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The Efficiency of Urban–Rural Integration in the Yangtze River Economic Belt and Its Optimization

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Abstract: China has entered a new stage of integrated development of urban and rural areas under the constraints of scarce land resources and the need for high-quality economic and social development. While there is concern about the state and speed of urban–rural integrated development (URID), increasing attention is being paid to efficiency improvement. This paper comprehensively measures the efficiency of URID from the input–output perspective, taking into account the impact of carbon emissions; it also studies the efficiency of URID and its developmental spatiotemporal characteristics in 73 cities within three major city clusters in the Yangtze River Economic Belt (YREB) from 2010 to 2019, and analyzes the input–output optimization strategies for URID within each of these major urban systems. The results show that (1) the comprehensive efficiency evaluation system constructed by the study can more objectively reflect the state and trends of URID. From 2010 to 2019, the efficiency of URID in the three major city clusters in the YREB showed a downward trend; in cities with better economic development, the efficiency of URID was lower than in cities with average economic development, where carbon emission indicators showed a significant impact. (2) The spatial distribution of URID efficiency in the three major city clusters in the YREB follows an inverted "U" shape; URID efficiency in the urban agglomeration in the middle reaches of the Yangtze River (MRYRUA) is higher than in the Chengyu urban agglomeration (CYUA), where it is higher than in the Yangtze River Delta urban agglomeration (YRDUA). (3) The input redundancy rates are high in the indicators for culture, sports and media, energy conservation and environmental protection, urban and rural communities, and housing security expenditures. Carbon emission redundancy has a negative impact on efficiency in URID. Based on the high redundancy rates of each input–output indicator, this paper proposes methods to optimize the efficiency of URID in each of the three major city clusters and provides directional guidance for promoting the high-quality development of regional urban–rural integration.

Keywords: integrated urban–rural development; efficiency; spatiotemporal evolution; carbon emissions; urban agglomerations

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Citation: Muga, G.; Hu, S.; Wang, Z.; Tong, L.; Hu, Z.; Huang, H.; Qu, S. The Efficiency of Urban–Rural Integration in the Yangtze River Economic Belt and Its Optimization. *Sustainability* **2023**, *15*, 2419. https://doi.org/10.3390/su15032419

Academic Editors: Lu Zhang, Bing Kuang and Bohan Yang

Received: 2 December 2022
Revised: 16 January 2023
Accepted: 19 January 2023
Published: 29 January 2023

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1. Introduction

Urban–rural integrated development (URID) is seen as the model for coordinated urban–rural development in China's new era and is no longer equivalent to the one-directional emphasis on industrial development feeding the agricultural sector in "promoting agriculture with industry". URID is committed to the preservation of the characteristics of urban and rural areas, respectively, and the establishment of a new type of urban–rural relationship characterized by comprehensive integrated development to replace the previous rural–urban dichotomy [1,2]. The integrated development of urban and rural areas has always been an important goal for China to achieve urban and rural coprosperity. In the past 70 years, urban–rural relations have changed from the initial division to the current stage of integration and development, and although significant achievements have been made, integration still faces problems, such as unbalanced urban–rural development, inadequate rural development, an inadequate two-way flow of factors, and unreasonable allocation of public resources, which hinder further integration and development [3–5]. Improving the distribution of basic public services and the reasonable allocation of public resources in urban and rural areas is of great practical significance to the success of the strategy for urban–rural integration and development [6]. At the same time, it also puts the governance capacity of administrative departments at all levels to a severe test. For local governments, as the main enforcer of urban–rural integration policy, obtaining the best output efficiency while controlling input costs has become important to effectively promoting urban–rural integration strategies. Therefore, it is necessary to measure the efficiency of the current implementation of integrated urban–rural development in government departments across China and propose measures to improve efficiency.

Data envelopment analysis (DEA) is used to assess the relative validity of decision units in a "multiple input, multiple output" model [7,8]. This method has been applied to multiple fields of research. For example, in government management, scholars have conducted an overall assessment of service efficiency by examining the public services provided by local governments in Portugal and Norway [9,10]; in corporate management, scholars have analyzed the technical efficiency of American Airlines from 1970 to 1990 and the relationship between the stock market and the technical efficiency of the company [11]. In bank management, scholars have constructed a bank efficiency evaluation system to measure the efficiency of Swedish banking services as well as the average efficiency level of the industry, based on the concept of service efficiency [12]; in agricultural production, researchers measured the efficiency of agricultural production in 18 developing countries from 1961 to 1985 and confirmed that the results were consistent with the findings of previous studies that agricultural production efficiency was declining in developing countries [13].

Due to different national conditions, international research on urban–rural integration is still lacking. Most foreign countries explore the definition of urban and rural patterns, influencing factors, and policy recommendations. For example, for the definition of urban–rural patterns, some European countries use urban–rural typology for the definition of urban–rural spatial patterns. In Denmark, a study has compared urban–rural typologies from OECD, Eurostat, and ESPON, and reduced them to the level of Danish municipalities; the reduced typologies are largely consistent in terms of overall spatial patterns, and their urban–rural patterns are more diverse than the original typologies, providing a clearer picture of the urban–rural structure in Denmark [14]. In terms of influencing factors, a researcher used migration patterns to analyze urban–rural relationships. The study elaborated the spatial distribution of types of in-migration and the relation to selected location determinants in the metropolitan area of Copenhagen for the years 1986–2011 [15]. In addition to this, there are studies in Spain that have used an integrated approach based on statistical and cartographic techniques, incorporating socioeconomic and land use variables using a multivariate statistical framework to explore the processes of change in urban–rural relations in Spain [16]. In terms of policy recommendations, in Europe, policy documents at national and regional levels are increasingly emphasizing urban–rural interdependence, moving toward regionalization and shifting the focus of development more toward functional regions rather than towns and villages [17,18]. Research on urban–rural integration in China has focused on theoretical analysis [19–21], level measurement [22–26], assessment of implementation [27,28], and research on policy tools to manage it [29,30], while relatively little research has been conducted on the efficiency of urban–rural integrated development (URID). The existing studies mainly use the data envelopment analysis (DEA) method to study the efficiency of URID from the input–output perspective without considering undesired outputs, and mainly involve static studies at the provincial and municipal levels in a single year at the spatial and temporal scales. For example, at the provincial level, the DEA model, combining analytical hierarchical processes (APH) and DEA methods, was used to measure the efficiency of URID in 30 Chinese provinces; it was found that there was a gradient of higher efficiency in the eastern region than in the central region and higher efficiency in the central region than in the western region [31,32]. Expanding and refining the URID index system and analyzing the efficiency measurement of urban and rural planning overall with spatial differentiation laws for 30 provinces in China, the results show that the eastern region still has the highest efficiency and that regional socioeconomic development is not related to the overall efficiency of urban–rural development [33,34]. There are obvious differences in natural conditions and the human geographic environment in different regions of China. Therefore, it is necessary to conduct research on urban–rural relations at the regional level and formulate regional urban–rural integration policies according to local conditions. After measuring the urban–rural integration efficiency of different prefecture-level cities in Gansu and Jiangsu Provinces and analyzing the spatial divergence pattern and influencing factors at the regional level, researchers found that 14 prefecture-level cities in Gansu Province showed spatial distribution characteristics of high efficiency in the west and low efficiency in the east, with a north-south divergence in 2009; 13 prefecture-level cities in Jiangsu Province showed low overall efficiency in 2015, with a spatial distribution pattern of south Jiangsu > north Jiangsu > middle Jiangsu [35,36]. Considering the undesirable output of regional carbon emissions, the efficiency of URID and its dynamic evolutionary characteristics in 27 cities in the Yangtze River Delta region from 2008–2017 were analyzed using a superefficient epsilon-based measure (super EBM) model, including total factor productivity changes and driving factors. Researchers found that efficiency is low across the delta and the efficiency of URID in economically developed cities is lower than in less economically developed cities. The redundancy of undesirable indicators of carbon emissions has a greater impact on the loss of URID efficiency, but the overall trend in total factor productivity is improving [37]. The above shows that China and Europe differ in their research directions and approaches to urban–rural integration. European countries focus on developing toward functional areas rather than towns and villages, while China focuses on urban–rural parity and tends to develop villages. In future research, the methodology and indicator construction of European countries can be used to make studies more comprehensive.

In summary, systematic and mature cases of research into the efficiency of URID are still lacking, especially in city clusters with rapid economic development and obvious urban–rural differences. At the same time, most existing studies are static studies on a single year, lacking dynamic monitoring and an analysis of the variance in efficiency at different time scales. Furthermore, most of the current research on urban–rural integration efficiency mostly measure using traditional DEA methods, and less consideration is given to the influence of unexpected values, especially carbon emissions, leading to an overestimation of efficiency. In this regard, the three major city clusters of the Yangtze River Economic Belt (YREB) (hereafter referred to as the three major city clusters), which span three major regions of east, central, and west China, are targeted for research in this paper. The low-carbon concept is introduced using the EBM superefficiency model, taking carbon emissions into consideration as an undesired output. Based on the panel data of 73 cities in the three major city clusters that carried out urban–rural integration from 2010 to 2019, the efficiency, characteristics of spatiotemporal evolution, and the correlation between URID efficiency, carbon emissions and efficiency improvement are all analyzed. The study purpose is to reveal the spatial and temporal patterns of URID efficiency of the three major urban agglomerations in the YREB, to provide a basis for policy formulation on URID efficiency of the urban agglomerations in the YREB, and provide direction for promoting the high-quality development of regional urban–rural integration.

2. Materials and Methods

2.1. Study Area

The YREB spans the three major regions of China's east, center, and west, covering 9 provinces and 2 municipalities directly under the Central Government, with a total area of approximately 2.05 million km^2; its population and GDP exceed 40% of that of the country. In these three regions of the YREB, the Yangtze River Delta urban agglomeration (YRDUA), the urban agglomeration in the middle reaches of the Yangtze River (MRYRUA), and the Chengyu urban agglomeration (CYUA) are the strategic core areas of economic growth [38,39] and are located in the lower, middle, and upper reaches of the Yangtze River (Figure 1). The Yangtze River Delta region is one of the regions with the most active economic development, the highest degree of openness, and the strongest innovation capacity in China, and it has a pivotal strategic position in the general plan for national modernization and the overall pattern for economic opening. Promoting the integrated development of the Yangtze River Delta, enhancing the innovation and competitiveness of the Yangtze River Delta region, and improving the efficiency of economic agglomeration, regional connectivity, and policy synergy are all highly significant to leading the country's development of a high-quality modern economic system. The city cluster in the middle reaches of the Yangtze River is an important part of the YREB and is also a key area in the strategy to promote the rise of the central region, deepen reform and opening, and promote new urbanization in all aspects. The central region also occupies an important position in the pattern of regional development in China. The CYUA is an important ecological barrier in the upper reaches of the Yangtze River, as a comprehensive transportation hub that integrates the east and the west and connects the north and the south in southwest China. As the connection point between the "Belt and Road" and the YREB, the region has the substantial responsibility to integrate and promote the development of the YREB. The development of the YREB must prioritize ecological and green development, and the Chengdu-Chongqing city cluster plays a leading role in this green development. The three major city clusters are important engines to support and lead the high-quality and integrated development of the YREB, and they are also important functional areas in the strategic pattern of China's regional development. To this end, the efficiency and spatial and temporal evolutionary characteristics of URID in the three major city clusters were scientifically analyzed. This study provides a basis for the YREB to achieve high-quality development and to collaboratively promote the policy guidelines for URID.

2.2. Materials

The data in the paper were mainly obtained from the China City Statistical Yearbook, the statistical yearbooks of provinces and municipalities in the Yangtze River Economic Zone, and the Final Statement of General Public Budget Expenditure in each city. Some data were calculated based on the yearbook data, and the missing data for individual years were made up by linear interpolation. Carbon emission data were obtained from Oda et al. [40] and counted by ArcGIS software.

2.3. Methods

For this article, we constructed an index system that can calculate a comprehensive coefficient to measure the development efficiency of urban–rural integration using the EBM superefficiency model. The degree of development of urban–rural integration in this index system is calculated using another index system and the vertical and horizontal scatter degree method. In addition, the temporal and spatial variations of URID efficiency in the YREB are analyzed by the trend surface method.

2.3.1. Evaluation of URID Efficiency

1. Efficiency measurement index system

As an indicator to measure the maximum efficiency of inputs and outputs between urban and rural areas, the efficiency of urban–rural integration refers to the efficiency of the allocation of capital, technology, talent, land, and other factors between urban and rural areas. Maximum efficiency is the optimal combination of factor inputs to produce the "best" product mix, so that the allocation of input and output resources between urban and rural areas is optimized.

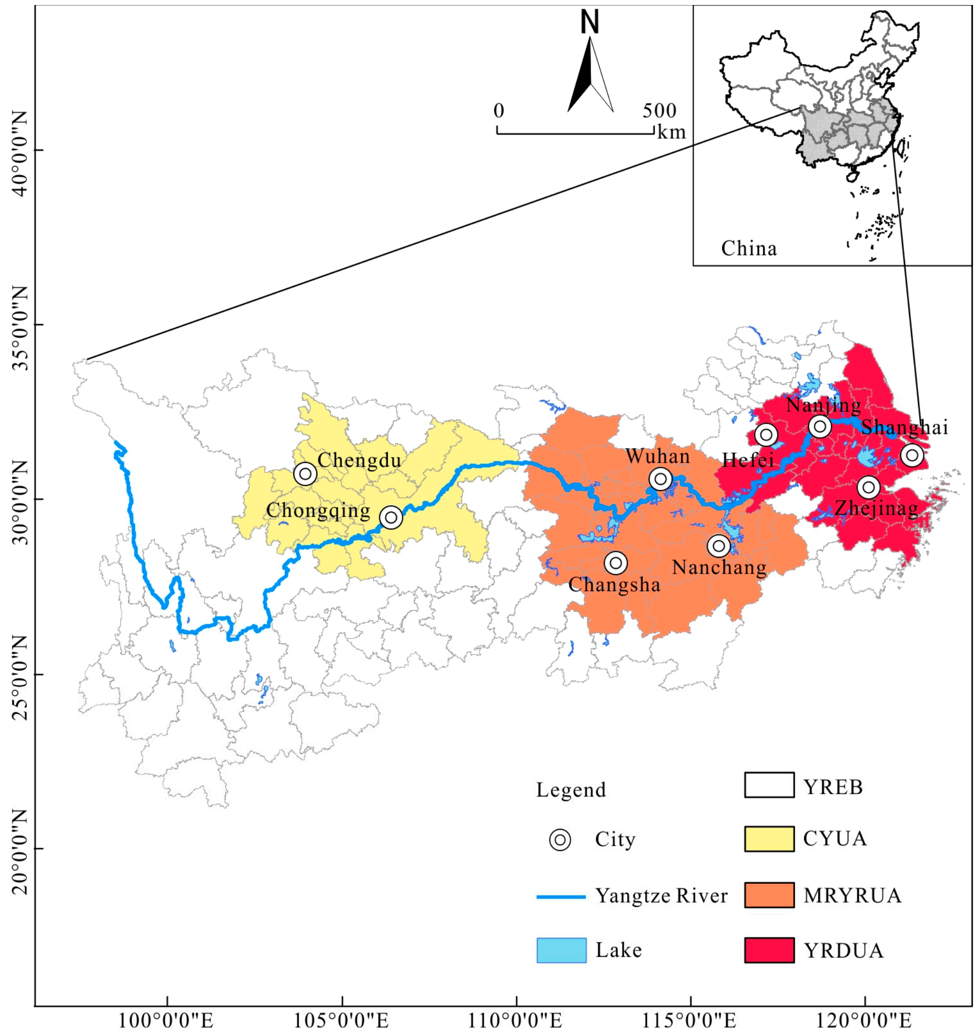

Figure 1. Location diagram of the three major city clusters in the YREB. Note: YREB = Yangtze River Economic Belt, CYUA = Chengyu Urban Agglomeration, MRYRUA = Urban Agglomeration in the Middle Reaches of Yangtze River, YRDUA = Yangtze River Delta Urban Agglomeration.

The study combined the connotations of urban–rural integration referred to in the literature [34,37], and followed the principles of objectivity, systematicity, comparability, and operability to evaluate URID efficiency in the three major city clusters in the YREB for both inputs and outputs (Table 1). URID, as an important public project led by the government, has intricate and complex forms and structures of inputs, which are difficult to refine. At the same time, various elements measuring URID efficiency are derived from financial inputs and transformations. Combined with general public service expenditure from government finance, 11 indicators, such as education, science and technology, culture, sports, and media, were selected. In terms of outputs, the level of urban–rural integration and carbon emission efficiency were selected as the expected values, and total carbon emissions were selected as the unexpected value. Carbon emissions, as an important indicator reflecting the quality of URID, are closely related to urban and rural social and economic activities. Taking carbon emissions into consideration can more objectively examine whether URID is performing as expected, reflecting low-carbon and sustainable urban–rural development. For example, traditional productivity measures that ignore carbon emissions and other undesirable outputs will lead to overestimation of the true efficiency of urban–rural integration.

Table 1. Input–output index system of efficiency for URID.

Index Attribute	Index Selection	ID
Input indicators	Education (100 million yuan)	Ip^1
	Science and technology (100 million yuan)	Ip^2
	Culture, sports, and media (100 million yuan)	Ip^3
	Social security and employment (100 million yuan)	Ip^4
	Hygiene and health (100 million yuan)	Ip^5
	Energy conservation and environmental protection (100 million yuan)	Ip^6
	Urban and rural communities (100 million yuan)	Ip^7
	Agriculture, forest, and water (100 million yuan)	Ip^8
	Public transportation (100 million yuan)	Ip^9
	Business services (100 million yuan)	Ip^{10}
	Expenditure on housing security (100 million yuan)	Ip^{11}
Output indicators	The level of integrated urban and rural development	Op^1
	Carbon emission efficiency (ton/10,000)	Op^2
	Carbon emissions (10,000 tons)	Op^3

2. The EBM superefficiency model

The traditional DEA model cannot measure slack variables, while the slack-based measure (SBM) model loses the proportional information between the actual value of inputs and outputs and the target value. Aiming at these shortcomings, Tone et al. [41,42] proposed a hybrid model: an epsilon-based measure (EBM) model that includes both radial and SBM distance functions. This model can measure not only the improvement ratio between the target value and the actual value, but also the gap between the target value and the actual value by solving the nonradial values of each input–output so that the efficiency of the decision-making unit (DMU) can be measured more accurately. The conventional EBM model cannot compare multiple input DMUs at the frontier, but the superefficiency EBM model can make up for this deficiency. In view of this, this paper uses MaxDEA9 software, selects the EBM model to be nonoriented, sets the superefficiency option, and calculates the efficiency of URID. The expressions are as follows:

$$r^* = \min \frac{\theta - \varepsilon^- \sum_{i=1}^{m} \frac{\omega_i^- s_i^-}{x_{i0}}}{\varphi + \varepsilon^+ \left(\sum_{r=1}^{s} \frac{\omega_r^+ s_r^+}{y_{r0}} + \sum_{p=1}^{q} \frac{\omega_p^{u-} s_p^{u-}}{u_{p0}} \right)} \quad (1)$$

$$s.t. \sum_{j=1}^{n} x_{ij}\lambda_j + s_i^- = \theta x_{i0} \quad (2)$$

$$\sum_{j=1}^{n} y_{rj}\lambda_j - s_r^+ = \varphi y_{r0} \quad (3)$$

$$\sum_{j=1}^{n} u_{pj}\lambda_j + s_p^- = \varphi u_{p0} \quad (4)$$

In the formula, $r^*(0 \leq r^* \leq 1)$ is the optimal efficiency value and x_{i0}, y_{1r0}, u_{p02}, and s_i^- are the DMU_0 input, expected output, and undesired output, respectively, followed by DMU_0 as the input slack. s_r^+ and s_p^- are the expected output and undesired output slack, respectively; ω_i^-, ω_r^+, ω_p^{u-} are the input and expected output of each indicator, respectively, followed by the importance of undesired outputs. θ is the efficiency value under radial conditions; ε is the core parameter of the importance degree of the nonradial part when $0 \leq \varepsilon \leq 1$ is satisfied.

2.3.2. Evaluation of the URID Level

1. Level measurement index system

Above, the expected value output is used as an indicator of the level of URID efficiency to measure the level of urban–rural integration in a scientific way. Seventeen indicators were selected from five dimensions, including integration, cultural integration, spatial integration, and ecological integration (Table 2) [22,43–47]. In addition, the indicators of the URID level are divided into comprehensive and comparative categories, where the comprehensive category mainly reflects the overall development of regional urban and rural areas while the comparative category mainly reflects the differences between urban and rural areas. The two are indispensable and complement each other. If there is a lack of comparative indicators, the level measurement results will deviate from the stated research goals and become an evaluation of the comprehensive development level of the region; similarly, if there is a lack of comprehensive indicators, the measurement results will also deviate from the research goals.

Table 2. Indicator system for measuring the level of URID.

Dimensionality	Indicator Name	Indicator Calculation and Description	Attribute	Category
Economic integration	Per capita GDP	GDP/regional resident population (yuan)	+	Comprehensive
	Disposable income ratio of urban and rural residents	Per capita disposable income of urban residents/per capita disposable income of rural residents (%)	−	Comparison
Social integration	Per capita consumption ratio of urban and rural households	Per capita consumption expenditure of urban residents/per capita consumption expenditure of rural residents (%)	−	Comparison
	Engel's coefficient ratio between urban and rural areas	Urban Engel's coefficient/rural Engel's coefficient (%)	+	Comparison
	Binary contrast coefficient	(Output value of primary industry/employees of primary industry)/(output value of secondary and tertiary industries/employees of secondary and tertiary industries) (%)	+	Comparison
	Urban and rural cultural, educational and entertainment comparison coefficient	Per capita expenditure on cultural, educational and recreational services for urban residents/per capita expenditure on cultural, educational and recreational services for rural residents (%)	−	Comparison
	Teacher–student ratio in basic education	Number of elementary education teachers/number of elementary education students (%)	+	Comprehensive
	Contrast coefficient of medical care per capita between urban and rural areas	Per capita health care expenditure of urban residents/per capita health care expenditure of rural residents (%)	−	Comparison
	Urban and rural unemployment insurance coverage	Number of urban and rural residents covered by unemployment insurance/number of permanent residents (%)	+	Comprehensive
Population integration	Urban and rural population contrast coefficient	Urban population/rural population (%)	+	Comparison
	The ratio of nonagricultural employment to agricultural employment	Number of employees in the secondary and tertiary industries/number of employees in the primary industry/(%)	+	Comparison
	Population urbanization level	Total urban population/total population (%)	+	Comprehensive
Ecological integration	Vegetation index	Urban and rural NDVA (normalized difference vegetation index)	+	Comprehensive
	Urban and rural sewage treatment	Centralized treatment rate of sewage treatment plant (%)	+	Comprehensive
	Urban and rural domestic waste treatment	Harmless treatment rate of domestic waste (%)	+	Comprehensive
Space integration	Road network density	Highway operating mileage/total land area (km/km2)	+	Comprehensive
	Urban and rural internet user rate	Number of internet users in urban and rural areas/total number of households at the end of the year (%)	+	Comprehensive

Note: 1. An index with an attribute of "+" means that the larger the index value is, the more conducive it is to improving URID; an index with an attribute of "−" means that the larger the index value is, the less conducive it is to improving URID.

2. Vertical and horizontal scatter degree method

There are many methods for measuring the level of URID, such as the commonly used principal component analysis and entropy value methods, but these methods are difficult to evaluate dynamically. The comprehensive evaluation method of a three-dimensional time series can not only reflect the difference of the evaluation objects at certain time section, but can also show the distribution of the evaluation objects longitudinally over time and has strong objectivity [48,49].

$$H_t = A(t)''^T A(t)'' \quad (5)$$

$$H = \sum_{t=1}^{N} H_t \quad (6)$$

$$e^2 = \sum_{t=1}^{T}\sum_{i=1}^{m}(y_i(t) - \overline{y})^2 = \sum_{t=1}^{T}\sum_{i=1}^{m}(y_i(t))^2 = \sum_{t=1}^{T} W^T H_t W = W^T H W \quad (7)$$

$$gti = \text{w}1X_{til} + \text{w}2X_{til}'' + \cdots + \text{w}nX_{til}'' \quad (8)$$

In the formula, T is the research year, m is the number of cities, N is the number of indicators, and the eigenvector u corresponding to the largest eigenvalue of the matrix H is the weight determination vector. After u is obtained, normalization is performed. At this time, e^2 takes the maximum value. This determines the weight vector u, where u(w1, w2, w3, w4...wn). Among these terms, t is the research year, n is the research city, n is the number of indicators in the study, and gti is the urban–rural integration degree of the ith city in the tth year. The weight of each index is multiplied by the corresponding standardized index value of the city in the current year to obtain the urban–rural integration degree of the ith city in the tth year.

2.3.3. Evaluation of the URID Level

A trend surface is a semiquantitative study of geographic data from a large area based on spatial data and simulated spatial surfaces using mathematical fitting, which can be used to explore the spatial trends and distribution patterns of research objects [9]. In this paper, the characteristics of spatial and temporal variation in urban–rural integration in the three major city clusters since 2010 are simulated by means of trend surface analysis with the value of URID efficiency. Let (x_i, y_i) be the spatial location of the ith municipality; then, Z_i (x_i, y_i) is the trend function of the ith municipality, where the X-axis represents the east–west direction and the Y-axis represents the north–south direction.

3. Results

3.1. General Change Characteristics in the Efficiency of URID

Selecting the vertical and horizontal scatter degree method and EBM superefficiency model and using MATLAB and MaxDEA9 software, the URID level and efficiency of 73 cities in the three major city clusters were obtained, as shown in Figure 2a. The level of urban–rural integration has been increasing linearly over time, with an average annual growth rate of 5%. Total carbon emissions show an overall upward trend, as shown by a rapid rise from 2010 to 2014 and a small fluctuation from 2014 to 2019 of "first falling and then rising"; the efficiency of URID shows an overall decreasing trend over time, as shown by a gradual decrease in efficiency from 2010 to 2015 and a small fluctuation from 2015 to 2019 of "gradually rising and then falling", which is the opposite of the trend in carbon emissions.

Further analysis of the change in characteristics of different city clusters shows that, as shown in Figure 2b–d, the URID level of each city cluster is on the rise as a whole, and YRDUA > MRYRUA > CYUA. In the past 10 years, URID has maintained a trend of growth; the overall carbon emissions of the three major city clusters have also shown an upward trend, with YRDUA > CYUA > MRYRUA, and the carbon emissions of YRDUA are on average 3–4 times higher than the other two city clusters. There are obvious differences in the efficiency of URID of the three major city clusters, with MRYRUA > CYUA > YRDUA. The overall efficiency declines from 2010–2015, followed by small fluctuations in 2015–2019, among which the most significant are found in CYUA, "rising first and then falling".

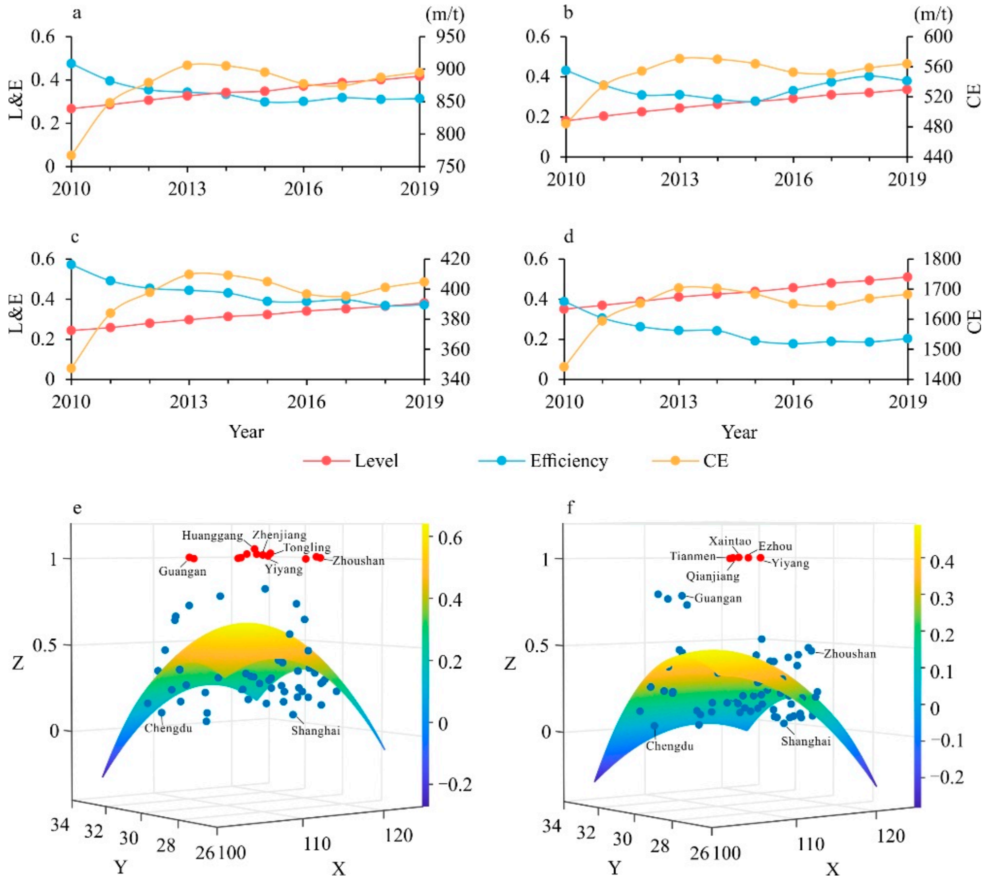

Figure 2. Changes in the level, efficiency, and surface trends of URID in the three major city clusters in the YREB. Note: (**a**) denotes the three major city clusters, (**b**) denotes CYUA, (**c**) denotes MRYRUA, (**d**) denotes YRDUA, (**e**,**f**) denote trend surface analysis of three major city clusters. Dots are efficiency values and red dots are ≥1 (effective efficiency). L&E denotes the level and efficiency of URID, CE denotes carbon emissions, Level (red line) denotes the level of URID, Efficiency (blue line) denotes the efficiency of URID, and CE (orange line) denotes carbon emissions.

The trend surface analysis method (Figure 2e,f) helps to reveal the spatial divergence in URID efficiency in the three major city clusters in the YREB. On the whole, from 2010 to 2019, the efficiency of URID in the three major city clusters roughly shows spatial divergence in an inverted U-shape in the east–west and north–south directions: MRYRUA > CYUA > YRDUA. The trend results are the same as those in Figure 2b–d. In 2010 (Figure 2e), the efficiency of URID in the east–west direction increased significantly from Shanghai, Suzhou, and Hangzhou in the eastern Yangtze River Delta city cluster to Qianjiang, Xiantao, and Ezhou in the midstream city cluster, and fell back again in the Chengdu-Chongqing city cluster, with cities such as Guang'an, Chengdu, and Chongqing. The north–south direction shows increases in efficiency from Yiyang, Tongling, and Zhoushan in the south to Huanggang, Ezhou, and Zhenjiang in the middle; it then decreases to Yancheng, Chuzhou, and Mianyang in the north. There are 13 cities with an effective urban–rural integration efficiency > 1, which are mainly concentrated in the central MRYRUA, represented by cities such as Huanggang, Qianjiang, and Yiyang. The change in the URID efficiency trend east–west in 2019 (Figure 2f) is significantly different from that in 2010, gradually increasing from the eastern YRDUA to the western CYUA and decreasing from south to north. The effective coefficient of urban–rural integration efficiency for the total region has been reduced to 5, with representative cities concentrated in the central MRYRUA, with cities such as Ezhou, Xiantao, and Yiyang.

3.2. Evolution of the Spatiotemporal Pattern of URID Efficiency at the City Level

In this paper, the city-level URID efficiency of the three major city clusters from 2010–2019 was divided into five hierarchical gradients by the natural breakpoint method in ArcGIS software, and the spatial distribution diagram for each year was drawn (Figure 3). On the whole, the efficiency of URID in each of the three major city clusters shows a decreasing trend over time in the order MRYRUA > CYUA > YRDUA, which corresponds to the results in Figure 2b–d. The first and second gradients are mainly concentrated in the midstream city cluster, the third and fourth gradients are mainly concentrated in the Chengyu city cluster, and the fifth gradient is mainly concentrated in the Yangtze River Delta city cluster.

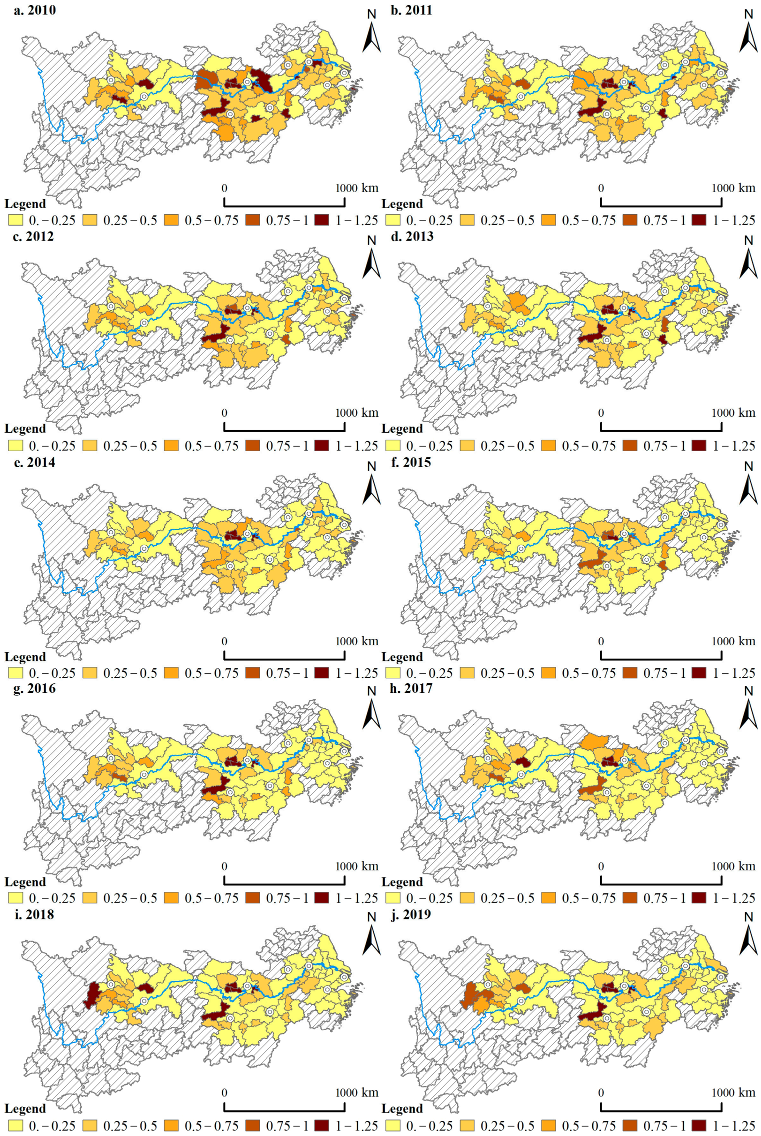

Figure 3. Schematic diagram of the spatial distribution of the efficiency of URID in the three major city clusters. Note: (**a**–**j**) denotes the spatial distribution of the efficiency of URID in the three major city clusters from 2010–2019, respectively. The efficiency of urban-rural integration development is divided into five categories, which are indicated by different colors.

Combined with the spatiotemporal trends of each city, the URID efficiency of the eastern cluster, the YRDUA, shows a decreasing trend from 2010 to 2019, with an overall mean value of 0.24. In 2010, the average value of URID efficiency was 0.39, and there were three cities with an effective efficiency in the first gradient, including Zhenjiang, Zhoushan, and Tongling; in 2011, the average value of URID efficiency of the first gradient was 0.31, and the cities with effective efficiency were reduced to 1, Tongling, while Zhoushan and Zhenjiang dropped to the third and fourth gradients, respectively. In 2012–2019, the average annual values of URID efficiency were 0.26, 0.244, 0.24, 0.19, 0.18, 0.19, 0.18, and 0.20, dominated by the fourth and fifth gradients, in which the relatively economically developed cities of Shanghai, Suzhou, Nanjing, and Hangzhou show low efficiency. From 2010 to 2019, the central midstream city group had a decreasing trend in URID efficiency, with an overall mean value of 0.43, the highest among the three city groups. In 2010, the average value of URID efficiency was 0.57, the highest of the 10 years measured, and there were eight cities with effective efficiency values in the first gradient, namely, Ezhou, Huanggang, Xiantao, Qianjiang, Tianmen, Yiyang, Yingtan, and Xinyu. In 2011, the average value of URID efficiency was 0.49 and the cities with effective efficiencies in the first gradient decreased to 6, namely, Ezhou, Xiantao, Qianjiang, Tianmen, Yiyang, and Yingtan. Huanggang and Xinyu dropped to the third and fourth gradients. The average values of URID efficiency in 2012–2019 were 0.45, 0.44, 0.43, 0.39, 0.39, 0.40, 0.37, and 0.37, mainly representing cities in the third and fourth gradients. The cities of Xiantao, Ezhou, Xiantao, Qianjiang, and Tianmen fluctuated little and remained stable in the first gradient, while the cities of Yiyang and Yingtan were more volatile and showed instability. The same low efficiency also appeared in Wuhan, Changsha, Nanchang, and other relatively economically developed cities. The overall average value of URID efficiency in western CYUA from 2010 to 2019 is 0.43, with annual averages showing a "U" shape, first decreasing, then increasing. In 2010, the average URID efficiency was 0.43, and there were two cities with effective efficiencies in the first gradient, namely, Guang'an and Zigong. From 2011 to 2015, the URID efficiency showed a decreasing trend and from 2015 to 2019, an increasing trend. The city with effective efficiency in the first gradient is Guang'an; Ya'an was added in 2018, bringing the number of cities with effective efficiency in the first gradient to two. Similar to the first two city clusters, Chengdu, Chongqing, Mianyang, and other relatively developed cities are generally inefficient.

4. Discussion

4.1. Analysis of the Changing Law of URID Efficiency

4.1.1. Analysis of the Overall Laws of Change for URID Efficiency

The results of measuring the level and efficiency of URID in the three major city clusters (Figure 2a) reveal that the level of URID, efficiency, and carbon emissions show different development trends over time. The level of URID rises linearly over time, mainly because the central government attached importance to the "three rural issues" that are part of the "urban–rural integration" and "new socialist countryside construction" that were proposed and implemented in the early stage (2003–2011). In the later stage (2012–present), "urban–rural integration", "precise poverty alleviation", "rural revitalization", and "new socialist countryside construction" policies were proposed. A series of policy strategies such as "URID" have strongly promoted the rapid development of rural areas, gradually narrowing the gap with urban areas and promoting the improvement of urban–rural integration. The overall trend of total carbon emissions is upward, showing a rapid rise from 2010 to 2014 and a temporary dip followed by a rise from 2014 to 2019. The gradual slowdown in emissions after 2014 is closely related to the transformation of the industrial structure and large-scale application of low-carbon technologies following the 2014 declaration of a "new normal" defining the new economic development stage proposed by the central government. By contrast, the efficiency of URID has generally shown a decreasing trend with the passage of time, specifically in 2010–2015. In general, cities increase their efficiency input indicators year by year, which promotes social, economic, and environmental development, and to a certain extent, improves the URID level. However, in the process of rapid urbanization and industrialization, a large number of low-end industries with crude production methods have resulted in the ineffective use of a large number of resource inputs and failed to play a practical role in the integrated development of urban and rural areas. In addition, carbon emissions grew rapidly during this period, indicating that these crude low-end industries relied on resources to a high degree, resulting in regional environmental pollution and increased urban and rural energy consumption. This is also opposite of the general trend of carbon emissions, mainly because the economy entered a new normal in 2015, with economic growth shifting from high-speed to medium-speed, from sloppy upscaling and acceleration to an intensive focus on improving quality and efficiency, and from factor investment-driven growth to quality-, innovation-, and efficiency-driven growth. The effective use of various resources resulted in a steady improvement in the level of urban–rural integration and a slowdown in the growth of carbon emissions.

4.1.2. Analysis of the Change Pattern of URID Efficiency at the City Cluster Level

There are obvious differences in the URID efficiency among city clusters. The URID efficiency of MRYRUA is the highest from 2010 to 2019, which is mainly influenced by the "Rise of Central China", the "YREB Development Strategy", and other plans. However, it is also worth noting that the efficiency values of these regions show a decline, probably due to the fact that the traditional industries, such as steel, automobiles, and transportation equipment manufacturing, are dominated by high dependence on resources and underutilization of resource inputs, resulting in increased carbon emissions and lower efficiency. From 2010 to 2015, the three major urban agglomerations showed a decreasing trend with little difference between them; from 2015 to 2019, the efficiency difference with MRYAUA and YRDUA gradually increased and showed an increasing trend (Figure 2b). The possible reason for this is that although the "Western Development" strategy proposed by the government in the early stage has promoted urban–rural integration in CYUA to a certain extent, on the whole, the infrastructure and industrial development of CYUA is weak and the resources inputs are not fully utilized, resulting in a decrease in efficiency and an increase in carbon emission. After 2015, the strong cooperation between Chongqing and Sichuan has, to a certain extent, contributed to the transformation and upgrading of their industrial structures, effective utilization of resource inputs, and improvement of efficiency. YRDUA had the lowest efficiency of URID but the highest level of URID and carbon emissions from 2010–2019 (Figure 2d). The possible reason for this is that the Yangtze River Delta region has paid more attention to URID in the past decade and its relatively high investment has contributed to the progress of its urban–rural economic, social, and environmental dimensions. However, at the same time, it must be acknowledged that the development pattern of a large number of urban and rural low-end industries in the Yangtze River Delta region is still relatively crude, resulting in a large number of less efficient inputs.

From the analysis of urban–rural function, YRDUA has developed social economy and a high urbanization rate, and the urban and rural areas play their respective functional advantages to form complementary urban–rural functions, which leads to the improvement of the level of urban–rural integrated development. There is no longer a single rural area supporting the urban area and the urban area feeding the rural area, but rather a large number of low-end and rough industrial gatherings in the rural area, which leading to s resource inputs not being ineffectively used and resulting in a large amount of carbon dioxide emission and low efficiency of urban–rural integration development. To avoid this, these areas should reasonably plan their industrial layout and increase scientific and technological innovation. CYUA and MRYRUA are relatively less developed socio-economically, with low urbanization rates, large urban–rural gaps, and better urban functions and lack of rural functions, creating single urban areas feeding rural areas and a low level of urban–rural integrated development. However, the resource inputs from urban functions to rural areas are effectively utilized, improving of the efficiency of urban–rural integration development. The future relies on the rural revitalization strategy to promote rural development, promoting the two-way flow of urban and rural elements and the mutual promotion of urban and rural functions.

4.2. Correlation between Carbon Emissions and URID Efficiency

In this paper, the efficiency of URID in 73 cities in three major city clusters was analyzed in comparison with carbon emissions; the results showed cities in three categories: positive correlation, inverse correlation, and insignificant correlation (Figure 4). There are three cities that were positively correlated, accounting for 4%. As shown in Figure 4a, the efficiency of URID in cities represented by Dazhou gradually increases with carbon emissions, which this paper believes may be due to weak socioeconomic development in cities with small economic volume, low industrialization, limited amounts of resource inputs, and low carbon emissions. Consequently, the efficiency value gradually increases with carbon emissions. However, it is worth noting that, although it becomes positive, the efficiency value fluctuates and does not form a stable trend of growth, There are 54 cities with a reverse correlation with carbon emissions, distributed in each city group, accounting for 74%, the majority of total cities. As shown in Figure 4b, the efficiency of URID represented by Wuhu decreases with the gradual increase of carbon emissions, While carbon emissions increased rapidly in 2010–2014, the efficiency value decreased, probably because of rapid urbanization and industrialization, with a large number of low-end industries with crude production methods making poor use of resource allocation and resource inputs. From 2014 to 2019, as the economy entered the "new normal", all inputs effectively improved, and the efficiency value increased with the reduction of carbon emissions. There are 16 cities, accounting for 22% of the total, that are not significantly correlated with carbon emissions; they are also distributed among all urban clusters. As shown in Figure 3c, the efficiency of URID in cities represented by Ningbo gradually flattens out with increasing carbon emissions, generating a nonsignificant correlation. Among these cities, the more socioeconomically developed the city is, the flatter the urban–rural integration efficiency is, and the larger the carbon emissions are (Figure 3d–f). It may be that resource allocation is unreasonable and the various resources inputs are used only in a limited way, resulting in the waste of some resources, high carbon emissions, and relatively low efficiency values.

4.3. Improvement of URID Efficiency

The EBM model is able to measure the redundancy of inputs, the shortfall of desired outputs, and the redundancy of undesirable outputs in terms of proportional improvement values and slack improvement values. The sum of both the proportional improvement value and the slack improvement value is the overall redundancy value [32]. The analysis of the redundancy (deficiency) of each input–output indicator can reflect the causes of efficiency loss and help to provide guidance for the improvement of URID efficiency in the three major city clusters in the YREB. This paper divides the average value of redundancy (deficiency) of each indicator for the 73 cities in the three major city clusters from 2010 to 2019 by the average value of the corresponding input (output) indicator and obtains the input redundancy rate and output insufficiency (redundancy) rate of each indicator. The calculation results are shown in Table 3.

4.3.1. Input–Output Analysis of URID Efficiency

From the perspective of input indicators, the overall redundancy rate in the three major city clusters is high. The redundancy rates of individual input indicators are all above 50%, indicating that the large amount of resource inputs has not played a practical role in promoting the integrated development of urban and rural areas. From the mean values of each input in Table 3, it is found that redundancy in the inputs for cultural, sports and media (Ip^3), energy conservation and environmental protection (Ip^6), urban and rural communities (Ip^7), and housing security expenditures (Ip^{11}) in most cities are the primary influencing factors of their efficiency loss in URID. This indicates that the three major city clusters, as strategic core areas of economic growth in the YREB, still have unbalanced urban–rural development, with inadequate rural development in the process of integrated development. Urban–rural resource allocation remains unreasonable and unbalanced, and urban–rural factor flow and distribution are still mainly one-way, with two-way interactions largely unformed.

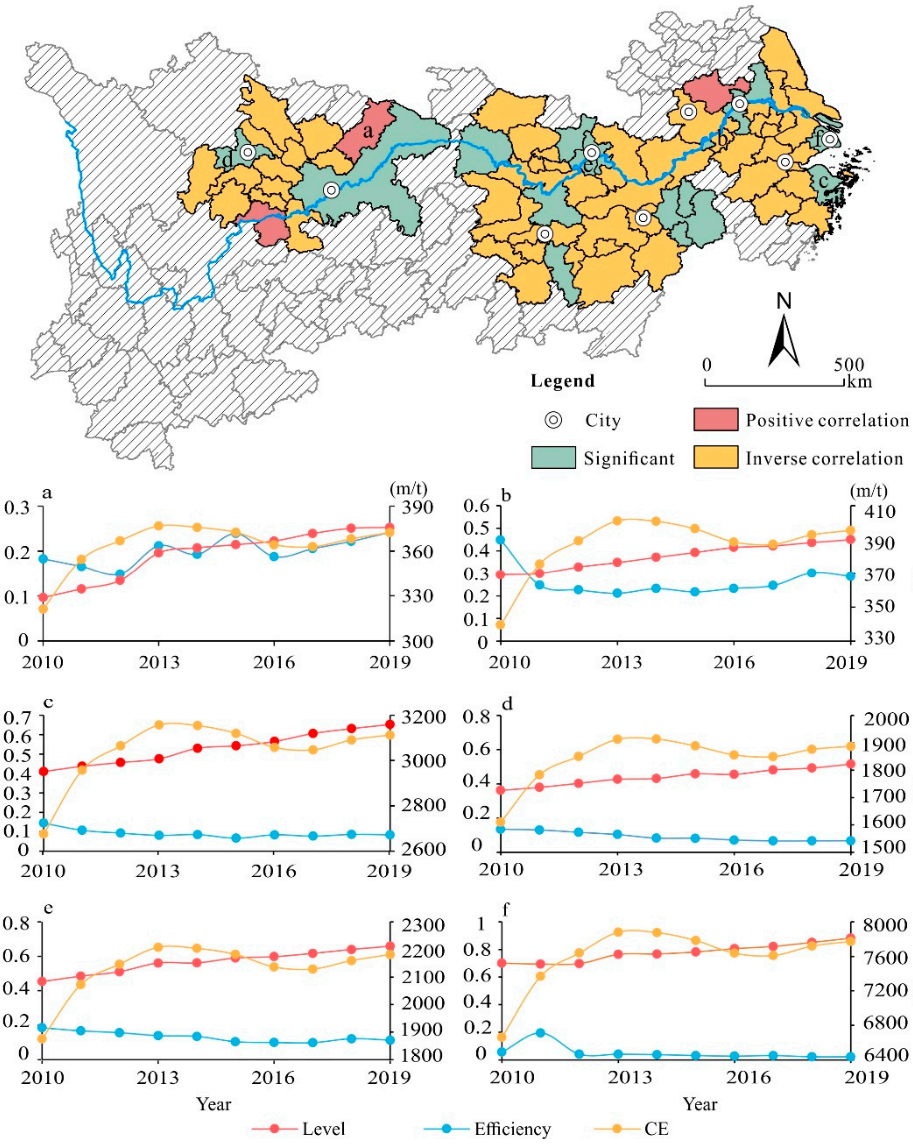

Figure 4. Schematic diagram of the spatial-temporal relationship between URID efficiency and carbon emissions in the three major city clusters. Note: (**a**) (Dazhou) denotes a positive correlation, (**b**) (Wuhu) denotes an inverse correlation, (**c**) (Ningbo) denotes an insignificant correlation, and (**d**–**f**) denote Chengdu, Wuhan, and Shanghai. L&E denotes the level and efficiency of URID, CE denotes carbon emissions, Level (red line) denotes the level of URID, efficiency (blue line) denotes the efficiency of URID, and CE (orange line) denotes carbon emissions.

In recent years, the state has strongly supported the deepening of cultural system reform, promoting the development of cultural industries especially in the countryside, building a large number of cultural centers, rural bookstores, and fitness venues, which have enriched and improved rural cultural life. There is a disconnect between the content of rural cultural construction and the needs of rural residents, a lack of innovation in cultural system construction, a shortage of cultural service personnel, and a lack of investment in construction funds, which have all hampered the role of rural cultural construction in narrowing the gap with urban areas and promoting URID. There are obvious differences between urban and rural areas in terms of energy conservation and environmental protection (Ip^6), with cities being effectively targeted as the center of gravity for pollution prevention and control, while rural areas are devoid of pollution prevention and control, which also hampers integrated urban–rural development. The urban and rural community (Ip^7) input is mainly used for urban and rural community management affairs, community planning and management, public facilities, community housing, environmental sanitation, and construction market management and supervision, which have played a certain role in promoting urban and rural social life and the improvement of urban and rural living environments. However, due to the lack of strict budgetary management in the use of these funds and the relative absence of consideration of the geographical and regional differences in the development of urban and rural communities, the performance of this indicator for promoting URID is not high. Housing security expenditure input (Ip^{11}) is mainly used to support the construction of secure housing projects and secure housing to accelerate the transformation of shantytowns and the renovation of dilapidated houses in the countryside and, in general, to improve the living conditions of urban and rural people in difficulty. This input helps improve urban and rural living conditions and narrow the gap between urban and rural integration development. However, the method for assigning land for guaranteed housing still needs to be improved, and the lack of unified and standardized planning for housing and shantytown renovation leads to unreasonable construction costs. The waste of resource inputs again inhibits the efficient and high-quality development of urban–rural integration. It is worth noting that the YRDUA is different from other city clusters in terms of investment in science and technology (Ip^2), which has a high redundancy rate, similar to the investment in energy conservation and environmental protection. The long-standing development strategy of "emphasizing urban over rural areas" has caused a serious imbalance in the investment in science and technology between urban and rural areas. The high level of redundancy in this indicator thus narrows the urban–rural development gap and promotes urban–rural integration, but the indicator's actual role in development is limited.

Table 3. Results of the input–output optimization of URID in the three major city clusters.

City	Input Redundancy Rate											Underproduction (Redundancy) Rate		
	Ip^1	**Ip^2**	**Ip^3**	**Ip^4**	**Ip^5**	**Ip^6**	**Ip^7**	**Ip^8**	**Ip^9**	**Ip^{10}**	**Ip^{11}**	**Op^1**	**Op^2**	**Op^3**
CYUA	−0.69	−0.54	−0.79	−0.71	−0.74	−0.80	−0.78	−0.70	−0.66	−0.63	−0.85	0.54	1.42	−0.62
MRYRUA	−0.57	−0.58	−0.59	−0.59	−0.54	−0.62	−0.68	−0.53	−0.51	−0.53	−0.60	0.45	1.38	−0.54
YRDUA	−0.76	−0.87	−0.82	−0.66	−0.70	−0.76	−0.90	−0.67	−0.68	−0.71	−0.77	0.60	3.91	−0.78
Average value	−0.66	−0.68	−0.71	−0.64	−0.64	−0.71	−0.78	−0.62	−0.60	−0.62	−0.71	0.52	2.29	−0.64

Note: 1. Negative numbers in the table indicate that the input is redundant and positive numbers indicate that the output is insufficient. The redundancy (insufficiency) rate refers to the absolute value of the corresponding value of each indicator. 2. The color blocks in the table represent the top three indicators of the redundancy rate. CYUA = Chengyu Urban Agglomeration, MRYRUA = Urban Agglomeration in the Middle Reaches of the Yangtze River, YRDUA = Yangtze River Delta Urban Agglomeration.

The output deficiency (redundancy) rate varies widely among city clusters, which is related to factors such as resource endowment and industrial structure in different cities. The YRDUA has the highest deficiency rate in desired outputs and the highest redundancy rate in unexpected outputs. This indicates that the efficiency of URID in the YRDUA is also largely constrained by output deficiency in URID level and the excess of carbon emissions, which is consistent with the findings of Figures 2d and 4f above. Comparing the desired output deficiency rate and the unexpected output redundancy rate of each city, it can be found that the impact of excessive carbon emissions on efficiency loss in URID is relatively large.

4.3.2. URID Efficiency Input–Output Path Optimization

In terms of improving the efficiency of integrated urban–rural development, the above indicators have great potential for improving resource utilization. Culture, sports, and media (Ip^3) should be oriented toward normalizing rural cultural services and optimizing its financial input structure. The construction of grassroots cultural teams should be increased; mass cultural workers, folk artists, professional cultural workers, comprehensive law enforcement managers, and other cultural teams should all be trained; the healthy development of rural private culture should be actively guided and encouraged, and rural cultural teams should continue to grow. To make full use of the advantages of rural cultural resources, combined with the actual needs of rural residents, the creation of innovative rural cultural industries, such as the Chongqing Fengjie "navel orange cultural festival" and Hubei Zigui commemorative Qu Yuan "dragon boat race" competition, are needed to enrich local cultural life and simultaneously promote the development of local tourism. Rural grassroots cultural institutions should be reformed and improved, as should mechanisms to improve the effectiveness of rural public cultural services. Townships are the link between rural and urban areas; the cultural construction of townships has an influential effect on the surrounding rural areas, which can be promoted through "new urbanization". A stable growth mechanism for financial investment in rural energy conservation and environmental protection is needed (Ip^6), and the financial investment structure for energy conservation and environmental protection should be optimized. Green and clean energy should be promoted, such as the construction of natural gas pipelines, photovoltaic power generation, and other green and clean energy to support rural households. The "toilet revolution" should be accelerated, fully popularizing rural public toilets, connecting domestic sewage treatment, and promoting the effective treatment or resource utilization of toilet sewage and manure. Rural household garbage collection should be connected with village collection, transportation to local waste facilities, and the district treatment system. The concept of urban and rural communities should be strengthened (Ip^7). Budget management should be funded and special personnel for budget management should be hired to refine fund management and optimize the fund input structure for urban and rural communities. A strict budget monitoring and assessment system should be established and developed, with a budget information feedback system; the budget implementation should be widely publicized so that residents are more willing to accept public supervision and reporting. The housing security expenditure (Ip^{11}) focuses on the construction of secure housing projects, promoting the construction of secure housing while increasing investment in the countryside, carrying out scientific and reasonable architectural planning and renovation according to the resource endowments of different villages, reducing unnecessary resource investments, and narrowing the gap between urban and rural areas.

Further analysis of the input–output path optimization of each city cluster was conducted. The input–output results of the CYUA show that the redundancy of housing security expenditure (Ip^{11}) inputs is the primary cause of efficiency loss. Housing security (Ip^{11}) in the Chengdu-Chongqing city cluster can be improved through the following measures. First, liaisons for housing security in the Chengdu-Chongqing city cluster should be established with regular joint meetings and collaboration to promote the improvement of the housing security system. Second, each housing and urban–rural development management authority in the Chengdu-Chongqing city cluster should adhere to integration and coordination plans to promote the construction of guaranteed rental housing and improve the accuracy of guaranteed housing and the efficient utilization of public rentals, further standardizing public rental housing. Third, the common construction and sharing of housing security information in the CYUA should be promoted. The housing security policies of each city should be centralized and unified, including the channels for application for residency in each city in the CYUA. Most of the villages in the CYUA are located in mountainous areas with complicated terrain, so reasonable planning and transformation with engineers should be carried out according to local conditions to reduce unnecessary resource inputs. The redundancy of investment in urban and rural communities (Ip^7) is the primary reason for the loss of input–output efficiency in the city clusters in the middle reaches and the YRDUA. By optimizing financial investments, the use of funds in urban and rural communities can be improved. According to the actual needs of residents, various special funds should be budgeted, and the community fund budget should be reasonably arranged and refined. The next step is to conduct in-depth investigation and research on ways to expand the use of community funds, effectively integrating funds and maximizing benefits. Third, the community should strictly allocate funds for special purposes and separate accounts. Fourth, the construction of smart community infrastructure should be promoted, improving the smart community governance system and building an open community service complex. Examples include "Community Access" in Baoshan District, Shanghai [50] and "Garden Digital Village" in Zhejiang [51]. In addition to urban and rural community (Ip^7) input, the energy saving and environmental protection (Ip^6) input results in a large loss of efficiency in the city cluster in the middle reaches of the Yangtze River; these inputs can be assessed with actual needs, and resources can be moved toward rural areas through reasonable budgeting to accelerate the improvement of rural infrastructure for environmental protection. The science and technology input (Ip^2) is a source of a large loss of efficiency for the YRDUA, which should optimize the structure of expenditures for science and technology to reasonably distribute the ratio of technology inputs between urban and rural locations. Rural modern agricultural science and technology research should be improved and the results converted into practices. The advantages of the density of universities, high-tech enterprises, and scientific research institutions in the Yangtze River Delta city cluster should be optimized to accelerate improvement in industry–university research and optimize the training and management of scientific research talent.

It is noteworthy that the high output deficiency (redundancy) rate of the URID level and carbon emissions in Table 3 has a negative impact on URID efficiency. Considering carbon emissions as an important indicator of the quality of URID, as it is closely related to urban–rural social and economic activities, the inclusion of carbon emissions in assessments of URID levels can more objectively review whether low-carbon and sustainable URID has been achieved. Ignoring carbon emissions as a unexpected output will lead to overestimation of the efficiency of URID. In view of the impact of the high rate of carbon emissions on output deficiency (redundancy) leading to loss of URID efficiency, the development of regional urban–rural integration should be guided toward sustainable development with the concept of "innovation, coordination, green, openness and sharing". Under the framework of a top-level design, the high energy-consuming, high-polluting, and high-emission enterprises in the industrial chain should be gradually phased out by increasing the supervision of emission reduction policies and improving the carbon trading market and its operations. With these measures in place, competition should be reasonably introduced to gradually eliminate enterprises with high energy consumption, high pollution, and high emissions in the industrial chain. The removal of these low performing enterprises will eliminate the restraining effect of environmental factors such as carbon emissions on the efficient and high-quality development of urban–rural integration

There are certain limitations to this study. First, the indicator system of URID needs to be improved, because the unavailability of data makes it difficult to reflect URID comprehensively. In future data updates, the indicator system should be improved, for example, to supplement the space integration indicators, and the output indicators should be considered to include indicators such as poverty headcount and Gini coefficient, because they can reflect the differences in income distribution between urban and rural residents. Secondly, the continuous development of satellite remote sensing technology provides some potential data for the study of urban–rural integration development, and relevant technical methods should be strengthened in further research to extract new data to more comprehensively evaluate URID. Finally, future research address efficiency input–output analysis by using quantitative methods to further in-depth analysis of the mechanism.

5. Conclusions

Based on the vertical and horizontal spread method, the EBM superefficiency model, and the trend surface analysis method, and considering the undesired output of carbon emissions, this paper studies the urban and rural areas of 73 cities in the three major city clusters of the YREB from 2010 to 2019. The efficiency of URID and the characteristics of its temporal and spatial evolution are revealed, and correlations are identified for some cities between URID efficiency and carbon emissions. Efficiency improvement analysis is conducted for all three major city clusters. The main conclusions drawn from the study are as follows:

(1) The level of URID in the three major city clusters in the YREB during 2010–2019 showed a steady improvement; the total carbon emissions showed an overall upward trend, as shown by a rapid upward phase from 2010 to 2014, and a temporary decline and recovery from 2014 to 2019. The overall trend of URID efficiency is decreasing.

(2) The URID efficiency of the three major city clusters in the YREB is spatially distributed in decreasing order from MRYRUA > CYUA > YRDUA, and the gap between cities is gradually widening. In cities with better economic development, the URID level is generally higher than that of cities with average economic development, while the URID efficiency is low.

(3) The URID efficiency of the majority of the 73 cities in the three major city clusters is mainly inversely correlated with carbon emissions and decreases inversely with the gradual increase in carbon emissions. The more developed the socioeconomic structure of the cities is, the flatter the urban–rural integration efficiency is, and the larger the carbon emissions are.

(4) Regarding the input–output efficiency in the URID, the overall redundancy rate of the three major city clusters in the YREB is high in each input indicator, though the redundancy rate of each input indicator varies. Among these indicators, the redundancy of inputs into cultural, sports and media support, energy conservation and environmental protection, urban and rural communities, and housing security expenditures is the primary influence on efficiency loss; in addition, the redundancy of carbon emissions also has an impact on efficiency loss in the URID. Based on these results, optimization paths to improve the efficiency of the URID in the three major city clusters are proposed.

Author Contributions: Conceptualization, G.M., S.H. and L.T.; methodology, G.M., S.Q. and Z.H.; data curation, H.H.; writing—original draft preparation, G.M.; writing—review and editing, S.H., Z.W. and L.T. All authors have read and agreed to the published version of the manuscript.

Funding: This work was supported by the Key Project from the National Social Science Foundation of China (grant no. 18ZDA053).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data used in this study can be obtained by contacting the corresponding author.

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

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