land

MDPI

Article

Coupling Coordination Development of New-Type Urbanization and Cultivated Land Low-Carbon Utilization in the Yangtze River Delta, China

Yue Zhang, Yaqiang Dai, Yuanyuan Chen and Xinli Ke *

College of Public Administration, Huazhong Agricultural University, Wuhan 430070, China;
yuez@webmail.hzau.edu.cn (Y.Z.); yaqiang_dai@webmail.hzau.edu.cn (Y.D.);
chenyuan2022@webmail.hzau.edu.cn (Y.C.)
* Correspondence: kexl@mail.hzau.edu.cn; Tel.: +86-18696161515

Abstract: Although urbanization greatly benefits economy-society development in China, it poses enormous challenges to cultivated land utilization. In the context of urbanization acceleration and carbon neutrality, it's of significance to achieve high-quality economy-society development and sustainable agricultural development. Thus, the coupling coordination relationship between new-type urbanization and cultivated land low-carbon utilization (CLLCU) needs to be examined. However, this topic has not been adequately addressed in previous studies. To fill the gap, this paper adopted a comprehensive evaluation model and a super-efficiency SBM (Slacked Based Measure) model to evaluate the level of new-type urbanization and the cultivated land low-carbon utilization efficiency (CLLCUE) of cities in the Yangtze River Delta in China from 2000 to 2018. Furthermore, the coupling coordination degree model (CCDM) and the relative development degree model (RDDM) were employed to measure the coupling coordination degree and the relative state of the new-type urbanization and CLLCU The results show that the coupling coordination degree between the new-type urbanization level and CLLCUE experienced a process of "rapid increase-steady develop" and presented a spatial pattern of "polarization-regional equilibrium". In addition, the relative state of the new-type urbanization and CLLCU presented the "reversal" phenomenon. In other words, the relative state changed from the new-type urbanization lagging behind CLLCU to the new-type urbanization ahead of CLLCU. None of the cities were in the state of simultaneous development. Finally, this paper puts forward policy recommendations to explore differentiated CLLCU modes and improve the quality and efficiency of new-type urbanization.

Keywords: the Yangtze River Delta; new-type urbanization; cultivated land low-carbon utilization; coupling coordination

1. Introduction

Urbanization is the process of urban spatial expansion whereby non-agricultural industries and populations gather in cities and towns [1,2]. With the recovery and growth of the global economy, urbanization has become the mainstream and increased steadily in both developed and developing countries. The urban population proportion rose from 39% in 1980 to 55% in 2018, and is as high as 82% in north America and as low as 43% in Africa in 2018 [3–5]. High-speed urbanization and industrialization comes at the cost of more ecological resource consumption, ultimately resulting in resource degradation and environmental pollution, especially for agro-ecological environment, which has drawn great attention from countries around the world. Future earth, the United Nations' 2030 Agenda for Sustainable Development, and the Agricultural Protection and Food Control Act emphasize the coupling coordinated development of agricultural ecosystem and economic system [6,7]. As a country with a long history of agriculture and a large-scale rural population, China has experienced a massive scale of urbanization

since the reform and opening-up. The urbanization level in China has soared from 17.92% to 59.58% from 1978 to 2018, with an average annual growth rate of 3% [8]. China's urbanization releases the potential and accelerates to outpace the global level continuously, creating a miracle of fast urbanization development.

In spite of considerable progress in urbanization, China faces constraints and challenges in the dual choice of high-quality urbanization and ecological protection. Driven by the overexploitation of urban areas and the agglomeration of urban population [9,10], the improvement of urban radiation capacity exerts impacts on the surrounding cultivated land and agriculture production [11]. To ensure food provision with shrinking cultivated land, the extensive utilization relying on agricultural material consumption has become the predominant mode of cultivated land utilization. Excessive input and inefficient use of high-carbon production materials increase evidently, such as fertilizers, pesticides, plastic film, and agricultural machinery [12–14]. The economy-society benefits are at the cost of more carbon emissions directly or indirectly [15,16]. Since the developing concept of "innovative, coordinated, green, open, and shared" was put forward, green agriculture has become an inevitable trend [17]. Thus, cultivated land low-carbon utilization (CLLCU) becomes an essential approach to achieving the goal. The core task of CLLCU is to reduce high-carbon agricultural material investment to promote ecological functions and reduce carbon emissions while ensuring benefits, which effectively drives green agriculture development in China.

There is a consensus that interactive coupling between urbanization and cultivated land utilization is an open, massive, and complex system [18,19]. Specifically, urbanization not only creates positive externalities through technological innovation and shared information, such as outstanding economic growth and increasing farming production, but also generates negative externalities in the quantity-quality-ecology of cultivated land [9,20]. In details, recent studies have found that cultivated land significantly decreased due to uneven patterns of urban sprawl in different geographical regions [21,22]. In addition to the reduction in quantity, the massive loss of high-quality cultivated land in peri-urban areas leads to a decline in the cultivated land quality and productivity. At the same time, the large-scale infrastructure construction in the process of urbanization easily results in ecological problems, such as soil degradation and soil erosion, which destroy the ecology of cultivated land. Although urbanization imposes pressure on cultivated land, its active role in promoting the benefits and efficiency of cultivated land utilization is gradually becoming identified. Urbanization drives the transition of cultivated land utilization through scale management and intensive development [23,24]. In turn, due to the efficient pattern of cultivated land utilization, agricultural development guarantees the coordination of the urban-rural relationship by the growing agriculture production, surplus labor, ecosystem services, and development space [25–27]. Therefore, urbanization and cultivated land utilization have formed reciprocal, supportive, symbiotic relationships.

To investigate the interactions, the first step is to evaluate the level of urbanization and cultivated land utilization. In terms of the urbanization level, the measurement framework mainly contains two aspects, the single attribute and comprehensive dimensions. The single index usually refers to the degree of population urbanization and land urbanization [28–31]. Comprehensive urbanization includes multiple aspects, such as population, spatial, economy, society, ecology and so on [32–35]. In terms of cultivated land utilization level, cultivated land utilization efficiency is an important indicator that demonstrates the rationality of various input factors in cultivated land utilization and the realized value of cultivated land resources in agricultural production [36–38]. Currently, there has not formed a unified standard to evaluate cultivated land utilization efficiency. Kendall initially measured the cultivated land utilization efficiency based on the output per unit area [39,40]. Since then, other common indicators for cultivated land utilization efficiency have appeared, for instance, yield ratio [41], the land equivalent ratio [42], and the area-time equivalent ratio [43]. Notably, the complex process of cultivated land utilization can also

include undesirable outputs. The measurement of input-output structure is supposed to be a more comprehensive method to evaluate the cultivated land utilization efficiency.

In general, most studies on cultivated land efficiency focus on the economic and social benefits, referring to economic contribution and food provision, which neglect the carbon sequestration and carbon emissions of cultivated land utilization synchronously. Cultivated land has dual attributes of carbon source and carbon sink [44–46]. In other words, it potentially improves carbon sequestration and reduces carbon emissions. If the dual carbon effects caused by cultivated land utilization are not taken into account, the evaluation of cultivated land utilization efficiency will inevitably lead to a biased reflection of the actual situation. Therefore, this study aimed to develop an overall framework to analyze the evolution trend and coordination development of new-type urbanization and CLLCU. First, this study analyzed the theoretical mechanism of coupling coordination development between new-type urbanization and CLLCU. The comprehensive index system was constructed to evaluate the new-type urbanization and CLLCU. Second, the evolution trend of new-type urbanization and CLLCU were demonstrated. Finally, taking the Yangtze River Delta (YRD) as an example, we identified the coupling coordination relationship between new-type urbanization and CLLCU between 2000 and 2018.

Compared with the previous research, this study has two main innovations and contributions: (1) Method innovation. The study constructed an overall index system of cultivated land low-carbon utilization efficiency (CLLCUE), taking both carbon sequestration and carbon emissions into consideration. In addition, the Super-SBM model was employed to calculate utilization efficiency with undesirable outputs. The final results not only reflected the negative effect scientifically, but also distinguished multiple valid units adequately. (2) Perspective innovation. The study provided the theoretical mechanism of coupling coordination development between new-type urbanization and CLLCU. Based on the comprehensive evaluation of new-type urbanization and CLLCU, the dynamic evolution trend of new-type urbanization and CLLCU was described. And the coupling coordination development and relative development of new-type urbanization and CLLCU were analyzed.

The paper is structured as follows. Section 2 constructs the theoretical mechanism of coupling coordination development between new-type urbanization and CLLCU. Section 3 introduces the methodology and the data source. Section 4 describes the spatio-temporal evolution trend of new-type urbanization and CLLCUE, which analyzes the coupling coordination degree and relative development degree of new-type urbanization and CLLCUE. Section 5 includes a discussion of the relationship between new-type urbanization and CLLCU, similarities and differences compared with previous studies, and limitations of this paper. Section 6 draws main conclusions and provides policy implications.

2. Theoretical Framework

2.1. The Concept of New-Type Urbanization

Urbanization is the process transforming from a traditional rural society dominated by agriculture to a modern urban society dominated by non-agricultural industry [47]. Since the reform and opening up, China's urbanization has continually accelerated, creating a miracle of large-scale global urbanization. The rapid advancement of urbanization has absorbed a large number of rural laborers for non-agricultural employment, improved the utilization efficiency of urban-rural production factors, and promoted rapid socioeconomic development. Urbanization has become not only an important driving force for economic growth, industrial transformation, and regional coordinated development but also the powerful engine for China's socialist modernization course. Traditional urbanization is typically characterized by a massive migration of rural populations, rapid urban land expansion, and pre-emptive growth of urban economy [48]. It takes resource expenditure as the driving force for economy development, forming a high-cost, high-pollution, high-emission, and low-efficiency development model. Although traditional urbanization has promoted the national economy development and social structure transformation to a

certain extent, the concomitant contradictions and problems are hardly ignored, such as extensive land utilization, unbalanced spatial distribution, inefficient public services, and frequent environmental problems. These problems have seriously hindered the stable and benign development of urbanization [49].

Since entering the decisive stage of building a moderately prosperous society in an all-round way and the transition stage of economy-society development, the Chinese government proposed a strategy to construct new-type urbanization on the basis of the comprehensive understanding of urbanization status and the scientific judgment of future trend. In particular, following the people-oriented and ecological civilization concept, the new-type urbanization advocates the basic principles of fair sharing, urban-rural integration, layout optimization, ecological civilization, and low carbon [49]. It aims to achieve the comprehensive, coordinated, and sustainable development of the economy, society, and ecology [50]. Therefore, new-type urbanization is a strategic choice for China's modernization course and a huge driving force for high-quality growth.

In order to fully demonstrate the people-oriented and ecological civilization concept, the new-type urbanization emphasizes an all-dimensional, multi-layered and wide-ranging construction pattern, covering demographic, spatial, economic, social, and ecological urbanization [33,51]. To be specific, demographic urbanization emphasizes the orderly transfer and stable development of rural populations, reflecting the absorption and resettlement capacity for population migration. Spatial urbanization underlines the matching of urban expansion and population growth, reflecting the expansion speed and intensive degree of urban space utilization. Economic urbanization emphasizes the level and scale of economic output, reflecting the improvement of social economy and residents' welfare. Social urbanization emphasizes the quality improvement and fair sharing of public services, reflecting the guaranteed degree of urbanization construction for residents' living security. Ecological urbanization highlights a resource-conserving and environmental-friendly development mode, reflecting the mitigation method of keeping balance between urbanization construction and ecological protection. Thus, the above five dimensions represents both quantity and quality of new-type urbanization development.

2.2. The Concept of CLLCU

Land use is a process in which massive materials, information and energy are circulated, combined and transferred in the human-resource-environment system, reflecting the interaction and mutual restriction of economic, social and ecological subsystems [52]. As the link between the natural geographical process and economy-society actions, land use is not only a specific means to achieve economy-society growth but also an important activity to reflect the concept of resource conservation and environmental protection. Cultivated land is an important component of land resources which provide the essential basis for food security, agricultural development and social stability. According to the resource endowment, cultivated land utilization aims to obtain multiple benefits through a certain input of production factors (e.g., labor and capital).

To achieve the carbon neutrality goal and promote ecological civilization construction, cultivated land utilization should meet the demands of economy-society development and maintain the balance between human society and the ecological environment [36]. Therefore, CLLCU has become an important means for sustainable cultivated land utilization, and an important guarantee for high-quality agricultural development [53]. Particularly, based on scientific input/output structure, CLLCU refers to a new concept and mode of sustainable utilization aiming to reduce carbon emissions and alleviate the negative ecological effects of cultivated land utilization, which takes economic, social, and ecological benefits into consideration [54]. Differing from the traditional cultivated land utilization with extensive inputs and high carbon emissions, CLLCU improves economy-society-environment benefits by using moderate production investment, advanced production technology and a complete management system. At the same time, under the reasonable constraints of environmental protection, CLLCU reduces undesirable carbon emissions as

much as possible to realize efficient, green and sustainable utilization goals. Rooted in the concept of CLLCU, CLLCUE refers to the comprehensive reflection of production inputs (i.e., land, labor and capital) and targeted outputs (i.e., economic, social and ecological benefits) under the current conditions of cultivated land endowment and agricultural production technology. In conclusion, CLLCUE is an important indicator to evaluate both the economy-society-environment benefits and negative carbon emission effect with the cost of production inputs in the process of cultivated land utilization.

2.3. The Mechanism of Coupling Coordination Development between New-Type Urbanization and CLLCU

Coupling refers to the interaction between subsystems to form a complex structure and provide comprehensive functions and utility [55]. The coupling state can be divided into positive coupling and negative coupling [56]. Positive coupling refers to those subsystems which generate a promotion effect through orderly interaction, while negative coupling refers to subsystems generating a restraint effect through disorderly interaction. New-type urbanization and CLLCU are essential practices in the transition period of Chinese economic society. The mutual effect indicates the close connection between the development goals and the realization path. The mechanism of coupling coordination development between new-type urbanization and CLLCU is demonstrated in Figure 1.
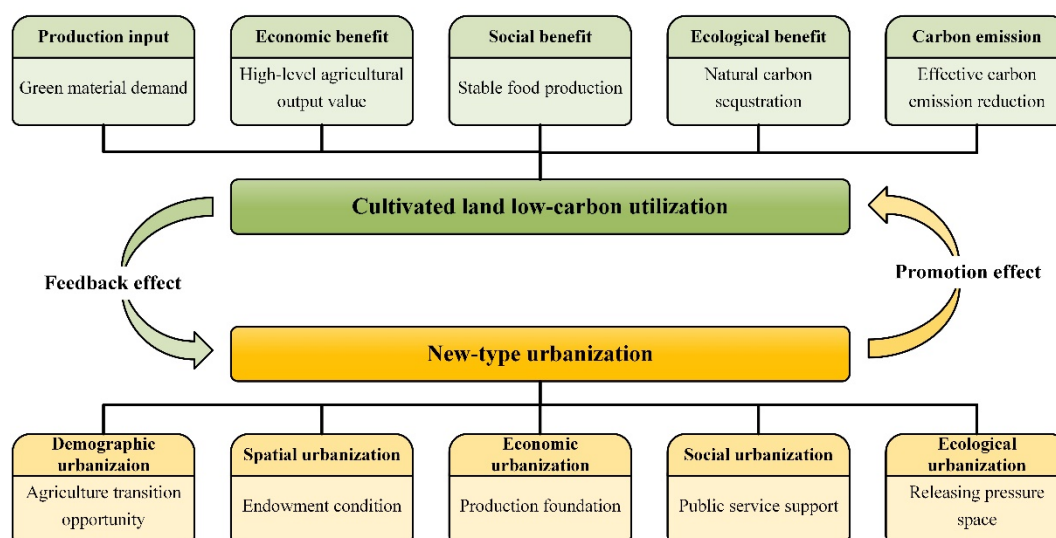

Figure 1. Mechanism of coupling coordination development between new-type urbanization and CLLCU.

New-type urbanization has a driving effect on CLLCU. It provides an internal driving force and development foundation for CLLCU. Firstly, new-type urbanization is guided by people-oriented principle, referring to accelerating the transfer of rural populations to urban areas, which effectively promotes the agricultural labor migration and creates an opportunity to transform traditional cultivated land utilization into CLLCU [57]. Secondly, new-type urbanization alleviates the conflict between urban construction and cultivated land utilization by promoting intensive urban land utilization, which mitigates the quantity and quality loss of cultivated land. Thirdly, new-type urbanization emphasizes high-quality economic development, which accelerates the flow and spillover of important production factors, such as capital and technology, to agriculture [58]. It can provide the internal driving force for CLLCU. Fourthly, new-type urbanization strengthens the urban-rural integration and public infrastructure construction, which comprehensively affects cultivated land utilization and agricultural development modes, and has a radiating effect on CLLCU and sustainable agriculture development [59]. Fifthly, new-type urbanization advocates the environment-friendly transformation path led by the targets of environmental governance

and carbon emission reduction [50]. It can reduce the ecological and environmental costs and provide the space to achieve CLLCU and sustainable agriculture development.

CLLCU has a feedback effect on new-type urbanization and provides the material basis and continuous assistance for the new-type urbanization. CLLCU not only pursues high-level, high-quality economy-society-environment benefits, but also emphasizes the co-ordinated coexistence and harmonious development of the human-resource-environment, which is the high-level and multi-objective land use [14]. CLLCU transforms the advan-tages of agriculture and rural development into the basis for urban-rural integration to establish urban-rural links and achieve comprehensive development. Firstly, the moderate and scientific production mode of CLLCU generates the demand for intensive, green, and sustainable production factors, which promotes the high-quality and healthy development of new-type urbanization [8]. Secondly, CLLCU pursues the coordination of the economy-society-environment benefits, which provides a stable and green material guarantee and ecological base for constructing new-type urbanization. Meanwhile, CLLCU realizes effi-cient, intensive, and sustainable utilization of cultivated land by reducing carbon emissions, reducing the negative externalities, and releasing environmental pressure of cultivated land use, which continuously contributes to the healthy and stable development of new-type urbanization.

3. Methodology and Data

3.1. Study Area

The Yangtze River Delta (YRD) is China's largest urban agglomeration and rapid urbanization development region in China, composed of 16 prefecture-level cities (Figure 2). Due to its excellent natural conditions and high-quality cultivated land, the YRD has become an important food production region in China [60]. Driven by the rapid economic growth and disordered urban expansion, the cultivated land in the YRD has shrunk rapidly, resulting in a decline in agricultural output [61]. At the same time, owing to the extensive use of agricultural machinery and the continuous input of high-carbon materials such as pesticides and fertilizers, the cultivated land utilization intensity and carbon emissions in the YRD have continued to increase [61].
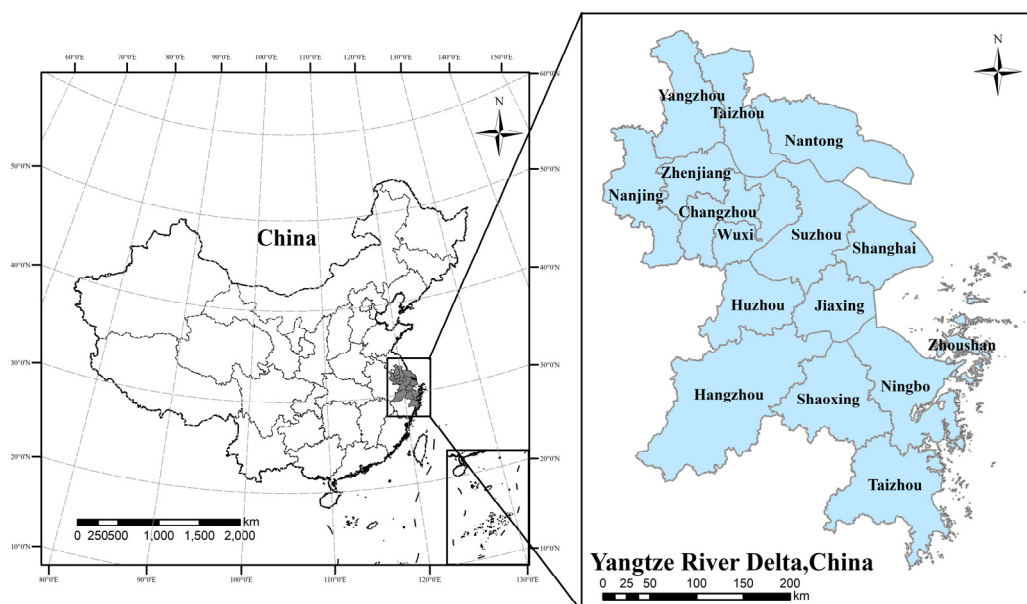

Figure 2. Location of the study area.

3.2. Methodologies

The research methods and main processes adopted in this study are shown in Figure 3, including the following procedures: (1) constructing the appropriate indicator systems for

new-type urbanization level and CLLCUE through literature research; (2) evaluating the new-type urbanization level and CLLCUE with the linear weighting method and Super-SBM model, respectively; (3) analyzing the coupling coordination development and relative development of new-type urbanization level and CLLCUE with coupling coordination degree model (CCDM) and relative development degree model (RDDM), respectively. The specific research methods are described as follows.
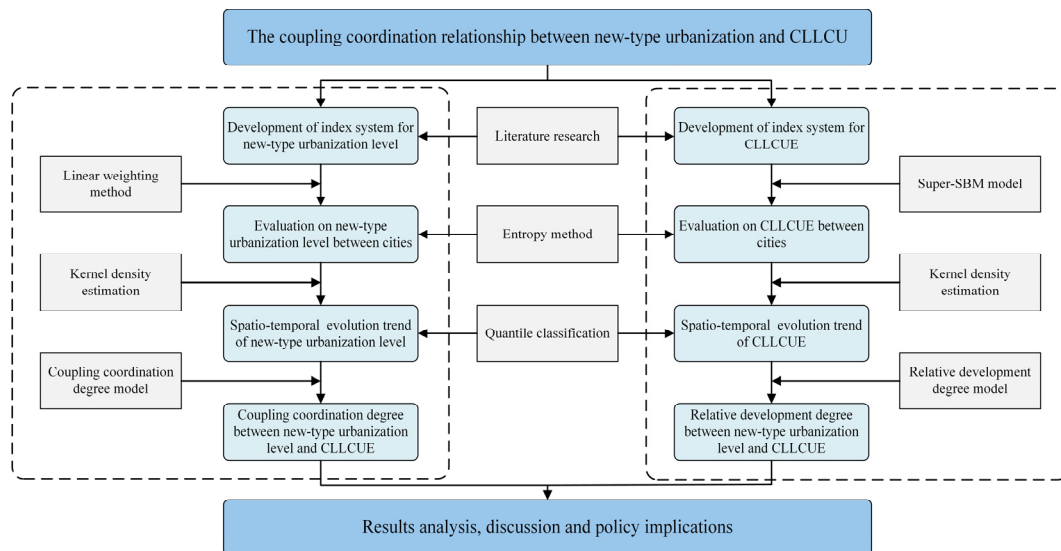

Figure 3. Evaluation framework of coupling coordination relationship between new-type urbanization and CLLCU.

3.2.1. Evaluation of New-Type Urbanization

Based on the concept of new-type urbanization, the new-type urbanization level is described in five dimensions: demographic, spatial, economic, social, and ecological urbanization. Specifically, demographic urbanization is indicated by the proportion of urban population, the urban registered rate and the proportion of labor force in secondary and tertiary industries. Particularly, the proportion of urban population reflects the scale of population migration. The proportion of the labor force in secondary and tertiary industries and the urban registered rate reflects the employment mode and stability of the population. Spatial urbanization is indicated by the built-up area, the urban road area and the urban population density. Particularly, the built-up area and urban road area reflect the degree of urban land development, and the urban population density reflects the matching between urban land expansion and urban population absorption. Economic urbanization is indicated by the per capita GDP, the per capita disposable income of urban residents and the total investment in fixed assets. The above indicators reflect economic growth and residents' benefits. Social urbanization is indicated by the number of hospital beds per 10,000 people, the number of people with unemployment insurance and the number of people with endowment insurance. The above indicators reflect the public service security and residents' life quality. Ecological urbanization is indicated by the per capita cultivated land, energy consumption per GDP and the total investment in environmental pollution treatment. Particularly, the per capita cultivated land and energy consumption per GDP reflect the load and consumption of material resources in the process of new-type urbanization, and the total investment in environmental pollution treatment reflects the government's attention to environmental pollution and its ability to control pollution.

There are three main functions of indicators, including quantification, simplification, and communication. In line with it, this paper adopts the following indicator selection criteria: (1) the indicator system should be comprehensive to reflect the concept of new-type urbanization; (2) the indicators should be representative; (3) indicators should be chosen

in the simplest form to facilitate data collection. Therefore, the new-type urbanization indicator system consists of 5 primary and 15 secondary indicators (Table 1).

Table 1. Evaluation indicator system of new-type urbanization.

System	Primary Indicator	Secondary Indicator	Indicator Type	References
New-type urbanization	Demographic urbanization	Proportion of urban population (%)	+	Li et al. [19]
		Urban registered unemployment rate(%)	−	Xiong and Xu [62]
		Proportion of labor force in secondary and tertiary industries(%)	+	Zhu et al. [63]
	Spatial urbanization	Built-up area (km^2)	−	Cai et al. [5]
		Urban road area (km^2)	+	Cai et al. [5]
		Urban population density (people/km^2)	−	Peng et al. [64]
	Economic urbanization	Per capita GDP (yuan)	+	Cai et al. [5]
		Per capita disposable income of urban residents (yuan)	+	Xiong and Xu [62]
		Total investment in fixed assets (yuan)	+	Ding et al. [65]
	Social urbanization	Number of hospital beds per 10,000 people	+	Li et al. [19]
		Number of people with unemployment insurance	+	Yang et al. [66]
		Number of people with endowment insurance	+	Xiong and Xu [62]
	Ecological urbanization	Per capita cultivated land (km^2/people)	+	Zhao et al. [67]
		Energy consumption per GDP (ton/10,000 yuan)	−	Zhao et al. [67]
		Total investment in environmental pollution treatment (yuan)	+	Fan et al. [68]

The new-type urbanization level is calculated based on the following two procedures: (1) the entropy method was applied to determine the weight of each indicator. The entropy method is based on the dispersion degree of the evaluation indicators, which has been widely used in many fields due to its objectivity, comprehensive and less complexity [69]; (2) the linear weighting method was adopted to calculate the new-type urbanization level. The specific new-type urbanization calculation steps are as follows.

(1) Normalize the data with the maximum-minimum method

$$X'_{ij} = (X_{ij} - minX_{ij})/(maxX_j - minX_j) \text{ (for positive indicator)} \tag{1}$$

$$X'_{ij} = (maxX_{ij} - X_{ij})/(maxX_j - minX_j) \text{ (for negative indicator)} \tag{2}$$

(2) Calculate the proportion of the indicator *j* for city *i*.

$$P_{ij} = X'_{ij} / \sum_{i=1}^{n} X'_{ij} \tag{3}$$

(3) Calculate the entropy value of the indicator j.

$$e_j = -1/lnm \sum_{i=1}^{m} P_{ij}lnP_{ij} \tag{4}$$

(4) Calculate the weight of the indicator j.

$$w_j = \left(1 - e_j\right) / \sum_{i=1}^{n} \left(1 - e_j\right) \tag{5}$$

(5) Calculate the new-type urbanization level.

$$U_i = \sum_{i=1}^{n} w_j X'_{ij} \tag{6}$$

where U_i represents the new-type urbanization level, w_j represents the weight value of indicator j, X'_{ij} represents the stand value of indicator j for city i, and n represents the number of indicators.

3.2.2. Measurement of Cultivated Land Low-Carbon Utilization Efficiency (CLLCUE)

Based on the concept of CLLCU, 11 variables were selected to construct a measurement system of the CLLCUE according to existing literature (Table 2).

Table 2. Input and output variables for measuring the CLLCUE.

Element	Variable	Unit	References
Input	Sown area of crops	1000 hectares	Kuang et al. [8]
	Population employed in primary industry	10,000 persons	Yang et al. [12]
	Consumption of fertilizers	10,000 tons	Wang et al. [70]
	Consumption of pesticides	tons	Lu et al. [71]
	Consumption of agricultural film	tons	Zang et al. [72]
	Effective irrigation area	1000 hectares	Ji et al. [73]
	Total power of agricultural machinery	10,000 kW	Liu et al. [74]
Desirable output	Gross agricultural production	10,000 yuan	Zhang et al. [75]
	Output of grain	tons	Zhang et al. [75]
	Carbon sequestration	10,000 tons	Ke et al. [54]
Undesirable output	Carbon emissions	10,000 tons	Ke et al. [54]

The measurement system of the CLLCUE consists of input, desirable output, and undesirable output. The input includes land, labor, and agricultural capitals. In detail, the land refers to cultivated land used for agricultural production. It's represented by the sown area of crops, which is a more accurate indicator of the actual utilization rate than cultivated land area. The labor refers to population employed in the primary industry. The agricultural capitals consist of fertilizer, pesticide, agricultural film (the plastic film covering the cultivated land to keep warm and maintain soil moisture), irrigation, and agricultural machinery. The desirable output is composed of economic output, social output, and ecological output, represented by gross agricultural production, the output of grain, and cultivated land carbon sequestration (CLCS), respectively. The CLCS refers to

the net carbon sequestration after photosynthesis absorbs carbon and crops growth releases carbon. The specific formula is as follows:

$$S = \sum_{i=1}^{n} S_i = \sum_{i=1}^{n} [C_i \times Y_i \times (1 - W_i) \times (1 + R_i)] / H_i \tag{7}$$

where S represents the total amount of CLCS, S_i represents the net carbon sequestration of crop i, C_i, Y_i, W_i, R_i and H_i represent the carbon content, economic output, moisture coefficient, root shoot ratio and economic coefficient of crop i, respectively, n represents the number of main food crops in the YRD. According to the existing studies [76], the parameters of crops' carbon sequestration are shown in Table 3.

Table 3. Calculation parameters of carbon sequestration in crops.

Crop	Carbon Content	Moisture Coefficient	Economic Coefficient	Root Shoot Ratio
Wheat	0.4707	0.1167	0.3632	0.3930
Corn	0.4637	0.1223	0.4628	0.1560
Paddy	0.4171	0.1186	0.4854	0.6000
Cotton	0.4500	0.1150	0.2767	0.1220
Oil-bearing crop	0.4500	0.1500	0.4300	0.7200
Vegetable	0.4500	0.9000	0.6000	0.0000

The undesirable output is the total carbon emissions from cultivated land utilization. It's calculated by the comprehensive evaluation method of carbon emission coefficients: the formula is $E = \sum E_i = \sum (G_i \times \delta_i)$, where E represents total carbon emissions, E_i represents the carbon emissions of ith carbon source, the G_i and δ_i represent the amount and coefficient of ith carbon source, respectively. According to the existing studies, the coefficient of each carbon source is shown in Table 4.

Table 4. Carbon emission sources and coefficients of cultivated land utilization.

Carbon Source	Fertilizer	Pesticide	Agricultural Film	Agricultural Machinery	Irrigation	Tillage
Coefficient	0.8965	4.9341	5.1800	0.1800	20.4760	3.1260
Unit	kg/kg	kg/kg	kg/kg	kg/kW	kg/hm^2	kg/hm^2

3.2.3. Super-SBM Model with Undesirable Outputs

Data Envelopment Analysis (DEA) is a nonparametric technique efficiency analysis method. The relative efficiency level of a group of decision-making units (DMUs) is determined by comparing the deviation degree between a group of DMUs and their production frontiers through mathematical programming [77], which aims to find the optimal production frontier. The evaluation results are more objective without building functional relationships or setting parameters in advance. As one kind of DEA, the Super-SBM model considers the undesirable outputs in calculating ecological efficiency. It can solve the relaxation problem and distinguish between DMUs effectively while studying their comprehensive benefits of them with multi-inputs and multi-outputs [78]. In this paper, each city is treated as a DMU. And every city has an input vector, an expected output vector, and an undesired output vector. The specific evaluation method is established as in Equation (8)

$$\mathrm{Min}\varphi = \frac{\frac{1}{m} \sum_{i=1}^{m} \left(\frac{\overline{x_i}}{x_{ik}} \right)}{\frac{1}{s_1+s_2} \left(\sum_{p=1}^{s_1} \frac{\overline{y^d_p}}{y^d_{pk}} + \sum_{q=1}^{s_2} \frac{\overline{y^u_q}}{y^u_{qk}} \right)} \tag{8}$$

$$\text{Subject to} \begin{cases} x_{ik} \geq \sum_{j=1,\neq k}^{n} x_{ij}\lambda_j - \overline{x_i} \\ y_{pk}^d \leq \sum_{j=1,\neq k}^{n} y_{pj}^d\lambda_j - \overline{y^d}_p \\ y_{qk}^u \leq \sum_{j=1,\neq k}^{n} y_{qj}^u\lambda_j - \overline{y^u}_q \\ \overline{x}, \overline{y^d}, \overline{y^u}, \lambda_j \geq 0 \\ j = 1, 2, \cdots, n; k = 1, 2, \cdots, n \end{cases}$$

where φ represents the CLLCUE, n represents the number of DMUs, m, s_1 and s_2 represent the number of inputs, desirable outputs, and undesired outputs, respectively, $\overline{x_i}$, $\overline{y^d}_p$ and $\overline{y^u}_q$ represents the slack variable of input i, desirable output p, and undesired output q, respectively, x_{ik}, y_{pk}^d and y_{qk}^u represent the optimal amount of input i, desirable output p, and undesired output q in DMU k improved through slack variables, x_{ij}, y_{pj}^d and y_{qj}^u represent the input i, desirable output p, and undesired output q in DMU j, λ_j represents the weight vector determined according to the statistical characteristics of data.

3.2.4. Super-SBM Model with Undesirable Outputs

The KDE is a representative model for describing the distribution patterns of random variables. It has been widely used in economics and management research [79]. As a non-parametric method, the KDE can effectively avoid the subjectivity of function setting in parameter estimation and capture the objective reality of data distribution [8]. This study applied it to show the dynamic distribution of new-type urbanization and CLLCU. Suppose the density function of the random variable x is $f(x)$, and the probability density at point x can be defined as:

$$f(x) = (1/nh) \sum_{i=1}^{n} K((x_i - x)/h) \tag{9}$$

where n is the number of observations, h is the bandwidth, K is the kernel function, a weighting function or smoothing transfer function, and x_i is the independent and identically distributed random variable.

The kernel function is known as a weighting function or smoothing transfer function. It can be divided into Gaussian kernel, epanechnikov kernel, triangular kernel, quartic kernel, and so on. Epanechnikov kernel was adopted to reduce the computational complexity and improve the operation speed in this paper. Since non-parametric estimation has no definite function expression, the graphical comparison was usually used to examine its distribution variation [8]. The kernel density function distribution expressed the dynamic evolution of the geographical phenomena with the changes in its location, shape, and extensibility (Table 5).

Table 5. Relationship between the kernel density function distribution and the degree of disparity.

Degree of Disparity	Number of Peaks	Height of the Peak	Location of the Peak	The Left Tail	The Right Tail
Increase	Increase	Flat	Move left	Longer	Shorter
Decrease	Decrease	Steep	Move right	Shorter	Longer

3.2.5. Coupling Coordination Degree Model (CCDM)

The CCDM is widely used in many fields to measure the degree of interaction and coupling level between two or more systems, which determines the development trend of the integrated systems from disorder to order [80]. Here we applied it to investigate the interactive coupling relationship between new-type urbanization and CLLCU. In detail,

we calculated the coupling degree between new-type urbanization and CLLCU, and then measured the coupling coordination degree. The specific formulas are as follows:

$$C = \left[\frac{4u_1u_2}{(u_1 + u_1)^2} \right]^{1/2} \tag{10}$$

$$T = \alpha u_1 + \beta u_2 \tag{11}$$

$$D = \sqrt{C \times T} \tag{12}$$

where u_1 represents the new-type urbanization level, u_2 represents the CLLCUE, C represents the coupling degree, T represents the comprehensive evaluation index, and D represents the coupling coordination degree between new-type urbanization and CLLCU. Since the new-type urbanization and CLLCU are both significant practices in the transition period of economy-society development, the new-type urbanization and CLLCU are equally important to the evaluation of the coupling coordination degree. Thus, they are given the same weight, that is, $\alpha = \beta = 0.5$. Referring to previous research [81], we divided the coupling coordination degree between them into five types (Table 6).

Table 6. The standards and types of the coupling coordination degree.

Stage	Level	Type
Coordinated development	$0.8 < D \le 1$	High balanced
Transformation development	$0.6 < D \le 0.8$ $0.4 < D \le 0.6$	Moderate balanced On the verge of imbalance
Uncoordinated development	$0.2 < D \le 0.4$ $0 \le D \le 0.2$	Moderate imbalanced High imbalanced

3.2.6. Relative Development Degree Model (RDDM)

Although the CCDM is used to reflect the state of interaction and coupling level among systems, it's unable to reflect the degree of relative development. Thus, this study applied RDDM to evaluate the degree of relative development between new-type urbanization and CLLCU and identify which lags [5]. The specific formula is as follows:

$$E = u_1 / u_2 \tag{13}$$

where u_1 represents the new-type urbanization level, u_2 represents the CLLCUE, C represents the coupling degree, and E represents the relative development degree between new-type urbanization and CLLCU. Referring to previous research [5], we divided the relative development degree into three types: New-type urbanization lag ($0 \le E \le 0.8$), Simultaneous development ($0.8 < E \le 1.2$) and CLLCU lag ($1.2 < E$).

3.3. Data Acquisition

The data includes statistical data and an administrative map. The statistical data are mainly from public information sources including the China Statistical Yearbook (2001–2019), China Rural Statistical Yearbook (2001–2019) and China Statistical Yearbook on Environment (2001–2019). The administrative map is from the Resource and Environment Science and Data Center of the Institute of Geographic Sciences and Natural Resources Research, CAS (http://www.resdc.cn/ (accessed on 31 May 2021)).

4. Results and Analysis

4.1. Temporal and Spatial Evolution of New-Type Urbanization

4.1.1. Temporal Evolution of New-Type Urbanization

The evolution of the new-type urbanization level was examined from the perspective of the peak, shape, and ductility of the curve. As shown in Figure 4, the distribution

of new-type urbanization levels in the YRD has three main characteristics: (1) the peak value decreased continuously, indicating that the degree of discrepancies among new-type urbanization levels continued to decrease. (2) The kernel density had a "main peak-double peaks-main peak" differentiation trend. The shape of the curve reflected a "bipolar-multipolar-bipolar" development tendency. (3) The location of the curve kept moving towards the right side. The left tail of the curve became thinner while the right tail of the curve became longer and thicker, suggesting that the new-type urbanization level increased continuously.
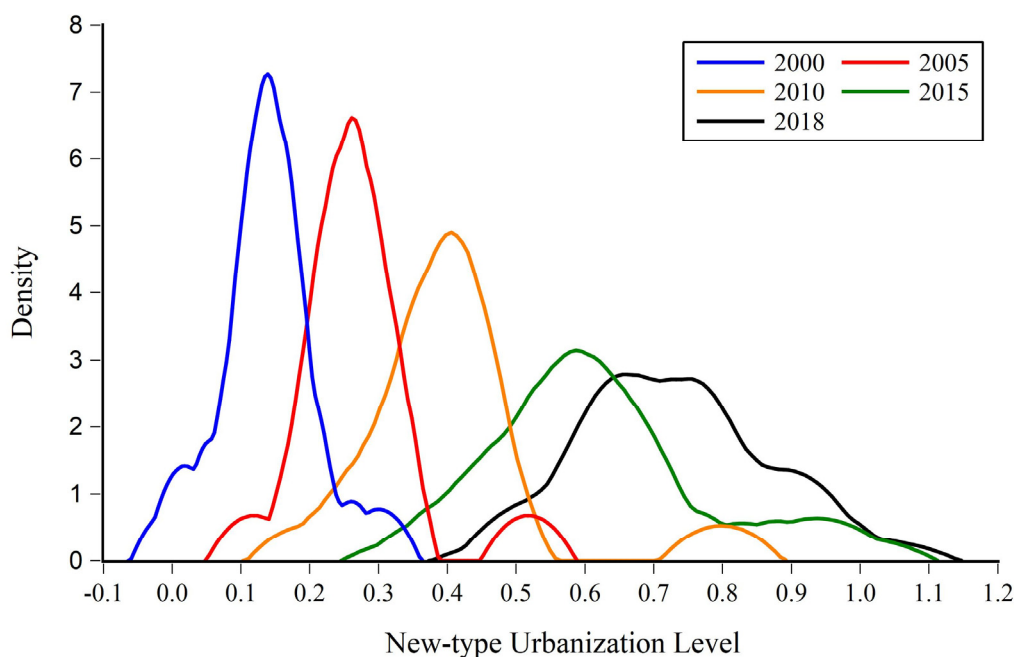

Figure 4. Temporal evolution trend of new-type urbanization levels of the Yangtze River Delta during 2000–2018.

4.1.2. Spatial Pattern of New-Type Urbanization

The new-type urbanization level was divided into four levels by the quantile classification method: lowest level, lower level, higher level, and highest level (Figure 5). The new-type urbanization level of the YRD showed a "single-core, north-south symmetry" spatial pattern. In detail, (1) except for Shanghai, the new-type urbanization level of other cities was at the lowest level during 2000–2005. Disequilibrium of the new-type urbanization level dominated in the period. (2) The new-type urbanization level of most cities improved during 2005–2015. Shanghai was the core of the spatial distribution of new-type urbanization. From the north to south parts, high levels of new-type urbanization gradually changed into low levels. (3) The new-type urbanization level continued to increase during 2015–2018. Although most cities were at high levels, the new-type urbanization level of peripheral cities in the YRD was still lower than that of inner cities. With its strategic position and strong competitiveness, Shanghai has become an important engine for the development of new-type urbanization in the YRD. Due to the advantageous geographical location and transportation network, Suzhou and Wuxi provide Shanghai with necessary elements and space for urbanization, and gradually form a community of interest with Shanghai. Driven by the radiation of Shanghai, the new-type urbanization of Suzhou and Wuxi has developed steadily. Suzhou-Wuxi-Shanghai has become the advantaged belt of the whole region, thereby forming a spatial pattern with Suzhou-Wuxi-Shanghai as the center and radiating to the north and south parts of the YRD.
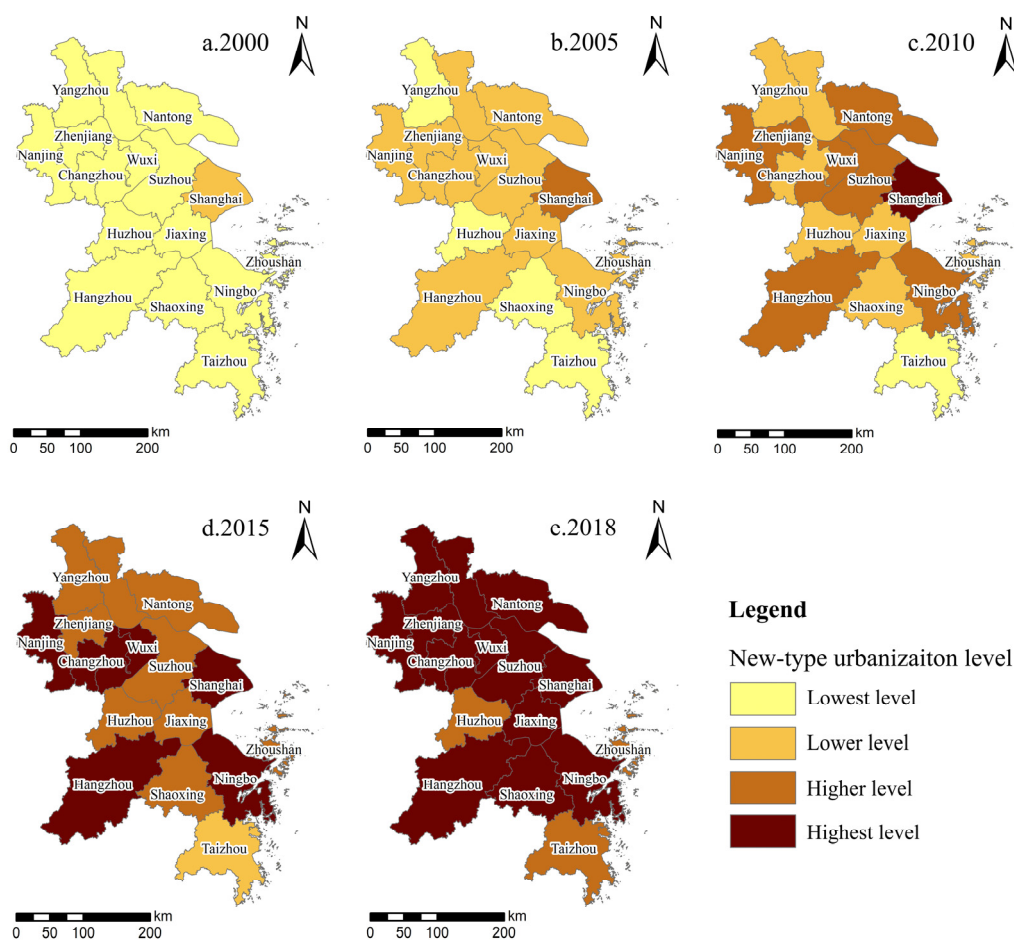
Figure 5. The spatial pattern of new-type urbanization levels of the Yangtze River Delta during 2000–2018.

4.2. Temporal and Spatial Evolution of CLLCUE

4.2.1. Temporal Evolution of CLLCUE

As shown in Figure 6, the distribution of CLLCUE in the YRD has three main characteristics. (1) The peak value increasing first and then decreasing indicated that the degree of discrepancies among CLLCUE decreased first and then increased. (2) The shape of the curve with the main peak and multiple subpeaks coexisted, which reflected a multipolar development state. (3) The location of the curve moved towards the right slightly, suggesting that the CLLCUE increased a little bit.

4.2.2. Spatial Evolution of CLLCUE

The CLLCUE was divided into four levels by the quantile classification method: lowest efficiency, lower efficiency, higher efficiency and highest efficiency. As shown in Figure 7, the CLLCUE in the YRD showed a spatial pattern of "high in the north and low in the south, high in the east and low in the west". In detail, (1) cities with higher and highest efficiency agglomerated in the northern region, while cities with lower and lowest efficiency agglomerated in the southern region, showing a polarization pattern of "high in the north and low in the south" during 2000–2010. (2) The CLLCUE of southern cities improved slightly, but generally didn't exceed the CLLCUE of northern cities during 2010–2015. (3) The difference in CLLCUE between the southern and northern regions shrank. Conversely, the difference in CLLCUE of the eastern and western regions gradually expanded, showing a polarization pattern of "high in the east and low in the west" during 2015–2018. In summary, since the spatial pattern of the CLLCUE was characterized by "high in the

north and low in the south, high in the east and low in the west", the CLLCUE in the YRD was in a disequilibrium state from 2000 to 2018.
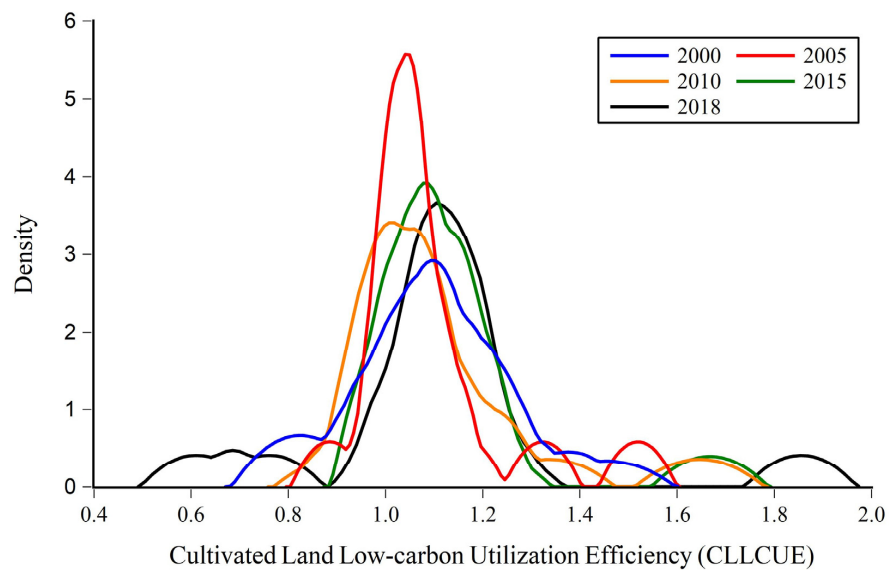

Figure 6. The characteristics of the time-series of cultivated land low-carbon utilization efficiency of the Yangtze River Delta during 2000–2018.
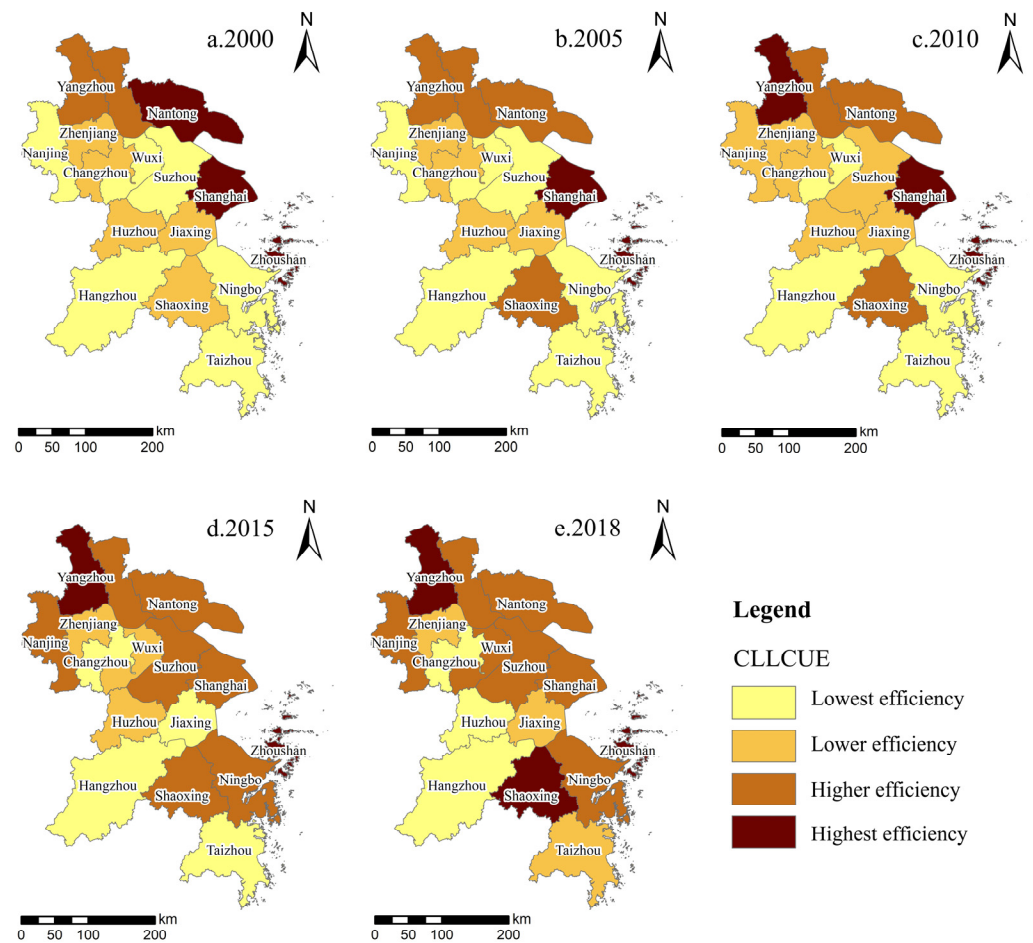

Figure 7. The spatial pattern of cultivated land low-carbon utilization efficiency of the Yangtze River Delta during 2000–2018.

4.3. Dynamic Evolution of Coupling Coordination Degree between New-Type Urbanization Level and CLLCUE

As shown in Figure 8, the coupling coordination degree between the new-type urbanization level and CLLCUE shows the dynamic evolution of cities in the YRD. The coupling coordination degree between new-type urbanization level and CLLCUE of most cities changed from a rapid rise period (2000–2010) to steady development (2010–2018). Initially, the state of uncoordinated development dominated the Yangtze River Delta. Then from 2005 to 2010, the coupling coordination degree intensely increased. There was no city in the uncoordinated development state. Finally, the new-type urbanization and CLLCU of most cities achieved a high balance during 2015–2018.
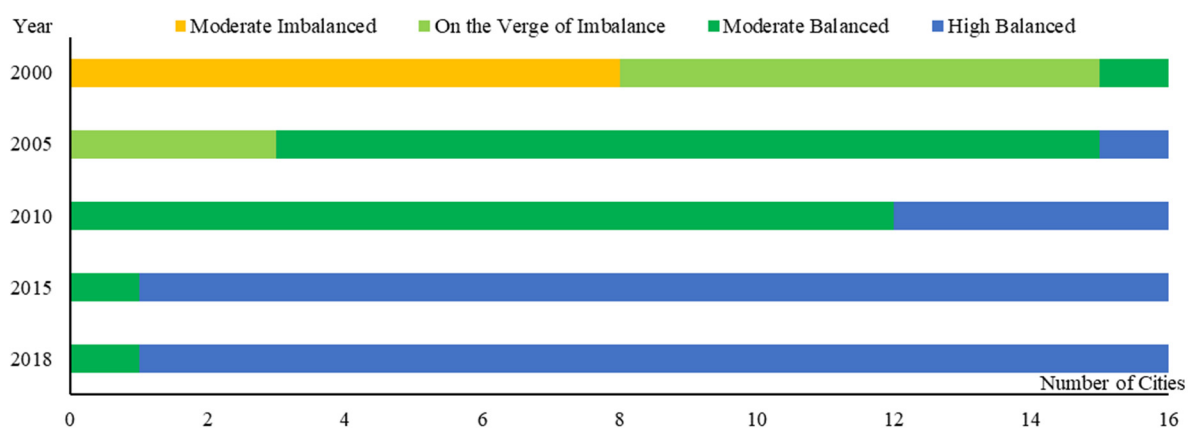

Figure 8. The type of coupling coordination development between new-type urbanization and cultivated land low-carbon utilization of the Yangtze River Delta during 2000–2018.

At the beginning of the period, the coupling coordination degree between the new-type urbanization level and CLLCUE showed a spatial pattern of "high in the north and low in the south", and gradually changed from disequilibrium to equilibrium (Figure 9). Except for Shanghai, the rest of the cities were moderately balanced and on the verge of imbalance in 2000, showing a regional disequilibrium pattern. Then, the coupling coordination degree between the new-type urbanization level and CLLCUE increased during 2005–2015. With Shanghai as the growth core, Suzhou-Wuxi-Shanghai formed the advantageous area belt, which drove the northern and southern cities to development. Meanwhile, as the provincial capitals with sound market and policy support, Nanjing and Hangzhou actively promoted the new-type urbanization and green agricultural development, which led to the spatial pattern of coupling coordination degree shifting from unipolar to multi-polar and the polarization eased slightly. But the coupling coordination degree in the north is slightly higher than that in the south. Finally, the coupling coordination degree between new-type urbanization level and CLLCUE of most cities were highly balanced, and the spatial pattern was in equilibrium.

4.4. Dynamic Evolution of Relative Development Degree between New-Type Urbanization Level and CLLCUE

As shown in Figure 10, the relative development degree between the new-type urbanization level and CLLCUE showed a reversal trend, changing from new-type urbanization lagging to CLLCUE lagging. Specifically, the new-type urbanization of cities in the YRD lagged behind CLLCU in 2000. The number of cities in which new-type urbanization lagged dropped from 10 to 1, and the number of cities in which CLLCU lagged increased from 1 to 12. From the perspective of figure shape, it changed from a positive-triangle-shaped pattern to an inverted-triangle-shaped pattern during 2005–2015. Finally, the CLLCU of most cities lagged behind new-type urbanization, and no cities developed simultaneously.
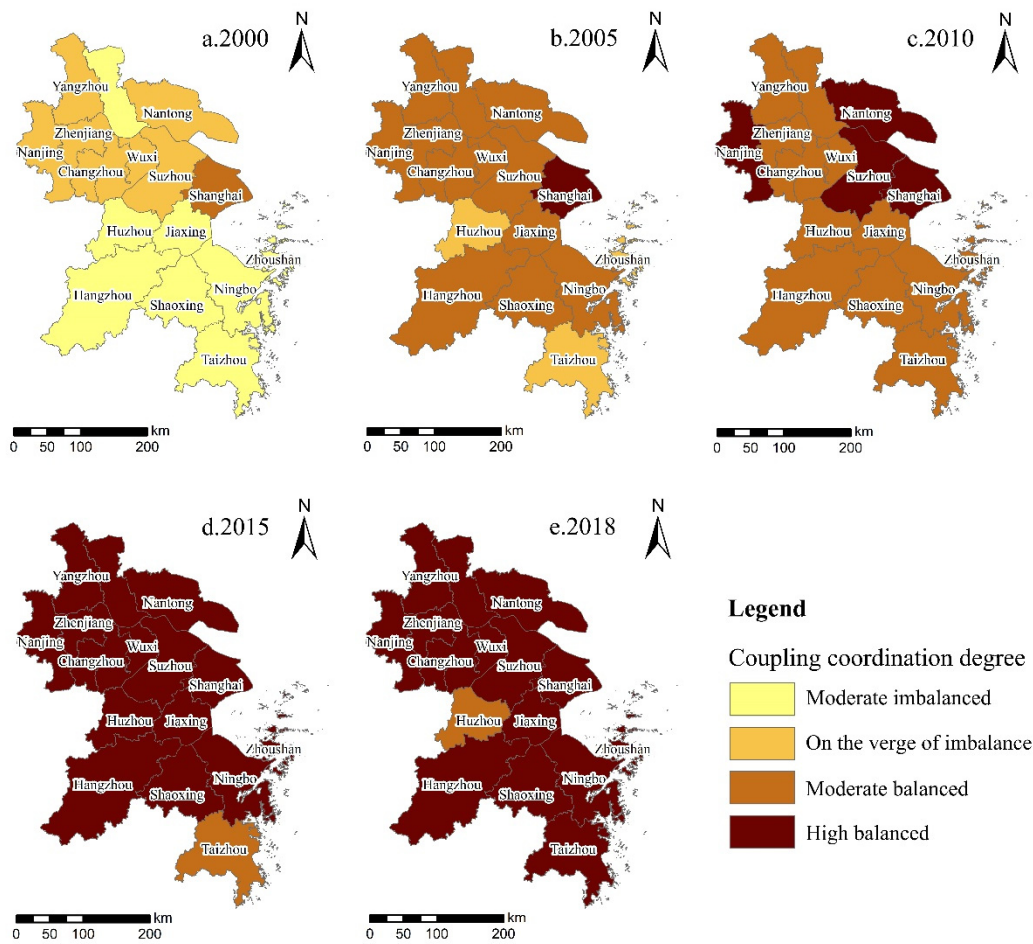
Figure 9. The spatial pattern of coupling coordination development between new-type urbanization and cultivated land low-carbon utilization of the Yangtze River Delta during 2000–2018.
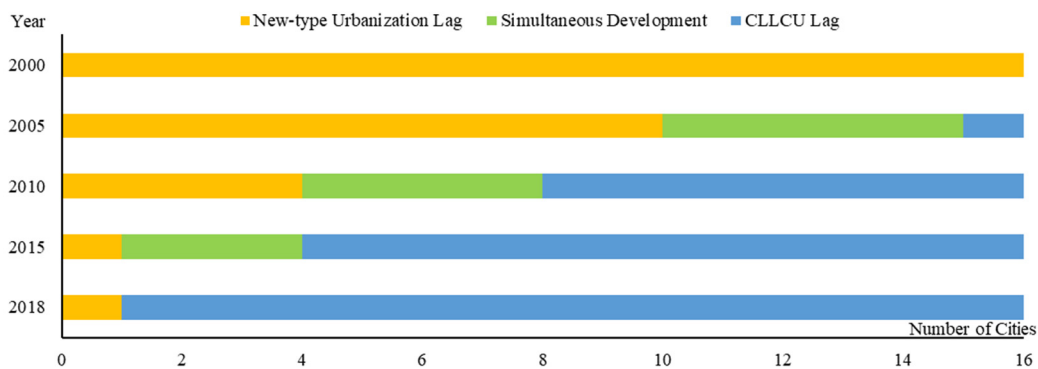

Figure 10. The type of relative development between new-type urbanization and cultivated land low-carbon utilization of the Yangtze River Delta during 2000–2018.

As shown in Figure 11, the relative development degree between the new-type urbanization level and CLLCUE changed from "north-south symmetry" to an equilibrium pattern. In detail, the new-type urbanization of cities lagged behind CLLCU in 2000. Later, except for Ningbo, the new-type urbanization of most cities lagged behind the CLLCU. Nanjing, Hangzhou, and Suzhou-Wuxi-Shanghai areas took the lead in entering the state of simultaneous development by 2005. Then, driven by the radiation of Nanjing, Hangzhou, and Suzhou-Wuxi-Shanghai area, the new-type urbanization formed a relatively obvious scale effect, resulting in that CLLCU lagged behind the new-type urbanization in most

cities during 2010–2015. Eventually, the CLLCU of all cities lagged behind the new-type urbanization in the year 2018.
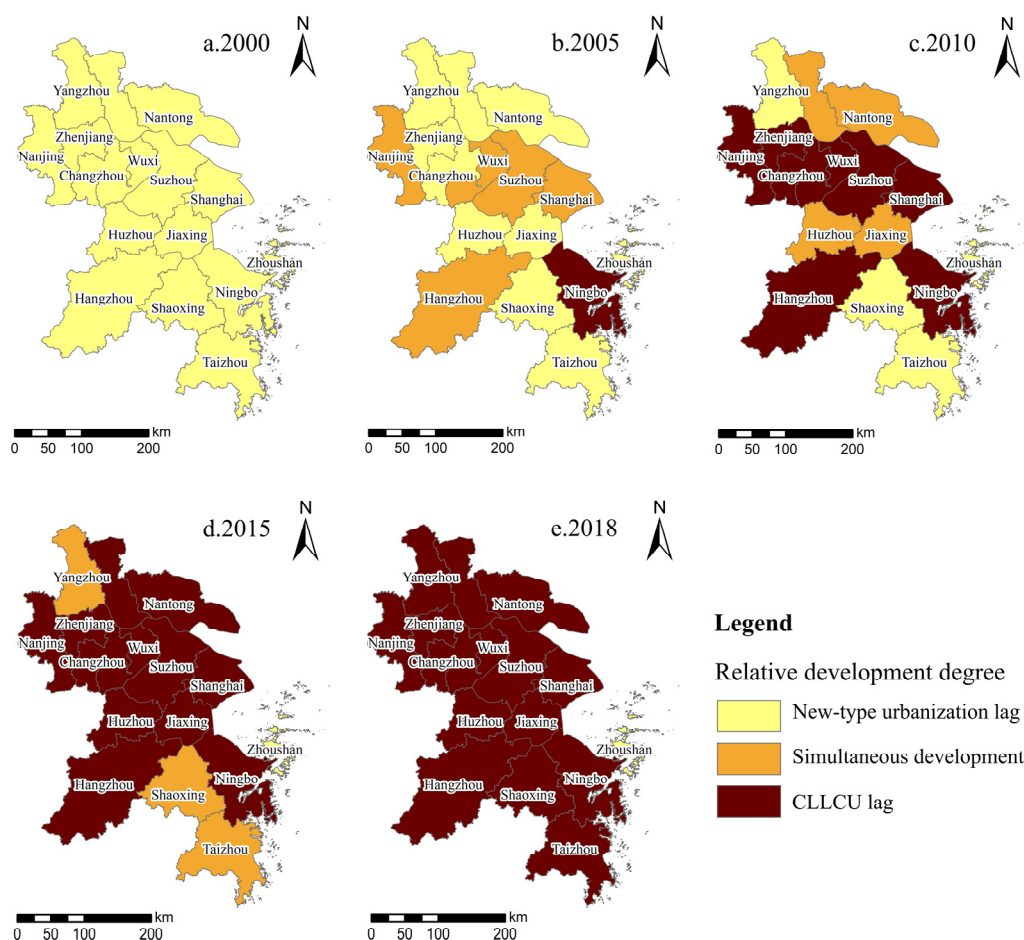

Figure 11. The spatial pattern of relative development between new-type urbanization and cultivated land low-carbon utilization of the Yangtze River Delta during 2000–2018.

5. Discussion

New-type urbanization and CLLCU are important practices to achieve high-quality economy-society-ecology development. In support of coordinated and sustainable development, it's meaningful to explore the relationship between new-type urbanization and CLLCU. The findings of this study showed that the relationship between new-type urbanization and CLLCU follows a dynamic process, rather than being static. The coupling coordinated degree of new-type urbanization and CLLCU evolved towards higher levels in the YRD. The results of the present study are in line with the findings of previous studies [5,82]. This paper constructed the comprehensive evaluation systems of the new-type urbanization and CLLCU according to the principles of comprehensiveness, scientificity, and typicality. The new-type urbanization was evaluated from the perspective of demographic urbanization, spatial urbanization, economic urbanization, social urbanization, and ecological urbanization. Different from traditional urbanization measurement in the previous study, this paper took the economy-society-ecology effect of urbanization into consideration, reflecting the connotation of new-type urbanization. Additionally, CLLCU was evaluated exhaustively by taking carbon sequestration and carbon emission as a desirable output and undesirable output of cultivated land utilization, respectively. The objective evaluation of the new-type urbanization and CLLCU provides the scientific basis for the coupling coordination analysis of new-type urbanization and CLLCU.

The continuous improvement of the coordinated development level of new-type urbanization and CLLCU indicates that new-type urbanization and CLLCU form positive interactions. With the development of new-type urbanization, agricultural scale management and intensive utilization can be promoted by large capital investment, complete infrastructure, and advanced technology, which contributes to the improvement of CLLCUE [57,58]. Taking Jiangsu Province as an example, new-type urbanization not only promotes the rapid flow of important production factors such as capital and technology, but also promotes the application of green production methods, which have a positive effect on the transition and upgrade of cultivated land utilization. Under the premise of ensuring a stable food supply, most cities attach importance to the protection of cultivated land and their ecosystems, and advocate the coordination of economy-society-ecology benefits, thereby enhancing the development of sustainable agriculture to a great extent. Meanwhile, the transfer of rural surplus labor drives urban-rural land use transition and the improvement of urban public infrastructure, which has a feedback effect on the new-type urbanization [83]. For example, the cultivated land utilization has gradually shifted towards a green and low-carbon mode in cities with a high new-type urbanization level, such as Shanghai, Nanjing, and Hangzhou. Cultivated land with economy-society-ecology functions ensures the development of new-type urbanization, thereby promoting the co-evolution of new-type urbanization and CLLCU.

Although most cities have been in a state of high coordination between new-type urbanization and CLLCU, the CLLCU of each city lags behind new-type urbanization. The rapid advancement of new-type urbanization and the andante promotion of CLLCU make it difficult to develop simultaneously. Though the new-type urbanization emphasizes green and low-carbon development, it is still an important carrier of industrialization and population migration. The unavoidable negative problems such as land resource waste and "out-of-control" urban sprawl will exert pressure on cultivated land utilization. The urban expansion occupies a large amount of high-quality cultivated land in the suburbs, resulting in a decline in the quality and productivity of cultivated land resources [84]. Cultivated land loss induces excessive and inefficient utilization of high-carbon production materials, which leads to massive carbon emissions. Moreover, although the cultivated land protection policy is a strict and powerful institutional guarantee system composed of specific laws and regulations, it's unable to solve a series of problems in cultivated land utilization [20]. The phenomenon, for instance, occupying the superior to make up for the inferior and occupying paddy fields to make up for the dryland not only leads to the decline in the quality and the increase in utilization intensity of cultivated land but also results in the damage to the cultivated land ecosystem and its carbon sequestration capacity. In conclusion, since the rapid development of new-type urbanization exerts the pressure on the cultivated land resources, the cultivated land utilization still relies on high-intensity agricultural material inputs to ensure its productivity so that the spread of CLLCU lags. Therefore, in the process of social and economic transition, the new-type urbanization should not only maintain the speed of development but also focus on improving the quality and efficiency of development. In particular, it is necessary to further alleviate conflicts among important subsystems such as construction land and cultivated land, urban and rural areas, and prevent the continuous escalation of unbalanced and uncoordinated problems accumulated in the development. The cultivated land utilization also needs to be actively combined with the concept of green and low-carbon. Based on cultivated land protection, the balance between improving cultivated land productivity and reducing carbon emissions could strengthen the promotion of sustainable cultivated land utilization.

This study sheds light on the relationship between new-type urbanization and cultivated land utilization, and provides a scientific basis for promoting the high-quality development of new-type urbanization and sustainable utilization of cultivated land. However, there are certain inadequacies. Firstly, due to the availability of data, our research area is from the perspective of cities, which leads to a relatively rough estimation of regional heterogeneity of the coupling coordinated development. Secondly, the driving factors of the

coupling coordinated relationship between new-type urbanization and CLLCU were not addressed in the present study. However, the interaction between new-type urbanization and CLLCUE has heterogeneous features and is droved by multiple factors. Thus, in order to provide the scientific reference for differentiated policy-making, it's necessary to conduct an in-depth exploration of the relationship between new-type urbanization and CLLCUE from a more detailed spatial scale and detect its driving factors comprehensively in future study.

6. Conclusions and Policy Implications

6.1. Conclusions

This paper constructed systematic evaluation models for new-type urbanization and CLLCU based on the concept of new-type urbanization and CLLCU. Taking the YRD as the typical research area, the evolution of new-type urbanization and CLLCU was analyzed from the spatial and temporal scales. Furthermore, the CCDM and RDDM were applied to reflect the coordinated and relative development of new-type urbanization and CLLCU, which has strong theoretical guiding significance for the realization of high-quality economy-society development and sustainable agricultural development.

Firstly, the new-type urbanization level of cities in the YRD increased, showing a spatial pattern of "single-core, north-south symmetry". The YRD formed a radiate development model of "growth pole-advantage area-overall region", and took full advantage of the scale effect. Due to differences in the geographical location conditions, and economic growth patterns, the new-type urbanization level continued to be polarized in the YRD.

Secondly, the CLLCUE of cities in the YRD increased but polarized obviously, showing a spatial pattern of "high in the north and low in the south, high in the east and low in the west". Under the guidance of sustainable development, cultivated land utilization transformed from extensive and inefficient mode to a low-carbon and efficient state, although there were still significant differences in the CLLCUE of cities due to natural endowments, agricultural mode, development intensity, etc.

Thirdly, the coupling coordination development of cities in the YRD showed the trend of "rapid increase-stable development". Most cities shifted from uncoordinated development to coordinated development, and the spatial pattern shifted from "high in the north and low in the south" to the regional equilibrium. It proved that the new-type urbanization drove the development of CLLCU and the CLLCU fed back to the new-type urbanization positively.

Fourthly, the relative development of new-type urbanization and CLLCU of cities in the YRD showed a "reversal" trend. In other words, the relative development state transformed from the new-type urbanization lagging behind the CLLCU to the new-type urbanization ahead of the CLLCU. None of the cities were in simultaneous development and the spatial pattern has shifted from "north-south symmetry" to regional equilibrium.

Although the new-type urbanization and CLLCU have reached a state of coordinated development, the rapid advancement of new-type urbanization and the slow development of CLLCU might hinder the sustainable utilization of cultivated land. It is necessary to further emphasize the high-quality development of new-type urbanization and the low-carbon development of cultivated land utilization.

6.2. Policy Implications

Firstly, the differentiated modes of CLLCU should be explored to realize the dual goals of efficient utilization and low-carbon emission. Under the premise of reasonable evaluation of natural endowment and development period, cities in the phase of low CLLCUE should strengthen the optimization of cultivated land to avoid the loss of cultivated land and improve the CLLCUE. Cities in a period of high CLLCUE should improve the intensity of agricultural carbon emissions reduction with multiple approaches such as scientific fertilization, innovative techniques, moderate scale management, and pollution detection. At the same time, it is necessary to establish relevant laws and regulations to

improve the supportive system and compensation mechanism to ensure the promotion of CLLCU successfully.

Secondly, the quality and efficiency of new-type urbanization need to be promoted in the YRD. On one hand, cities with a higher new-type urbanization level such as Shanghai, Nanjing, and Hangzhou should continue to promote new-type urbanization steadily. These cities should focus on strictly delimiting growth boundaries, exploring the potential within the city, optimizing the urban spatial layout, and promoting the circulation of resources. As the stable growth pole of the YRD, these cities should not only improve their comprehensive competitiveness and form the low-carbon development mode but also drive the development of surrounding cities. On the other hand, cities with a lower new-type urbanization level, for example Taizhou, Huzhou, and Zhoushan, should learn from the experience of cities with high-levels of new-type urbanization to make up for shortcomings of urbanization construction. These cities must solve the basic problems of new-type urbanization such as spatial layout, public service, and environmental governance. Specifically, these cities should effectively control the city scale and promote intensive space utilization. At the same time, they should actively expand the sharing scope of public services and strictly control production-living pollution to improve residents' well-being.

Finally, the coordinated development of new-type urbanization and CLLCU should be promoted comprehensively to reduce the region gap through the linkage effect. Shanghai and Jiangsu should further play a leading role in the radiating development. It's essential to build an open and sharing development community in the YRD by promoting the integration and coordination of natural resources and social resources, especially innovative technology and information. Various resources should be allocated out of the balance between equity and efficiency, and administrative barriers should be broken down to avoid the formation of a polarized pattern due to the strengthening of the "Matthew effect". In other words, cities with a high development level and strong radiation ability continue to use advantageous conditions to promote the new-type urbanization and CLLCU, while cities with lagging development levels are difficult to change the passive roles, and continue to lag. Therefore, cities in Zhejiang Province should actively promote the interconnection of various production factors to promote the positive interaction and coordinated development of new-type urbanization and CLLCU, especially marginal cities.

Author Contributions: Y.Z.: Data curation, Methodology, and Writing the original draft. Y.D.: Software and Visualization. Y.C.: edit the draft and review the manuscript. X.K.: Conceptualization, Funding acquisition, and Supervision. All of the authors contribute to improving the quality of the manuscript. X.K. is responsible for the academic opinion of this manuscript. All authors have read and agreed to the published version of the manuscript.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

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

References

1. Chen, M.; Liu, W.; Lu, D. Challenges and the way forward in China's new-type urbanization. *Land Use Policy* **2016**, *55*, 334–339. [CrossRef]
2. Long, H. Land use policy in China: Introduction. *Land Use Policy* **2014**, *40*, 1–5. [CrossRef]
3. Wang, S.; Hu, M.; Wang, Y.; Xia, B. Dynamics of ecosystem services in response to urbanization across temporal and spatial scales in a mega metropolitan area. *Sustain. Cities Soc.* **2022**, *77*, 103561. [CrossRef]
4. Kundu, D.; Pandey, A.K. *World Urbanisation: Trends and Patterns*; Springer: Singapore, 2020; pp. 13–49.

5. Cai, J.; Li, X.; Liu, L.; Chen, Y.; Wang, X.; Lu, S. Coupling and coordinated development of new urbanization and agro-ecological environment in China. *Sci. Total Environ.* **2021**, *776*, 145837. [CrossRef] [PubMed]

6. Truffer, B.; Coenen, L. Environmental innovation and sustainability transitions in regional studies. *Reg. Stud.* **2012**, *46*, 1–21. [CrossRef]

7. Hu, Y.; Tian, Z. How to achieve rural revitalization? An examination of the experience of rural development policy change in the United States. *Chin. Rural. Econ.* **2019**, *3*, 128–144.

8. Kuang, B.; Lu, X.; Zhou, M.; Chen, D. Provincial cultivated land use efficiency in China: Empirical analysis based on the SBM-DEA Model with carbon emissions considered. *Technol. Forecast. Soc. Change* **2020**, *151*, 119874. [CrossRef]

9. Deng, X.; Huang, J.; Rozelle, S.; Zhang, J.; Li, Z. Impact of urbanization on cultivated land changes in China. *Land Use Policy* **2015**, *45*, 1–7. [CrossRef]

10. Huang, Z.; Du, X.; Castillo, C.S.Z. How does urbanization affect farmland protection? Evidence from China. *Resour. Conserv. Recycl.* **2019**, *145*, 139–147. [CrossRef]

11. Li, Q.; Hu, S.; Du, G.; Zhang, C.; Liu, Y. Cultivated land use benefits under state and collective agrarian property regimes in China. *Sustainability* **2017**, *10*, 7. [CrossRef]

12. Yang, B.; Wang, Z.; Zou, L.; Zou, L.; Zhang, H. Exploring the eco-efficiency of cultivated land utilization and its influencing factors in China's Yangtze River Economic Belt, 2001–2018. *J. Environ. Manag.* **2021**, *294*, 112939. [CrossRef] [PubMed]

13. Xie, H.; Huang, Y.; Choi, Y.; Shi, J. Evaluating the sustainable intensification of cultivated land use based on emergy analysis. *Technol. Forecast. Soc. Change* **2021**, *165*, 120449. [CrossRef]

14. Yin, Y.; Hou, X.; Liu, J.; Zhou, X.; Zhang, D. Detection and attribution of changes in cultivated land use ecological efficiency: A case study on Yangtze River Economic Belt, China. *Ecol. Indic.* **2022**, *137*, 108753. [CrossRef]

15. Yang, H.; Wang, X.; Bin, P. Agriculture carbon-emission reduction and changing factors behind agricultural eco-efficiency growth in China. *J. Clean. Prod.* **2022**, *334*, 130193. [CrossRef]

16. Liu, D.; Zhu, X.; Wang, Y. China's agricultural green total factor productivity based on carbon emission: An analysis of evolution trend and influencing factors. *J. Clean. Prod.* **2021**, *278*, 123692. [CrossRef]

17. Chen, Z.; Sarkar, A.; Rahman, A.; Li, X.; Xia, X. Exploring the drivers of Green Agricultural Development (GAD) in China: A spatial association network structure approaches. *Land Use Policy* **2022**, *112*, 105827. [CrossRef]

18. Elmqvist, T.; Andersson, E.; Frantzeskaki, N.; McPhearson, T.; Olsson, P.; Gaffney, O.; Takeuchi, K.; Folke, C. Sustainability and resilience for transformation in the Urban Century. *Nat. Sustain.* **2019**, *2*, 267–273. [CrossRef]

19. Li, J.; Lei, J.; Li, S.; Yang, Z.; Tong, Y.; Zhang, S.; Duan, Z. Spatiotemporal analysis of the relationship between urbanization and the eco-environment in the Kashgar Metropolitan Area, China. *Ecol. Indic.* **2022**, *135*, 108524. [CrossRef]

20. Zhou, Y.; Li, X.; Liu, Y. Cultivated land protection and rational use in China. *Land Use Policy* **2021**, *106*, 105454. [CrossRef]

21. Van Vliet, J.; Eitelberg, D.A.; Verburg, P.H. A global analysis of land take in cropland areas and production displacement from urbanization. *Glob. Environ. Change* **2017**, *43*, 107–115. [CrossRef]

22. Qiu, B.; Li, H.; Tang, Z.; Chen, C.; Berry, J. How cropland losses shaped by unbalanced urbanization process? *Land Use Policy* **2020**, *96*, 104715. [CrossRef]

23. Li, J.; Li, Y. Influence measurement of rapid urbanization on agricultural production factors based on provincial panel data. *Socio-Econ. Plan. Sci.* **2019**, *67*, 69–77. [CrossRef]

24. Tian, Y.; Jiang, G.; Zhou, D.; Li, G. Systematically addressing the heterogeneity in the response of ecosystem services to agricultural modernization, industrialization and urbanization in the Qinghai-Tibetan Plateau from 2000 to 2018. *J. Clean. Prod.* **2021**, *285*, 125323. [CrossRef]

25. Zhong, C.; Hu, R.; Wang, M.; Xue, W.; He, L. The impact of urbanization on urban agriculture: Evidence from China. *J. Clean. Prod.* **2020**, *276*, 122686. [CrossRef]

26. Pribadi, D.O.; Pauleit, S. The Dynamics of peri-urban agriculture during rapid urbanization of Jabodetabek Metropolitan Area. *Land Use Policy* **2015**, *48*, 13–24. [CrossRef]

27. Hou, M.; Deng, Y.; Yao, S. Coordinated relationship between urbanization and grain production in China: Degree measurement, spatial differentiation and its factors detection. *J. Clean. Prod.* **2022**, *331*, 129957. [CrossRef]

28. Cao, Y.; Kong, L.; Zhang, L.; Ouyang, Z. The balance between economic development and ecosystem service value in the process of land urbanization: A case study of China's land urbanization from 2000 to 2015. *Land Use Policy* **2021**, *108*, 105536. [CrossRef]

29. Zhang, G.; Zhang, N.; Liao, W. How do population and land urbanization affect CO_2 emissions under gravity center change? A spatial econometric analysis. *J. Clean. Prod.* **2018**, *202*, 510–523. [CrossRef]

30. Li, J.; Huang, X.; Chuai, X.; Yang, H. The impact of land urbanization on carbon dioxide emissions in the Yangtze River Delta, China: A multiscale perspective. *Cities* **2021**, *116*, 103275. [CrossRef]

31. Zhou, Y.; Chen, M.; Tang, Z.; Mei, Z. Urbanization, land use change, and carbon emissions: Quantitative assessments for city-level carbon emissions in Beijing-Tianjin-Hebei Region. *Sustain. Cities Soc.* **2021**, *66*, 102701. [CrossRef]

32. Wu, J.; Cheng, D.; Xu, Y.; Huang, Q.; Feng, Z. Spatial-temporal change of ecosystem health across China: Urbanization impact perspective. *J. Clean. Prod.* **2021**, *326*, 129393. [CrossRef]

33. Zhang, M.; Tan, S.; Zhang, Y.; He, J.; Ni, Q. Does land transfer promote the development of new-type urbanization? New evidence from urban agglomerations in the Middle Reaches of the Yangtze River. *Ecol. Indic.* **2022**, *136*, 108705. [CrossRef]

34. Qiu, M.; Yang, Z.; Zuo, Q.; Wu, Q.; Jiang, L.; Zhang, Z.; Zhang, J. Evaluation on the relevance of regional urbanization and ecological security in the nine provinces along the Yellow River, China. *Ecol. Indic.* **2021**, *132*, 108346. [CrossRef]

35. Tian, Y.; Tsendbazar, N.-E.; van Leeuwen, E.; Fensholt, R.; Herold, M. A global analysis of multifaceted urbanization patterns using earth observation data from 1975 to 2015. *Landsc. Urban Plan.* **2022**, *219*, 104316. [CrossRef]

36. Li, H.; Zhang, X.; Zhang, X.; Wu, Y. Utilization benefit of cultivated land and land institution reforms: Economy, society and ecology. *Habitat. Int.* **2018**, *77*, 64–70. [CrossRef]

37. Han, H.; Zhang, X. Exploring environmental efficiency and total factor productivity of cultivated land use in China. *Sci. Total Environ.* **2020**, *726*, 138434. [CrossRef]

38. Qu, Y.; Lyu, X.; Peng, W.; Xin, Z. How to evaluate the green utilization efficiency of cultivated land in a farming household? A case study of Shandong Province, China. *Land* **2021**, *10*, 789. [CrossRef]

39. Kendall, M.G. The geographical distribution of crop productivity in England. *J. Roy. Stat. Soc.* **1939**, *102*, 21–62. [CrossRef]

40. Reddy, N.; Ramanaiah, Y.V. Changes in agricultural land use efficiency in Andhra Pradesh. *Land Use Policy* **1985**, *2*, 210–216. [CrossRef]

41. Seufert, V.; Ramankutty, N.; Foley, J.A. Comparing the yields of organic and conventional agriculture. *Nature* **2012**, *485*, 229–232. [CrossRef]

42. Agegnehu, G.; Ghizaw, A.; Sinebo, W. Yield performance and land-use efficiency of barley and faba bean mixed cropping in Ethiopian Highlands. *Eur. J. Agron.* **2006**, *25*, 202–207. [CrossRef]

43. Polthanee, A.; Trelo-ges, V. Growth, Yield and land use efficiency of corn and legumes grown under intercropping systems. *Plant Prod. Sci.* **2003**, *6*, 139–146. [CrossRef]

44. Ansari, M.A.; Choudhury, B.U.; Mandal, S.; Jat, S.L.; Meitei, C.B. Converting primary forests to cultivated lands: Long-term effects on the vertical distribution of soil carbon and biological activity in the foothills of Eastern Himalaya. *J. Environ. Manag.* **2022**, *301*, 113886. [CrossRef] [PubMed]

45. Wu, H.; Guo, S.; Guo, P.; Shan, B.; Zhang, Y. Agricultural water and land resources allocation considering carbon sink/source and water scarcity/degradation footprint. *Sci. Total Environ.* **2022**, *819*, 152058. [CrossRef] [PubMed]

46. Wang, S.; Zhou, M.; Adhikari, K.; Zhuang, Q.; Bian, Z.; Wang, Y.; Jin, X. Anthropogenic controls over soil organic carbon distribution from the cultivated lands in Northeast China. *Catena* **2022**, *210*, 105897. [CrossRef]

47. Chen, M.; Ye, C.; Lu, D.; Sui, Y.; Guo, S. Cognition and construction of the theoretical connotation fornew-type urbanization with Chinese characteristics. *Acta Geogr. Sin.* **2019**, *74*, 633–647. (In Chinese)

48. Yao, S.; Zhang, P.; Yu, C.; Li, G.; Wang, C. The theory and practice of new urbanization in China. *Sci. Geogr. Sin.* **2014**, *34*, 641–647. (In Chinese)

49. Yang, S.; Shi, L. Prediction of long-term energy consumption trends under the New National Urbanization Plan in China. *J. Clean. Prod.* **2017**, *166*, 1144–1153. [CrossRef]

50. Yu, B. Ecological Effects of new-type urbanization in China. *Renew. Sust. Energ. Rev.* **2021**, *135*, 110239. [CrossRef]

51. Li, X.; Lu, Z. Quantitative measurement on urbanization development level in urban agglomerations: A case of JJJ Urban Agglomeration. *Ecol. Indic.* **2021**, *133*, 108375. [CrossRef]

52. Liang, L.; Yong, Y.; Yuan, C. Measurement of urban land green use efficiency and its spatial differentiation characteristics: An empirical study based on 284 cities. *China Land Sci.* **2019**, *33*, 80–87. (In Chinese)

53. Ding, B.; Yang, S.; Zhao, Y.; Yi, S. Study on spatio-temporal characteristics and decoupling effect of carbon emission from cultivated land resource utilization in China. *China Land Sci.* **2019**, *33*, 45–54. (In Chinese)

54. Ke, N.; Lu, X.; Kuang, B.; Han, J. Regional differences and influencing factors of green and low-carbon utilization of cultivated land under the carbon neutrality target in China. *China Land Sci.* **2021**, *35*, 67–76. (In Chinese)

55. Li, Y.; Li, Y.; Zhou, Y.; Shi, Y.; Zhu, X. Investigation of a coupling model of coordination between urbanization and the environment. *J. Environ. Manag.* **2012**, *98*, 127–133. [CrossRef] [PubMed]

56. Zhu, S.; Huang, J.; Zhao, Y. Coupling coordination analysis of ecosystem services and urban development of resource-based cities: A case study of Tangshan City. *Ecol. Indic.* **2022**, *136*, 108706. [CrossRef]

57. Busso, M.; Chauvin, J.P.; Herrera, N.L. Rural-urban migration at high urbanization levels. *Reg. Sci. Urban Econ.* **2021**, *91*, 103658. [CrossRef]

58. McGowan, D.; Vasilakis, C. Reap what you sow: Agricultural technology, urbanization and structural change. *Res. Policy* **2019**, *48*, 103794. [CrossRef]

59. Zheng, W.; Barker, A. Green infrastructure and urbanisation in Suburban Beijing: An improved neighbourhood assessment framework. *Habitat. Int.* **2021**, *117*, 102423. [CrossRef]

60. Wu, C.; Wei, Y.D.; Huang, X.; Chen, B. Economic transition, spatial development and urban land use efficiency in the Yangtze River Delta, China. *Habitat. Int.* **2017**, *63*, 67–78. [CrossRef]

61. Duan, Z.; Yang, Y.; Wang, L.; Liu, C.; Fan, S.; Chen, C.; Tong, Y.; Lin, X.; Gao, Z. Temporal characteristics of carbon dioxide and ozone over a rural-cropland area in the Yangtze River Delta of Eastern China. *Sci. Total Environ.* **2021**, *757*, 143750. [CrossRef]

62. Xiong, X.; Xu, Z. Research on financial support system under the guidance of new urbanization. *J. Quant. Tech. Econ.* **2015**, *32*, 73–89. (In Chinese)

63. Zhu, Y.; Wang, Z.; Luo, J.; Cui, J. Coupling and coordinated development of new urbanization and food security in main agricultural production regions in central China: A case study of Henan Province. *Sci. Geogr. Sin.* **2021**, *41*, 1947–1958. (In Chinese)

64. Peng, C.; Chen, L.; Han, F. The analysis of new-type urbanization and the intensive urban land use: Spatial-temporal evolution and their relationship. *Geogr. Res.* **2014**, *33*, 2005–2020. (In Chinese)

65. Ding, T.; Chen, J.; Fang, Z.; Chen, J. Assessment of coordinative relationship between comprehensive ecosystem service and urbanization: A Case Study of Yangtze River Delta Urban Agglomerations, China. *Ecol. Indic.* **2021**, *133*, 108454. [CrossRef]

66. Yang, Y.; Huang, C.; He, C.; Huang, Q. The spatiotemporal dynamics of new-type urbanization comprehensive level in Shandong Peninsula Urban Agglomeration. *Econ. Geogr.* **2017**, *37*, 77–85. (In Chinese)

67. Zhao, J.; Liu, Y.; Zhu, Y.; Qin, S.; Wang, Y.; Miao, C. Spatiotemporal differentiation and influencing factors of the coupling and coordinated development of new urbanization and ecological environment in the Yellow River Basin. *Resour. Sci.* **2020**, *42*, 159–171. (In Chinese) [CrossRef]

68. Fan, P.; Liang, L.; Li, Y.; Duan, L.; Wang, N.; Chen, C. Evaluation of coordinated development of urbanization from the perspective of system coupling in the Beijing-Tianjin-Hebei Region. *Resour. Sci.* **2016**, *38*, 2361–2374. (In Chinese)

69. Yan, X.; Liu, B.; Wang, S.; An, D.; Zhu, F.; Yang, Y. Efilter: An effective fault localization based on information entropy with unlabelled test cases. *Inform. Softw. Technol.* **2021**, *134*, 106543.

70. Wang, X.; Li, C.; Liu, Y.; Ji, Z.; Li, L.; Wei, L. Zoning and improving path of cultivated land use efficiency based on evaluation of cultivated land suitability. *Trans. Chin. Soc. Agric. Mach.* **2021**, *52*, 212–218. (In Chinese)

71. Lu, X.; Kuang, B.; Lu, J. Regional differences and its influencing factors of cultivated land use efficiency under carbon emission constraint. *J. Nat. Resour.* **2018**, *33*, 657–668. (In Chinese)

72. Zang, J.; Tang, C.; Wang, Q.; Li, K.; Li, L. Research on spatial imbalance and influencing factors of cultivated land use efficiency in Guangdong Province based on Super-SBM Model. *China Land Sci.* **2021**, *35*, 64–74. (In Chinese)

73. Ji, Z.; Wang, X.; Li, L.; Guan, X.; Wei, L.; Xu, Y. The evolution of cultivated land utilization efficiency and its influencing factors in Nanyang Basin. *J. Nat. Resour.* **2021**, *36*, 688–701. (In Chinese) [CrossRef]

74. Liu, M.; Zhang, A.; Wen, G. Temporal and spatial pattern and evolution trend of cultivated land use ecological efficiency in the main grain producing areas in the Lower Yangtze Region. *China Land Sci.* **2021**, *35*, 50–60. (In Chinese)

75. Zhang, L.; Zhu, D.; Xie, B.; Du, T.; Wang, X. Spatiotemporal pattern evolvement and driving factors of cultivated land utilization efficiency of the major grain producing area in China. *Resour. Sci.* **2017**, *39*, 608–619. (In Chinese)

76. Chen, L.; Hao, J.; Wang, F.; Yin, Y.; Yang, G.; Duan, W.; Yang, J. Carbon sequestration function of cultivated land use system based on the carbon cycle for the Huang-Huai-Hai plain. *Resour. Sci.* **2016**, *38*, 1039–1053. (In Chinese)

77. Farrell, M.J. The Measurement of productive efficiency. *J. R. Stat. Soc. A* **1957**, *120*, 253–290. [CrossRef]

78. Du, Y.W.; Jiang, J.; Li, C.H. Ecological efficiency evaluation of marine ranching based on the Super-SBM Model: A case study of Shandong. *Ecol. Indic.* **2021**, *131*, 108174. [CrossRef]

79. Lu, X.; Kuang, B.; Li, J. Regional difference decomposition and policy implications of China's urban land use efficiency under the environmental restriction. *Habitat. Int.* **2018**, *77*, 32–39. [CrossRef]

80. Xiao, R.; Lin, M.; Fei, X.; Li, Y.; Zhang, Z.; Meng, Q. Exploring the interactive coercing relationship between urbanization and ecosystem service value in the Shanghai–Hangzhou Bay Metropolitan Region. *J. Clean. Prod.* **2020**, *253*, 119803. [CrossRef]

81. Ariken, M.; Zhang, F.; Chan, N.W.; Kung, H. Coupling coordination analysis and spatio-temporal heterogeneity between urbanization and eco-environment along the Silk Road Economic Belt in China. *Ecol. Indic.* **2021**, *121*, 107014. [CrossRef]

82. Hou, X.; Liu, J.; Zhang, D.; Zhao, M.; Xia, C. Impact of urbanization on the eco-efficiency of cultivated land utilization: A case study on the Yangtze River Economic Belt, China. *J. Clean. Prod.* **2019**, *238*, 117916. [CrossRef]

83. Sheng, Y.; Zhao, Y.; Zhang, Q.; Dong, W.; Huang, J. Boosting rural labor off-farm employment through urban expansion in China. *World Dev.* **2022**, *151*, 105727. [CrossRef]

84. Cheng, C.; Liu, Y.; Liu, Y.; Yang, R.; Hong, Y.; Lu, Y.; Pan, J.; Chen, Y. Cropland use sustainability in Cheng–Yu Urban Agglomeration, China: Evaluation framework, driving factors and development paths. *J. Clean. Prod.* **2020**, *256*, 120692. [CrossRef]