sustainability

MDPI

Article

Data-Driven Analysis and Evaluation of Regional Resources and the Environmental Carrying Capacity

Aiyong Lin [1,2], Yujia Liu [1,*], Shuling Zhou [1], Yajie Zhang [1,3], Cui Wang [1,4] and Heping Ding [1]

[1] Business School, Suzhou University, Suzhou 234000, China; linay05@ahszu.edu.cn (A.L.); zsl@ahszu.edu.cn (S.Z.); zhangyj@ahszu.edu.cn (Y.Z.); wangcui@ahszu.edu.cn (C.W.); dingheping@ahszu.edu.cn (H.D.)
[2] School of Mathematics and Statistics, Lanzhou University, Lanzhou 730000, China
[3] School of Economics and Management, Dalian University of Technology, Dalian 116024, China
[4] Center for International Education, Philippine Christian University, Manila 1004, Philippines
[*] Correspondence: lyj@ahszu.edu.cn; Tel.: +86-155-5570-0092; Fax: +86-0557-2871003

Abstract: The resources and environmental carrying capacity (RECC) of a region are considered the key and the foundation for achieving sustainable development and the benchmark of environmental protection and pollution control. However, to improve the regional RECC, we need to comprehensively consider the data information and correlation of the economy, society, resources, and the environment. Therefore, we propose a data-driven method for RECC measurement and evaluation of the regional RECC. Based on data collection and the application of the pressure-state-response (PSR) framework to reflect RECC, an evaluation index system for the regional RECC is constructed. The technique for order of preference by similarity to the ideal solution (TOPSIS) model with the entropy weight method is used to measure and evaluate the regional RECC. The obstacle degree model is adopted to select and identify the key factors affecting the regional RECC and to propose targeted policy suggestions for data application. The results indicate that the RECC level in three provinces and one city of the Yangtze River Delta region fluctuated slightly from 2010 to 2019, with an overall upward trend. Anhui Province has a relatively weak carrying capacity, and the main obstacles to RECC improvement in the region are the proportion of wetland area and the ownership of water resources. This study provides theoretical and methodological support for regional RECC research and management as well as a basis for formulating policies related to environmental protection and pollution control.

Keywords: data-driven; sustainability; resources and environmental carrying capacity; environmental pollution; entropy weight method; obstacle degree model

check for updates

Citation: Lin, A.; Liu, Y.; Zhou, S.; Zhang, Y.; Wang, C.; Ding, H. Data-Driven Analysis and Evaluation of Regional Resources and the Environmental Carrying Capacity. *Sustainability* **2023**, *15*, 8372. https://doi.org/10.3390/su15108372

Academic Editor: Grigorios L. Kyriakopoulos

Received: 4 April 2023
Revised: 15 May 2023
Accepted: 18 May 2023
Published: 22 May 2023

1. Introduction

With the sustained and rapid development of the global economy and society, the process of industrialization and urbanization is accelerating, and the ecological environment and resources on which human beings depend are being used without restraint. A series of problems have emerged, such as high pollutant emissions, low efficiency of energy and resource utilization, and the deterioration of the ecological environment [1]. The United Nations Environment Programme posits that the carrying capacity of the ecological environment in many areas seriously exceeds the standard and that the consumption of natural resources far exceeds the Earth's regeneration capacity, which is causing regional tension and affecting the goal of human sustainable development [2]. Therefore, different countries have proposed building land space development standards based on the resources and environmental carrying capacity (RECC) of a region and promoting green development and harmonious coexistence between humans and nature [3]. For example, in the 14th Five-Year Plan, China indicated that it aims to strengthen the construction of an ecological civilization and build a resource-saving and environmentally friendly society with sustainable development as the goal based on RECC and the law of nature. To meet the new challenges faced by the world's regional sustainable development, based on measuring the current RECC situation in different regions [4], it is necessary to accurately and objectively evaluate RECC, identify key constraints, and determine the carrying capacity of regional resources and the environment based on the RECC status of different regions. Doing so is essential for promoting sustainable regional social and economic development. However, to accurately quantify the regional RECC, there are problems such as single evaluation indicators, the lack of dynamic data, and inappropriate evaluation methods. Therefore, adopting a data-driven approach to studying the regional RECC is an important motivation for this paper.

Given their importance, RECC has become a hot issue among scholars. The concept of carrying capacity originated from the field of mechanical engineering [5] and was later extended to apply to the RECC on population [6], socioeconomic, and biological population development [7]. Additionally, it has been used to conduct research on the maximum carrying capacity of single elements such as regional water [8], atmosphere [9], land [10], and noise. Scholars also study the comprehensive RECC from the perspective of a regional "nature, economy, society" composite ecosystem [11]. As humankind enters an ecological civilization society, influenced by global climate change and frequent human activities [12], the focus of scholars' research on carrying capacity has shifted to environmental change and the stability, vulnerability, adaptability, and steady-state transformation of ecosystems [13]. To quantify the evaluation system of RECC, Scholars have comprehensively considered factors such as land [14], water [15], climate [9], and energy [12], such as calculating the number of people who can be supported per hectare of land [16], land utilization rate and potential, and the ECCO model of regional RECC is established [17]. Furthermore, the evaluation index system for RECC has been constructed from the perspectives of resources and environmental factors [18]. However, the RECC is the result of the joint action of the three major systems of resources, environment, and society [19]. Therefore, starting from the structure and function of the "resource- environment-society economy" composite system [20], a universal evaluation system for the carrying capacity of resources and environment has been further constructed. Afterward, the "Pressure State Response" (P-S-R) model emerged, which better explained the causal relationship of sustainable changes in the human nature composite ecosystem [21]. Therefore, some scholars have also constructed an evaluation index system from the P-S-R level [22]. the evaluation methods and influencing factors of RECC are studied [1,23,24]. Scholars have evaluated the RECC, starting from static evaluation methods, such as the agricultural ecological zone (AEZ) method [25], supply—demand balance method [9], and gradually changing to dynamic analysis [11], prediction models [14], and methods based on time series [26], system dynamics [27], and neural networks [28]. However, static analysis lacks systematicity, and the application scope of the dynamic analysis model is uncertain and lacks consistency. The evaluation of RECC is developing towards digitization and integration, such as the multiobjective decision-making method, ecological footprint method [29], energy analysis method [5], material flow analysis method [28], fuzzy comprehensive evaluation method [30], principal component analysis method [31], and analytic hierarchy process [32], to make up for the defects of any single method. Studies on the influencing factors of carrying capacity have analyzed the influencing factors of carrying capacity from the aspects of natural conditions [33], regional development and management systems; examined their causes; used a time series Tobit model to analyze the driving factors of RECC in the Guiyang [34], etc.

Research by scholars in China and elsewhere on the connotation of, the evaluation index system for and evaluation methods for the regional RECC provides a solid foundation for this paper. However, such research can be further expanded in the following ways. (1) Previous studies on carrying capacity have mainly focused on single elements and comprehensive elements. On this basis, we can build a multi-dimensional dataset to more comprehensively and systematically measure RECC in a quantitative manner. (2) It is necessary to build a data-driven measurement and evaluation method for the regional RECC to objectively evaluate the regional RECC and reflect its dynamics and evolutionary trend. (3) Dynamic and appropriate monitoring methods can be used to accurately and quantitatively evaluate the impact of different regions to determine the main driving factors for different regions.

To meet the research challenges above, we propose regional RECC methods based on the research ideas of Feng et al. [1], Peng and Deng [34–36], Wang and Liu [5], Swiader, et al. [6], and Liu et al. [37,38]. This paper uses a data-driven comprehensive evaluation of the level of the regional RECC and identifies the key factors restricting an improvement in carrying capacity. Taking the Yangtze River Delta as an example, this paper studies the changes in its RECC and the key obstacles from 2010 to 2019 to provide suggestions for formulating sustainable development policies for this region. Therefore, the research of this paper holds certain theoretical and practical significance. In terms of theory, first, when constructing the evaluation index for the regional RECC, the three levels of state, pressure, and response are considered, and 16 indices are selected to provide a more perfect evaluation index system. Second, the data-driven method can more objectively and accurately analyze and evaluate the regional RECC. Third, we enrich and improve the theoretical research basis for regional RECC measurement and evaluation, thus providing a practical basis for regional environmental decision-makers. In terms of practice, this study provides a basis for practitioners to build on the new development stage, implement the new development concept, accurately identify the key factors affecting the carrying capacity and dynamically adjust their development ideas. It also provides suggestions for researchers and national policy-makers to improve RECC.

To achieve the research objectives above, this study is organized as follows. The second section, regarding the method, introduces the method and process of data collection, data modeling, data analysis, and data application to reflect the regional RECC. The third section describes the case study. Taking the Yangtze River Delta as an example, this paper evaluates and analyses the regional RECC level of three provinces and one city and identifies the key factors restricting an improvement in carrying capacity. The fourth section is the conclusion.

2. Method

This section comprehensively introduces the methods of measurement, evaluation, and identification, including the method flow, data collection, data processing, data modeling, and data application.

2.1. Method of Flow

To promote the sustainable development of the regional economy and to realize environmental protection and pollution control, it is necessary to construct a measurement framework and an evaluation system for the regional RECC from the perspective of system theory and to carry out systematic and holistic exploration from the perspective of global optimization. Doing so is urgently necessary for accurate regional RECC evaluation. However, RECC involves a complex system. There are regional differences in influencing factors. There are significant differences across datasets and in the selection of evaluation methods for different regions. Accurately evaluating the regional RECC poses a challenge for research.

In order to accurately evaluate the regional RECC, this article first cites two hypotheses:

Assumption 1. *Assuming that the regional resource environment is a closed-loop system, only considering relevant subsystems such as state, pressure, and response, and not considering the interaction between the region and external resources, environment, economy, and society.*

Assumption 2. *Assuming that the regional state, pressure, and response subsystems can be quantified through relevant indicators and a dynamic database can be established.*

To meet this challenge, based on hypotheses, this paper establishes a data-driven, comprehensive evaluation method to measure, evaluate and identify the regional RECC.

Data collection is mainly used to construct the three-level indicators of state, pressure, and response from the perspectives of the economy, society, resources, and the environment. Regarding data processing, applied IBM SPSS Statistics 26 to standardize data, entropy, and the TOPSIS method [39]. normalization is used for dimensionless standardization and processing, and the entropy weight method is used to determine the weight of indicators. Data modeling is used to construct a comprehensive evaluation model of the regional RECC, and an obstacle degree model is adopted to clarify the obstacle factors. Through data analysis based on a comprehensive evaluation and obstacle degree model, the relationship between various influencing factors and the regional RECC is studied, the main factors hindering the carrying capacity are determined, and targeted methods are proposed to improve the regional RECC in practice. From the perspective of system theory and the PSR framework, the regional RECC is measured. Based on the construction of a comprehensive evaluation model and obstacle degree model, the main factors affecting the regional RECC are studied.

The procedure is shown in Figure 1.

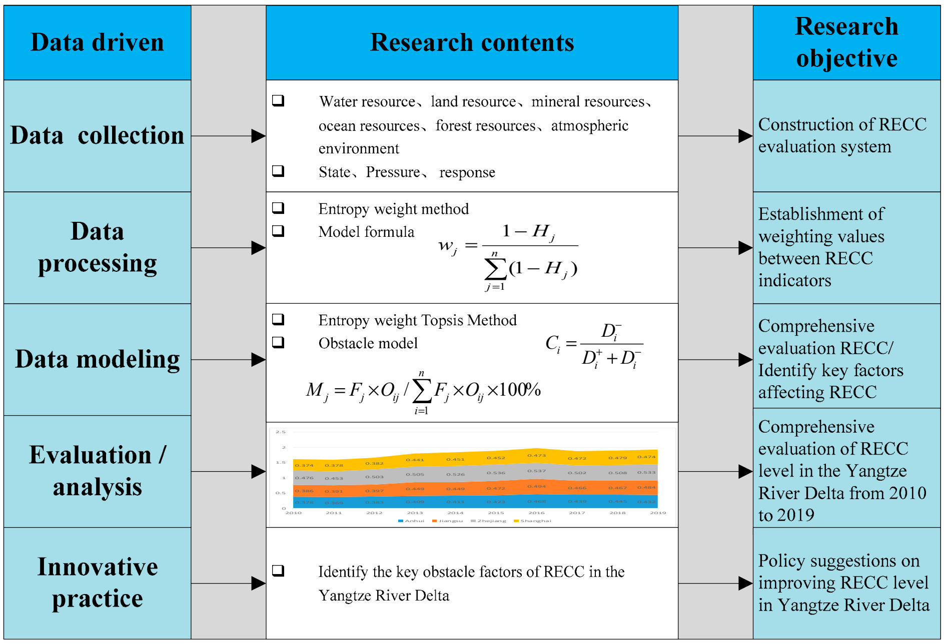

Figure 1. Method flow.

2.2. Data Collection

The essence of RECC is the coupling relationship among the economy, society, resources, and environmental economics [1]. This relationship can be revealed by the PSR model. That is, human activities exert pressure on the ecological environment, leading to changes in the state of the ecological environment. In addition, human society responds to changes in the ecological environment and then restores the quality of the ecological environment. Therefore, the model can be used to evaluate the regional RECC.

Following the principles of scientificity, systematization, operability, and typical representativeness and incorporating the actual situation of the study area, this paper constructs a regional RECC comprehensive evaluation index system based on the PSR model based on four aspects: the economy, society, resources, and the environment. Among them, the pressure layer includes social and economic pressure and resource and environmental pressure. While selecting indicators such as population density for representation, the regional economy reflects the relative level of RECC, and compared with Wang and Liu [5], Added indicator per capita GDP. The state layer includes three aspects: the state of the environmental background, resource endowment conditions, and the state of social and economic development. It is measured by indicators such as per capita cultivated land area.

However, the wetland area in regional resources is relatively significant. Compared with Niu et al. [25], the wetland area proportion index is added. The response layer mainly refers to environmental protection measures. Five indicators, such as investment in industrial pollution control, are selected for characterization. To better reflect the response layer, the index of investment in industrial pollution control is added in compared with Liao et al. [9], the index of investment in industrial pollution control is added. The comprehensive evaluation index system is shown in Table 1.

Table 1. Construction of the regional RECC evaluation index system.

Target Layer	Criterion Layer	Index	Nature	Index Layer	Interpretation
RECC	State	X1	+	Per capita water resources	Total water resources/total population
		X2	+	Per capita park green space area	Park green space area/total population
		X3	+	Per capita road area	Road area/total population
		X4	−	Energy consumption per unit of GDP	Energy consumption/GDP
		X5	+	Proportion of cultivated land area	Total cultivated land area/land area
		X6	+	Proportion of wetland area	Total wetland area/land area
	Pressure	X7	−	Population density	Total population/land area
		X8	+	Per capita GDP	GDP/total population
		X9	−	Waste gas emissions per unit of industrial value added	Exhaust emissions/industrial value added
		X10	−	10,000 yuan industrial value-added wastewater discharge	Wastewater discharge/industrial value added
		X11	−	Output of industrial solid waste	Regional total industrial solid waste
	Response	X12	+	Urban green coverage	Urban green coverage/urban area
		X13	+	Forest coverage	Forest area/land area
		X14	+	Investment in industrial pollution control	Funds for industrial pollution control
		X15	+	Comprehensive utilization rate of industrial solid waste	Effective utilization ratio of industrial solid waste
		X16	+	Sewage treatment rate	Annual sewage treatment capacity/total sewage

2.3. Data Sources and Processing

Data reflecting the state, pressure, and response of the regional RECC in the Yangtze River Delta were collected and sorted. The data used in this study were mainly from the China Statistical Yearbook, China Environmental Statistical Yearbook, Jiangsu Statistical Yearbook, Anhui Statistical Yearbook, Zhejiang Statistical Yearbook, and Shanghai Statistical Yearbook, as well as relevant data published by the Ministry of Ecological and Environmental Protection of China from 2010 to 2019. To better distinguish the importance of each index, the entropy weight method was used to process the original data. The specific steps are as follows:

(1) Construction of a standardized evaluation matrix reflecting the regional RECC

It is assumed that the original evaluation index matrix of the regional RECC is as follows:

$$X = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix} \quad (1)$$

x_{ij} is the specific value of the i-th research object and the j-th index.

Because the indicators for evaluating the regional RECC have different dimensions and are divided into positive indicators and negative indicators, larger values of positive indicators indicate a higher carrying capacity and smaller values of negative indicators also indicate a higher carrying capacity. To make the index data unified and comparable, normalization is used for dimensionless standardization. A positive index is treated based on Formula (2), a negative index is treated based on Formula (3), and the standardized matrix Y (Formula (4)) is obtained as follows:

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

$$y_{ij} = \frac{\max(x_{ij}) - x_{ij}}{\max(x_{ij}) - \min(x_{ij})} \tag{3}$$

$$Y = \begin{bmatrix} y_{11} & y_{12} & \cdots & y_{1n} \\ y_{21} & y_{22} & \cdots & y_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ y_{m1} & y_{m2} & \cdots & y_{mn} \end{bmatrix} \tag{4}$$

$\mathrm{y_{ij}}$ represents the standardized value of the i-th research object and the j-th index, where $i = 1, 2, \cdots, m$ and $j = 1, 2, \cdots, n$.

(2) Determination of the index weights based on the entropy weight method

The entropy weight method can objectively reflect the importance of each index of RECC. The specific method determines the information entropy $\mathrm{H_j}$ (Formula (5)). The greater the value of $\mathrm{H_j}$ is, the higher the information utility value of the index and the greater its weight in the RECC evaluation. Then, the weight of each index $\mathrm{w_j}$ is determined (Formula (6)).

$$H_j = -\frac{1}{\ln m} \sum_{i=1}^{m} f_{ij} \ln f_{ij} \tag{5}$$

$$\mathrm{f_{ij}} = \frac{\mathrm{y_{ij}}}{\sum\limits_{\mathrm{i=1}}^{\mathrm{m}} \mathrm{y_{ij}}}$$

$$w_j = \frac{1 - H_j}{\sum\limits_{j=1}^{n} (1 - H_j)} \tag{6}$$

2.4. Data Model

2.4.1. Entropy Weight TOPSIS Method

Regarding the comprehensive evaluation of the regional RECC, previous studies have mainly focused on principal component analysis [4], the AHP [10], fuzzy comprehensive evaluation [12], the entropy weight method [16], and the entropy weight technique for order of preference by similarity to ideal solution (TOPSIS) method [24]. However, principal component analysis is not very accurate in explaining the regional RECC, and the extracted principal components have a high cumulative contribution rate. In addition, when studying RECC, the general sample size is small and cannot fully reflect the differences between the evaluation objects, and the degree of discrimination is not high. The AHP and fuzzy comprehensive evaluation are greatly affected by subjective factors when determining the weights, and there are many indicators when studying RECC. Therefore, it is difficult to determine the weights using the AHP [40]. Moreover, fuzzy comprehensive evaluation can be too fuzzy, resulting in evaluation failure [41]. The entropy weight method is more objective in determining the weights and can determine the difference between the index positions. However, when evaluating the same region, it cannot reflect the gap between the actual level and the ideal level of RECC [42]. The entropy weight TOPSIS method is used to evaluate the regional RECC, which improves the value formula of the evaluation object and the positive and negative ideal solution and makes the evaluation results more consistent with the real situation, to estimate the mean error of the normalization methods for TOPSIS, also indicated the superiority of this method [43]. The specific calculation steps are as follows:

(1) Construction of the weighted decision matrix

In the evaluation of the regional RECC, to improve the objectivity and reflect the differences in different indicators, the weighted value and entropy weight w_j are used to construct the weighted evaluation matrix, as shown in Formula (7):

$$V = \begin{bmatrix} v_{11} & v_{12} & \cdots & v_{1n} \\ v_{21} & v_{22} & \cdots & v_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ v_{m1} & v_{m2} & \cdots & v_{mn} \end{bmatrix} = \begin{bmatrix} y_{11}\cdot w_1 & y_{12}\cdot w_2 & \cdots & y_{1n}\cdot w_n \\ y_{21}\cdot w_1 & y_{22}\cdot w_2 & \cdots & y_{2n}\cdot w_n \\ \vdots & \vdots & \vdots & \vdots \\ y_{m1}\cdot w_1 & y_{m2}\cdot w_2 & \cdots & y_{mn}\cdot w_n \end{bmatrix} \tag{7}$$

(2) Determination of the positive and negative ideal solutions of the index

Let V^+ represent the maximum value of the j-th index of the i-th object in the weighted evaluation data, that is, the best scheme, as a rational solution. Let V^- represents the minimum value of the j-th index of the i-th object in the weighted evaluation data, that is, the least ideal scheme, as the negative ideal solution. See Formulas (8) and (9) for the specific calculations:

$$\begin{aligned} V^+ &= \left(V_1^+, V_2^+, \cdots, V_\mathrm{n}^+\right) \\ &= (\max\{\mathrm{v}_{11}, \mathrm{v}_{21}, \cdots, \mathrm{v}_{\mathrm{m}1}\}, \max\{\mathrm{v}_{12}, \mathrm{v}_{22}, \cdots, \mathrm{v}_{\mathrm{m}2}\}, \cdots, \max\{\mathrm{v}_{1\mathrm{n}}, \mathrm{v}_{2\mathrm{n}}, \cdots, \mathrm{v}_{\mathrm{mn}}\}) \end{aligned} \tag{8}$$

$$\begin{aligned} V^- &= \left(V_1^-, V_2^-, \cdots, V_\mathrm{n}^-\right) \\ &= (\min\{\mathrm{v}_{11}, \mathrm{v}_{21}, \cdots, \mathrm{v}_{\mathrm{m}1}\}, \min\{\mathrm{v}_{12}, \mathrm{v}_{22}, \cdots, \mathrm{v}_{\mathrm{m}2}\}, \cdots, \min\{\mathrm{v}_{1\mathrm{n}}, \mathrm{v}_{2\mathrm{n}}, \cdots, \mathrm{v}_{\mathrm{mn}}\}) \end{aligned} \tag{9}$$

(3) Calculation of the Euclidean distance from the positive (negative) ideal solution

Let the distances from each evaluation object vector to the positive and negative ideal solutions be ${D_i}^+$ and ${D_i}^-$, respectively. They are obtained as follows:

$$D_i^+ = \sqrt{\sum_{j=1}^{n} \left(V_{ij} - V_j^+\right)^2} \; (i = 1, 2, \cdots, m) \tag{10}$$

$$D_i^- = \sqrt{\sum_{j=1}^{n} \left(V_{ij} - V_j^-\right)^2} \; (i = 1, 2, \cdots, m) \tag{11}$$

(4) Calculation of closeness C_i

$$C_i = \frac{D_i^-}{D_i^+ + D_i^-} \tag{12}$$

Sticking progress indicates the closeness between the RECC of the evaluation object and the positive ideal solution, that is, the optimal scheme. Its value range is [0, 1]. The closer the value of C_i is to 1, the higher the RECC of the research object. In contrast, the closer the value of C_i is to 0, the lower the RECC. Using past progress, we can judge the RECC of each research object and determine the order of advantages and disadvantages.

2.4.2. Obstacle Degree Model

The evaluation of the regional RECC lies not only in evaluating carrying capacity but also in clarifying the obstacle factors restricting the regional RECC to propose relevant policy suggestions and to increase RECC strength [44]. Therefore, it is necessary to further explore the regional RECC. The specific method is to introduce the contributions of factors (F_j) to express the impact of the j-th index on the regional RECC. The index deviation degree (O_{ij}) refers to the gap between each index and the evaluation objectives of the regional environmental carrying capacity. The obstacle degree (M_{ij}), which indicates the negative impact value of a single or classified index on the regional RECC, is analyzed and diagnosed. The specific calculation formula is as follows:

$$F_j = r_i \times w_j \tag{13}$$

r_i is the weight of the i-th subsystem in the RECC comprehensive evaluation model, and W_j is the weight of the j-th indicator.

$$O_{ij} = 1 - x'_{ij} \tag{14}$$

O_{ij} represents the deviation degree of the j-th index in the i-th region and x'_{ij} represents the standardized value of a single index.

$$M_{ij} = F_j \times O_{ij} / \sum_{i=1}^{n} F_j \times O_{ij} \times 100\% \tag{15}$$

n indicates the number of system indicators. A larger value of M_{ij} indicates that a basic indicator poses a greater obstacle to the regional RECC. The primary and secondary relationships of obstacle factors can be determined in order from large to small.

2.5. Data Application

This research is based on the data-driven measurement, evaluation, and identification of the regional RECC. The specific data application is as follows (see Figure 2 for details):

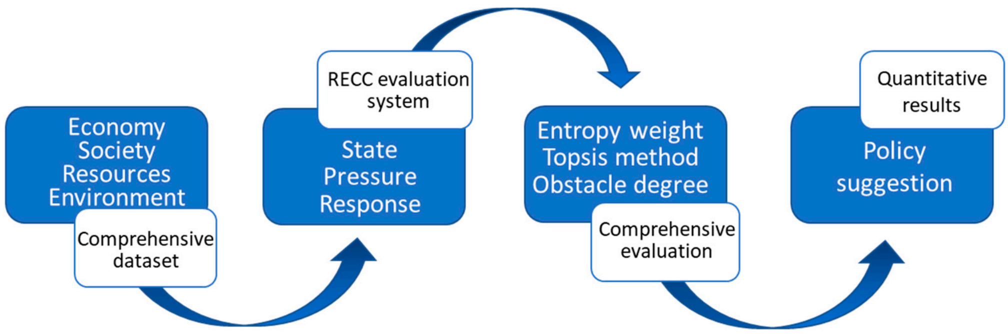

Figure 2. Application diagram of regional RECC data.

The first step is to establish a comprehensive dataset. Based on the coupling relationship among the economy, society, resources, and the environment, a comprehensive database is established.

The second step is to establish the RECC evaluation system. With reference to the results of the relevant literature, an evaluation system reflecting the regional RECC in terms of the PSR framework is established to dynamically reflect and monitor the regional carrying capacity.

The third step is to evaluate the regional RECC and identify key influencing factors. The entropy weight method weights the index layers of the regional RECC based on the influence importance, uses the TOPSIS method to comprehensively quantify and evaluate the regional carrying capacity, obtains quantitative results in a time series format at the regional carrying capacity level, compares the changes in different periods, and differentiates across regions. The obstacle degree model is used to identify the key factors restricting the regional RECC and to provide a methodological reference for accurately grasping the regional carrying capacity based on the quantitative results.

The fourth step is to propose countermeasures for sustainable social and economic development based on the regional RECC measures.

3. Case Study

Using the research methods above, this paper takes the Yangtze River Delta as an example. We focus on the regional RECC of the Yangtze River Delta, accurately and quantitatively evaluate the regional RECC from the PSR perspective, identify the key factors affecting the regional RECC, make policy suggestions to improve the RECC of the Yangtze River Delta, and realize sustainable economic development, and summarize recommendations for managers.

3.1. Background

The Yangtze River Delta region (Anhui Province, Jiangsu Province, Zhejiang Province, and Shanghai City) is the most economically developed region in China. In 2021, the regional GDP reached 27.59 trillion yuan, an increase of 8.4% over the previous year and accounting for 24% of the national GDP. It is the most important growth pole of China's economy. However, for a long period of time, the Yangtze River Delta region has mainly relied on the mode of large-scale investment to drive economic growth. It has high energy consumption, intensive pollutant emissions, and particularly serious volatile organic compound air pollution. According to the announcement of China's environmental situation in 2020, although the proportion of excellent days in the Yangtze River Delta increased in 2020, O_3 and $PM_{2.5}$ were still present. The number of days on which pollutants such as PM_{10} and NO_2 exceeded the standard seriously affected the public's health. Given that the Yangtze River Delta is an urbanized area with the most developed economy and the highest degree of urban agglomeration in China, its regional RECC is representative of researchers seeking to alleviate the contradiction between resource utilization, environmental protection, and economic development in the Yangtze River Delta and to realize sustainable economic development. Additionally, it can provide a reference for other regions.

3.2. Results

3.2.1. Determination of the Weight of Each Index

On the basis of normalizing the original data with Formulas (2) and (4), Formula (6) is used to determine the weight of each index. The specific results are shown in Table 2 below:

Table 2. Summary of the weight calculation results based on the entropy weight method.

index	w_1	w_2	w_3	w_4	w_5	w_6	w_7	w_8	w_9
weight	0.1044	0.0322	0.0685	0.015	0.086	0.1565	0.073	0.0508	0.0457
index	w_{10}	w_{11}	w_{12}	w_{13}	w_{14}	w_{15}	w_{16}		
weight	0.045	0.0358	0.0362	0.1361	0.0692	0.0311	0.0148		

Table 2 shows that among the indicators reflecting the regional RECC of the Yangtze River Delta, due to the large differences in the proportion of wetland area, per capita water resources, population density, and other indicators, their values are large when the entropy weight method is used to determine the weights. However, the performance weights of indicators such as the urban green coverage rate and sewage treatment rate are small.

3.2.2. Schedule Calculation

First, the positive and negative ideal solutions are determined based on Formulas (8) and (9). Then, Formulas (10) and (11) are used in combination with the weighted normalization matrix to determine how far the RECC of the Yangtze River Delta from 2010 to 2019 deviated from the positive and negative ideal solutions. See Table 3 for details.

Based on Formula (12) and the data in Table 3, the closeness and ranking of the RECC in the Yangtze River Delta from 2010 to 2019 are obtained. The results are shown in the figure below.

Table 3. Deviation of RECC from the positive and negative ideal solutions in the Yangtze River Delta (2010–2019).

	Anhui		**Jiangsu**		**Zhejiang**		**Shanghai**	
year	D_i^+	D_i^-	D_i^+	D_i^-	D_i^+	D_i^-	D_i^+	D_i^-
2010	0.225	0.137	0.217	0.136	0.210	0.190	0.227	0.136
2011	0.226	0.132	0.212	0.136	0.208	0.172	0.227	0.138
2012	0.220	0.136	0.211	0.139	0.195	0.198	0.224	0.139
2013	0.206	0.143	0.193	0.157	0.186	0.190	0.223	0.176
2014	0.207	0.145	0.192	0.156	0.181	0.200	0.216	0.177
2015	0.203	0.149	0.185	0.165	0.179	0.207	0.215	0.177
2016	0.190	0.167	0.179	0.175	0.178	0.206	0.207	0.186
2017	0.198	0.155	0.188	0.165	0.187	0.188	0.208	0.186
2018	0.197	0.158	0.188	0.165	0.184	0.190	0.203	0.187
2019	0.204	0.155	0.189	0.177	0.178	0.203	0.205	0.185

In Figure 3, we observe the regional RECC of three provinces and one city in the Yangtze River Delta from 2010 to 2019.

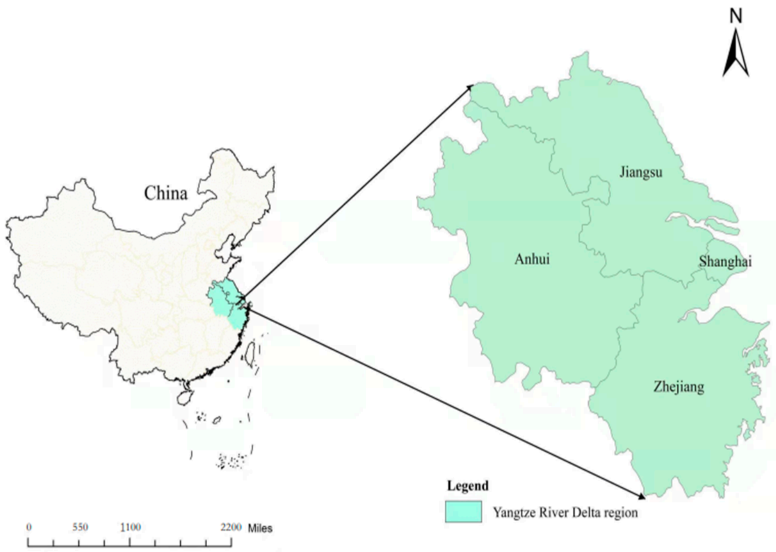

Figure 3. The position of the Yangtze River Delta in China.

By horizontally comparing the three provinces and one city in the 2010–2019 period, as shown in Figure 4, it can be roughly seen that the RECC of Zhejiang Province is high, followed by that of Jiangsu Province and Shanghai City, and the RECC of Anhui Province are low. From 2010 to 2016, the RECC in all regions continuously improved, and the RECC peaked in 2016. From 2017 to 2019, the RECC decreased with the ranking but also continuously improved. Further in-depth analysis shows the following differences in RECC across the Yangtze River Delta.

Zhejiang Province has the strongest RECC, indicating that its ecological and environmental quality is more perfect and optimized and that remarkable achievements have been made in ecological civilization construction and in environmental protection. The maximum per capita water resources reach 2608.7 m^3/person, with a minimum of 1365.7 m^3/person. The forest coverage rate ranges from 60.58% to 61.17% over the 10-year period. Indicators such as the number of beds in health institutions per 10,000 people are much higher than those in the other regions, indicating that Zhejiang Province performs well at the state-response level.

Jiangsu Province leads in terms of RECC performance, which is specifically reflected in the per capita park and green space area of 15 m^2 per capita, ranking first among the three provinces and one city. The proportion of wetland areas and urban green coverage rate has increased year by year, the per unit emissions of the industrial three wastes have decreased year by year, and the investment in industrial pollution control has been increasing, placing Jiangsu Province in the lead in the Yangtze River Delta.

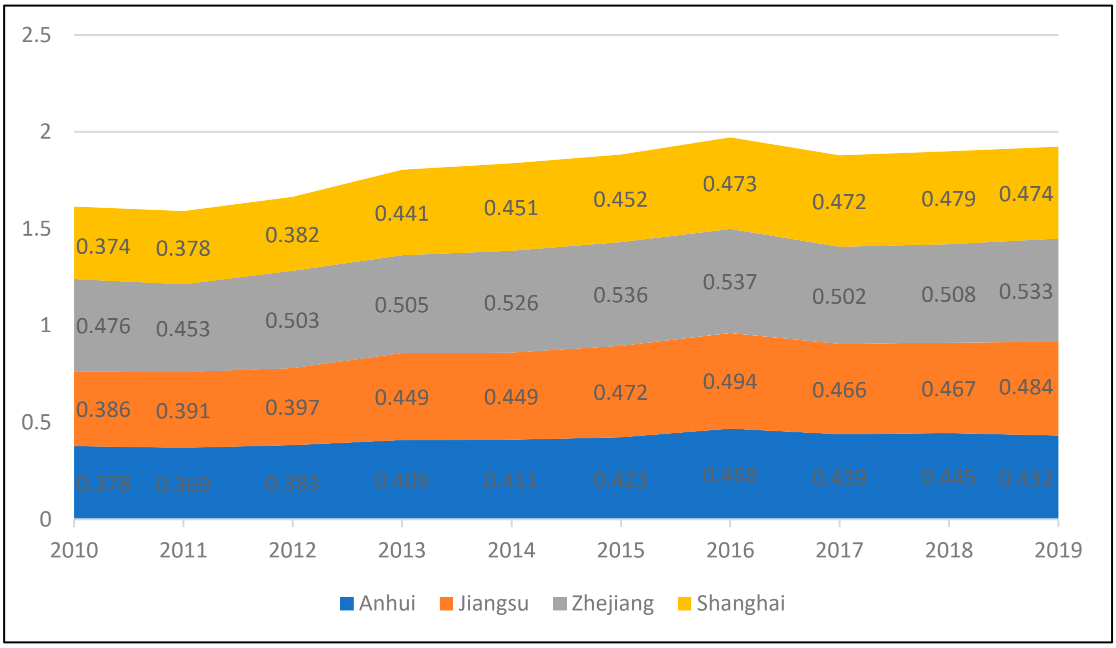

Figure 4. RECC evaluation results of the Yangtze River Delta region (2010–2019).

The overall RECC performance of Shanghai is average. This result is mainly because, among the regions studied, the city has the lowest per capita cultivated land area, per capita water resources, per capita road area, and population density. However, the per capita GDP of Shanghai is at a high level, and the output of industrial wastewater, waste gas, and solid waste per 10,000 yuan GDP is at a low level. This result shows that the state of resources and the environment in this area is relatively tense. However, the region has high resource utilization efficiency and strong environmental protection.

The RECC of Anhui Province is poor. Although the per capita cultivated land area, per capita water resource ownership, and population density are relatively low, the overall performance of per capita GDP, energy consumption per unit of regional GDP, and waste gas emissions per unit of industrial value added is poor. The state of resources and the environment in Anhui Province is good, but the response is not ideal.

3.2.3. Obstacle Factor Diagnosis

Because there are many factors in the index system reflecting the regional RECC, to explore in depth the key obstacle factors affecting the RECC of each region, the top five obstacle factors reducing the RECC of each region are selected as the basis for identifying the main obstacle factors. Considering the large sample size of data for the 10 years from 2010 to 2019, 2019 data are selected as the sample for obstacle factor analysis.

(1) Ranking of PSR obstacle factors in 2019

According to Figure 5, in 2019, the calculation results of obstacle factors of the regional RECC in terms of pressure and response in the Yangtze River Delta show that the main factor affecting an improvement in the regional RECC is the system state, with values above 70, especially in Zhejiang Province. The system response factor is the second most influential factor. The values of Anhui Province, Jiangsu Province, and Shanghai City are approximately 20, while the value of Zhejiang Province is 6.68. These results show that the main factor restricting the RECC in the Yangtze River Delta is the state factor, highlighting that there is an urgent need for the region to protect the cultivated land area and wetland area, make rational use of water resources, and continuously increase the area of park green space and roads. Moreover, policymakers should strengthen environmental governance, increase the amount of investment in industrial pollution control, improve the reuse rate of wastewater and solid waste, and improve urban green coverage and forest coverage.

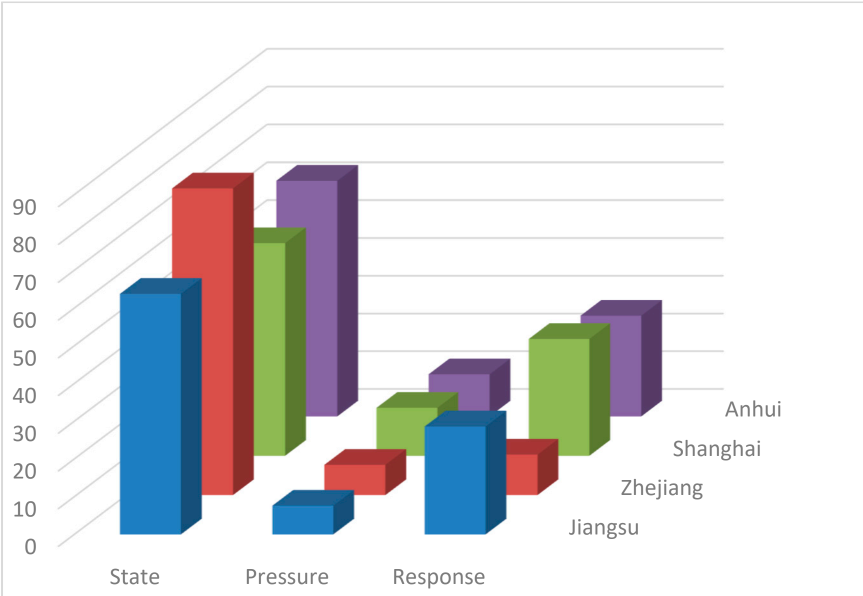

Figure 5. Ranking of PSR obstacle factors in the Yangtze River Delta in 2019.

(2) Major obstacles to the regional RECC in the Yangtze River Delta in 2019

Figure 6 shows that the main obstacle factors affecting the regional RECC of the Yangtze River Delta are as follows:

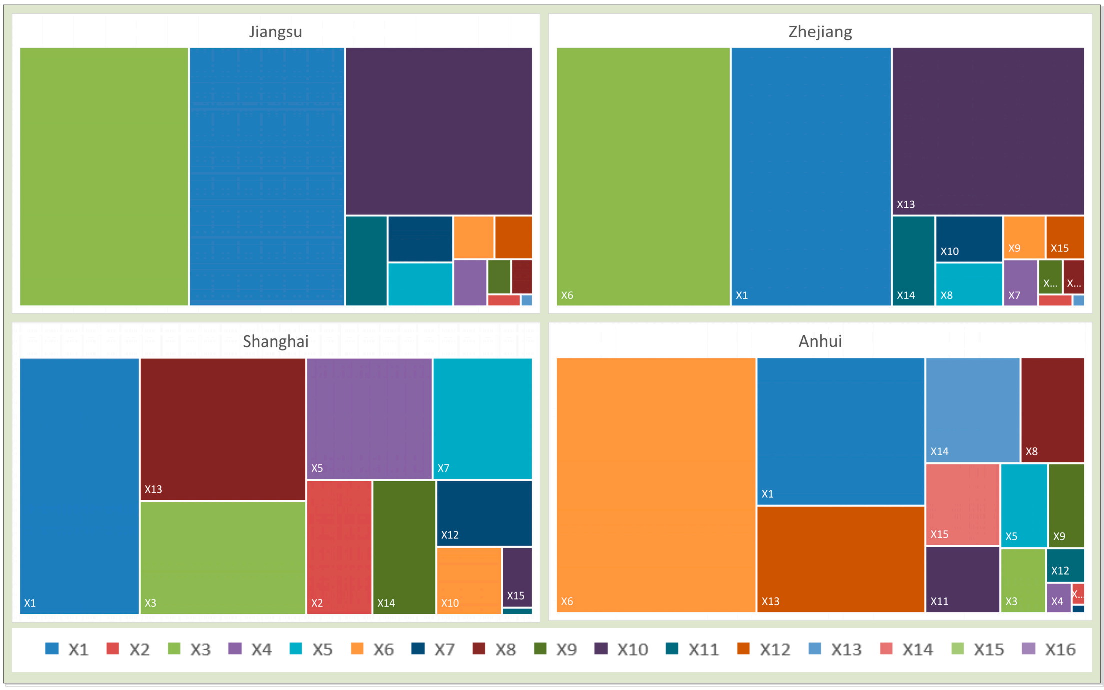

Figure 6. Major obstacles to the regional RECC in the Yangtze River Delta in 2019.

In Anhui Province, Jiangsu Province, and Zhejiang Province, the top obstacle factor is the proportion of wetland area. Specifically, the proportion of wetland areas is too low. Therefore, it is necessary to strengthen wetland protection and increase the wetland area.

In Shanghai, the top obstacle factor is the number of water resources per capita. Shanghai lacks water resources, and the amount of water resources per capita is low, which places great pressure on the RECC in the region.

In Anhui Province and Jiangsu Province, the second greatest obstacle factor is the number of water resources per capita. Compared with Zhejiang Province, the number of water resources per capita is not high. We should strengthen the protection of water resources, especially considering the great difference in water resources between the northern and southern parts of the country, and strengthen the internal regulation of water resources. In Zhejiang Province, the second greatest factor is cultivated land. Due to the relatively high proportion of mountainous areas and the small area of cultivated land, this factor has become a factor restricting the improvement in regional resources and the environment. In Shanghai, the second greatest factor is the per capita road area. Due to Shanghai's small area and large population, the per capita road area is low.

In Anhui Province, Jiangsu Province, and Shanghai City, the third greatest obstacle is forest coverage, while in Zhejiang Province, it is the per capita road area.

In Anhui Province and Zhejiang Province, the fourth greatest obstacle factor is investment in industrial pollution control, while in Jiangsu Province and Shanghai City, it is the proportion of cultivated land.

In Anhui Province, the fifth greatest obstacle factor is the comprehensive utilization rate of industrial solid waste; in Jiangsu Province, it is the discharge of industrial wastewater; in Zhejiang Province, it is the per capita water resources; and in Shanghai, it is the population density.

3.3. Policy Recommendations

With the transformation of the economy to high-quality development, a low-carbon economy based on low energy consumption, low pollution, and low emissions has become the focus of regional development. Based on the regional RECC, realizing regional sustainable development has become the key to the economic development of the Yangtze River Delta. Therefore, given the analysis of RECC in the Yangtze River Delta conducted in this paper, the following specific suggestions are made:

(1) Accelerate the green transformation and upgrading of the regional industrial structure

The RECC of the three provinces and one city in the Yangtze River Delta increased from 2010 to 2016, while it decreased from 2017 to 2019. In the past 10 years, with the rapid development of the social economy in the Yangtze River Delta, the per capita area of park green space, per capita area of roads and proportion of wetland area have increased. These results indicate that the region has paid attention to improving the regional ecological state and constructing an ecological civilization. The discharge of wastewater, waste gas, and solid waste per unit of industrial value added is declining, the investment in industrial pollution control is increasing, and the comprehensive utilization rate of wastewater and waste solid is further improving. These trends indicate that the Yangtze River Delta has strengthened pollution emission reduction, deepened pollution prevention and control, promoted the rationalization of industrial structure adjustment, gradually improved the quality of the ecological environment, improved the efficiency of resource utilization, and strengthened environmental protection. To further improve the regional RECC, we should strengthen technological innovation; implement energy conservation and emission reduction based on the industrial structure, technology, and social life; form an industrial chain of resource optimization, energy conservation, and environmental protection; realize the reduction, recycling, and harmless treatment of industrial and agricultural solid waste; and develop a circular economy and carbon-neutral economy.

(2) Promote regional synergy in pollution reduction and carbon reduction, and enhance regional resources and environmental protection

The main factors restricting an improvement in the regional carrying capacity of the Yangtze River Delta are concentrated at the state level, indicating that to improve the carrying capacity, the effective utilization of resources is still an urgent task. The comprehensive utilization rate of industrial solid waste and the amount of investment in industrial pollution control are the key obstacles to improving the regional carrying capacity. This means that the region should promote the agricultural and industrial innovation mode, promote carbon peaking and carbon neutrality, and strengthen the utilization rate of wastewater, waste gas, and waste residue to effectively improve the regional RECC.

(3) Establish ecological green integration in the Yangtze River Delta based on local conditions and classified guidance

The Yangtze River Delta region focuses on the science and innovation industry, infrastructure, the ecological environment, public services, and other fields and comprehensively establishes integration among them [42]. To accelerate the development of regional integration, on the basis of clarifying the RECC of the three provinces and one city under study, we should accelerate the construction of an ecological green integration development demonstration area in the Yangtze River Delta; explore the transformation of ecological advantages into economic and social development advantages on the premise of ecological and environmental protection; realize joint consultation, joint construction, management and win—win sharing; and explore the path and provide a demonstration for the development of ecological green integration in the Yangtze River Delta. Moreover, we should adopt the development strategy of adjusting measures to local conditions and classified guidance, actively develop characteristic industries suitable for resources and the environment, and effectively improve the comprehensive production capacity of the region.

3.4. Discussion and Managerial Implications

Compared with previous studies [1,26,32,40,45], this paper has the following advantages. First, the data-driven comprehensive evaluation model of the regional RECC measures carrying capacity from the PSR perspective and comprehensively evaluates and identifies the carrying capacity by using the entropy weight TOPSIS method and obstacle degree model, which provides theoretical support for quantifying the regional RECC. Second, by identifying the contributions of various factors to the evaluation of carrying capacity and obstacle factors, we determine the key elements affecting the regional RECC, make differential use of resources, reduce pollution and waste discharge, and improve the carrying capacity level for different regions, which is the basis of the sustainable development of the regional economy based on local conditions. Finally, based on the data-driven method, a quantitative tool for measuring, evaluating, and identifying the regional RECC is obtained. The identification of key elements can improve the carrying capacity level.

Synthesizing the research and conclusions above, we obtain the following managerial implications:

First, the accurate quantitative evaluation of RECC is the main basis for the rational development of regional land and space, and the regional resource structure should be maintained in line with the needs of sustainable development. Although different regions have been trying to simultaneously improve their RECC and utilization efficiency, making full use of the relevant data can help us accurately grasp the level of regional carrying capacity and make rational use of regional resources and the environment.

Second, RECC evaluation involves a complex system that includes the resource system, the environmental system, the economy, society, and other related subsystems in the ecosystem. Any given system will affect accurate evaluation to a certain extent, and there are differences in different regions. Therefore, it is necessary to identify, analyze and optimize these influencing factors as much as possible on the basis of the quantitative evaluation of carrying capacity.

Finally, based on the quantitative results, this paper makes targeted suggestions to improve the regional RECC level, give full play to the comparative advantages of various regions, promote the rational flow and efficient agglomeration of factors, and form the basis of a new pattern of land and spatial development and protection with complementary main advantages and high-quality development. The key is to accurately grasp the differences in regional resources and the environment as well as the quantitative level of carrying capacity. This quantitative evaluation and identification are the aim of this study.

4. Conclusions

With increasing global efforts to prevent ecological degradation and environmental pollution and to constantly promote the needs of regional ecological civilization construction and high-quality development, it is necessary to base these efforts on RECC. Therefore, scientific evaluation of the regional RECC has become extremely important. We propose a data-driven method to evaluate the regional RECC and to identify its key factors. The research results show that the level of RECC in the Yangtze River Delta region fluctuated slightly from 2010 to 2019, with an overall upward trend. Zhejiang Province has a strong carrying capacity, while Anhui Province has a relatively weak carrying capacity. The main obstacles to improving the RECC of the region are the proportion of wetland area and water resource ownership. Based on the quantitative results, policy recommendations are proposed to improve the regional RECC based on local conditions.

Innovations: From the perspective of the economy, society, resources, and the environment, as well as the internal trade-off relationship between them, based on the specific research area, a more comprehensive and local condition-based evaluation index system for the regional RECC is constructed based on the three interaction subsystems of state, pressure, and response. A data-driven measurement and evaluation method for the regional RECC is constructed. This method can more objectively and accurately evaluate the regional RECC, comprehensively and objectively reflect the dynamics and changing trends of the regional RECC and improve the accuracy of decision-making. Using the obstacle analysis method, we select and identify the key factors affecting carrying capacity by index layer and index and propose suggestions to improve the level of regional carrying capacity based on local conditions.

Future research directions: Carrying capacity is a dynamic concept. A certain technical level (such as scientific and technological innovation) and resource utilization mode (such as the circular economy) can dynamically affect the carrying capacity level. For example, the regional adoption of precision agriculture, intensive land use, and water-saving models will enhance the regional RECC to varying degrees, which also reflects that static research has certain limitations. In future research, we will pay more attention to the horizontal comparison of the RECC of different regions at the same time point, considering the impact of soft factors, such as science and technology as well as culture and the humanities. We will further investigate the spatial differences in regional RECC and divide the compared regions based on high, medium, and low carrying capacity to make more operational and targeted policy suggestions.

Author Contributions: Conceptualization, A.L. and Y.L.; resources, Y.Z. and Y.L.; writing—original draft preparation, A.L., S.Z. and H.D.; writing—review and editing, A.L. and C.W. All authors have read and agreed to the published version of the manuscript.

Funding: This research was supported by the Anhui Philosophy and Social Science Planning Project (No. AHSKY2021D35); the Key Research Projects of Philosophy and Social Sciences in Anhui Province (No. 2022AH051349); Anhui Key Project for Arts and Social Sciences Research in Universities (No. SK2016A1007); Anhui Province Excellent Youth Talent Support Project for Universities (No. gxyq2022102).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Conflicts of Interest: The authors declare no conflict of interest.

Glossary

Symbol Definitions
X1: Per capita water resources
X2: Per capita park green space area
X3: Per capita road area
X4: Energy consumption per unit of GDP
X5: Proportion of cultivated land area
X6: Proportion of wetland area
X7: Population density
X8: Per capita GDP
X9: Waste gas emissions per unit of industrial value added
X10: 10,000 yuan industrial value-added wastewater discharge
X11: Output of industrial solid waste
X12: Urban green coverage
X13: Forest coverage
X14: Investment in industrial pollution control
X15: Comprehensive utilization rate of industrial solid waste
X16: Sewage treatment rate
x_{ij} is the specific value of the i-th research object and the j-th index
y_{ij} represents the standardized value of the i-th research object and the j-th index
H_j is the determined information entropy
w_j is the weight of each index determined
V^+ is the maximum value of the j-th index of the i-th object in the weighted evaluation data
V^- is the minimum value of the j-th index of the i-th object in the weighted evaluation data
D_i^+ is the positive ideal solution
D_i^- is the negative ideal solution
C_i is the closeness between the RECC and the evaluation object
F_j is the impact of the j-th index on the regional RECC
O_{ij} is the gap between each index and the evaluation objectives of RECC
M_{ij} is the obstacle degree

References

1. Feng, Z.M.; Sun, T.; Yang, Y.Z.; Yan, H.M. The progress of resources and environment carrying capacity: From single-factor carrying capacity research to comprehensive research. *J. Resour. Ecol.* **2018**, *9*, 125–134. [CrossRef]
2. Peng, B.; Li, Y.; Elahi, E.; Wei, G. Dynamic evolution of ecological carrying capacity based on the ecological footprint theory: A case study of Jiangsu province. *Ecol. Indic.* **2019**, *99*, 19–26. [CrossRef]
3. Wang, R.; Cheng, J.; Zhu, Y.; Lu, P. Evaluation on the coupling coordination of resources and environment carrying capacity in Chinese mining economic zones. *Resour. Policy* **2017**, *53*, 20–25. [CrossRef]
4. Wang, Z.; Chen, Q. Comprehensive partitions and optimisation strategies based on tourism urbanisation and resources environment carrying capacity in the Yellow River Basin, China. *Environ. Sci. Pollut. Res.* **2021**, *29*, 23180–23193. [CrossRef] [PubMed]
5. Wang, L.; Liu, H. Comprehensive evaluation of regional resources and environmental carrying capacity using a PS-DR-DP theoretical model. *J. Geogr. Sci.* **2019**, *29*, 363–376. [CrossRef]
6. Świąder, M.; Lin, D.; Szewrański, S.; Kazak, J.K.; Iha, K.; van Hoof, J.; Belčáková, I.; Altiok, S. The application of ecological footprint and biocapacity for environmental carrying capacity assessment: A new approach for European cities. *Environ. Sci. Policy* **2019**, *105*, 56–74. [CrossRef]
7. Zhang, J.; Zhang, C.; Shi, W.; Fu, Y. Quantitative evaluation and optimized utilization of water resources-water environment carrying capacity based on nature-based solutions. *J. Hydrol.* **2019**, *568*, 96–107. [CrossRef]
8. Zhang, F.; Wang, Y.; Ma, X.; Wang, Y.; Yang, G.; Zhu, L. Evaluation of resources and environmental carrying capacity of 36 large cities in China based on a support-pressure coupling mechanism. *Sci. Total. Environ.* **2019**, *688*, 838–854. [CrossRef]
9. Liao, S.; Wu, Y.; Wong, S.W.; Shen, L. Provincial perspective analysis on the coordination between urbanization growth and resource environment carrying capacity (RECC) in China. *Sci. Total Environ.* **2020**, *730*, 138964. [CrossRef]
10. Wang, C.; Zhang, C.; Hu, F.; Wang, Y.; Yu, L.; Liu, C. Emergy-based ecological efficiency evaluation and optimization method for logistics park. *Environ. Sci. Pollut. Res.* **2021**, *28*, 58342–58354. [CrossRef]
11. Fu, J.; Zang, C.; Zhang, J. Economic and resource and environmental carrying capacity trade-off analysis in the Haihe River basin in China. *J. Clean. Prod.* **2020**, *270*, 122271. [CrossRef]
12. Wang, D.; Shi, Y.; Wan, K. Integrated evaluation of the carrying capacities of mineral resource-based cities considering synergy between subsystems. *Ecol. Indic.* **2019**, *108*, 105701. [CrossRef]

13. Zhou, J.; Chang, S.; Ma, W.; Wang, D. An unbalance-based evaluation framework on urban resources and environment carrying capacity. *Sustain. Cities Soc.* **2021**, *72*, 103019. [CrossRef]
14. Yang, H.; Tan, Y.; Sun, X.; Cheng, X.; Liu, G.; Zhou, G. Comprehensive evaluation of water resources carrying capacity and analysis of obstacle factors in Weifang City based on hierarchical cluster analysis-VIKOR method. *Environ. Sci. Pollut. Res.* **2021**, *28*, 50388–50404. [CrossRef] [PubMed]
15. Aalianvari, A.; Katibeh, H.; Sharifzadeh, M. Application of fuzzy Delphi AHP method for the estimation and classification of Ghomrud tunnel from groundwater flow hazard. *Arab. J. Geosci.* **2010**, *5*, 275–284. [CrossRef]
16. Du, Y.-W.; Li, B.-Y.; Quan, X.-J. Construction and application of DPPD model for evaluating marine resources and environment carrying capacity in China. *J. Clean. Prod.* **2019**, *252*, 119655. [CrossRef]
17. Liu, X.J.; Wang, J. Evaluation of Regional Water Resources Carrying Capacity in Yan'an Based on Principal Component Analysis. *Adv. Mater. Res.* **2013**, *864*, 2331–2334. [CrossRef]
18. Wang, S.; Yang, F.-L.; Xu, L.; Du, J. Multi-scale analysis of the water resources carrying capacity of the Liaohe Basin based on ecological footprints. *J. Clean. Prod.* **2013**, *53*, 158–166. [CrossRef]
19. Zhang, Z.; Lu, W.; Zhao, Y.; Song, W. Development tendency analysis and evaluation of the water ecological carrying capacity in the Siping area of Jilin Province in China based on system dynamics and analytic hierarchy process. *Ecol. Model.* **2014**, *275*, 9–21. [CrossRef]
20. Liu, Z.; Li, B.; Chen, M.; Li, T. Evaluation on sustainability of water resource in karst area based on the emergy ecological footprint model and analysis of its driving factors: A case study of Guiyang city, China. *Environ. Sci. Pollut. Res.* **2021**, *28*, 49232–49243. [CrossRef]
21. Cui, Y.; Feng, P.; Jin, J.; Liu, L. Water Resources Carrying Capacity Evaluation and Diagnosis Based on Set Pair Analysis and Improved the Entropy Weight Method. *Entropy* **2018**, *20*, 359. [CrossRef] [PubMed]
22. Li, X.; Cundy, A.; Chen, W.; Liu, R.; Lv, S. Dynamic capacity modelling of soil environment carrying capacity, and developing a soil quality early warning framework for development land in China. *J. Clean. Prod.* **2020**, *257*, 120450. [CrossRef]
23. Li, M.; Sun, H.; Singh, V.P.; Zhou, Y.; Ma, M. Agricultural Water Resources Management Using Maximum Entropy and Entropy-Weight-Based TOPSIS Methods. *Entropy* **2019**, *21*, 364. [CrossRef] [PubMed]
24. Ghazali, M.; Honar, T.; Nikoo, M.R. A hybrid TOPSIS-agent-based framework for reducing the water demand requested by stakeholders with considering the agents' characteristics and optimization of cropping pattern. *Agric. Water Manag.* **2018**, *199*, 71–85. [CrossRef]
25. Niu, F.; Yang, X.; Zhang, X. Application of an evaluation method of resource and environment carrying capacity in the adjustment of industrial structure in Tibet. *J. Geogr. Sci.* **2020**, *30*, 319–332. [CrossRef]
26. Zhang, Z.; Hu, B.; Qiu, H. Comprehensive evaluation of resource and environmental carrying capacity based on SDGs perspective and Three-dimensional Balance Model. *Ecol. Indic.* **2022**, *138*, 108788. [CrossRef]
27. Shen, L.; Shu, T.; Liao, X.; Yang, N.; Ren, Y.; Zhu, M.; Cheng, G.; Wang, J. A new method to evaluate urban resources environment carrying capacity from the load-and-carrier perspective. *Resour. Conserv. Recycl.* **2020**, *154*, 104616. [CrossRef]
28. Wei, X.; Wang, J.; Wu, S.; Xin, X.; Wang, Z.; Liu, W. Comprehensive evaluation model for water environment carrying capacity based on VPOSRM framework: A case study in Wuhan, China. *Sustain. Cities Soc.* **2019**, *50*, 101640. [CrossRef]
29. Shi, Y.; Shi, S.; Wang, H. Reconsideration of the methodology for estimation of land population carrying capacity in Shanghai metropolis. *Sci. Total. Environ.* **2019**, *652*, 367–381. [CrossRef]
30. Nathaniel, S.P.; Nwulu, N.; Bekun, F. Natural resource, globalization, urbanization, human capital, and environmental degradation in Latin American and Caribbean countries. *Environ. Sci. Pollut. Res.* **2020**, *28*, 6207–6221. [CrossRef] [PubMed]
31. Irankhahi, M.; Jozi, S.A.; Farshchi, P.; Shariat, S.M.; Liaghati, H. Combination of GISFM and TOPSIS to evaluation of Urban Environment Carrying Capacity (Case study: Shemiran City, Iran). *Int. J. Environ. Sci. Technol.* **2017**, *14*, 1317–1332. [CrossRef]
32. Men, B.; Liu, H. Water resource system vulnerability assessment of the Heihe River Basin based on pressure-state-response (PSR) model under the changing environment. *Water Supply* **2018**, *18*, 1956–1967. [CrossRef]
33. Peng, T.; Deng, H. Evaluating urban resource and environment carrying capacity by using an innovative indicator system based on eco-civilization—A case study of Guiyang. *Environ. Sci. Pollut. Res.* **2020**, *28*, 6941–6955. [CrossRef]
34. Peng, T.; Deng, H. Comprehensive evaluation on water resource carrying capacity based on DPESBR framework: A case study in Guiyang, southwest China. *J. Clean. Prod.* **2020**, *268*, 122235. [CrossRef]
35. Peng, T.; Deng, H. Comprehensive evaluation on water resource carrying capacity in karst areas using cloud model with combination weighting method: A case study of Guiyang, southwest China. *Environ. Sci. Pollut. Res.* **2020**, *27*, 37057–37073. [CrossRef]
36. Peng, T.; Deng, H. Research on the sustainable development process of low-carbon pilot cities: The case study of Guiyang, a low-carbon pilot city in south-west China. *Environ. Dev. Sustain.* **2020**, *23*, 2382–2403. [CrossRef]
37. Liu, C.; Gao, M.; Zhu, G.; Zhang, C.; Zhang, P.; Chen, J.; Cai, W. Data driven eco-efficiency evaluation and optimization in industrial production. *Energy* **2021**, *224*, 120170. [CrossRef]
38. Liu, C.; Chen, J.; Wang, X. Quantitative Evaluation Model of the Quality of Remanufactured Product. *IEEE Trans. Eng. Manag.* **2023**, 1–12. [CrossRef]
39. Rahman, A.; Muktadir, G. SPSS: An Imperative Quantitative Data Analysis Tool for Social Science Research. *Int. J. Res. Innov. Soc. Sci.* **2021**, *5*, 300–302. [CrossRef]

40. Dai, D.; Sun, M.; Xu, X.; Lei, K. Assessment of the water resource carrying capacity based on the ecological footprint: A case study in Zhangjiakou City, North China. *Environ. Sci. Pollut. Res.* **2019**, *26*, 11000–11011. [CrossRef] [PubMed]
41. Tang, X.; Guan, X.L.; Lu, S.S.; Qin, F.; Liu, X.; Zhang, D.H. Examining the spatiotemporal change of forest resource carrying capacity of the Yangtze River Economic Belt in China. *Environ. Sci. Pollut. Res.* **2020**, *27*, 21213–21230. [CrossRef] [PubMed]
42. Zhang, M.; Liu, Y.; Wu, J.; Wang, T. Index system of urban resource and environment carrying capacity based on ecological civilization. *Environ. Impact Assess. Rev.* **2018**, *68*, 90–97. [CrossRef]
43. Sałabun, W. The mean error estimation of TOPSIS method using a fuzzy reference models. *J. Theor. Appl. Comput. Sci.* **2013**, *7*, 40–50.
44. Zuo, Y.; Shi, Y.-L.; Zhang, Y.-Z. Research on the Sustainable Development of an Economic-Energy-Environment (3E) System Based on System Dynamics (SD): A Case Study of the Beijing-Tianjin-Hebei Region in China. *Sustainability* **2017**, *9*, 1727. [CrossRef]
45. Tang, B.; Hu, Y.; Li, H.; Yang, D.; Liu, J. Research on comprehensive carrying capacity of Beijing–Tianjin–Hebei region based on state-space method. *Nat. Hazards* **2015**, *84*, 113–128. [CrossRef]