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Trends, Drivers, and Land Use Strategies for Facility Agricultural Land during the Agricultural Modernization Process: Evidence from Huzhou City, China

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Abstract: Facility agriculture is an important initiative to adopt an all-encompassing approach to food and build a diversified food supply system. Understanding the evolution of facility agricultural land and the factors that drive it can contribute to the development of scientifically strategic agricultural planning and agricultural modernization. Therefore, this paper constructs a "situation-structure-behavior-value" theoretical framework; quantifies the relevant driving factors (physical, proximal, and socioeconomic) and their impacts on the development and layout of facility agriculture land by using a multivariate logistic regression model; and provides a strategy for optimizing land use. The results showed that the area of facility agriculture in Huzhou is rapidly expanding. Regarding drivers, facility agricultural land tends to be located in areas with higher slopes according to plot selection. Facility agriculture is more likely to develop in plots with convenient transportation and closer proximity to markets. At the economic level, economic efficiency, agricultural resource superiority, and policies significantly impact facility agriculture expansion. Finally, we propose three land use policy options to facilitate the sustainable development of facility agriculture. This study elucidates the underlying factors driving different types of facility agricultural land and offers methodological guidance for policy support, planning, control, and optimization strategies for facility agriculture.

Keywords: facility agricultural land; spatiotemporal dynamics; multilevel analysis; situation-structure-behavior-value

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1. Introduction

In densely populated regions such as China and India, a significant number of the rural population lives on small-scale subsistence family farms [1,2]. These small farms provide the bulk of the food supply for the local market [3]. However, in recent years, the quality of farmland has deteriorated due to increased poor land mismanagement. Furthermore, rapid urbanization has increased competition for land use from agriculture and other sectors of the economy [3]. Thus, these small farms are facing the challenge of agricultural restructuring and transformation. China has developed an innovative agricultural system that uses marginal, infertile, or uncultivable land to produce high-quality food [4]. This rapidly developing farming system is known as "facility agriculture". Different countries and regions have different names for facility agriculture, such as "protected agriculture" in Europe and Japan and "controlled environmental agriculture" or "greenhouse agriculture" in the United States. Facility agriculture refers to the use of facilities to artificially modify elements of the internal environment to create favorable conditions for improving the quality of agricultural production and increasing agricultural yields [5]. Currently, facility agriculture is becoming a steadily growing agricultural sector worldwide [6–8]. Facility agriculture is a high-input, high-output, labor-, capital-, and technology-intensive industry. Its degree of development has become one of the most important indicators for measuring the level of agricultural modernization in a country or region [9].

The demand for quality horticultural products has been rising over the past two decades due to the growing interest in nutritious, fresh, and high-quality new produce [10,11]. Extensive exploration of greenhouse cultivation techniques, design, and management has been undertaken worldwide [12–14]. A comprehensive history of greenhouses over the last thirty years can be found in [8,15,16]. Hanan, Critten, and Bailey have reviewed greenhouse engineering research since the 1990s [17,18]. Since the start of the 21st century, greenhouses have gradually graduated from hobby-scale operations to commercial-scale operations driven by precision technology, data processing, and smart agriculture. According to statistics, the global greenhouse vegetable production area in 2019 was 496,800 hectares. Nearly 80% of this greenhouse area is distributed in eight countries: China, Spain, South Korea, Japan, Turkey, Italy, Morocco, and France [19]. Due to the early development of their facility agriculture industry, these countries have developed more complete systems of facility agriculture cultivation technology, thus enabling more comprehensive research in the fields of facility environment regulation, land use, planting technology, development and breeding varieties, and other areas. Factors such as long-term climate and annual weather variability, crop genetics, input costs (e.g., fertilizers and pesticides), availability of farm machinery, and farm size are all factors that influence facility-based agricultural practices [20]. Furthermore, efficient large-scale commercial greenhouse production also must account for other conditions, including environmental, economic, and social factors [21–23]. Therefore, an exploration of the drivers of facility agriculture practices is important for future large-scale commercial greenhouse production.

China is well-known worldwide for its challenging relationship with land [24]. Arable land resources are limited and subject to strict use controls. Since the 20th century, facility agriculture in China has expanded rapidly, and the development of facility agriculture has further given rise to the creation of facility agricultural land [25]. At present, Chinese scholars have made relatively great progress in exploring facility agricultural land and have established research on facility agricultural land, mainly focusing on engineering technology [26,27], ecological and environmental effects [28–31], assessments of economic benefits [32,33], development status, and policy recommendations [34–36]. The dynamic evolution of agricultural land has typically been an important factor in the study of land use change [37], but most of the established studies have focused on the contradiction between the expansion of construction land and the protection of arable land [38,39] or the reconfiguration of multiple types of land use and functions in a certain region [40,41], neglecting the relationship between land used for facilities, land used for arable land, and land used for nonagricultural construction. Land use challenges can be summarized as follows: insufficient supply of land for facility agriculture, lack of a sound security system, uneven regional development, low level of mechanization, and inefficient land use [25,35,42,43]. However, few studies have quantitatively revealed the linkages and interactions between the dynamic evolution and drivers of facility agriculture land use. In this context, two key questions should be addressed for better management of facility agricultural land: (1) what are the trends of facility agriculture in relation to other land use changes across time and space? (2) what are the determinants of the facility agricultural land and their variations with crop types and scales?

At present, in the context of implementing China's rural revitalization strategy, a study of the intrinsic mechanisms, modes, and feasibility of promoting rural industrial revitalization on facility agricultural land is urgently needed. Considering the above shortcomings, via a review of the history of facility agricultural land development in China, the inner logic of facility agriculture for rural industrial revitalization is explored. Huzhou City is adopted as a typical case study to examine the spatial and temporal evolution and driving force analysis of facility agricultural land, thus providing a scientific basis for formulating sustainable facility agricultural development plans and land use policies. The specific objectives of this paper are as follows: (1) to determine the development history and logical mechanism of the value realization of facility agricultural land in China; (2) to monitor the changes in land use for facility agriculture in Huzhou City from 1999 to 2021; (3) to quantify the driving factors for the expansion of facility agricultural land; and (4) to provide insights for designing sustainable land use practices and policy tools.

2. Theoretical Framework

2.1. The Evolution of Land Use Policy for Facility Agriculture

China is one of the leading countries in the field of facility agriculture. According to statistics, the area of facility agriculture in China has reached over 13 million hm^2, ranking first in the world and accounting for approximately 80% of the total area of facility agriculture in the world. Since the concept of "facility agriculture land" was first introduced in 2007, relevant departments have explored policies related to facility agricultural land management based on the development needs of facility agriculture and the requirements of farmland use control. The control of land for facility agriculture has moved through four periods: the gap period (before 2007), the initial period (2007–2010), the development period (2010–2021), and the perfection period (after 2021), as shown in Figure 1.

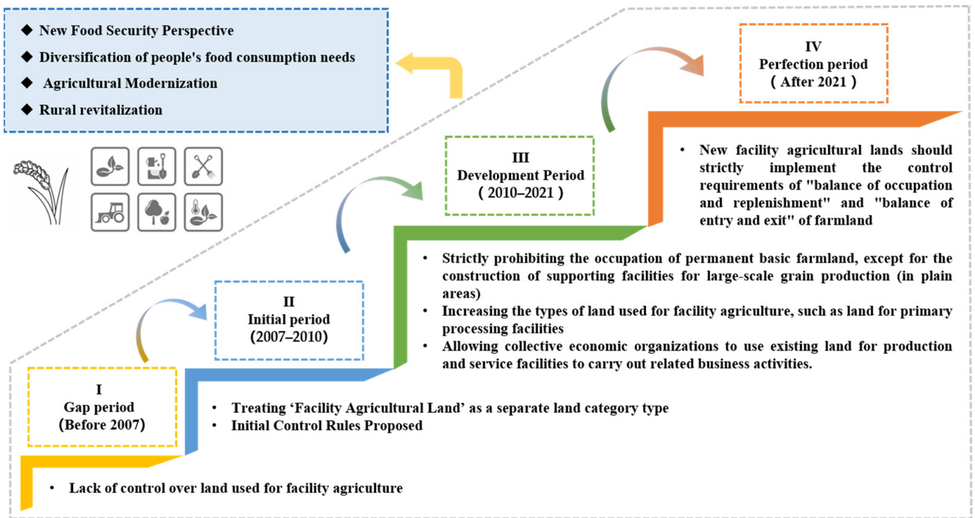

Figure 1. Evolution of land use policy for facility agriculture in China since 2007.

2.2. Research Framework

Over 15 years of development and exploration have led to the rapid expansion of facility agriculture areas in China. However, under the multiple pressures of rural revitalization and arable land protection, the continued increase in demand for facility agricultural land has posed management challenges. The optimization of facility agricultural land is widely recognized as an important undertaking. Facility agricultural land optimization is influenced by the external environment, the local government, village collectives, enterprises, and other relevant entities; furthermore, it is impacted by the interactions of both general and specific governance policies and processes. In the 1980s, a group of scholars led by Ostrom proposed and perfected the Institutional Analysis and Development analytical framework for explaining collective action by summarizing and outlining the main factors within various types of institutional arrangements, such as external variables, arenas of action, and correlated outcomes [44]. Chinese scholars have further developed a general analytical framework with four dimensions, known as the "context-structure-behavior-outcome" framework, which can be used to analyze and identify the mechanism of each element in the complex system of land governance in China [45,46]. Optimization of facility agricultural land requires full-cycle management, and the high efficiency of agricultural land for facilities can improve the utilization efficiency of land and the income of operators, generating more value. Therefore, based on the "situation-structure-behavior-result" framework, we focus on the dimension of value enhancement of facility agricultural land and innovatively propose the analysis framework of "situation-structure-behavior-value". We innovatively put forward the analysis framework of "situation-structure-behavior-value" to analyze the internal and external factors, policy support, and optimization paths for optimizing facility agricultural land (Figure 2).

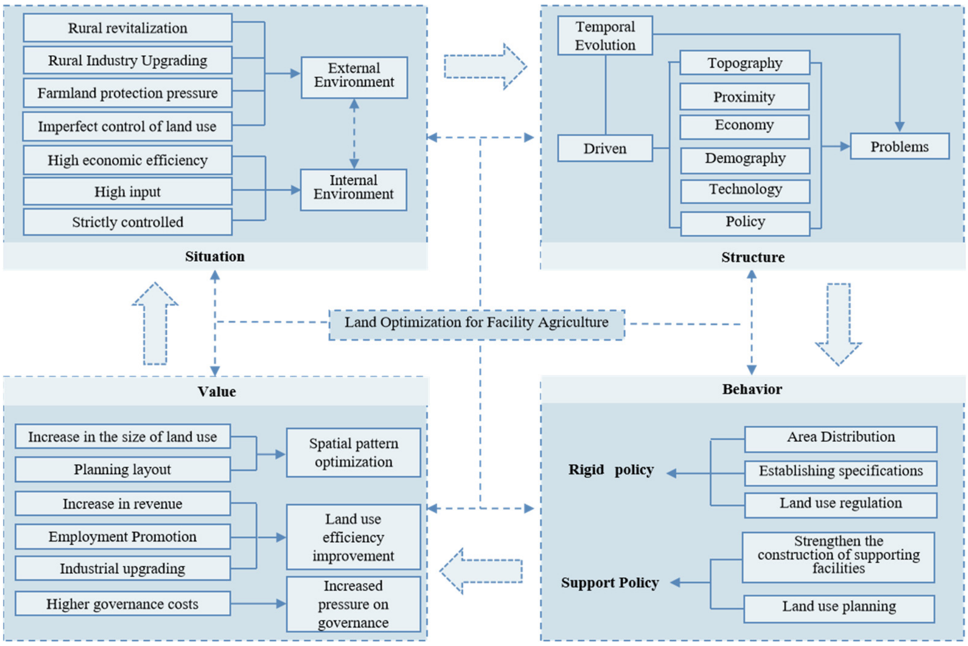

Figure 2. The theoretical framework of value optimization for facility agricultural land.

Situation: Facility agriculture is an essential part of China's modern agricultural system and plays a major role in rural economic development and agricultural supply. However, in the process of rapid urbanization, the scale of construction land is expanding, leading to the serious phenomenon of nonagriculturalization and nongrain production, which substantially increases farmland protection contradictions. In 2022, China proposed gradually building all permanent basic farmland into high-standard farmland, which means that arable land production will be increased to guarantee the supply of food. Therefore, from a spatial point of view, the incremental area of farmland that can be used to produce nongrain products is relatively small; thus, facility agriculture needs to be developed to improve the land output rate and increase the supply of agricultural products. In terms of variety, facility agriculture has gradually expanded from facility horticulture to facility aquaculture, facility aquaculture, and other fields to better meet people's diverse needs. Thus, the combination of the macro background and the micro status quo provides a foundation for action to optimize the land used for facility agriculture.

Structure: With the rapid development of agricultural technology in China, facility agriculture has gradually matured, and the area of facility agriculture has expanded rapidly. However, the industry is still challenged by unsound management systems, insufficient land supply, decentralized layouts, and inefficient facility agricultural land use. Given the current problems associated with facility agriculture land, in this paper, the driving factors of facility agriculture land expansion are explored from the dimensions of topography, proximity, economy, population, technology, and policy to further grasp the layout preference and type selection of facility agriculture land and to provide important support for future development planning and land use optimization in facility agriculture.

Behavior: According to previous research, a multilevel and multiperspective policy mix is necessary for innovative governance [47]. Rigid policies strengthen bottom-line thinking and rule awareness in the development of land for facility agriculture, mainly in the areas of spatial planning, index allocation, and the establishment of whole-process norms. Incentive policies encourage village collectives and villagers to cultivate leading industries according to local conditions, revitalize idle land in villages, and establish a long-term "blood-making mechanism" to stimulate village development.

Value: The optimization of the value of facility agricultural land is intended to harmonize high-quality agricultural development and resource reallocation. First, the increased supply of land for facility agriculture and detailed planning and layout can guide the future development and layout of facility agriculture. Second, due to its high yield, facility agriculture can increase rural employment and promote rural economic development and industrial upgrading. When the value of facility agriculture is optimized to a certain level, a new round of transformation of facility agriculture land will begin.

3. Materials and Methods

3.1. Study Area

This research was conducted in Huzhou City (Figure 3), which is located in northwestern Zhejiang Province (119°14′–120°29′ E, 30°22′–31°11′ N) at the junction of Jiangsu, Zhejiang, and Anhui provinces, covering an area of 5820 km^2. The terrain is roughly inclined from southwest to northeast; the eastern part is a watered plain, and the western part is dominated by mountains and hills. Huzhou city is located in the North Asian tropical monsoon climate zone and is characterized by four distinct seasons and abundant rainfall during the same season. The annual sunshine hours range from 1613 h to 2430 h, the annual precipitation ranges from 761 to 1780 mm, and the annual average relative humidity is above 80%. Owing to geographical and climatic characteristics, the region has focused on developing special advantageous industries, such as tea, fruits and vegetables, and Hu sheep, which account for more than 80% of the agricultural output. With the development of modern agriculture, local governments have actively encouraged the large-scale development of facility agriculture and the active participation of agricultural families in facility agriculture. In the past two decades, Huzhou City has been vigorously upgrading its level of intensive horticulture, ecological livestock, and aquatic knowledge in facility agriculture, leading to its rapid growth. The area is a role model for the development of facility agriculture in the Lake Tai Rim region of China and can therefore be typically selected to examine the multilevel determinants of facility agriculture.

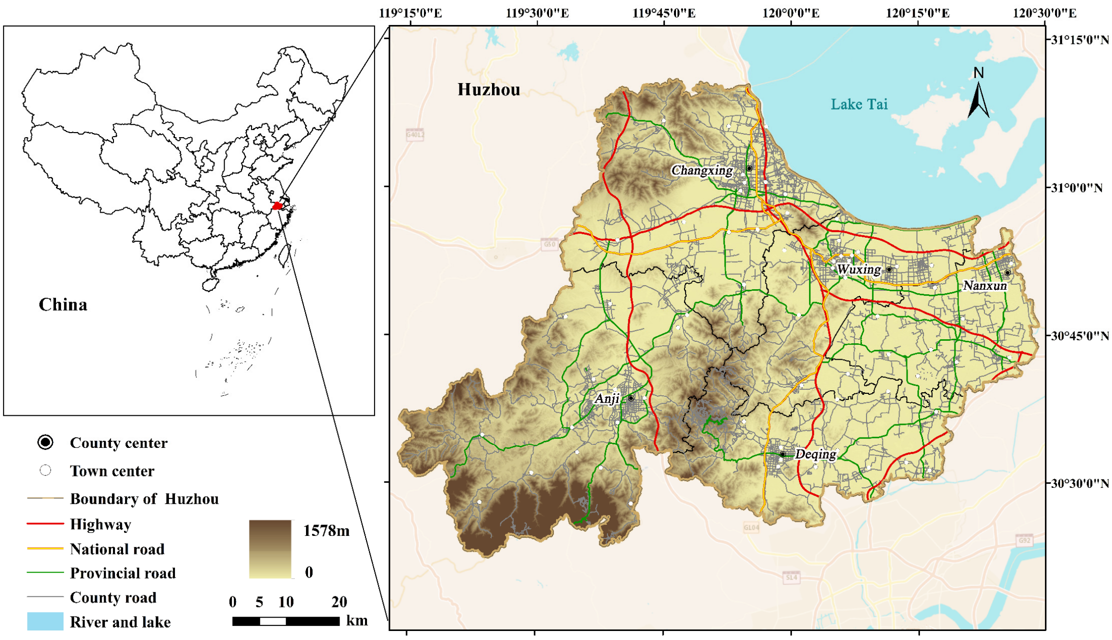

Figure 3. Location of Huzhou City (China), with transportation routes, rivers, and lake within it.

3.2. Data Source and Processing

Multiple sources of data, such as spatial and statistical data, were utilized to screen potential influencing factors on the expansion of agricultural land for facilities (Table 1). All spatial data were harmonized to the same spatial reference. We utilized auxiliary data such as topography, buildings, and high-resolution images for visual interpretation. Considering land use patterns and cultivation types, facility agriculture land was divided into three categories, namely, facility cultivation, facility breeding, and facility aquaculture, and nine land use types, namely, grain, tea, vegetables, fruits, floriculture and nursery, live pigs, Hu sheep, poultry, and aquaculture.

Table 1. Data sources and description in this study.

Data Name	Data Description	Data Source
Socioeconomic data	Statistical Yearbook of Huzhou; the basic unit is the county	Huzhou Municipal Bureau of Statistics http://tjj.huzhou.gov.cn/ (accessed on 25 August 2022)
DEM data	Raster, 30 m × 30 m	Geospatial Data Cloud http://www.gscloud.cn/ (accessed on 18 October 2022)
Land use/cover data	Vector data 1:500,000 m	Huzhou Bureau of Planning and Natural Resources
Facility agricultural land data	Vector	Huzhou Bureau of Planning and Natural Resources
Road nets data	Vector	Open Street Map (OSM)
POI data	Geographic Data	Gaode Open Platform https://lbs.amap.com/ (accessed on 20 February 2023)
Satellite image	Raster, 1 m	Geospatial Data Cloud http://www.gscloud.cn/ (accessed on 18 October 2022)

3.3. Land Use Center of Gravity Migration Model

The center of gravity model is an important analytical tool for studying the spatial changes in elements during the process of regional development; it was initially used to study the changes in the centers of gravity of the population and the economy [48,49]. The land use center of gravity migration model is used to reveal the process of changes in the spatial pattern of various types of land resources by drawing on the principle of changes in the center of gravity of the population distribution. In this paper, the land use center of gravity migration model is used to calculate the coordinates of the center of gravity of each type of facility agriculture in different periods to visualize the process of the spatial pattern change in facility agriculture in the region. The formula is:

$$x_j = \frac{\sum_{i=1}^{n} \left(T_{ij} \times x_i\right)}{\sum_{i=1}^{n} T_{ij}} \tag{1}$$

$$y_j = \frac{\sum_{i=1}^{n} \left(T_{ij} \times y_i\right)}{\sum_{i=1}^{n} T_{ij}} \tag{2}$$

where T_{ij} (i = 1, 2, 3, . . ., n) denotes the area of facility agriculture in the jth year of the $\boldsymbol{i}$th evaluation unit, x_i and y_i are the geographic latitude and longitude, respectively, of the $\boldsymbol{i}$th evaluation unit, and x_j and y_j are the horizontal and vertical coordinates, respectively, of the center of gravity in the J^{th} year for the different types of facility agriculture.

3.4. Rate of Expansion of Facility Agricultural Land

Expansion speed indicates the magnitude of change in land use area per unit of time and can be used to analyze the speed of change in land expansion. In this paper, we calculate the expansion speed of different types of facility agricultural land and further explore the change in the type of facility agricultural use. The formula is as follows:

$$V_i = \frac{S_b - S_a}{T_b - T_a} \times 100\% \tag{3}$$

where V_i is the rate of expansion of facility agricultural land in category i, S_b indicates the area of facility agricultural land at the end of the facility agricultural land, S_a indicates the area of facility agricultural land at the beginning of the facility agricultural land, T_b is the time at the end of the study time period, and T_a is the time at the beginning of the study period.

3.5. Multilevel Regression

Logistic regression can be used as a multilevel determining factor for the probability of facility agriculture planting. Multilevel logistic regression is a variant of logistic regression, the concept of which is consistent with that of logistic regression analysis [50,51]. The multilevel logistic regression model is suitable for explaining variables with three or more categories, and there is no order relationship between the categories. Considering the dependent variable, multilevel logistic regression takes one category as the benchmark category and calculates the regression coefficient of the benchmark category. The logistic model uses binary data (occurrence and nonoccurrence) to analyze the ratio of occurrence to nonoccurrence (odds ratio). Considering a multilevel logistic model, a dependent variable is paired with a baseline category, and the dominance ratio of the baseline category is calculated. Assuming that Class J is the benchmark class, the logic of the benchmark class is:

$$\lambda = Log\left(\frac{\pi_j}{\pi_J}\right) = \alpha_j + \beta_1 x_{1j} + \ldots + \beta_{ij} x_{1j} \quad (4)$$

where $j = 1, \ldots, J-1$, λ represents the logit value of the baseline category, α represents the intercept, β represents the independent variable, and x represents the regression coefficient. The polynomial logistic model can be expressed in probabilistic form as follows:

$$P_j = \frac{exp\left(x_0 + \sum_{j=1}^{k} \beta_i x_i\right)}{1 + \sum_{i=1}^{k-1} exp\left(x_0 + \sum_{j=1}^{k} \beta_i x_i\right)} \quad (5)$$

where P_j is the probability of the jth category dependent variable, k is the number of potential influencing factors, x_0 is the constant term, x_j is the independent variable, and β_j is the corresponding regression coefficient. The probability of the reference category can be calculated as follows:

$$P_J = \frac{1}{1 + \sum_{i=1}^{k-1} exp\left(x_0 + \sum_{j=1}^{k} \beta_i x_i\right)} \quad (6)$$

where P_J is the probability of the $Jth\ (J \neq j)$ class-dependent variable and J is the reference class dependent variable, k is the potential influence number of factors, x_0 is the constant term, x_i is the independent variable, and β_i is the corresponding regression coefficient.

Multilevel regression was used to determine the determinants of land expansion for facility agriculture. The principle of multilevel regression is similar to multilevel logistic regression:

$$Y_i = b_0 + b_1 x_1 + b_2 x_2 + \ldots + b_n x_n \quad (7)$$

where Y_i is the probability of arable land becoming facility agricultural land, b_0 is the intercept of the model, b_n (n = 0, 1, 2, . . . n) is the slope coefficient of the logistic regression model, and x_n (n = 0, 1, 2, . . . n) is the independent variable. The linear model generated is a logistic regression on the presence or absence of land for facility agriculture conditional on the dependent variable.

Before performing multilevel regression, we first normalized and standardized all the variables. Diagnosis of multicollinearity between the drivers was performed to ensure that the correlation coefficient between the factors that were eventually included in the model was less than 0.5. In addition, Moran's I index [52] was calculated to test the autocorrelation of the model residuals. In this study, based on SPSS 22.0, multinomial logistic regression was performed and Percentage of Correct Prediction (PCP), Cox & Snell R^2, and McFadden R^2 values were used to describe the effect of multilevel logistic regression.

3.6. Potential Explanatory Variables

Land use changes are determined by multiple factors. Spatially, land use determinants are usually divided into four categories: topography, proximity (distance to roads, rivers, and township centers), socioeconomic factors (markets, outputs, policies), and neighborhoods (neighboring land use patterns) [53–55]. A large amount of literature indicates that this framework can be used to effectively identify potential factors that affect land use changes. Therefore, based on the literature review and the characteristics of facility agriculture, we selected eleven potential explanatory variables from six dimensions: topography, proximity, economy, population, technology, and policy. At the plot level, we selected two physical variables (slope and elevation) and three proximity variables (distance to road, distance to river, and distance to town center). All the variables were calculated in GIS via a data elevation model of the study area (1:500,000), a digital traffic map (1:500,000), and a land use map (1:500,000).

At the village level, macroeconomics has a significant impact on land use decisions. Therefore, we selected three socioeconomic variables (economic benefits, agricultural resource superiority, and distance from leading enterprises). At the population level, we used the proportion of people engaged in agriculture to represent the local labor situation. At the technical level, the total power of agricultural machinery was used to reflect the local level of agricultural mechanization. In addition, we selected a variable: land use policy. If land use policies were implemented in an environment that required farmers to actively engage in facility agriculture, the policy variable was assigned a value of 1; otherwise, it was assigned a value of 0. The data on socioeconomic variables were provided by the local government. Other variables were calculated using GIS. The general statistics of the potential explanatory variables are shown in Table 2.

Table 2. Descriptive statistics of the explanatory variables.

Dimension	Determinants	Implications
Topography	Slope (°)	Average slope of each piece of facility agricultural land
	Elevation (m)	Average elevation of each piece of facility agricultural land
Proximity	Distance to county road (m)	Distance of the facility agricultural land from the nearest road
	Distance to town center (m)	Distance of the facility agricultural land from the nearest town center
	Distance to water sources (m)	Distance of the facility agricultural land from the nearest river
Economy	Economic benefits (RMB)	Average value of output of different types of agricultural industries in the current year × plot area
	Agricultural resources superiority: whether it is located in the main production area of special agricultural products	Whether it is located in a village with Special Agricultural Products (0/1)
	Distance to leading agricultural product enterprises	Distance of the facility agricultural land from leading agricultural product enterprises (POI data)
Demography	Agricultural population proportion (%)	The population is engaged in agriculture/Rurally employed population
Technology	Total agricultural machinery power (kw)	Reflecting the level of agricultural mechanization
Policy	Availability of policy support	Whether major policies were issued in the current year (0/1)

4. Results

4.1. Spatiotemporal Characteristics of the Expansion of Facility Agricultural Land

4.1.1. Quantitative Characteristics of Facility Agricultural Land Expansion

Huzhou City is estimated to have more than 1250 registered projects for facility agricultural land, with a land area of approximately 273.93 ha, accounting for 5.2% of the area of facility agriculture in Zhejiang Province (Figures 4 and 5). From 1999 to 2021, the net increase in the area of facility agricultural land in Huzhou was 272.1 ha, with an average annual increase of 12.96 ha and an average land area of more than 2200 square meters. In 2007, the total area of facility agricultural land in Huzhou was approximately 1.51 ha, which was mainly used for livestock and poultry breeding, vegetable planting, tea drying, and small-scale agricultural equipment storage.

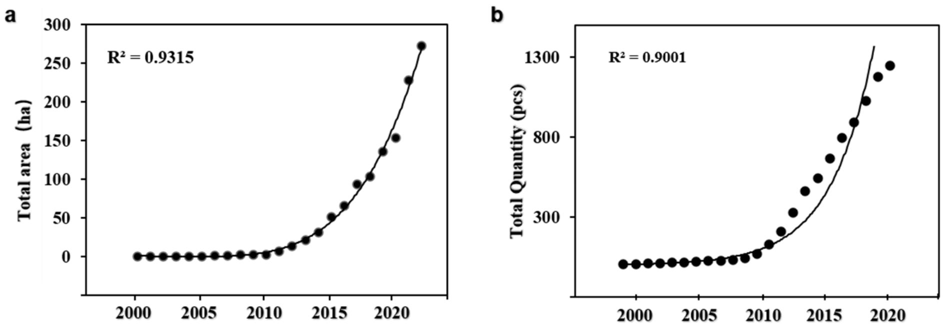

Figure 4. Temporal trends (**a**) and quantity change of plots (**b**) of land for facility agriculture from 2007–2021 in Huzhou City, China.

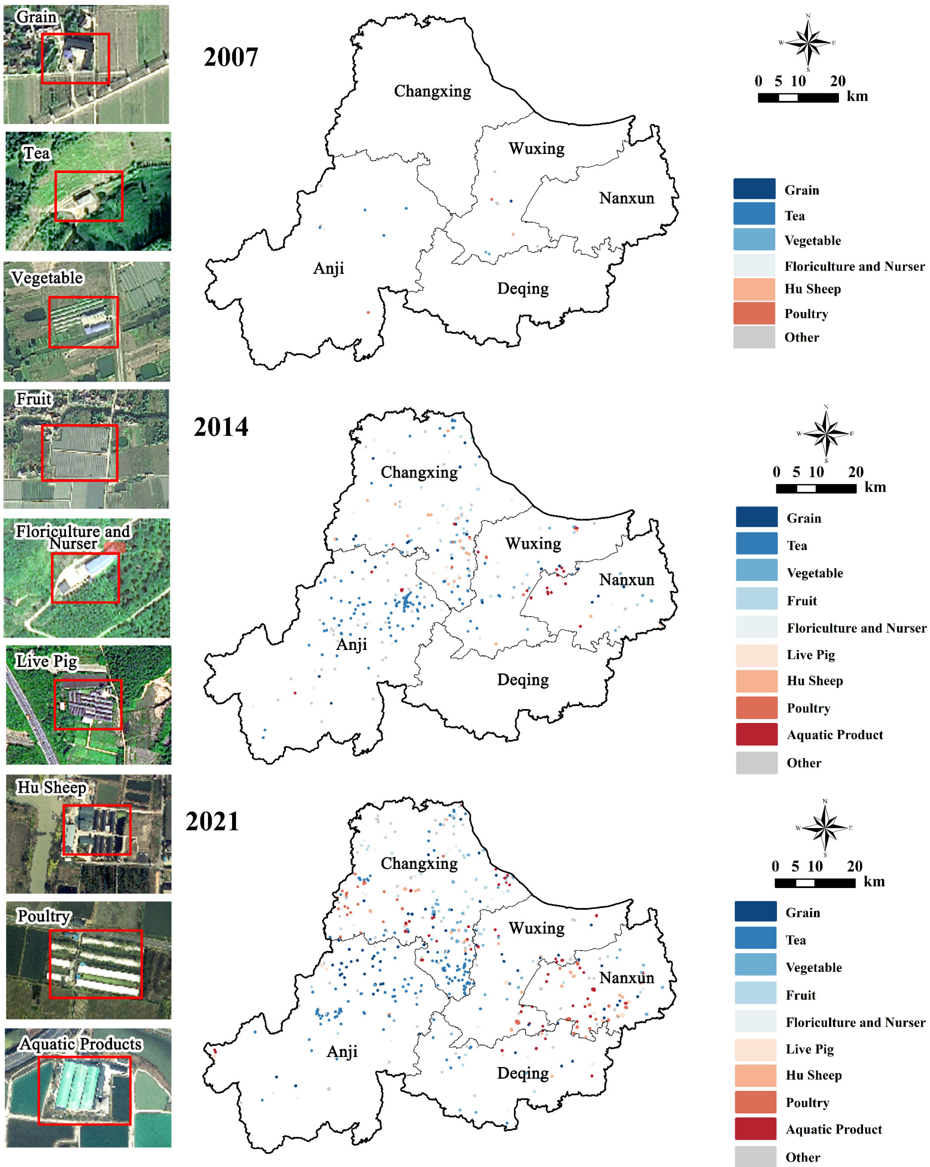

Figure 5. Spatial patterns and remote sensing image samples of different types of facility agriculture in Huzhou City, China, from 2007 to 2021.

From the calculation results of the expansion rate of facility agricultural land (Table 3) during the period from 2008 to 2014, the area of facility agricultural land for grain, tea, Hu sheep, and aquaculture expanded rapidly, and tea, livestock, and poultry farming became important types of facility agriculture in Huzhou City. After 2015, as the scale of agricultural production and operation in Huzhou City continued to expand, land expansion for facility agriculture further accelerated. Livestock and poultry farming became the fastest-expanding type of facility agriculture. With the in-depth implementation of the arable land protection policy, the area supporting land for grain cultivation also proliferated. Currently, the tea industry, livestock breeding, and aquaculture are important types of facility agriculture in Huzhou city.

Table 3. Rate of Expansion of Facility Agricultural Land Area in Huzhou City, 2007–2021.

Type		2007		2014		2021	
		Expansion Area (km^2)	Expansion Rate Value (km^2/Year)	Expansion Area (km^2)	Expansion Rate Value (km^2/Year)	Expansion Area (km^2)	Expansion Rate Value (km^2/Year)
Planting	Grain	0.57	0.07	42.99	6.14	100.97	12.62
	Tea	1.34	0.17	82.22	11.75	76.56	9.57
	Vegetable	0.51	0.06	22.92	3.27	43.49	5.44
	Floriculture and Nursery	0.54	0.07	30.90	4.41	32.96	4.12
	Fruit	0.00	0.00	21.22	3.03	27.23	3.40
Livestock breeding	Live Pigs	0.00	0.00	26.78	3.83	502.23	62.78
	Poultry	0.75	0.09	22.87	3.27	583.19	72.90
	Hu Sheep	4.60	0.57	135.45	19.35	336.30	42.04
Aquaculture	Aquatic Product	0.00	0.00	50.70	7.24	333.94	41.74

4.1.2. Spatial Characteristics of the Facility Agricultural Land

The spatial distribution of facility agricultural land in Huzhou is extensive but uneven. Between 1999 and 2007, facility agriculture was practiced mainly in Anji County in the southwest and Wuxing District in the central region, though sporadically. The industrial centers of gravity for tea, flowers, and seedlings are in the northern part of Anji County, while the industrial centers of gravity for vegetables, livestock, and grain are concentrated in the central Wuxing District (Figure 6). During the period 2008–2014, facility agriculture expanded rapidly and increased in diversity. For instance, Anji, a typical representative of tea cultivation, has a large number of tea-related facility land operations, many of which are clustered. The northwestern and central areas of Huzhou, which are hilly, contain facility land clusters of specialty agricultural products such as fruits, flowers, and seedlings. Facility aquaculture is mainly concentrated in the central part of Huzhou city, and the center of gravity has moved northward, i.e., the area of livestock and poultry farming in the northern part of Huzhou city has expanded significantly. Facility aquaculture is mainly located in the western plains near Tai Lake. For facility cultivation, the tendency for the center of gravity to migrate is not obvious, showing a trend toward balanced development or clustering. After 2014, the expansion of facility agriculture to the southern region was obvious. The center of gravity of the development of facility agriculture as a whole moved southward, with a clear trend of expansion of facility farming to the southeast. In terms of the overall spatial layout, the central region is characterized by a concentration of land used for facility agriculture and a variety of land types.

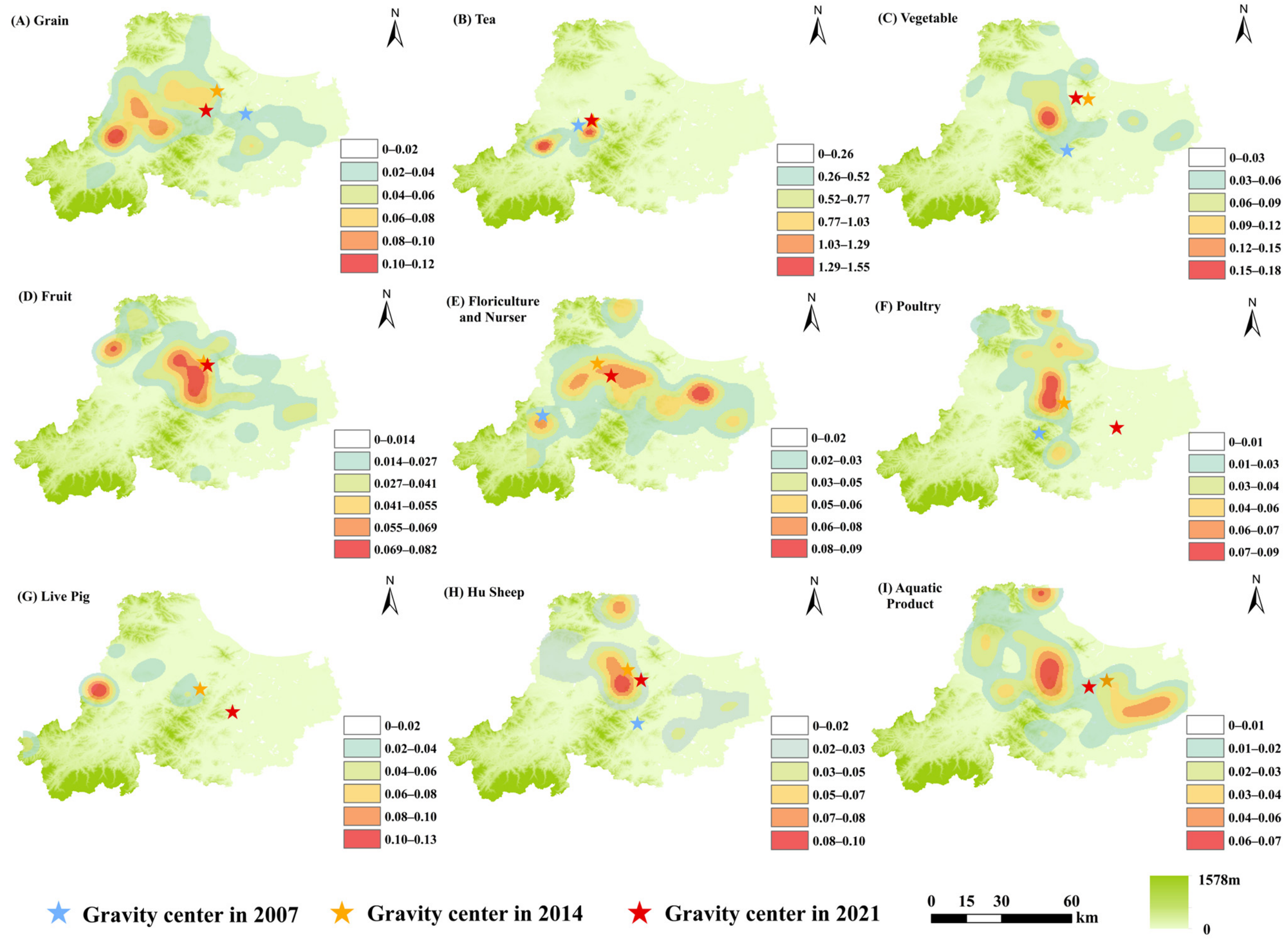

Figure 6. Center of gravity migration and kernel density for different types of facility agriculture, 2007–2021.

Different types of facility agricultural land have obvious spatial differences (Figure 7). The Moran's I indices for tea and vegetable cultivation were 0.187 and 0.16, respectively, indicating significant spatial autocorrelation. The hotspot areas of tea primary processing land are mainly distributed in the core tea production areas in the central and western parts of Huzhou. The vegetable growing facilities are mainly located in the north-central region. Seedling and flower cultivation and aquaculture also exhibited strong spatial correlations. Flower and seedling planting facilities are mainly concentrated in the central and northwestern hilly areas. The land for aquaculture facilities is clustered in the eastern and central regions. The spatial agglomeration type of grain, fruit, poultry, pig, and Hu sheep was weak, with global Moran's I values all being less than 0.1. Overall, all types of land for facility use exhibited some positive spatial correlation. This finding suggests that pioneers of facility agriculture may encourage neighboring farmers to partake.

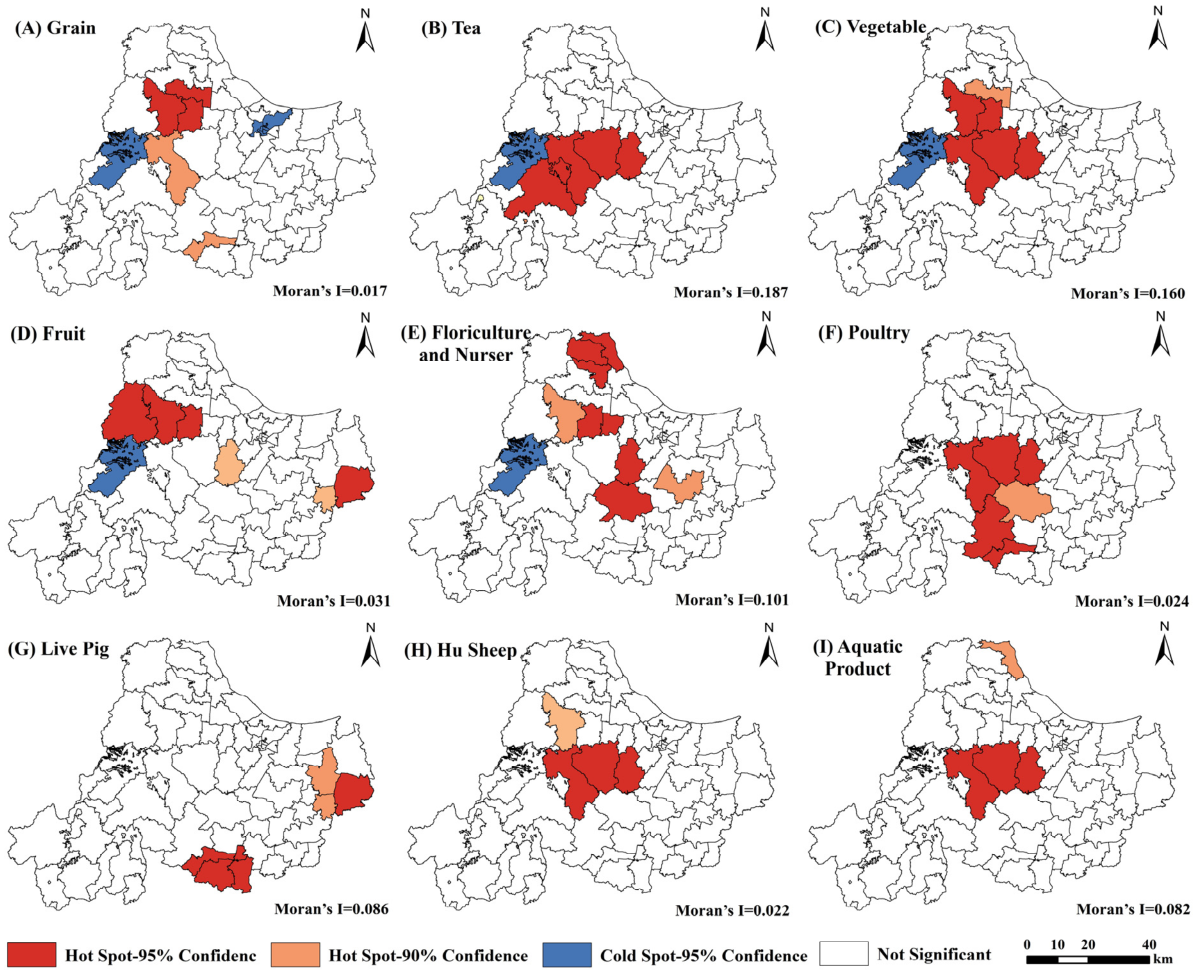

Figure 7. Spatial hotspot map of different types of facility agricultural land.

4.1.3. Characteristics of Land Use Change in Facility Agriculture

The sources of increased land use for facility agriculture mainly include cropland, forestland, garden land, and nonagricultural construction land. In general, land use change to facility agriculture mainly comes from cultivated land and nonagricultural construction land. This change has been drastic over time (in Figure 8). Between 1999 and 2007, the scale of land used for facility agriculture was low; thus, there was little movement between lands. After 2008, nonagricultural construction land and cultivated land were the main sources of increases in land used for facility agriculture in Huzhou City. Especially after 2014, a large amount of arable land and nonagricultural construction land was converted into land for facility agriculture. During this period, most of the land diverted to facility farming was used for hogs, sheep, and poultry. In terms of land outflow, a small amount of outflow of facility agriculture land has occurred since 2008. From 2014 to 2021, with the modernization of agriculture and the transformation of rural industrial diversification, the demand for facility agricultural land continued to increase, and the corresponding changes in the increase or decrease in the amount of facility agricultural land became more drastic. Overall, approximately 40% of the existing facility's agricultural land was converted to nonagricultural construction land, and approximately 25% was restored to cropland. Livestock and poultry farming constitute the main type of existing facility agricultural land.

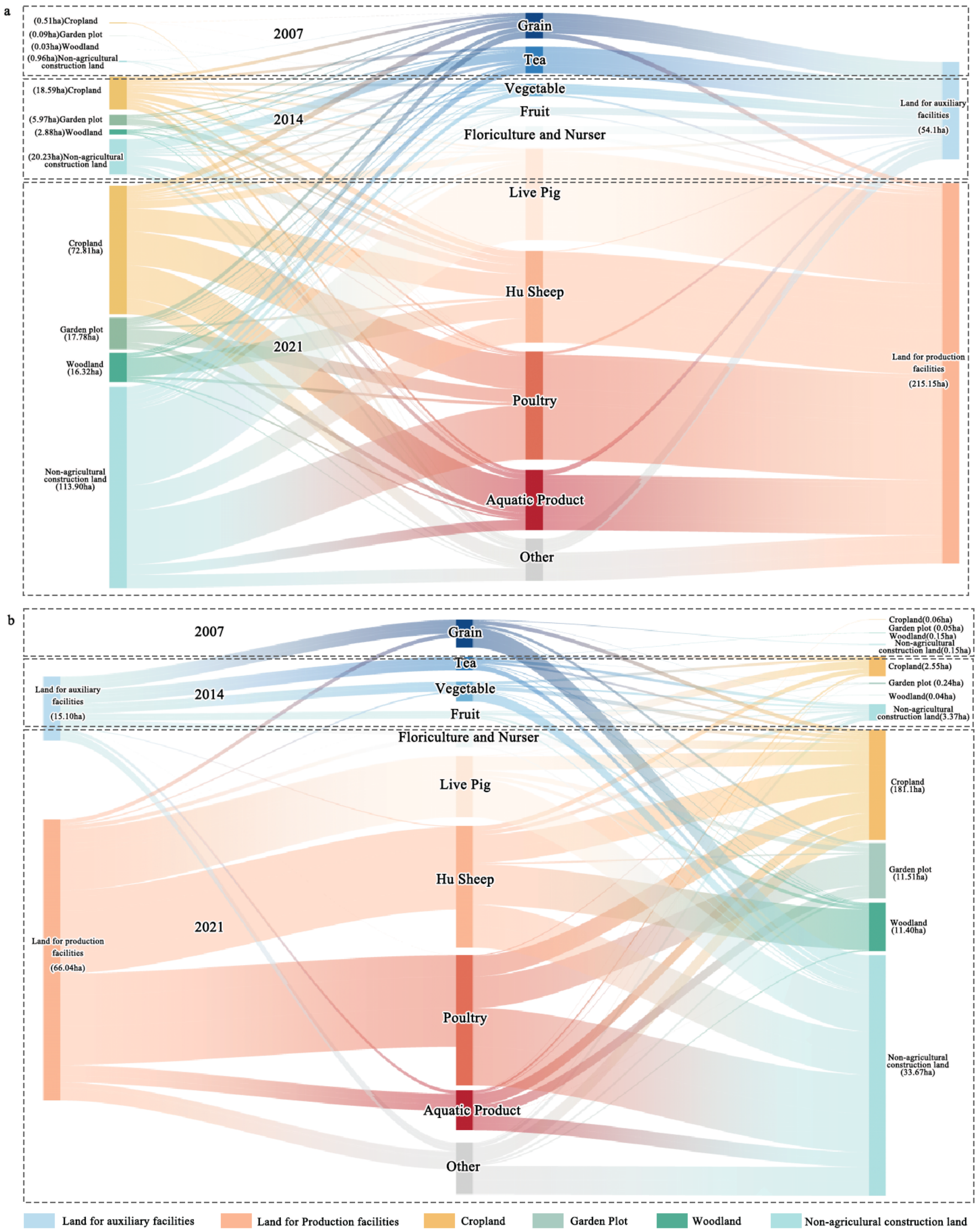

Figure 8. Facility agricultural land use transfer matrix in Huzhou City: (**a**) transfer in, (**b**) transfer out.

4.2. Multilevel Determinants of the Expansion of Facility Agricultural Land

Table 4 shows the determinants of land expansion for facility agriculture identified via multilevel logistic regression. The *p*-value was less than 0.05, indicating that the multilevel regression was able to predict the expression of facility agricultural land. Economic efficiency, local agricultural advantages, and a population that is engaged in agriculture and policies are strongly correlated and are key factors influencing the expansion of facility agriculture. Among them, economic efficiency has a significant negative correlation with facility agriculture, i.e., when the economic efficiency of cultivated land decreases, it will greatly increase the probability of farmers developing facility agriculture.

Table 4. Determinants of land expansion of facility agriculture in Huzhou (China) identified by multilevel logistic regression.

Determinants	Planting	Livestock Breeding	Aquaculture
Constant	2.515 *	1.972 *	0.431
Slope	0.484 *	−0.079	−0.426
Elevation	0.999 **	1.009 *	−0.121
Distance to county road	−0.056	−0.019	0.200
Distance to town center	0.152	0.175	−0.034
Distance to river	−0.181	0.225	−0.433 *
Agricultural resources superiority	2.216 **	0.854 *	2.086 **
Agricultural population proportion	0.054 **	0.793 **	0.598 *
Economic benefits	−3.042 *	−5.653 *	−1.991 *
Distance to leading agricultural product enterprises	−0.174	−0.0137	0.019
Total agricultural machinery power	0.580 **	0.087 **	0.265
Policy	0.230 *	0.426 *	0.420 *
PCP (%)	95.86	65.41	61.15
McFadden R^2	0.429		
Cox & Snell R^2	0.590		
Moran's I for residuals	0.000	0.000	0.000

Abbreviations: Agricultural resources superiority (whether it is located in the main production area of special agricultural products); Agricultural base (whether it is located in the village or near special agricultural products); PCP (Predicted Probability of Correctness). * $p < 0.05$, ** $p < 0.01$.

At the plot level, there is a positive effect of slope and elevation on the probability of expansion of facility planting. This suggests that the expansion of land for facility planting is more likely to occur in gently sloping areas at higher elevations. Given the negative coefficient of distance from county roads and the positive coefficient of distance from township centers for facility farming, it can be inferred that plots with convenient transportation and those far from administrative centers are hotspots for facility farming. A positive coefficient for the distance from the administrative center indicates that facility farms are more inclined to be laid out in areas close to the market. In addition, there is a negative coefficient for the distance from water sources for facility aquatic land and facility planting land, indicating that the layout of these two types of facility agricultural land needs to be located close to water sources. At the population level, the proportion of the local agricultural population has an impact on the expansion of facility agriculture but has little effect on facility aquaculture. At the technological level, the level of agricultural machinery contributes to the expansion of facility agriculture. In addition, policy is an important factor in promoting the development of facility agriculture.

4.3. Optimized Zoning of Agricultural Facility Land

Land use zoning enables scientific planning and effective management of land use, while township land use zoning provides an important basis for guiding the direction of land use in townships and promoting the utilization of land on a large scale. According to the results of multiple logistic regression, economic benefits are the decisive factor in determining the expansion of facility agriculture. Therefore, following the "principle of maximizing benefits", we determined the dominant type of facility-based agricultural development, taking the village as the smallest unit and considering the integrated natural conditions, land use characteristics, and spatial continuity of the zoning unit. According to the village-level facility agriculture dominant function map, we divided Huzhou City into the Hills Facility Cultivation Advantageous Area, the Plain Key Development Zone, and the Optimizing Development Zone (Figure 9). The Hills Facility Cultivation Advantageous

Zone is dominated by low hills, and the number and scale of facility cultivation land accounts for a relatively high proportion and significant expansion. Facility agriculture in this region should utilize as much unused land as possible, such as barren hills and slopes and inefficient idle land, focusing on the development of high-efficiency facility planting industries. The Key Development Zone is in the plains of the waterways, where facility farming is clustered but the overall scale of facility agriculture is relatively small. As a key development area for facility agriculture, this region should encourage the development of facility agriculture, in terms of quantity and scale, and adjust the regional land use structure to ensure that the sources of land used for facility agriculture and the level of growth fully benefit facility agriculture. The Northwest Optimization and Development Zone has the largest proportion of land area available for facility agriculture, with a variety of types. The region should optimize the spatial structure of facility agriculture and upgrade the industry to improve the high-quality development of facility agriculture.

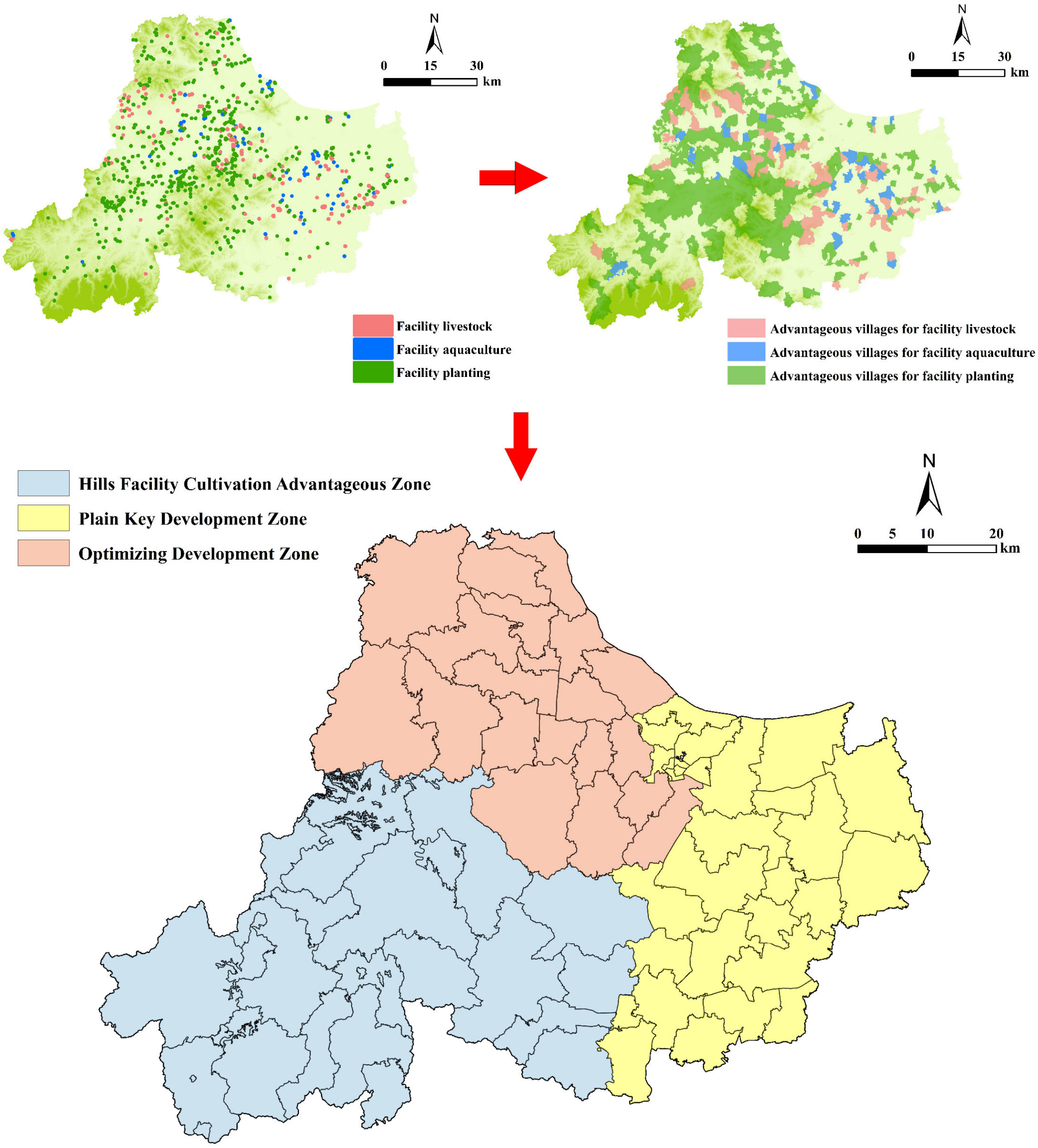

Figure 9. The land use optimization zoning of facility agriculture in Huzhou City.

5. Discussion

5.1. "Situation-Structure-Behavior-Value" Land Optimization System for Facility Agricultural Land

Currently, China has entered a new journey to build a modern socialist country in an all-encompassing manner, in which economic development, upgraded consumption by urban and rural residents, and increasingly diversified demands for food consumption rapidly transform traditional agriculture into modern agriculture. On the other hand, China's food supply and demand will remain tightly balanced in the medium- and long term. The scarcity of land, resources, and environmental constraints increasingly hinder efforts to increase the area of grain and its production levels [56]. The problems of nonagriculturalization and nonfood arable land in some areas cannot be ignored. Century epidemics, extreme weather, and other factors also bring uncertainty to food production [57–59]. As a consequence, influenced by external factors such as urbanization, industrialization, and land use management policies, facility-based agriculture has experienced a rapid expansion of land use areas because it provides a higher-quality, more efficient, and more sustainable form of modern agriculture.

Since the 1990s, facility agriculture in China has achieved significant results. However, with the full popularization of facility agriculture, land use problems associated with facility agriculture have also arisen [60]. According to the monitoring of facility agriculture land use in Huzhou City over the past 20 years, although the facility planting industry has a certain scale, the layout is not efficient enough and the equipment used is unsophisticated. The total number of facilities for animal husbandry and fisheries is insufficient and the scale rate is low. The expansion of facility agricultural land is influenced and constrained by a variety of factors, such as nature, technology, socioeconomics, and policies [61,62]. According to the study, different types of facility agriculture are driven by different factors. In general, economic efficiency and policy are the key factors influencing the development of facility agriculture. When the development of facility agriculture reaches a high level, the contradiction between the strong demand for land and imperfect policy intensifies [63]. On the one hand, the value of facility agriculture cannot be maximized; on the other hand, the pressure of land management further increases. Therefore, a better land use strategy is needed.

Land use management systems and policies may have a significant impact on land use transformation [64]. A multilevel, multiperspective policy mix is a necessary approach to innovation management. The land control of facility agriculture in China has progressed through three stages—none, initial, and development—and is still in the development stage. We propose a combination of rigid and incentive-based policies that can regulate the layout of agricultural facilities and promote the optimal allocation of rural land resources. This approach will lead to a subsequent surge in the development of facility agriculture as a result of the increased value of facility agricultural land.

5.2. Land Use Changes to Facility Agricultural Land: Types and Multilevel Determinants

Between 2007 and 2021, the area of facility agriculture in Huzhou City has increased by 272.42 hectares, of gradually diversified types, and the land used for facility agriculture is mainly derived from cultivated land and nonagricultural construction land. After 2010, the number of subjects involved in facility agriculture has been increasing, but the increase in scale has been relatively flat. The reason is that the development of the rural economy, the structural adjustment of the rural plantation industry, and the support of national policies for the development of facility agriculture have led more and more farmers to participate in facility agriculture. For example, the Government of Jamaica promotes the greenhouse model to revitalize agriculture and has incorporated greenhouses into its long-term strategic plan for agricultural development [65]. Greenhouse cultivation is a form of protected agriculture that maximizes plant growth and productivity. Developed countries also rely on protected vegetable production, such as the Republic of Korea (51%) [66] and France (40%, excluding potatoes) [67].

The nonlinear interactions of land cover change with a range of determinants, and their feedback is complex. The results of the multiple logistic regression showed that economic benefits, policies, and local agricultural resource advantages are the main drivers of facility agriculture development. For many farmers, the development of facility agriculture can bring economic benefits almost immediately. This result is consistent with previous findings that the practice of facility agriculture applied to a field is determined by its impact on the productivity and profitability of the field [68,69]. Likewise, the market demand for high-quality and diversified food will greatly increase the willingness of farmers to engage in facility farming.

At the plot level, most agriculture tends to occur in flat areas at low elevations with gentle slopes. This result is consistent with previous findings that cash crops are mainly grown in non-edge and flat locations [70,71] However, facility farms tend to be organized on plots with greater slopes. This is due to China's strict farmland protection policy, which prevents facility agriculture from occupying flat, high-quality farmland, requiring it to make greater use of woodlands, gardens, and other plots of land with a certain degree of slope.

At the proximity level, facility farms are negatively correlated with the distance to the main road and positively correlated with the distance to the township center [55]. This finding suggests that, as with arable land, facility farms are more likely to be established in places that are easily accessible by road but far from administrative centers. For facility farming, the distance from the town center was identified as a negative factor. Proximity to markets is preferred because it increases the opportunities to trade in regional markets. The distance of land for livestock farming from rivers showed a positive correlation. This result is different from the traditional view that agriculture is influenced by the distribution of rivers. This unexpected inconsistency may be attributed to two reasons: first, to prevent pollution from water sources, policies require facility agriculture to be a certain distance from water sources; second, with the development of technology, facility agriculture facilities can gradually be freed from natural conditions, for example, by using water-saving facilities such as drip and sprinkler irrigation [61,72].

Facility agriculture has strong regional characteristics that are closely related to local agricultural development conditions, resource advantages, and farming customs. For example, Anji is the hometown of white tea in China and thus has a greater demand for land for primary processing, such as drying and storage. For the northwestern and central areas of Huzhou, which have a high proportion of hills, plantation-type facility agriculture is more common because of its advantages for special agricultural products such as fruits, flowers, and seedlings. Facility aquaculture is commonly found in the eastern and central regions, which have dense river networks. The level of agricultural labor and agricultural machinery are also influential factors in the development of facility agriculture [34]. The findings of this paper also show that most facility farming occurs in areas with abundant labor and a high level of agricultural technology. Farmers in these areas are relatively more affluent and tend to choose more economically efficient farming methods. In addition, multiple policies significantly impact the probability of facility agriculture development. This study supports the view that policy is a key determinant of land use change [73].

5.3. Policy Implications

Facility agriculture is an important measure for achieving agricultural modernization, and multiple measures should be taken to support the development of modern and high-quality agriculture. Multilevel regressions demonstrate that local policies play a crucial role in facility agriculture development. Thus, the current challenge for policymakers is to identify the determinants of facility agriculture land expansion and assign the appropriate scale of regional facility agriculture land use to develop targeted political interventions.

(1) The land used for facility agriculture should be categorized and controlled differently, and a benefit evaluation system should be constructed. First, the planning and management of facility agricultural land should be improved and forward-looking layouts

for facility agricultural land should be implemented. This approach can enable the land supply to converge with structural adjustments in the agricultural industry. Second, a system for evaluating the benefits of facility agriculture should be constructed. The profit gap between food cultivation and facility-based agriculture is a key factor in farmers' participation in facility agriculture. Evaluating the benefits of land used for facility agriculture will help standardize the development of facility agriculture to obtain greater economic benefits. Finally, to improve the decentralized allocation of land for facility agriculture, the implementation of a moderately centralized supply model for facility agriculture land should be encouraged, the common needs of business entities should be accurately identified, and agricultural infrastructure sharing and scale effects should be achieved through intensive and efficient land use.

(2) The sources of land for facility agricultural land should be increased, and a life cycle regulatory system should be built. Nonagricultural construction land can be used to expand land for facility agriculture and thus improve the utilization efficiency of facility agriculture. By making full use of nonagricultural construction land, such as unused residential land, and integrating other agricultural land, such as forestland, grassland, garden land, and land for the construction of agricultural facilities, the supply of land for facility agriculture can be increased. On the other hand, there is a significant and mutually exclusive relationship between no grain farmland facility agriculture expansion. The expansion of facility agriculture must be carried out on the premise of ensuring rational food cultivation. Therefore, the actual utilization of facility agricultural land should be monitored regularly through remote sensing imagery, especially in areas that are highly likely to be converted to nonagricultural construction and in parcels where nonagricultural construction has already taken place in the surrounding areas. These actions can reduce the occupation of arable land and alleviate the pressure to protect arable land by local governments.

(3) Facility agriculture industry clusters should be built, and the integration of rural tertiary industries should be promoted. The integrated development of three rural industries is a new development model currently proposed by China to revitalize rural industries. An agricultural industry cluster is a type of agricultural organic community characterized by resource dependence, regional spatiality, industrial agglomeration, organizational (subject) cooperation, and complementary advantages. In recent years, with the emergence of new forms of facility agriculture such as plant factories, leisure agriculture, and composite agriculture, the role of facility agriculture in promoting the integration of industries in the region has become increasingly significant. Therefore, the government should relax the current land use restrictions on facility-based agriculture; promote facility-based agriculture industry clusters to complete the deep integration and development of the three major industries on the premise that agriculture is the foundation; and realize the expansion and extension of agriculture from pure crop production to the fields of processing and circulation of agricultural products and services, promoting the revitalization of the rural industry.

6. Conclusions

In the process of agricultural modernization, agriculturally developed countries worldwide have generally considered modern facility agriculture development as important for enhancing the international competitiveness of agriculture; however, the rapid expansion of facility agriculture has brought new challenges to land management. In this paper, based on the evolution of China's facility agriculture land policy, we construct a whole-process facility agriculture land optimization system based on the theoretical framework of "situation-structure-behavior-value". The authors also empirically analyzed the data of 72 townships in Huzhou city from 1999 to 2021 and analyzed the driving factors of three types of facility agricultural land via multiple logistic regression.

The area of land used for facility agriculture in Huzhou shows a trend of rapid growth, in terms of quantity. From the point of view of spatial characteristics, facility agriculture has shown a trend of steady expansion and gradual agglomeration, but overall, it is still at a point distribution level and has not yet formed a cluster effect. Land use pattern change results from the interaction and a combination of multiple drivers. The determinants of the expansion of different types of facility agriculture are different. Economic efficiency, local agricultural resource advantages, and policies are the most significant factors influencing the expansion of facility farming. In addition, the expansion of facility farms is influenced by factors such as topography and population. As seen from the modeling results, the areas that are more susceptible to future facility expansion agriculture will be those covered with forest and farmland in high proximity to county roads, water sources, and county centers.

The methodological framework demonstrated in this paper can be applied to understand the development and driving mechanisms in other areas of facility agricultural production. However, there are still some issues that need to be addressed. First, due to the variety of facility agriculture land types, the specific uses of facility agriculture land in this paper were obtained through field research and visual interpretation of remote sensing images, which can be optimized in the future in terms of identification methods. Second, additional driving factors, including soil tillage conditions, ecological benefits, and socioeconomic conditions, should be considered to obtain a more complete and in-depth understanding of the dynamic process of facility agriculture development. Finally, the trade-offs and synergies between food security and facility-based agricultural development can be further explored to predict the future development trends and spatial patterns of facility agriculture, which will provide a basis for land management policymakers.

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