2.2. Calculation method of index weight

Subjective assignment method

The subjective assignment method refers to a method in which the evaluation value is scored by experts within a specific weight. The evaluation index system of the subjective assignment method is usually set by analytic hierarchy process, expert scoring method, fuzzy comprehensive evaluation method, and other methods, but the weighted average data processing method is usually used to calculate the relationship between evaluation items. There are four most common weighted average data processing methods. Additive synthesis method (arithmetic average method), multiplicative synthesis method (geometric average method), additive multiplication hybrid method, and substitution method. For example, Lian[9] used the expert scoring method to determine the weight of indicators at all levels, dimensionless processed these indicators, and then evaluated the low-carbon development level of the city. Another example: Wen *et al*.[10] asked for the scores of experts, and then used the analytic hierarchy process to determine the weight of each factor. Ning and He[11] first consulted with experts to get the weight and then calculated the birth state level through the weighting method. The subjective assignment method has simple operation steps, easy interpretation of conclusions, and convenient calculation, but it will inevitably be mixed with too many human factors.

Objective assignment method

The traditional evaluation method usually selects the expert scoring method to screen the indicators, but many scholars prefer to use numerical calculations to determine the index weight. Using the method of data analysis can avoid human subjectivity in screening indicators and provide a more objective and reasonable method for establishing the evaluation index system. For example, Wu *et al*.[12], Liu and Jiang[13], Tan[14], and Fu and He[15] respectively use the full arrangement polygon

graphic method, threshold theory, factor analysis method, and grey correlation method to screen the evaluation indicators of ecocity from the aspects of ecology, economy, and society. Among them, the comprehensive evaluation of the index system by the fully arranged polygon graphic index method is simple and easy, the evaluation results are concise and intuitive, and the reflection content is systematic and comprehensive. Both the factor analysis method and the gray correlation method use the correlation degree between quantitative factors to measure the relationship between indicators. Compared with the factor analysis method, the gray correlation method requires less data capacity, stronger operability, and practical application, and it is clearer by describing whether the geometric similarity between sequence curves is close. Although the data obtained by quantitative analysis is objective and independent, it lacks a systematic theoretical basis and is not enough to be fully convincing.

Subjective and objective weighting analysis method

In contrast, the disadvantage of the subjective weighting method is that it relies too much on the opinions of experts. The disadvantage of the objective weighting method is that it relies too much on the nature of data and statistical mathematical quantitative methods, and ignores the practical significance of evaluation indicators. Therefore, the more scientific and effective way is to combine subjectivity and objectivity. The subjective and objective weighting analysis method provides a comprehensive method that can balance the subjective valuation method and the objective valuation method. It is also a method generally adopted by most scholars. For example, Hua and Ren[16] combed the existing research at home and abroad to obtain a quantifiable low-carbon city evaluation index, and then made a comprehensive evaluation of the regional low-carbon development level based on ANP (network analytic hierarchy process). Cheng and Feng [17] selected AHP (analytic hierarchy process) to calculate and evaluate the low-carbon development level of Zhejiang Province. Li *et al*.[18] used the fuzzy comprehensive evaluation method combining AHP and entropy weight method to determine the weight of the low-carbon development evaluation index. Zhong *et al*.[19] used the pressure state response (PSR) model to set the basic evaluation index of low-carbon cities, and then carried out relevant evaluations on the construction of low-carbon ecological cities through the index comparison method, AHP, and multi-dimensional space vector method. Wang *et al*.[20] believe that the weight determination in the domestic evaluation system is mostly determined by the scoring of experts, which is highly subjective. Therefore, he introduced information entropy to objectively describe the advantages and disadvantages of each evaluation index and combined it with TOPSIS to comprehensively investigate the gap between the evaluation index and the ideal solution to evaluate the construction level of low-carbon cities. Zhao and Hao[21] proposed that most of the research on evaluation methods is one-dimensional linear combination models, which lack the geometric attribute of multi-dimensional space in ecological cities, so it is difficult to comprehensively evaluate the development level of ecological cities in general. They comprehensively considered the main factors affecting the low-carbon ecological city, constructed the three-dimensional spatial structure model and three-dimensional target evaluation index system, and proposed a new comprehensive evaluation method based on the idea of analytic hierarchy process and spatial vector product to build the ecological city evaluation system[21]. The analysis method of subjective and objective assignment methods is relatively comprehensive. It can combine the advantages of the subjective assignment method and objective assignment method to evaluate the indicators, which can make the indicators more professional and scientific.

3. Evaluation dimension of ecocity

The existing research on the evaluation dimension mainly starts with the key factors constituting the ecological city. Through the interpretation of the literature, we find that most scholars generally agree that the key factors constituting an ecological

city include the economy, nature, society, and so on. We refer to the social-economic natural complex ecosystem diagram of Ma and Wang[1] and modify it accordingly. Take it as the classification basis of our evaluation dimension to further analyze the ideas of different scholars when creating the evaluation index system. Different scholars will come up with different evaluation systems from different functions, levels, and perspectives of these factors. Here we show several examples of constructing an index system from different dimensions.

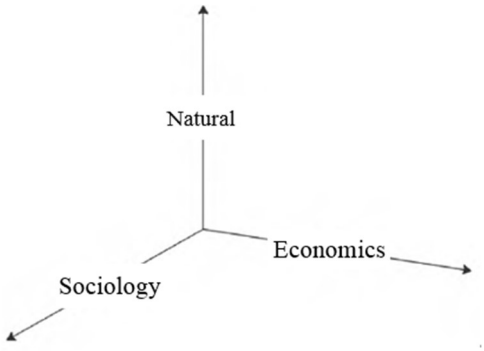

Figure 2. Schematic diagram of complex ecosystem.

(1) Take the economy as the main evaluation basis. For example, Wu *et al*.[12], Cheng and Feng[17] observed the indicators at the level of urban development. Wu *et al*.[12] divide them into development status, development dynamics, and development strength to design the evaluation system. Cheng and Feng[17] believe that urban low-carbon development pursues the coordinated development of the economy, society, and environment, which is a sustainable economic development model. Therefore, he proposed four comprehensive indicators that affect the evaluation of ecocity: economic development, social development, ecological environment, and low-carbon development.

(2) Taking society as the main evaluation basis, it can be analyzed at the level of urban function. For example, Wang *et al*.[22] classified the evaluation index system into five levels: production function, service function, settlement function, health and safety, management, and impact. Some scholars also analyze it from the perspective of environmental treatment technology such as Tan[14]. According to different urban environmental treatment technologies, observe the generation of urban carbon emissions, and get the results to measure the evaluation standard of low-carbon cities. In addition, from the perspective of people's lives and production experience, for example, Song *et al*.[23], Zhao and Hao[21] build three-dimensional goals of population index, ecological environment index, economic index, social index, ecological index, low-carbon index, and happiness index, respectively, from the perspective of human life and according to their natural, economic, and social subsystems, so as to pay attention to the impact of people's happiness in daily life on urban evaluation.

(3) Taking the ecological environment as the main evaluation basis, most scholars evaluate the ecocity indicators from the perspectives of low-carbon life, environmental friendliness, and resources. For example, Xin[24] set up economic low-carbon indicators, basic social low-carbon indicators, lifestyle low-carbon indicators, low-carbon technology development indicators, low-carbon policy improvement indicators, and excellent ecological environment indicators to carefully consider the urban low-carbon system. Gao *et al*.[2] observed the degree of urban environment-friendly and coordinated development based on the PSR model. Due to the large number of documents on the evaluation indicators of low-carbon cities when searching for documents, this may also lead to a large proportion of articles focusing on the ecological dimension when combing the evaluation index dimension.

In short, the establishment of the evaluation

system and the selection of dimensions are often subjective, with different emphases, and the evaluation system will be different. Scholars should not only consider the overall development of nature, economy, and society but also have a focus on development and highlight one link of development. It depends on which direction different scholars prefer to interpret the definition of ecocity. Because each city has its own unique ecological environment and policy conditions, these factors have different effects on the construction of low-carbon cities. For the evaluation of a single city, we still need to adjust measures to local conditions and select the evaluation dimension most suitable for the city. However, for the evaluation of multiple cities, there is still a lack of a unified standard.

4. Evaluation index system of ecocity

4.1. Establishment principle of evaluation indicators

The selection of indicators is the key to ecocity evaluation, and the establishment principle of the evaluation index system is the basis and standard for selecting evaluation indicators.

Although scholars have expressed different opinions on this, several principles are generally recognized by everyone. For example, Shao and Ju[3], and Zhu *et al*.[25], Tan[14], Cheng and Feng[17] all believed that the principles for establishing evaluation indicators should include: scientific principle, feasibility principle, and systematic principle. This requires that when building the evaluation index system, we should not only reflect the basic requirements of ecocity but also pay attention to practical operation, establish a simple and easy evaluation index system, and maintain the objectivity and independence of data.

4.2. Ecocity evaluation index system at home and abroad

Since the concept of eco-city was put forward, many relevant index systems have been established at home and abroad. The international research on ecocity has lasted for a long time and achieved a lot. This paper sorts out the index systems related to several influential low-carbon cities formulated by international institutions (see **Table 1**).

Table 1. Relevant index system of foreign institutions

Name	Mechanism	Set time	Frame	Number of end level indicators
Urban indicators	UN Habitat	1993	Housing, social development and poverty eradication, environmental management, energy management	42
Global urban indicators	Urban indicators fund	2007	Urban life and treatment	74
European green city index	Economist Intelligence Unit and Siemens	2009	Carbon dioxide emission, energy, construction, transportation, water, waste and land use, air quality and environmental governance	30
Asian green city index	Economist Intelligence Unit and Siemens	2011	Energy and carbon dioxide, energy utilization and construction, transportation, waste, water, sanitation, air quality and environmental governance	29

These indicator systems cover a wide range of regions and include many contents. In terms of several ecological-related index systems formulated by international institutions, it is difficult to find a recognized standard because they involve different situations in different countries. Therefore, there must be some limitations in studying the ecological development of cities in China.

In recent years, domestic governments and institutions have also released many evaluation index systems related to eco cities, covering a variety of urban development systems such as sustainable development cities, low-carbon cities, and green cities, which has played a great role in promoting the research of eco cities in China (see **Table 2**).

From the selected index systems, there is still

room for the development of these index systems for ecocity construction. From the geographical location of our country alone, China has a vast territory, complex landform, unbalanced economic development between coastal and inland areas, and

Table 2. Relevant index system of domestic government and institutional research

Name	Mechanism	Set time	Frame	Number of end level indicators
National ecological garden city standard	Ministry of Housing and Urban Rural Development	2004	Urban ecological environment indicators, urban living environment indicators, urban basic social indicators	19
Construction indicators of ecological county, ecological city and ecological province	Ministry of Environmental Protection	2007	Economic development, ecological and environmental protection, social progress	19
China green development index	National Bureau of Statistics	2010	Economic growth, greening, resource and environment carrying capacity and government policy support	57
Comprehensive evaluation index system of urban low carbon development in China	Institute of urban development and environment, Chinese Academy of Social Sciences	2012	Economic transformation, social transformation, low-carbon facilities, low-carbon resources and low-carbon environment	10
Elite cities low carbon ecocity index system	China Energy Research Office, Lawrence Berkeley National Laboratory	2013	Energy/climate, water resources, air, waste, transportation, economic health, land use, social health	33
Construction target system of national ecological civilization leading demonstration zone	National Development and Reform Commission	2013	Quality of economic development, conservation and utilization of resources and energy, ecological construction and environmental protection, ecological culture cultivation, system and mechanism construction	51

there are great differences in the construction of ecological cities under different geographical environments. Chinese scholars' research on ecocity evaluation indicators of cities around China is still in the exploratory stage and has not formed a standardized system.

A recognized index system has not been found at home or abroad.

4.3. Research on the construction of ecocity evaluation index system

Through the research of scholars, we have found that there are great differences between evaluation systems. This is because different evaluation dimensions also establish different evaluation index systems, and the diversity of evaluation methods will also affect the establishment of the final index system. However, according to the research of most scholars, the indicators are generally selected from the key factors of urban construction such as society, economy, and ecology. The indicator system is basically divided into secondary indicators or tertiary indicators.

Secondary indicators include target level, criterion level, and indicator level. Take Tan[14] as an example, taking technical and economic indicators, air environmental protection indicators, and urban construction indicators as primary indicators, under which there are 13 secondary indicators. Its indicators involve the discharge of industrial waste gas and wastewater, the measurement of air quality, urban travel habits, and greening coverage. Fu *et al*.[26] started with the five first-level indicators of low-carbon output indicators, low-carbon resource indicators, low-carbon consumption indicators, low-carbon policy indicators, and low-carbon environmental indicators, and established 14 second-level indicators. In addition to the usual indicators of some industrial waste gas, wastewater, and people's daily carbon emissions, he also added the indicator of carbon productivity and calculated the GDP created per unit of carbon to reflect the utilization of carbon resources. Cheng and Feng[17] constructed four first-level indicators of economic development index, social development index, ecological environment index, and low-carbon development index, as well as 16 second-level indi-

cators under them. Different indicators have different weights. Lian[9] established five first-level indicators of economic development, social progress, resource bearing, environmental protection, and quality of life, each of which includes six second-level indicators.

Compared with the secondary index system, the tertiary index system adds a transition index between the primary index and the tertiary index, that is, the decomposition and interpretation of the primary index and the generalization of the tertiary index. The role of secondary indicators helps to adjust the weight of evaluation indicators and straighten out the logical relationship between primary indicators and tertiary indicators but increases the difficulty of calculation[27]. The three-level indicator structure is target level, criterion level, indicator level, and specific indicators. For example, Hua and Ren[16] divided the explanation into 14 secondary indicators from the primary indicators of low-carbon economic development, low-carbon social development, and low-carbon resources and environment, and then subdivided them into 30 tertiary indicators. Zhao and Hao[21] took the ecological index, low-carbon index, and happiness index as the primary indicators, under which there are three secondary indicators and more than 40 tertiary indicators respectively. Wang *et al*.[28] set up four categories, including resource conservation, environmental friendliness, economic sustainability, and social harmony, nine secondary indicators, and nearly 40 tertiary indicators.

The author lists the sorting tables of some literature index systems, which can be compared directly (see **Table 3** for details). From the table, the number of authors using level 3 indicators is less than that of level 2 indicators, because the more indicators are graded, the more complex the calculation and weight determination of indicators are. Therefore, when selecting indicators, the most basic and effective indicators should be selected first; Secondly, when the number of indicators is large, it can be calculated as a comprehensive indicator by combining several related indicators. Comprehensive indicators indirectly reflect the development level of the urban economy, nature, society, and other aspects. Compared with simple parameter measurement, the value of comprehensive indicators has more connotation and simplifies the calculation between indicators.

5. Conclusions and suggestions

To sum up, scholars' research on ecocity evaluation indexes has effectively promoted the formation of a standard evaluation index system. Firstly, in the evaluation method, although the non model analysis is used flexibly and experts can add or delete different evaluation indicators according to the characteristics of different cities, it has the characteristics of strong subjectivity and an incomplete index system. The method of model analysis is helpful to more comprehensively reflect the characteristics of ecocity and select the index system. Secondly, with the deepening of scholars' research on evaluation methods, the method of combining subjective and objective weighting is gradually favored by more and more scholars, in view of its clearer mathematical logic and more authoritative index system. In addition, the selection of evaluation dimensions is mainly based on scholars' preferences for the definition of eco-city, as well as the differences in ecological and economic development between cities.

The following suggestions are put forward:

(1) The existing ecocity evaluation system often ignores its dynamic development. With the changes of the times, people's demand for ecocity construction has evolved from the sustainable development of protecting the environment and saving resources to the construction of a comprehensive city with beautiful mountains and rivers, suitable for living and ecological balance. Therefore, the setting of indicators can be updated with the continuous change in the urban environment.

(2) In the ecocity evaluation, it is suggested to add some comprehensive indicators. The comprehensive indicators combine the natural, economic,

social, and other ecocity development elements, and reflect the development level of the city in all aspects through one indicator, to make the indicators more meaningful and the evaluation results concise and clear.

Table 3. Partial literature index system

Focus on dimension	Specific direction	Author	Literature	Year	Evaluation dimension	Series	Number of end level indicators
Economics	Production and life	Song[29]	Evaluation of low-carbon development in 28 cities along the Yangtze River	2004	Socio economic development index, production and living carbon emission index, carbon emission reduction and carbon capture	Second level	28
	Urban development	Cheng and Feng[17]	Research on low carbon city evaluation based on ANP	2015	Economic development index, social development index, ecological environment index and low-carbon development index	Second level	16
Sociology	Urban function	Wang *et al*.[22]	Comparison and innovation of ecocity evaluation system	2007	Production function, service function, settlement function, health and safety, management and influence	Second level	15
	Scientific and technological level	Tan[14]	Construction and Empirical Study of low carbon city evaluation index system—Taking the dynamic comparison between Nanjing and Shanghai as an example	2011	Technical and economic indicators, air environmental protection indicators, urban construction indicators	Second level	13
	Human life	Zhao[21]	Low carbon ecological city: Research on three-dimensional objective comprehensive evaluation method	2011	Ecological index, low carbon index, happiness index	Tertiary	34
	Governmental functions	Yi[5]	Screening model and application of ecocity evaluation index	2017	Economy, society, nature and government	Tertiary	41
Ecology	Low carbon	Fu[26]	Concept identification and evaluation index system construction of low carbon economy	2010	Low carbon output index, low carbon resource index, low carbon consumption index, low carbon policy index and low carbon environment index	Second level	14
		Xin[24]	Construction of low carbon city evaluation index system	2011	Economic low-carbon index, basic social low-carbon index, lifestyle low-carbon index, low-carbon technology development index, low-carbon policy improvement index and excellent ecological environment index	Tertiary	42
	Environment friendly	Li and Yu[30]	Study on the construction of ecological city evaluation index system in China	2011	Resource saving, environment-friendly, sustainable economy and social	Tertiary	45
		Gao[2]	Evaluation of Zhengzhou ecocity construction based on P-S-R model	2013	Pressure index, status index and system response	Tertiary	36

(3) When building ecocity evaluation indicators, we should combine our own urban characteristics, or classify cities with similar geographical, economic and environmental conditions, and set up a set of evaluation index systems tailored for ourselves. In order to pursue the name of ecocity, we should not test other evaluation standards that are not suitable for our own city at will.

Conflict of interest

The authors declare no conflict of interest.

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