land

MDPI

Article

Evolution and Optimization of Territorial-Space Structure Based on Regional Function Orientation

Shilei Wang [1,†], Yanbo Qu [1,*], Weiying Zhao [1], Mei Guan [2,†] and Zongli Ping [2]

1 School of Public Administration and Policy, Shandong University of Finance and Economics, Jinan 250014, China; 192109028@mail.sdufe.edu.cn (S.W.); 212109016@mail.sdufe.edu.cn (W.Z.)
2 Shandong Institute of Territorial and Spatial Planning, Jinan 250014, China; guanmei@shandong.cn (M.G.); pingzongli123@163.com (Z.P.)
* Correspondence: 20126008@sdufe.edu.cn; Tel.: +86-1506-336-8282
† These authors contributed equally to this work.

Abstract: In accordance with the ecological civilization strategy, it is necessary to conduct in-depth analyses and provide a systematic elaboration of the characteristics of territorial-space structure (TSS). In the present paper, we examine Shandong Province and construct a framework for the evolution and optimization of TSS based on regional functions. The evolutionary process, pattern, and driving mechanisms of TSS are clarified using a geo-information atlas, the gravity center shift model, spatial autocorrelation analyses, and a geographic detector model. Furthermore, multi-scenario territorial-space simulations are carried out using the CA–Markov model, based on which an optimal pattern of territorial space is constructed. The results show that the comprehensive dynamic degree of territorial space in Shandong Province was valued at 0.56% from 2000 to 2020. Furthermore, six geo-information Tupu of TSS evolution changed, with a total area of 35,485 km^2, distributed mainly in the Yellow River Delta, the central and southern Shandong Mountain area, and the Jiaodong Peninsula. The migration route of the TSS gravity center curved over time. Territorial spaces are characterized by the exchange of ecological and agricultural space, while urban spaces occupy agricultural ones. The level of economic development, policy, and the institutional environment are driving forces in the transformation of ecological into agricultural spaces, as well as in transforming agricultural space into ecological and urban spaces. The trade-off connection of TSSs is made evident after a multi-scenario simulation of territorial space considering the 2020–2025 timeframe. Based on the goal of regional function co-ordination, Shandong Province is divided into three and four types of single and complex TSS, respectively. The obtained results may provide scientific reference for the co-ordination between human–land relationships and the sustainable use of territorial space, and serve to guide territorial spatial planning.

Keywords: LULCC; territorial-space structure; evolution; motivating mechanism; multi-scenario simulation; optimization; Shandong Province

check for updates

Citation: Wang, S.; Qu, Y.; Zhao, W.; Guan, M.; Ping, Z. Evolution and Optimization of Territorial-Space Structure Based on Regional Function Orientation. *Land* **2022**, *11*, 505. https://doi.org/10.3390/land11040505

Academic Editor: Chuanrong Zhang

Received: 21 February 2022
Accepted: 30 March 2022
Published: 31 March 2022

1. Introduction

Since the start of the 21st century, resource consumption and the environmental crisis caused by increases in human populations have become leading issues in sustainable development [1]. The matter in question has received considerable attention from global sustainability initiatives, such as the International Human Dimensions Programme on Global Environmental Change (IHDP) and Future Earth. As an important carrier of human production, life, and social and economic activities, the contradiction concerning the sustainable utilization of territorial space is an important one. This primarily manifests as the degradation of ecosystem service functions and the aggravation of ecological bearing constraints. However, it is also recognized as the insufficient utilization efficiency of natural resources and the aggravation of exploitation intensity, as well as the inefficient utilization of agricultural irrigation water, water shortage, the insufficiency of construction land, and disordered expansion [2]. The problems of the sustainable utilization of territorial space and optimization of the TSS have become prominent topics in need of an answer in both the fields of geography and resource science [3].

As a central project of the International Geosphere–Biosphere Program (IGBP), land-use and land-cover change (LULCC) is in close relation to the notions of global environmental change and sustainable development [4]. Existing studies have focused on the spatio-temporal characteristics [5], spatial pattern [6], driving forces [7], and spatial simulation [8] of LULCC. The key point is to explore the scale, spatial characteristics, and driving mechanism of the land-use change process at its current stage, as well as its trend in the future. With the increase in LULCC research, land-use fragmentation, land-use dynamic attitude, land-use transition, ecosystem service value, the ecological and environmental effects of land-use change, spatial justice, and "production–living–ecological" space have attracted the attention of a large number of scholars. The main research components among these include the evolutionary characteristics and driving mechanism of farmland fragmentation [9], the social response to the dynamic attitudes toward land-use [10], and the impacts of land-use change on ecosystem services at different scales [11,12]. In addition, land-use transformation and its optimization [13], and the ecological and environmental effects of land-use change in rapid urbanization [14], must also be considered. Finally, it includes the evolutionary process and complexity of urban green ecological spaces and their relationship with public health and environmental justice [15], spatial identification, and the spatio-temporal evolution of "production–living–ecological" space in rural areas [16].

Territorial-space structure, including ecological, agricultural, and urban space, involves the combination and re-organization of land-use types in accordance with rules for meeting the functional needs of ecological protection, agricultural production, and urban construction. In other words, territorial spatial structure is a systematic and integrated concept, and ecological, agricultural, and urban space are its elements. The evolution and optimization of TSS reflect the objective requirements needed for grasping the law of land-use change and realizing the optimal allocation of land resources in accordance with the basic goals of land-use system science. On this basis, building classification systems, clarifying spatio-temporal patterns, identifying resource and environmental effects, detecting driving factors, and implementing multi-scenario simulations are the main concerns of existing territorial spatial structure research. It embodies the paradigm of "process–pattern–effect–drive–simulation" in LULCC research [17]. According to recent research, the connotation of territorial spaces based on the regional "ecological–agricultural–urban" function has been further expanded [18]. However, the corresponding relationships between land-use type and TSS need to be further clarified. In terms of spatio-temporal patterns, factors such as amplitude, speed, and intensity are important dimensions for analyzing the spatio-temporal characteristics of TSS evolution. Amplitude concerns the quantitative change characteristics of different territorial spaces, while speed examines the change rate of territorial space. Intensity, on one hand, reflects the input–output status of territorial development and utilization [19]. On the other hand, the latter also visualizes the transformation between different territorial-space structures [20]. Additionally, the evolution of TSS involves spatial attributes as well. There have been few reports on the spatial expression of the degree of agglomeration or dispersion of quantitative change between adjacent administrative units. In terms of eco-environmental effects, this study includes the spatio-temporal evolution and coupling mechanism of territorial spaces and eco-environmental effects. Moreover, it identifies spatial differentiation and the driving mechanism of eco-environmental effects. Finally, we deal with the gradual transition associated with climate change [21], biodiversity and habitat maintenance [22,23], and carbon emissions [24]. In terms of driving-factor analysis methods, commonly used models include the logistic regression model [25], system dynamics [26], spatial econometric model [27], and geographic detector [28]. It is important to note that a geographic detector is a statistical method that detects spatial variability and the driving mechanism behind it [28]. Furthermore, this method has been widely used in land-use [29], public health [30], and regional planning [31]. In terms of spatial simulation, the Markov model [32], CLUE-S model [33], and FLUS model [34] are the primary simulation methods for optimizing TSS and achieving balance within the territorial space and human–environment systems. Among the aforementioned models, a combination of multi-criteria evaluation (MCE) and the CA–Markov model can help to resolve the problems of low simulation accuracy and a failure to consider constraints and conditions in the simulation process [35]. More importantly, for the purpose of TSS optimization and sustainable utilization, the integration of multi-scenario simulation results is an important issue in need of a solution in the field of territorial-space simulation. From the perspective of territorial spatial structure zoning, ideas such as ecosystem theory [36], land sharing versus land sparing [37], landscape planning [38], and "dual evaluation" [39] provide effective theoretical support and technical guidance for realizing territorial spatial structure trade-off optimization. However, the complexity of territorial-space structure has a profound impact on the process of territorial-space optimization, and enough attention should be paid to how to integrate constraints and adaptability to resolve spatial conflicts and realize territorial-space structure re-structuring.

Given the background of territorial-space planning in the new era, in-depth analyses and a systematic elaboration of TSS characteristics are urgently needed. In this paper, Shandong Province—characterised by urban expansion, cultivated land security, and ecological risk intensification—is selected as the research area. In order to elaborate upon the interactive relationships between the territorial-space regional function and TSS, we construct a corresponding relationship between TSS and land-use type, explore the evolutionary trend of TSS, and propose an optimization path for the sustainable utilization of territorial space. Our research objectives are as follows: (1) first, the transformation relationship between TSSs should be clarified and the degree of agglomeration or dispersion of changes in TSSs among different administrative units should be explored; (2) second, the driving mechanism of the natural environment, social economy, and policy system should be analyzed, in relation to the evolution of TSS; and (3) finally, the results of the multi-scenario TSS simulation should be used to construct the territorial spatial optimization pattern and put forward a sustainable utilization strategy for the territorial space. The results are expected to provide scientific reference for realizing human–land co-ordination and the sustainable utilization of territorial space.

2. Theoretical Framework

Taking into account the starting point and foothold of TSS optimization, the functions of land and space serve as the logical guide for research on TSS optimization (Figure 1). Ecological protection, agricultural development, and urban construction are important representations of the regional multi-functions of territorial space. Their necessity lies in meeting specific needs for the sustainable operation of the human–environment coupling system. This mainly manifests in the demand for environmental protection of resource-environment systems and the development and construction of social economic systems. At the same time, satisfying these demands depends on certain territorial space, resulting, in turn, in three types of TSS, namely ecological, agricultural, and urban space. In addition, providing necessary spatial carriers for the regional function of territorial space is essential. TSS has a distinctive spatial layout and quantitative characteristics which, with time, illustrate certain expansion or contraction phenomena, as well as the spatial pattern of increasing and decreasing with respect to each other, or increasing and decreasing at the same time among different territorial spaces. The reasons for the increase and decrease in territorial space are driven by the dual needs of both national protection and development. For example, the development and construction needs of the socio-economic system emphasize the exploitation and utilization of environmental resources through human activities, with the help of technological progress and capital input. This most often leads to the occupation of ecological or agricultural spaces by urban ones. Environmental protection needs resources and an environmental-system focus on the governance and improvement of the environment through the regulation of territorial space and ecological restoration. Generally, this will lead to an increase in ecological spaces and the disappearance of urban spaces in high-risk areas. For the satisfaction of ecological protection, as well as development and construction needs, it is necessary to detect the evolution of TSS from the perspectives of both the environment and society. The evolution of TSS may lead to ecological and environmental problems, thus endangering the sustainable use of territorial space. At the same time, grasping the law of multi-factor driving can allow us to effectively identify the key factors of territorial-space evolution. With regard to the aforementioned point, a multi-scenario simulation of ecological, agricultural, and urban spaces is carried out. To effectively realize co-ordinated TSS development and fulfil the needs of diversified territorial-space functions, it is necessary to eliminate the encroachment of territorial-space structures. In most cases, spatial planning constraints, such as "three red lines" (the ecological protection red line, permanent basic farmland, and urban development boundary) are chosen to co-ordinate the simulation results. An optimization pattern of territorial space, in which single and multiple functions co-exist under the diversified needs of the territorial-space system, should therefore be formed.

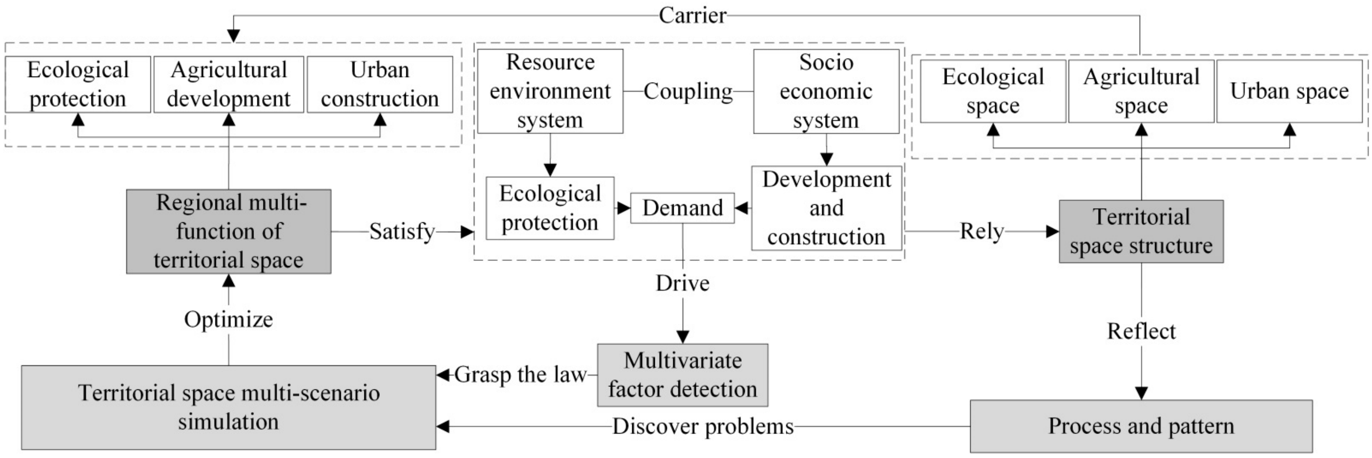

Figure 1. Theoretical framework of TSS based on regional function orientation.

3. Research Method

First, the evolution characteristics of TSS are analyzed from the two aspects of total change and type transformation. Furthermore, the spatial evolution characteristics of TSS are described from two aspects: the center of gravity trajectory and agglomeration. Next, the influencing factors and driving mechanism of TSS are explored by examining the natural conditions, transportation location, socio-economic level, and policy environment. Finally, the three scenarios of ecological protection, agricultural production, and urban construction are established using a CA–Markov model, in order to simulate and optimize the TSS of Shandong Province in 2025.

3.1. Comprehensive Analysis Method of Evolution of TSS

The land-use dynamic degree was separated into single and comprehensive land-use dynamic degrees, providing a quantitative evaluation of the change rate of land-use types [40]. In the present study, the above-mentioned degree was used to identify the change degree of TSS over time. The calculation method is illustrated in both Formulas (1) and (2):

$$K = \frac{U_j - U_i}{U_i \cdot T} \times 100\%, \quad (1)$$

$$C = \left[\frac{\sum_{i=1}^{n} \Delta U_{i-j}}{2\sum_{i=1}^{n} U_i} \right] \times \frac{1}{T} \times 100\%, \quad (2)$$

where K and C represent single and comprehensive dynamic attitudes, respectively; U_i and U_j represent initial and late territorial-space type areas, $i = 1, 2, \ldots, n$, $j = 1, 2, \ldots, n$; ΔU_{i-j} is the absolute value of area converted from category i territorial-space type to category j; n is the number of territorial spaces; and T is the time interval.

3.2. Analysis Method of Evolution of TSS

3.2.1. Analysis Method of Evolution Process

Geo-information atlas analysis reflects the degree to which the quantity and type of territorial space have changed. It also indicates the spatial relationships of one TSS transitioning into another (i.e., the transition potential) [41]. In this paper, the grid calculator of the ArcGIS software (https://developers.arcgis.com/, accessed on 1 October 2021) was used to superposition the TSS in different periods for the period between 2000 and 2020. As a result, the evolution of TSS in Shandong Province for different periods was obtained. The model is shown in Formula (3):

$$W = A \times 10 + B, \tag{3}$$

where W represents the newly generated atlas code, while A and B represent the atlas codes at the early and late stages of the study, respectively.

3.2.2. Analysis Method of Evolution Pattern

1. Gravity center shift model

The gravity center shift model reflects the changes in trajectory of TSS in different time periods. The calculation method is shown in Formulas (4) and (5):

$$M = \sum_{i=1}^{n} (S_i \times M_i) / \sum_{i=1}^{n} S_i, \tag{4}$$

$$N = \sum_{i=1}^{n} (S_i \times N_i) / \sum_{i=1}^{n} S_i, \tag{5}$$

where M and N represent the barycentric co-ordinates of TSS in a specific period; S_i and n are the area (km^2) and number of patches, respectively; and M_i and N_i represent the gravity center co-ordinates of the ith patch.

2. Spatial autocorrelation analysis

Spatial autocorrelation analysis includes both global autocorrelation analysis and local autocorrelation analysis [42]. In this case, they were divided into univariate and bivariate analyses. On one hand, univariate analysis is used to identify aggregated or discrete features between single geographical features. On the other hand, bivariate analysis is used to identify the spatial expression of the relationship between the increase and decrease in two variables. Based on the calculated TSS change in each period from 2000 to 2020, the GeoDa (http://geodacenter.github.io/, accessed on 21 October 2021) and Stata 15 software (https://www.stata.com/, accessed on 29 October 2021) were used to measure the univariate local Moran's I index, bivariate correlation coefficient, and global Moran's I index of territorial space. The spatial pattern characteristics of the TSS evolution of Shandong Province were also analyzed. The calculation formulas are shown in Formulas (6) and (7) below.

The univariate spatial autocorrelation formula is:

$$G = \frac{n \sum_{i=1}^{n} \sum_{j=1}^{m} W_{ij} (X_i - \overline{X})(X_j - \overline{X})}{\left(\sum_{i=1}^{n} \sum_{j=1}^{m} W_{ij}\right) \sum_{j=1}^{n} (X_i - \overline{X})^2}, \tag{6}$$

$$Z(I) = \frac{1 - E(I)}{\sqrt{\text{var}(I)}}, \tag{7}$$

where G represents the autocorrelation index of univariate space; X_i and X_j refer to the territorial-space variation in the ith and jth geographical units, respectively; n is the number of geographical units; and W_{ij} refers to the spatial weight matrix. Furthermore, $\overline{X}$ is the mean value of the change in territorial space, while $Z(I)$ is the threshold of standardized statistics. The symbol $E(I)$ stands for the expected value of the autocorrelation of the observed variables, and var(I) refers to variance. The value range of G is $[-1, 1]$. A value of $G > 0$ indicates that there is a positive correlation between territorial-space change, while $G < 0$ indicates a negative correlation between changes in territorial space. Finally, if $G = 0$, there is spatial randomness in the variation of territorial space. Moreover, if $Z(I) \geq 1.96$ or $Z(I) \leq -1.96$ ($\alpha = 0.05$), then it is suggested that a significant spatial correlation exists between territorial-space changes. The symbols HH and LL indicate that there is high value and high value agglomeration, or low value and low value agglomeration, in the change in the territorial space of adjacent administrative units, respectively. In addition, HL and LH indicate that there is high value and low value agglomeration, or low value and high value agglomeration, in the change in the territorial space of adjacent administrative units, respectively.

The bivariate spatial autocorrelation formula is represented in Formula (8):

$$I_i^{KI} = \frac{X_i^K - \overline{X^K}}{\sigma_K} \sum_{j=1}^{n} \left[W_{ij} \frac{X_j^I - \overline{X^I}}{\sigma_I} \right], \tag{8}$$

where I_i^{KI} refers to the bivariate local spatial autocorrelation coefficient of geographic unit I; X_i^K represents the Kth change in territorial space of geographical unit i and, so, X_j^I stands for the observed value of the Ith territorial-space variation of geographical unit j; $\overline{X^K}$ and $\overline{X^I}$ represent the average values of type K and I territorial-space changes, respectively; σ_K and σ_I are the variances of the Kth and Ith types of territorial-space change, respectively; and, finally, HH and LL represent the same relationship between the increase and decrease in TSS change, while HL and LH represent an opposite relationship between the increase and decrease in the TSS change.

3.3. Driving Analysis Method of Evolution of TSS

The geographical detector is a mathematical statistical method used to explain spatial differentiation that can also be used to detect explanatory factors. This statistical method has the advantages of relying on convenient operations and small sample constraints [28]. The calculation process is demonstrated in Formula (9). Based on the availability and representativeness of data, five factors—including natural environment, transportation location, social and living conditions, level of economic development, and policy and institutional environment—were used as driving factors for the evolution of TSS (Table 1). Finally, a pixel size of 90 m was used for the driving factors.

$$q = 1 - \frac{1}{n\delta^2} \sum_{i=1}^{m} n_i \delta_i^2, \tag{9}$$

where q denotes the detection index of influencing factors of TSS evolution; n represents the total number of samples in the area examined in this study; n_i is the number of samples, where i refers to the number of variables; and, finally, δ^2 represents the total variance for the entire region, and δ_i^2 is the discrete variance. The value range of q is [0, 1]. In cases where $q = 0$, the spatial elements are taken to be randomly distributed. Therefore, the larger the q value, the more the influence factors force the evolution of TSS.

3.4. Simulation Method of TSS

The CA–Markov method combines the spatial pattern simulation ability of the CA model with the quantitative analysis advantages of the Markov process [32]. This model defines the transfer rules between TSSs by using multi-criteria evaluation and a decision support system, thus predicting the quantitative scale and spatial layout of TSS effectively.

Table 1. Indicators of driving factors for the evolution of TSS.

Driving Factors	Variable	Indicator Description
Natural environment foundation	Annual average precipitation change rate	Precipitation conditions
	Annual average temperature change rate	Climatic conditions
Traffic location conditions	Road density change rate	Traffic accessibility
	Distance from coastline	External accessibility
Social living conditions	Urbanization change rate	Urbanization level
	Change rate of per capita sales of social consumer goods	Residents' consumption level
Economic development level	Change rate per capita GDP	Economic development level
	Average dynamic change rate of agricultural machinery	Scientific and technological progress level
	Proportion change rate of primary industry	Agricultural development level
Policy and institutional environment	Change rate of average fixed asset investment	Investment level
	Change rate of public financial expenditure	Financial expenditure level

3.4.1. Principle of CA–Markov Model

1. Markov model

(1) Markov model

The Markov prediction method is based on the Markov chain, which is a method used to predict the occurrence probability of an event according to its current situation. In this paper, the evolution process of TSS may be regarded as a Markov process. Within this process, the territorial-space type at a certain moment corresponds to the possible state in the Markov process which, in turn, is related only to the territorial-space type at the previous moment. The size of the area or proportion of the conversion between territorial-space types is the state transition probability. The transition probability $P(Ei \rightarrow Ej)$ from state E_i to E_j represents the conditional probability $P(Ej \mid Ei)$. The calculation formula is shown in (10):

$$P\left(E \rightarrow E_j\right) = P\left(E_j \mid E_i\right) = P_{ij} \quad (10)$$

Given that there are n possible states over the course of an event, in the process of event development from E_1 to E_n, the possibility of P_{ij} starting from a certain state (E_i) and transferring to other states (E_j) at the next moment is recorded. This is called the state transition probability P_{ij}. When the following conditions are met, it is called the ultimate state probabilistic Markov prediction.

$$P_{ij} = \begin{bmatrix} P_{11} & \cdots & P_{1n} \\ \vdots & \vdots & \vdots \\ P_{n1} & \cdots & P_{nn} \end{bmatrix}, \quad (11)$$

where $0 \leq P_{ij} \leq 1$ and $\sum_{j=1}^{n} P_{ij} = 1$ (i, j = 1, 2, 3, . . . , n).

2. Cellular Automata model

The Cellular Automata (CA) model represents a grid dynamic model characterized by spatial computation. Within this model, the time, space, and state are discrete, and spatial interactions and temporal relations are local. The cellular automata model has five parts, namely the cell, lattice, neighbour, rule, and a time-related conversion function. The CA model can be demonstrated by Formula (12):

$$S_{(t+1)} = f(S_{(t)},N) \tag{12}$$

where S is the set of finite and discrete states of a cell, while the symbols t and $t + 1$ represent different moments. Finally, N represents the neighbourhood of the cell, while the symbol f is the cell transformation rule for local space.

3.4.2. CA–Markov Model Implementation Process

Based on the CA–Markov model in the IDRISI15 software (www.clarklabs.org, accessed on 13 September 2021), the TSS evolution was simulated. The specific process was as follows:

(1) The determination of transformation rules was conducted based on the overlay analysis of the GIS software. We obtained the TSS transition area matrix and transition probability matrix of Shandong Province from 2015 to 2020. Furthermore, the transition probability matrix functioned as the transition rule within the simulation operation.

(2) For the establishment of a suitability atlas, natural factors (e.g., DEM, rainfall), distance factors, and socio-economic factors (e.g., population density, GDP) were selected, in order to complete the territorial-space suitability evaluation using a fuzzy evaluation method. According to the requirements of a multi-criteria evaluation (MCE), the suitable range was normalized between 0–255. This was used as the parameter for the CA transformation rule.

(3) For the construction of the CA filter, the CA standard 5 × 5 neighbourhood filter was defined as the neighbourhood, that is, the matrix space of 5 × 5 cells around each central cell; this had a significant influence on the change in the cell state [35].

(4) In order to support the implementation of the Shandong Provincial Territorial-Space Planning (2021–2035) more effectively, determination of the starting time and the CA iteration times was carried out, where the year 2020 was taken as the starting point. The number of CA iterations was set to 5. In other words, the simulation results of the TSS distribution characteristics for Shandong Province at a 1 km × 1 km resolution in 2025 were finally obtained.

3.4.3. Accuracy Test of Simulation Results

In this study, the calibration time interval was taken to be 2010–2015, while the verification time interval was set to 2015–2020, and the future simulation interval was 2020–2025. A CA–Markov model was used to simulate the territorial-space structure, in order to predict both quantity and spatial allocation. The transfer matrix limits only the quantity. However, suitability conditions and trade-offs among different territorial spatial structures influence the spatial allocation. This determines the deviation between the scale simulation results from 2015 to 2020 and the transition matrix, such as urban space expansion and the reduction in agricultural space. Moreover, this also led to the multi-scenario territorial-space-structure simulation from 2020 to 2025. Scholars have argued that the validity of land-use change model simulations should be confirmed through a comparison of three maps [43]. The Figure of Merit (FOM) is a regularly used metric for model verification through a three-map comparison [44]. The reference maps in 2015 and 2020, and the simulation map in 2020, were compared and analyzed using the crosstab module of the IDRISI software. The magnituded of misses, hits, wrong hits, false alarms, and correct rejections were 1.72%, 8.71%, 2.56%, 3.75%, and 83.26%, respectively, when the FOM value was 0.52. These results demonstrated that the CA–Markov model is capable of accurately modelling TSS through simulation. Furthermore, the fuzzy similarity index in the Dinamica EGO software (https://csr.ufmg.br/dinamica/, accessed on 3 January 2022) was used to test the accuracy of the model, and indicatied that the fuzzy similarity index increases with an increase in neighbourhood size [45]. The model can also be used to simulate the future evolution trend of TSS.

3.5. Optimization Path of TSS

Based on the multi-scenario territorial-space simulation results, the optimization of TSS was realized by using rigid constraints and elastic guidance. First, the three red lines (ecological protection, permanent prime farmland protection, and urban development boundary) were superimposed, in order to prioritize the ecological and agricultural space bottom-line, maintain ecological and food security, and strictly control the scope of urban space expansion. Secondly, in accordance with the simulation results, regions within and in conflict with ecological space were classified as ecological spaces. Urban spaces in mountainous and coastal areas, and other areas with a serious degree of fragmentation, were classified as agricultural spaces. As the possibility of an urban space in a centralized contiguous area changing to another type of space is very low, the current urban space layout should be maintained. This practice is due to the adaptability of the current urban spaces. Finally, the grid-scale TSS optimization results for Shandong Province in 2025 were obtained.

4. Overview of the Study Area and Data Sources

4.1. Overview of the Study Area

Shandong Province is located on the east coast of China, with the geographical coordinates 34°22.9′ N–38°24.01′ N, 114°47.5′ E–122°42.3′ E (Figure 2). The terrain differentiation of Shandong Province is remarkable, showing that the central mountains are uplifted, while the southwest and northwest are low-lying and flat, and the eastern hills are undulating. Shandong Province has a warm, temperate monsoon climate, with an average annual temperature of 11–14 °C and an average annual precipitation of 550–950 mm. The total territorial area is 157,995 km^2. This area is further divided into the provincial capital economic circle, the Lunan economic circle, and the Jiaodong economic circle. The permanent resident population is 101 million, and the urbanization rate is 61.8%. In 2019, its grain output was 53.57 million tons, while the GDP in 2020 was CNY 7.31 trillion. As an area with a large population, substantial amounts of grain, and a successful economy, Shandong Province is driven by the urbanization process to relocate a large number of people from rural areas to cities. This has, in turn, resulted in continuous expansion of the urban scale. Since 2000, the urban scale of Shandong Province has increased by 6005 km^2, with an annual growth rate of 1.9%. Accordingly, ecological and agricultural spaces decreased by 3986 km^2 and 2552 km^2, respectively, while the TSS became increasingly unbalanced. Shandong Provincial Territorial-Space Planning (2021–2035) proposes the territorial-space strategic layout of "a group of two centers, two screens, three belts, three districts, and nine fields". Taking Shandong Province as the research area, there is both theoretical and practical significance to determining the evolution and simulation optimization of TSS.

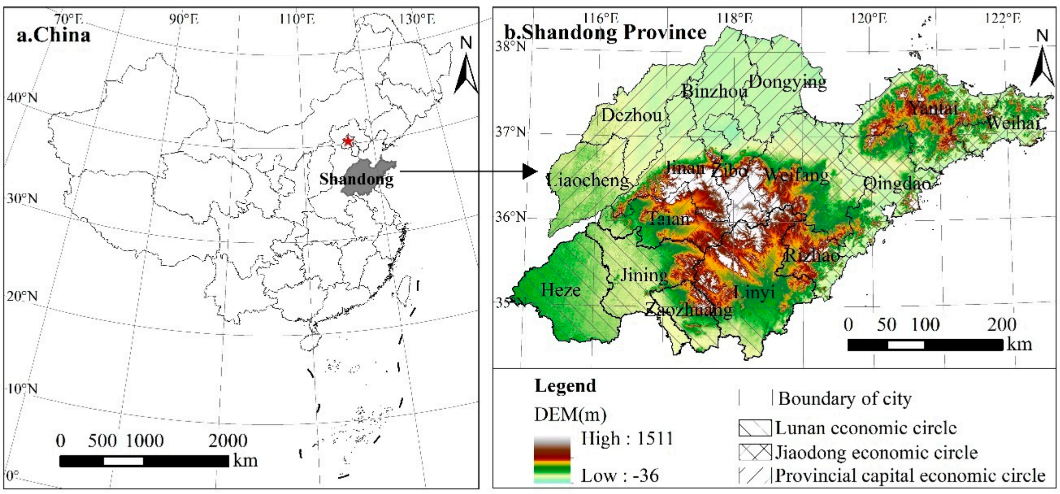

Figure 2. Location of study area.

4.2. Data Sources and Processing

The data types required for this study include geographic, land-use, and socio-economic data. Firstly, the geographic data needed refer to the administrative area and river surface data, which were obtained from the National Catalogue Service for Geographic Information (https://www.webmap.cn, accessed on 3 September 2021). Furthermore, DEM data were derived from Geospatial Data Clouds (http://www.gscloud.cn, accessed on 3 September 2021), with a spatial resolution of 90 m, while road traffic data were obtained from OpenStreetMap (https://www.openhistoricalmap.org/, accessed on 4 September 2021). Second, Landsat TM 5 data with a 30 m spatial resolution from August 2000, July 2005, and August 2010 were used, as well as Landsat OLI 8 data with a 15 m spatial resolution from August 2015 and June 2020. Furthermore, data gathered from Geospatial Data Clouds (http://www.gscloud.cn, accessed on 29 March 2022) were subjected to atmospheric and geometric correction. In accordance with the spectral characteristics, textural features, and shapes of remote sensing images, a human–computer interactive interpretation method was used to achieve the visual interpretation of remote sensing images using both the ENVI (https://www.envi-met.com/, accessed on 17 January 2022) and ArcGIS (https://developers.arcgis.com/, accessed on 17 January 2022) software. Finally, the socio-economic data used included data on social living conditions and economic development levels. They were obtained from the Statistical Yearbook of Shandong Province and the Statistical Yearbooks of counties, cities, and districts under its jurisdiction.

In order to meet the TSS classification requirements, we constructed a corresponding transformation relationship between TSS and LUCC classification systems based on remote sensing imagery (Table 2). In the process of TSS simulation, the Projected Raster tool of ArcToolbox was used to project Digital Elevation Model (DEM) data onto WGS84-UTM, and the spatial resolution was set to 90 m $\times$ 90 m. Secondly, the Raster Calculator was used to superposition DME and land-use data, obtain the intersection range of the two, and reclassify it into a value. In accordance with the above, the spatial range after reclassification was taken as the Mask. The DEM and multi-period land-use data were extracted using the Extract by Mask tool, and the elevation data of Shandong Province were obtained using the Slope tool with the DEM as input data. Accordingly, the Raster to ASCII tool was used to convert the raster data into text data and import them into the IDRISI software.

Table 2. Corresponding relationship between TSS and LULCC.

Territorial-Space Structure	Primary Land-Use Classification	Secondary Land-Use Classification
Ecological space	Forestry	Woodland, shrubwood, open woodland, other woodlands
	Grassland	High-coverage grassland, Medium-coverage grassland, Low-coverage grassland
	Water	Canal, lake, reservoir pit, permanent glacier and snow, intertidal zone, beach land
	Unused land	Sand, Gobi, saline alkali land, swamp, bare land, bare rock, other land
	Ocean	Ocean
Agricultural space	Farmland	Paddy field, dry land
	Construction land	Rural residential land
Urban space	Construction land	Urban construction land, industrial land, mining and transportation construction

5. Research Results

5.1. Analysis of the Overall Characteristics of TSS

5.1.1. Distribution Characteristics

There are significant differences in the spatial distribution of TSS in Shandong Province (Figure 3). The ecological space is characterized by four major patterns, showing obvious block characteristics: The mountainous area in mid-south Shandong Province, the central part of the Jiaodong Peninsula, the Yellow River Delta–Laizhou Bay, and the coastal area in southeast Shandong Province. The distribution characteristics of the ecological space are mainly determined by differences between natural attributes, such as terrain, climate, and the environment of different geographical units on one hand, and social attributes such as human development intensity and environmental governance ability on the other hand. The distribution of agriculture space is widespread and advantageous, due to concentrated contiguity, mainly centered in the northwest, southwest, and Weifang city of Shandong Province. The terrain in this area is flat and open, with a deep layer of soil, adequate light, and sufficient precipitation conditions. Urban spaces are primarily distributed in the form of point-planes in each county (city, district), with significant spatial dispersion. Compared with ecological and agricultural space, the formation and distribution pattern of urban spaces emphasizes the influence of social economy, transportation location, and national policies.

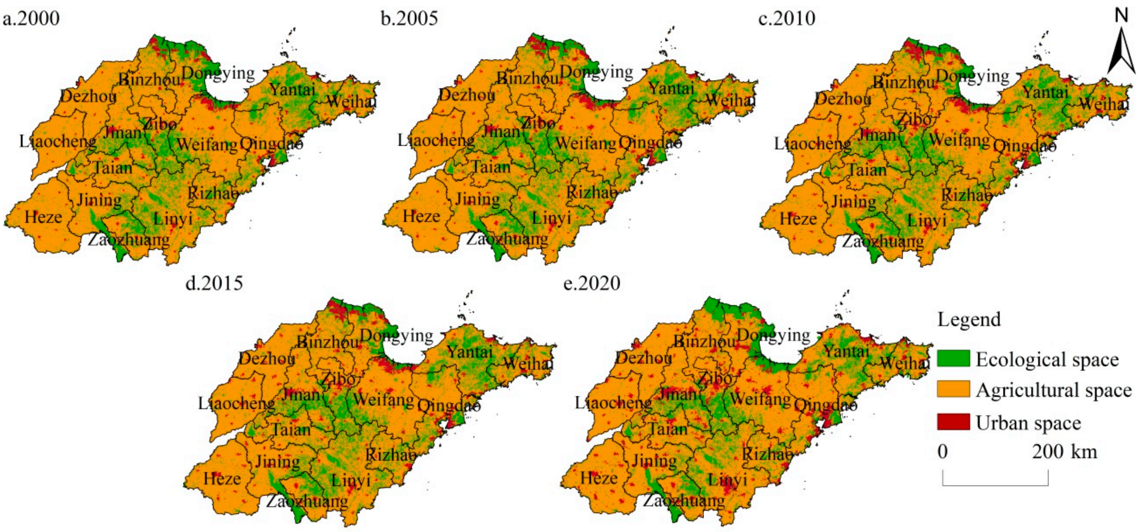

Figure 3. Distribution characteristics of TSS in Shandong Province.

5.1.2. Evolution Characteristics

The dynamic degree of TSS in Shandong Province was 0.16%, 0.09%, 0.05%, 2.23%, and 0.56% in the periods between 2000 and 2005; 2005 and 2010; 2010 and 2015; 2015 and 2020; and 2000 and 2020, respectively. This indicates that TSS has significantly changed and has been increasingly affected by human activities.

From the perspective of the different types of TSS, there are significant differences in the dynamic attitudes of different territorial spaces (Table 3), with ecological space decreasing year by year, and the dynamic degree showing alternating high and low values. In the early stage of the study, unused land was primarily occupied by cultivated land development and industrial and mining-construction land, mainly concentrated in the Yellow River Delta. In the later stages, the forest and grassland were predominantly occupied by arable land, and the spatial scope with less ecological space extended from the Yellow River Delta to the mountainous areas in the southern–central Shandong and Jiaodong hills. The agricultural space decreased annually, while the change in dynamic attitude remained relatively weak. In the early stage of this study, the expansion of construction land brought about by high-speed urbanization mainly occupied surrounding farmland. However, in the later stage, the policy of returning farmland to forest, mainly caused by the ecological civilization strategy, had a great impact. From 2000 to 2020, the amount of urban space continued to increase. The large-scale oil and salt field exploitation in the Yellow River Delta led to increases in industrial and mining land. At the same time, due to the continuous advancement of socio-economic development and urbanization, the amount of urban construction land continued to expand.

Table 3. Statistical table of evolution of TSS from 2000 to 2020.

Territorial-Space Structure	Area (km^2)					Dynamic Degree (%)				
	2000	2005	2010	2015	2020	2000–2005	2005–2010	2010–2015	2015–2020	2000–2020
Ecological space	34,178	33,312	33,190	33,185	30,163	−0.51	−0.07	0.00	−1.82	−0.59
Agricultural space	118,169	117,599	116,640	116,009	115,951	−0.10	−0.16	−0.11	−0.01	−0.09
Urban space	5648	7084	8165	8801	11,881	5.08	3.05	1.56	7.00	5.52
Territorial space	157,995	157,995	157,995	157,995	157,995	0.16	0.09	0.05	2.23	0.56

5.2. Analysis of the Evolution Process of TSS

5.2.1. Analysis of Scale Characteristics

With regard to the stages (see Figure 4), the evolution of TSS in Shandong Province from 2000 to 2005 was characterized by the exchange of ecological space and agricultural space, which covered areas of 760 km^2 and 350 km^2, respectively. In addition, it may be characterized by the occupation of ecological and agricultural space by urban space, covering areas of 461 km^2 and 1003 km^2, respectively. From 2005 to 2010, the characteristics of TSS evolution in Shandong Province demonstrated that the ecological and agricultural spaces were transformed into urban space, with areas of 882 km^2 and 255 km^2, respectively. Furthermore, between 2010 and 2015, the TSS of Shandong Province changed from agricultural space to urban space, with an area of 587 km^2. Following this trend, in the period from 2015 to 2020, the characteristics of the TSS evolution of Shandong Province were represented by an exchange of ecological space and agricultural space, with respective areas of 13,983 km^2 and 10,063 km^2. Additionally, this period was also characterized by urban space occupying agricultural space, with an area of 5858 km^2. The main reasons for these observations are the implementation of the balance policy of farmland occupation and supplementation in 2017, the rigid constraints of the tree-greening rate in the 13th Five-Year Plan of Shandong Province, and the policy influence of the New Urbanization Plan of Shandong Province (2014–2020).

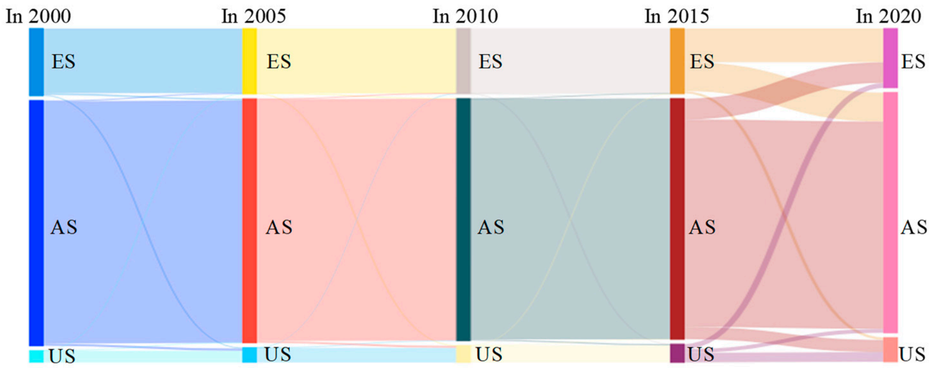

Figure 4. Direction of TSS evolution from 2000 to 2020. Note: ES, AS, and US denote ecological, agricultural, and urban space, respectively.

In reference to the entire research period (Figure 4), the TSS evolution in Shandong Province from 2000 to 2020 was characterized by the exchange of ecological and agricultural space, with areas of 14,172 km^2 and 10,041 km^2, respectively, and the occupation of agricultural space by urban space, with an area covering 7399 km^2.

5.2.2. Atlas Feature Analysis

With respect to the stages described above, the evolution of TSS in different time periods in Shandong Province generated nine types of atlas units, and six types of atlas units changed. Overall, compared with the period from 2000 to 2015, the TSS conversion relationships from 2015 to 2020 were more significant (Figure 5).

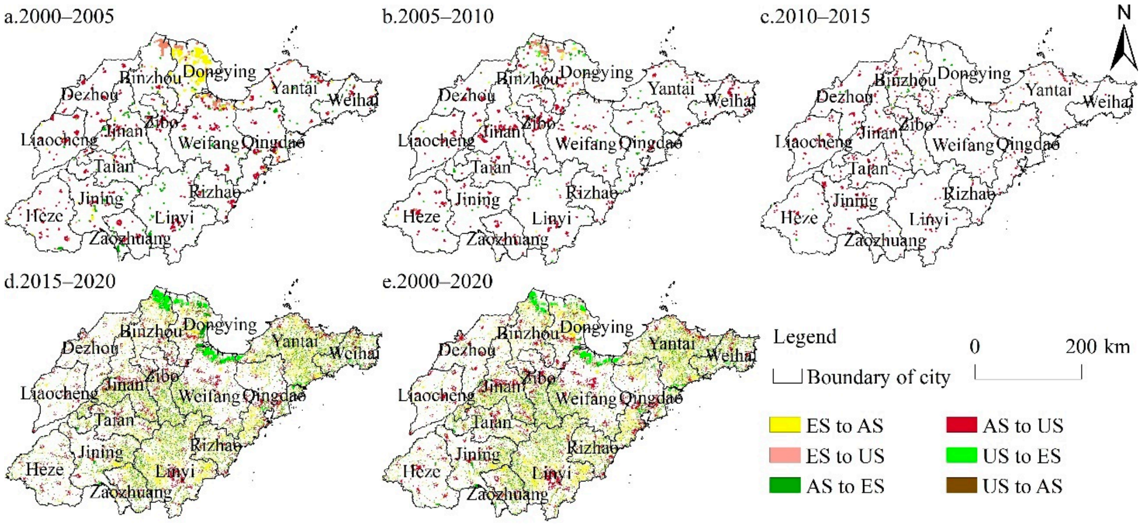

Figure 5. Geo-information atlas of the change in TSS from 2000 to 2020. Note: ecological, agricultural, and urban spaces are denoted by ES, AS, and US, respectively. The transformation relationships between TSSs are shown in the legend. ES to AS, for example, denotes the land that has been converted from ecological to agricultural space.

Among the above, between 2000 and 2005, AS to US conversion was the most prominent, mainly distributed along the periphery of the original urban space, while a significant amount of cultivated land was converted into urban construction land. During the period from 2005 to 2010, the most prominent conversion was AS to US, primarily distributed in Jinan City, Zibo City, and Heze City. Furthermore, between 2010 and 2015, the most significant conversion was AS to US, which was predominantly distributed in the western part of Shandong Province. Finally, from 2015 to 2020, ES to AS and AS to ES were the main conversion units, distributed primarily in the mountainous areas of south–central Shandong Province, the Yellow River Delta, and the Jiaodong Peninsula. Between 2000 and 2020, ES to AS and AS to ES conversions were primarily distributed in the mountainous areas of central and southern Shandong and the Jiaodong Peninsula. In addition, AS to US conversion was primarily distributed around the main urban areas of the existing cities, led by Jinan and Linyi. This distribution is considered to be driven by industrial agglomeration and industry logistics. Furthermore, the US to ES conversion was affected by decreases in industrial and mining land under the ecological protection policy, distributed mainly on the South Bank of Laizhou Bay and the coastal area of Binzhou City.

5.3. Analysis of the Evolution Pattern of TSS

5.3.1. Center of Gravity Migration Trajectory

As can be observed from Figure 6, the migration path of the TSS center of gravity over the whole period presents tortuous characteristics.

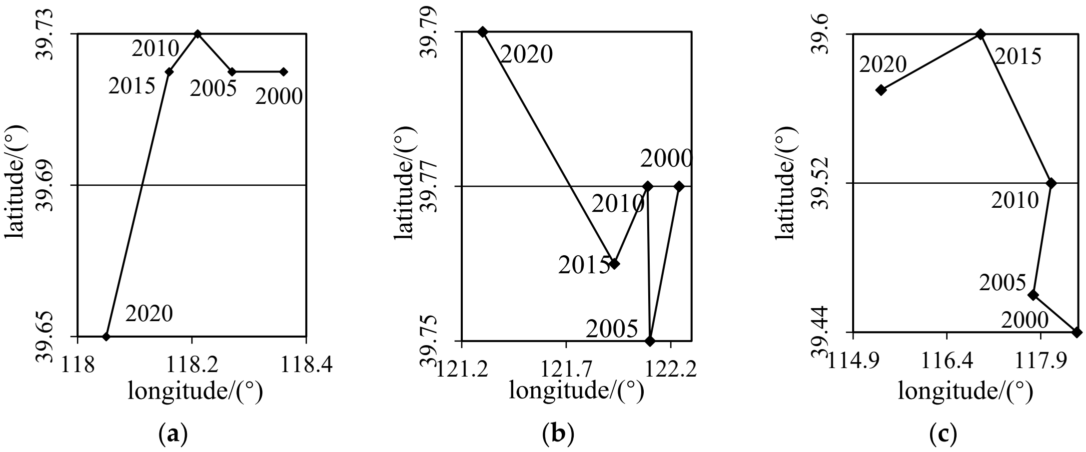

Figure 6. Migration path of territory space centers in Shandong Province from 2000 to 2020: (**a**) ecological space; (**b**) agriculture space; (**c**) urban space.

In the period from 2000 to 2020, the ecological-space center-of-gravity shifted 7.14 km from northeast to southwest. Furthermore, during this period, the center of ecological space shifted from south to north, then back to south, in a circuitous manner. The reason behind this shift is the ecological space of the Yellow River Delta–Laizhou Bay, which had been seriously degraded, causing the center of gravity to shift to the south. Between 2000 and 2020, the center of gravity of agricultural space was observed to have shifted 9.73 km from southeast to northwest. During this period, the center of gravity of the agricultural space alternately changed from north to south. Due to a significant amount of cultivated land being converted into construction land in the central and eastern parts of Shandong Province, a large portion of the rural population relocated to cities. This migration led to an acceleration in the decrease, or even extinction, of rural settlements; this, in turn, resulted in the shift of the agricultural-space center-of-gravity from southeast to northwest. Moreover, from 2000 to 2020, the urban-space center-of-gravity shifted 34.52 km from southeast to northwest. In this process, the center of gravity of urban space presented a circuitous migration path, alternating between east and west. As the provincial capital city group, with Jinan as the core, is an important growth pole of Shandong Province's economic development, the demand for urban construction is strong, and the urban space center shifted to the northwest.

5.3.2. Spatial Autocorrelation Analysis

1. Univariate space autocorrelation

For the period from 2000 to 2020, the Moran's I index for ecological, agricultural, and urban space changes in Shandong Province was always greater than 0, indicating a positive spatial agglomeration, where the agglomeration characteristics in coastal areas were stronger than those of inland areas (Figure 7).

The number of HH aggregation units of ecological space decreased from ten to seven from 2000 to 2020. Moreover, the concentrated areas shifted from the Jiaodong Peninsula in the east and Shandong Province in the south to the Yellow River Delta. All of the aforementioned areas are ecologically fragile, sensitive, and dominated by shores, mountains, and lakes. The number of LL aggregation units increased from five to eleven, while the concentration area shifted from the Yellow River Delta–Laizhou Bay coast to the eastern coastal area. The increase in economic development and population size accelerated the development of unused land and the reduction in ecological land. Between 2000 and 2020, there was a slight increase in the number of agricultural-space HH aggregation units, from five to six. This was primarily due to the development of forest and fruit industries on forest and grass land in mountainous areas, and was also a result of the formation of agricultural farming aggregation areas. The number of LL aggregation units increased from five to twelve. As a result of urbanized construction, the agricultural space scale was reduced, and the concentration area moved from the southeast coastal area of Shandong Province to the Laizhou Bay coast. From 2000 to 2020, the HH aggregation units of urban space were concentrated in the Yellow River Delta–Laizhou Bay, the provincial capital city circle, and southern Shandong city circle. These results illustrate the spatial differences in urban construction for different periods. In addition, the number of LL aggregation units decreased from twelve to seven, demonstrating a trend of migration from the mountainous areas in central and southern Shandong to the Yellow River Delta.

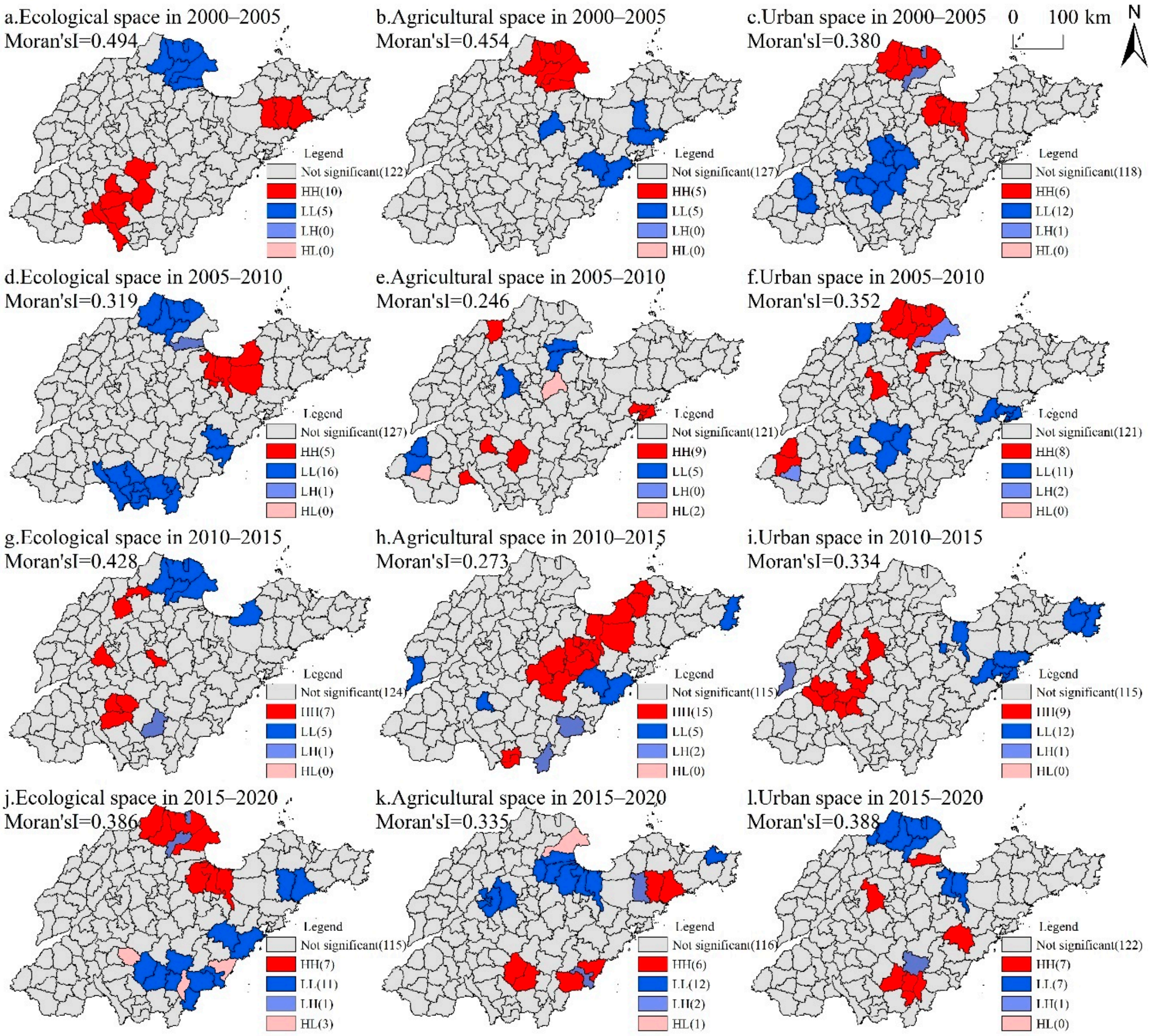

Figure 7. Single-variable spatial autocorrelation of territorial space.

2. Bivariate space autocorrelation

Based on county units, the changes in TSS for the time period of 2000 to 2020 were imported into StataSE15 for correlation analysis (Table 4). First, the negative correlation between ecological and agricultural space change in different periods was unbalanced. Second, the correlation between ecological and urban space change appeared to be weak. Finally, there was a significant negative correlation between agricultural and urban space change.

Table 4. Correlation coefficient of territorial-space change.

Years	Ecological–Agriculture Space	Ecological–Urban Space	Agriculture–Urban Space
2000–2005	–0.975 ***	0.0494	–0.2697 **
2005–2010	–0.1420 **	–0.1154 **	–0.9151 ***
2010–2015	–0.0108	0.1334 **	–0.4643 ***
2015–2020	–0.8253 ***	–0.1054 *	–0.4412 ***

Note: ***, **, and * denote explanatory variables with statistical significance levels of $p < 0.001$, $p < 0.01$, and $p < 0.05$, respectively.

With regard to the bivariate spatial correlation, the spatial heterogeneity in the relationships between the increase and decrease in different territorial-space changes was significant (Figure 8). First, with reference to the changes in ecological and agricultural space, the HL agglomeration area shifted from the south of Shandong Province to the coast of Laizhou Bay from 2000 to 2020. Moreover, the LH agglomeration area shifted from the Yellow River Delta to the southeast coast. Between 2000 and 2010, in terms of the change in ecological and urban space, the LH agglomeration area was distributed in southern Shandong and the eastern and western Jiaodong Peninsula. Furthermore, the HL agglomeration area was distributed in the Yellow River Delta. From 2010 to 2015, both the LH and HL agglomeration areas tended to be dispersed, distributed in the mountainous areas of central and southern Shandong and the Yellow River Delta. From 2015 to 2020, the LH agglomeration areas were distributed along the Yellow River Delta and Laizhou Bay, while the HL agglomeration areas tended to be distributed in the south portion of the Shandong Economic circle. In may be observed that, between the changes in agricultural and urban space, the LH and HL agglomeration areas tended to be scattered in the periods between 2000–2010 and 2015–2020. Finally, between 2010 and 2015, the LH agglomeration areas were mainly distributed in the intersection of the provincial capital economic circle and Jiaodong Peninsula economic circle, while the HL agglomeration areas remained more dispersed.

5.4. Driving Analysis Evolution of TSS

5.4.1. Driver Detection

We took the transformation from ecological to agricultural space, and that from agricultural to ecological and urban space, as the dependent variables (Table 5). First, based on the detection results, the main motivating factors leading to the spatial differentiation of ecological into agricultural space were: the average dynamic change rate of agricultural machinery, the change rate of annual average precipitation, and the proportion change rate of primary industries. Secondly, the primary motivating factors that led to the spatial differentiation of agricultural into ecological space were: the change rate of public financial expenditure, the change rate of annual average precipitation, and the change rate of fixed asset investment. Thirdly, the main factors motivating the spatial differentiation of agricultural into an urban space scale were: the change rate of fixed asset investment, the change rate of public financial expenditure, and the change rate of urbanization.

5.4.2. Analysis of Motivating Mechanism

The natural environment is the primary determinant of TSS evolution. The more frequently climatic conditions change, the greater the uncertainty of agricultural development and cultivation. From 2000 to 2020, precipitation levels increased in the Yellow River Delta and the coastal area of Laizhou Bay. In turn, they witnessed a decrease in the mountainous area of south-central Shandong Province, southwest Shandong Province, the Jiaodong Peninsula, and the coastal area of southeast Shandong Province. The rise in precipitation levels led to the development of unused land into arable land in Binzhou, Dongying, Weifang, and other cities; this, in turn, accelerated the transformation of ecological into agricultural space. However, precipitation in mountainous areas of central and southern Shandong decreased, and the temperature in high-altitude areas was low, while there were no adequate agricultural irrigation, light, and heat conditions. All of these factors accelerated the transfer of agricultural to ecological space.

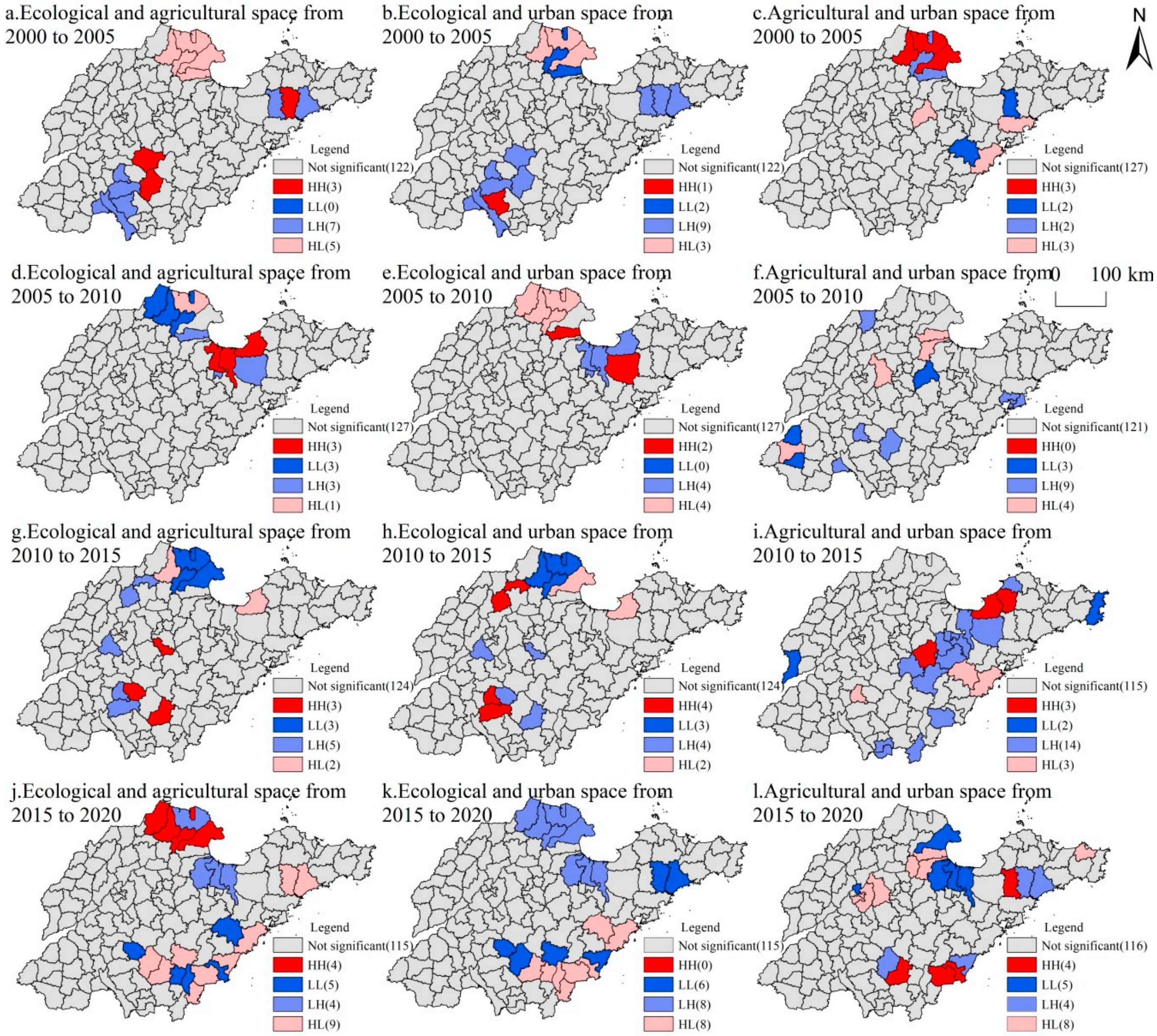

Figure 8. Bivariate spatial autocorrelation of territorial space.

Furthermore, transport location is an important motivating factor for TSS evolution. The construction of road infrastructure is the primary guarantee for the transport of multiple factors, such as people, logistics, information, and energy flow between regions. On one hand, traffic road construction occupies a large amount of cultivated land; on the other hand, urban construction land expansion occupies the surrounding farmland by strengthening the regional connection of different regions. Both of these lead to the transformation of agricultural into urban space.

Socio-economic metabolism is one of the primary motivators for the evolution of TSS. From 2000 to 2020, the urbanization rate of Shandong Province increased from 26.77% to 61.8%. On one hand, the rapid urbanization process solved the housing problem through real estate development. Nevertheless, this was reliant on the construction of industrial parks in order to solve the livelihood security of citizens. Both these occurrences accelerated the expansion of urban construction land, to varying degrees. On the other hand, the improvement of consumption levels stimulated a higher level of consumption demand, requiring the corresponding construction land to act as a carrier. As green land and parks in urban built-up areas are protected, the newly added urban construction land must typically occupy farmland.

Table 5. Detection of factors influencing the rate of territorial-space change.

Motivating Factors	Ecological Space to Agricultural Space		Agricultural Space to Ecological Space		Agricultural Space to Urban Space	
	q	*p*	*q*	*p*	*q*	*p*
Annual average precipitation change rate	0.61 ***	0.000	0.47 ***	0.000	0.43 ***	0.000
Annual average temperature change rate	0.46 ***	0.000	0.39 ***	0.000	0.31 ***	0.000
Road density change rate	0.39 ***	0.000	0.16 ***	0.000	0.48 ***	0.000
Distance from coastline	0.18 **	0.000	0.12 ***	0.000	0.23 ***	0.000
Urbanization change rate	0.36 ***	0.000	0.34 ***	0.000	0.56 ***	0.000
Change rate of per capita sales of social consumer goods	0.34 ***	0.000	0.27 ***	0.000	0.43 ***	0.000
Change rate per capita GDP	0.51 ***	0.000	0.24 ***	0.000	0.36 ***	0.000
Average dynamic change rate of agricultural machinery	0.72 ***	0.000	0.23 ***	0.000	0.27 ***	0.000
Proportion change rate of primary industry	0.54 ***	0.000	0.36 ***	0.000	0.33 ***	0.000
Change rate of average fixed asset investment	0.33 ***	0.000	0.45 ***	0.000	0.66 ***	0.000
Change rate of public financial expenditure	0.46 ***	0.000	0.57 ***	0.000	0.59 ***	0.000

Note: *** and ** ndicate variables significant at the level of $p < 0.001$ and $p < 0.01$, respectively.

The level of economic development is the leading factor in the evolution of TSS. In other words, economic and technological development improve the human ability to transform nature. With the popularization of agricultural mechanization and automation, the efficiency of agricultural production is improved. Furthermore, the input factors of agricultural production will increase. Due to increased demand for agricultural products in cities, ecological spaces must be transformed into agricultural spaces. In addition, due to the ageing of the rural population and migration of the labour force, farmland is either abandoned or converted into forest. As a result, this trend promotes the mutual transformation of ecological and agricultural spaces.

National policy and the institutional environment are external factors affecting TSS evolution. Ever since the implementation of the ecological civilization strategy, Shandong Province has supported ecological restoration through a significant amount of capital investment and financial transfer. As an example, the Zhangqiu District of Jinan completed an afforestation process of 4126.66 ha in 2011. In addition, in 2009, the Yellow River Delta High-Efficiency Ecological Economic Zone was formed, in order to protect ecological interests and accelerate the transformation of agricultural space into ecological space. At the same time, investments intended for the construction of transportation and industrial parks encourage regional social and economic development. This is primarily reflected in the transformation of agricultural land into construction land.

5.5. Multi-Scenario Simulation and Optimization of TSS

5.5.1. Simulation Results of TSS Based on Multi-Scenarios

In 2025, the areas of the three types of territorial space (ecological, agricultural, and urban) under the ecological protection scenario are expected to be 35,420 km^2, 100,644 km^2, and 21,931 km^2, respectively. In the agricultural production scenario, the areas of the three types of territorial space are 31,510 km^2, 107,145 km^2, and 19,340 km^2, respectively. Furthermore, under the urban construction scenario, these areas are 30,461 km^2, 99,228 km^2 and 28,306 km^2, respectively (Table 6). Overall, the ecological patterns in the mountainous area in the mid-south Shandong Province, the central part of the Jiaodong Peninsula, the Yellow River Delta–Laizhou Bay, and the coastal area in the south of Shandong Province are stable. Furthermore, the scale of ecological space in the central Shandong Mountain area and Jiaodong Peninsula will increase. On the other hand, the scale of agricultural space in the Yellow River Delta, the mountainous areas in central and southern Shandong, and the Jiaodong Peninsula have already increased. The pattern of urban space expansion is relatively evident, and the urban space scale of central Shandong and the Jiaodong Peninsula is expected to increase significantly (Figure 9).

Table 6. Comparison of simulation results of TSS in 2025 under various scenarios (Unit: km^2).

Scenario Types	Ecological Space	Agricultural Space	Urban Space
Status quo scale in 2020	30,163	115,951	11,881
Ecological protection scenario	35,420	100,644	21,931
Agricultural production scenario	31,510	107,145	19,340
Urban construction scenario	30,461	99,228	28,306

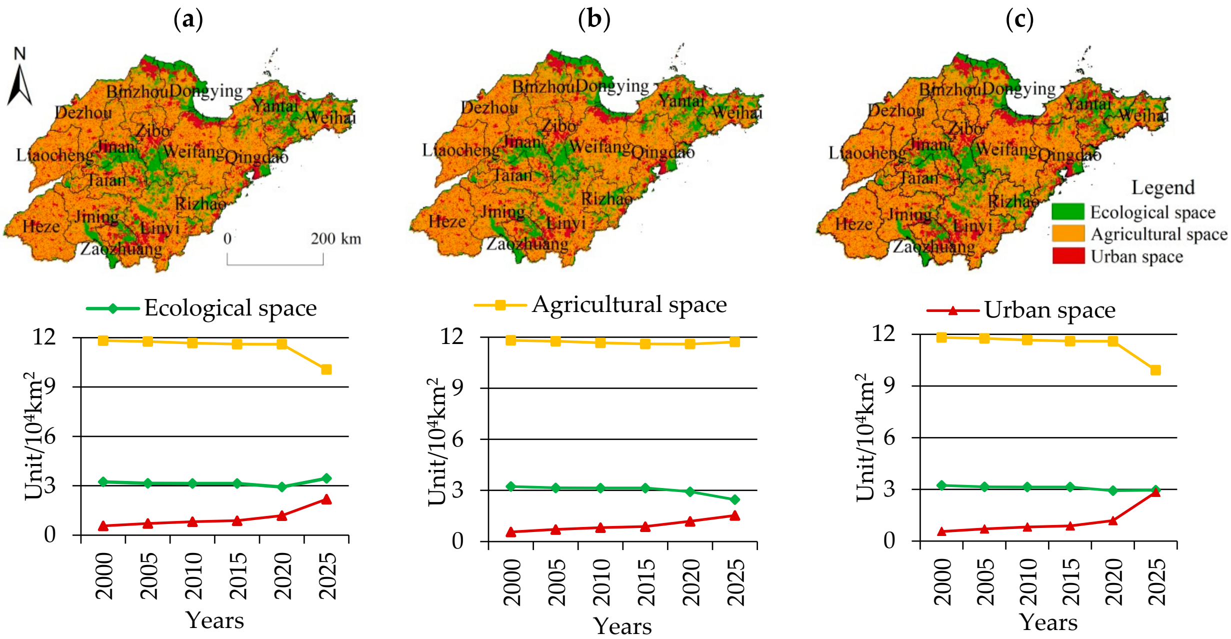

Figure 9. Multi-scenario simulation and evolution trend of TSS: (**a**) ecological protection scenario; (**b**) agricultural development scenario; (**c**) urban construction scenario.

The simulation results for TSS under the single scenarios of ecological protection, agricultural production, and urban construction indicated that an increase in the spatial scale of one territorial function leads to the decrease in that of another. This occurrence reflects a kind of trade-off relationship between different TSSs, and highlights the difficulties that occur in meeting the optimization requirements for the co-ordinated development of TSS. For example, the simulation results under the ecological protection scenario can effectively guarantee the ecological base, but restrict the development of agricultural production to some extent. Moreover, the simulation results under agricultural protection scenarios can adequately protect cultivated land resources and maintain food security; however, they will threaten the integrity of ecological spaces, which is conducive to the sustainable development of neither humans nor nature. Furthermore, the simulation results, with respect to the context of urban construction, are capable of meeting the construction land demands of both social and economic development. Nevertheless, it should be noted that this type of scenario will lead to urban land occupying both cultivated and ecological land, thus increasing the pressure on both resources and the environment. Based on the above, the TSS layout and scale under different scenarios reflect the predictions made regarding the needs of territorial spaces. In short, these needs can be defined as maintaining the ecological background, adhering to the red line of cultivated land, and supporting social and economic development. However, territorial space has objectivity and uniqueness. Coupling the needs of diversified territorial-space protection and development, using the multi-scenario territorial-space simulation results to optimize TSS, and providing guidance for future territorial-space utilization comprise important practical problems to be solved.

5.5.2. Optimization Pattern of TSS Based on Regional Function Co-Ordination

According to the dominant regional functions of territorial space, the TSS of Shandong Province can be divided into seven distinct categories: ecological, agricultural, urban, eco–agricultural, eco–urban, agricultural–urban, and eco–agricultural–urban space (Figure 10). The area proportions of these seven types of territorial space are 18%, 65%, 6%, 4%, 1%, 5%, and 1%, respectively. The layout and scale characteristics of different TSSs reflect the optimal path towards a sustainable relationship between humans and land, with respect to territorial space.

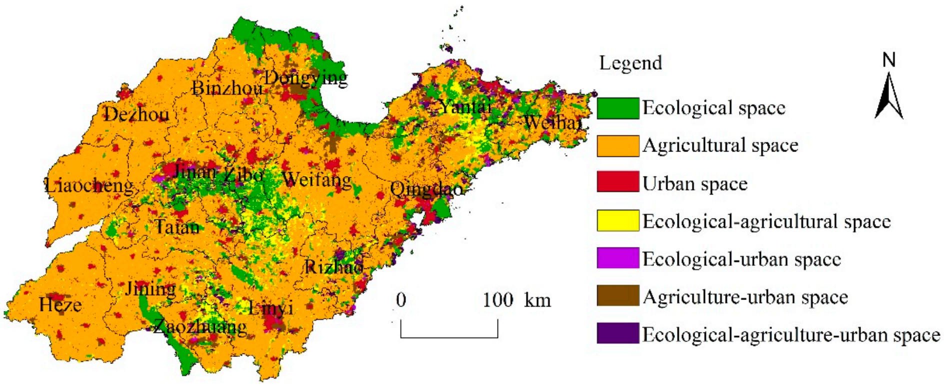

Figure 10. Optimal zoning of TSS.

Considering the optimization of ecological space, the ecological conditions of the Yellow River Delta–Laizhou Bay were observed to be unstable, while the ecological restoration of territorial space requires strengthening. In addition, while developing the fruit industry in the northern part of the Jiaodong Peninsula, water and soil resources should be co-ordinated in order to reasonably protect and utilize them. Furthermore, it may be concluded that traditional agricultural production should not be carried out in the mountainous areas of central and southern Shandong. The mountainous area of southeast Shandong has an abundance of tourism resources, which indicates that the construction of an eco-tourism brand should be strengthened. With respect to agricultural space, it is mainly distributed in the southwest portions of Shandong, northwest Shandong, and Weifang. The region should, on one hand, further strengthen the management of agricultural mechanization, scale, and industrialization in the future. On the other hand, the region should also strengthen the classification and management of rural settlements, and withdraw and revitalize the use of construction land in rural settlements with serious hollowing-out in an orderly manner. With respect to urban space, it is represented by an urban agglomeration, with Jinan and Qingdao City as its core. In the future, these spaces should rely on the radiation and leading roles of Jinan and Qingdao in order to develop an exemplary system structure, an optimized spatial layout, intensive land usage, and a beautiful ecological environment.

Furthermore, ecological–agricultural spaces are mainly distributed in the mountainous areas of central and southern Shandong and the Jiaodong Peninsula. In the future, we should speed up the construction of the forest and fruit industries' development chains, integrating picking, processing, and sales by relying on topographic advantages and light resources. With regard to ecological–urban spaces, they are dispersed across urban built-up areas, such as Jinan, Qingdao, Yantai, Zaozhuang, and other cities. In the future, with respect to urban planning, these types of areas should concern themselves with internal ecological space-shaping. In addition, they should also improve the quality of urban construction and human settlement environments. With respect to agricultural–urban space, it is mainly situated around the urban construction areas of Dongying city, Qingdao City, Zaozhuang City, and Linyi City. In the future, the utilization efficiency of urban construction areas should be improved, and their expansion should be restricted with respect to the red line of protection of basic farmland. Ecological–agricultural–urban spaces are mainly distributed in the mountainous areas of central and southern Shandong. The future of these areas lies in maintaining the stability of regional territorial-space utilization. High priority should be given to ensuring the integrity and connectivity of ecological space, as well as to fostering agricultural development models, such as agriculture with local characteristics, tourism, and picking agriculture. Additionally, tapping into the potential of construction land should also be considered to be of high priority.

6. Discussion

6.1. The General Law of the Evolution of TSS

In a narrow sense, "territorial" represents a collection of resources and environments with regional characteristics. However, in a broader sense, the term "territorial" refers to a "region" [46] to which resources and environments can be attributed, as well as social economy and national sovereignty. Secondly, the term "space" may be defined as the place in which the subject of human activities interacts with the object of the natural environment, having the unique attributes of all kinds of activity carriers. The integration of the concepts "territorial" and "space" may lead to several of the following meanings: (1) Territorial space may be structural, enveloping three types of space: ecological, agricultural, and urban; (2) territorial space is spatial, as its core parameters include spatial scope and quantitative scale; and (3) territorial space may be defined as interactive, with the expansion or contraction of one spatial type inevitably affecting others.

From a structural standpoint, the ecological, agricultural, and urban areas of Shandong Province satisfy the functional needs of ecological protection, agricultural production, and urban construction for resource and environmental sustainability, as well as social and economic sustainability. From a spatial standpoint, Shandong Province's ecological space is distributed in both point and line forms in mountainous areas, rivers, and coastlines. Secondly, agricultural space is distributed in plane form in flat areas, such as the West Shandong Plain. Finally, urban space is distributed in block form in each administrative region. Over the analyzed period, Shandong Province's ecological and agricultural spatial scales were in decline, while the size of urban space rapidly increased. Specifically, from 2000 to 2020, ecological space and agricultural space were reduced by 4015 km^2 and 2218 km^2, respectively. Under the same conditions, urban space increased by 6233 km^2, and the dynamic attitude of urban space was significantly higher than that of ecological and agricultural space. With respect to interactivity, the largest among the top three areas of TSS conversion was the conversion from ecological space to agricultural space by 14,172 km^2, followed by the change of agricultural space to ecological space (10,041 km^2), then the transformation of agricultural space to urban space (7399 km^2). Among them, the spatial trade-off relationship between ecological and agricultural space, as well as that between agricultural and urban space, is extremely significant. The spatial differences in precipitation changes affect the natural basis of ecological and agricultural space conversion. Furthermore, the level of economic development accelerates the improvement of agricultural mechanization and drives the transformation of ecological space into agricultural space. Moreover, the construction of transportation infrastructure promotes urban space expansion through the occupation of cultivated land and the strengthening of material information exchange. Furthermore, fixed asset investments lead to urban space expansion through increases in the intensity of territorial-space development. The advancement of urbanization and industrialization stimulates the consumption demands of citizens, which results in the occupation of surrounding agricultural land by urban space. The interaction of territorial space indicates that the balance and co-ordination of the original TSS is broken under the common drive of the natural environment and social economy, resulting in the trade-off between TSSs. It should be noted that the expansion of urban space leads to a continuous decline in ecosystem service values [47]. In addition to this, the harm of urban spaces occupying ecological ones is reflected mainly in their influence on carbon storage [48]. Finally, the main causes of harm to cultivated land and food are the de-agriculturalization of cultivated land and the spatial-coupling imbalance of the population–land–food system caused by the reduction in the rural labour force [49,50]. However, existing territorial-space-structure research has mainly focused on mechanism analysis and the structural optimization of territorial-space evolution [51,52], in turn, ignoring the spatial expression of increase and decrease among different TSSs. As a result, it is difficult to understand the harm that TSS evolution causes to resources and the environment.

6.2. Optimization Path and Strategy of TSS

TSS optimization may be linked to sustainable social and economic development, as well as to the improvement of livelihoods. It aims to establish a reasonable system for both territorial space protection and development. Within this framework, the term "structure" is taken to refer to the collocation and placement of various parts of a space, according to a specific set of rules. This is carried out in order to achieve a reasonable layout and optimized pattern [52,53]. Secondly, the concept of "function" represents the values and services constructed according to specific requirements within a certain structure [54]. The regional function of territorial space reflects the dual needs of both territorial-space development and protection.

The presented TSS simulation of Shandong Province consisted of a prediction made from three scenarios—ecological protection, agricultural production, and urban construction—as a response to the uncertainty of future development. Among these, the ecological protection scenario focused on maintaining the ecological environment background characteristics. In addition, the amount of ecological space in this scenario was the highest, accounting for up to 22.42% of the TSS. Secondly, in the agricultural production scenario, the positive response to ensuring food security and alleviating the risk of cultivated land is emphasized. In this scenario, the transfer of agricultural to urban space is reduced, and the amount of arable land is maximized. Finally, in the urban construction scenario, the unwavering demand for construction land for further social and economic development is highlighted. Under this scenario, the expansion of urban space increases at the cost of ecological and agricultural space. In this scenario, the urban space area is 28,306 km^2—an increase of 16,425 km^2 compared to 2020. Nevertheless, it is difficult for the TSS simulation results of different scenarios to provide decisive support for land space utilization within the actual state. Existing research has shown that the quantity, scale, and spatial layout are the most important factors for achieving optimal allocation [55,56]. Its advantage is its capability of meeting the needs of different land types and allocating land in an orderly manner; however, it is difficult to achieve co-ordination among different TSSs [18]. Therefore, to express the regional functional requirements of territorial space more clearly, and effectively control the high-frequency conversion between TSSs, the three control lines (the ecological protection red line, permanent basic farmland protection red line, and urban development boundary) were introduced in the process of TSS optimization. The aim of these lines is to promote TSS optimization, by means of both rigid constraints and elastic adaptability. The former of the two serves as the basis for constructing the order, according to which territorial-space protection and development function. This is achieved by using the three red lines as a means of control. Meanwhile, the latter of the two emphasizes the application of the simulation results, thus reflecting the adaptability of the relationship between humans and land, as well as the relative stability of the territorial-space state. In addition, the latter is mainly focused on the adaptability of resources and the environment, and uses the convertible ability of different space structures.

According to the TSS optimization results, the single territorial spaces consisting of ecological, agricultural, and urban spaces account for 89% of Shandong Province, which can meet the needs of ecological protection and social production to the greatest extent. At the same time, the complex ecological and agricultural territorial spaces take into account the needs of diversified subjects, and avoid the conflict of territorial-space utilization, which is of great significance for guiding the sustainable utilization of territorial space. With respect to the TSS optimization strategy, the sustainable utilization of territorial space in Shandong Province can be guaranteed through single-space agglomeration promotion and compound space co-operative utilization. On one hand, the protection of ecological space should be strengthened in accordance with the mountains, rivers, forests, farmland, lakes, and sea. This will result in the high-quality development of agricultural space, centered on quantity, quality, and ecology, which will improve urban space utilization efficiency by co-ordinating scale and quality. On the other hand, we should adhere to the unity of ecological benefits and economic benefits in order to realize the proper utilization of compound territorial space.

6.3. Theoretical Contributions, Limitations, and Future Prospects

In this study, we constructed a theoretical TSS framework based on regional function orientation. This revealed an interactive relationship between territorial-space function and TSS, reflecting the goal guidance of territorial-space function demand on the evolution and optimization of TSS. Finally, the results presented in this study are conducive to the systematic understanding and research of TSS. To some extent, in this study, we have resolved the limitations of TSS research from a single perspective. The theoretical framework proposed here may be applied to TSS research in different regions of the world simultaneously, and has a wide range of potential for popularization and universality. In other words, following the diversified needs of territorial-space functions to realize the composite utilization of territorial space may improve territorial-space efficiency and eliminate land-use conflicts. This will, in turn, allow the carrier role of territorial space to support complete ecological protection, agricultural production, and urban construction. It provides a decision-making basis for human activities, in terms of governing the use of territorial space by regulating the efficient use of natural resources and enhancing the pertinence of land-use planning. In addition, spatial analysis methods, such as the Geo-information atlas, spatial autocorrelation, geographic detector, and spatial simulation, were used to identify the evolutionary law and the optimization path of TSS in Shandong Province. Thus, we put forward a sustainable territorial-space utilization strategy. This realizes the effective combination of theory and application, and is expected to help enrich the theoretical research and practical application of LULCC worldwide.

Nevertheless, although this research provides new perspectives in the field of LULCC research, the research results are still uncertain in part. In terms of the driving factor analysis for the evolution of TSS, we considered only natural and socio-economic factors; however, human activities, as the dominant factors changing territorial space, are insufficient in the consideration of subjective wishes and behavioural preferences [57]. In terms of TSS simulation, the CA–Markov model is capable of meeting the needs of simulation accuracy to a large extent; however, the simulation process does not consider the driving mechanism of influencing factors. In future research, the territorial-space-structure simulation method should be improved [58]. Moreover, the Chinese government has proposed a carbon peak by 2030 and a carbon-neutral goal by 2060. Building a theoretical framework for optimizing territorial spatial structure around this goal and conducting empirical studies has important scientific significance in promoting global carbon emission reduction.

7. Conclusions

Based on the logical starting point and optimization goal of regional multi-function territorial space, we attempted to construct a theoretical framework to determine the evolution and optimization of TSS. In accordance with this, an empirical study of Shandong Province was carried out, according to the technical route of "process–pattern–driving–simulation–optimization".

For the period between 2000 and 2020, the dynamic degree of TSS was 0.56%. The scale of TSS changed significantly and the prominence of human activity became more intense. The evolution of TSS was mainly characterized by the change of ecological space into agricultural space. Furthermore, with respect to urban spaces occupying agricultural ones, the area was 7399 km^2. The geographical location of the changed geo-information atlas was mainly distributed in the Yellow River Delta, mountainous areas in central and southern

Shandong, and the Jiaodong Peninsula. During the period of 2000 to 2020, the migration route of the TSS gravity center curved over time. In addition, between 2000 and 2020, univariate spatial autocorrelation analysis indicated that the changes in ecological, agricultural, and urban spaces all presented positive-phase spatial agglomeration phenomena. Furthermore, bivariate spatial autocorrelation analysis indicated that agricultural space occupies and compensates for ecological space, while urban space occupies agricultural space. In summary, in our multi-scenario simulations of territorial space, the trade-off relationships observed between different territorial-space structures were remarkable. In accordance with the regional function co-ordination, the TSS optimization results obtained for Shandong Province in 2025 may be divided into seven categories: ecological space, agricultural space, urban space, eco–agricultural space, eco–urban space, agricultural–urban space, and eco–agricultural–urban space. The proportions of their areas were 18%, 65%, 6%, 4%, 1%, 5%, and 1%, respectively.

Author Contributions: Conceptualization, S.W. and Y.Q.; methodology, W.Z.; software, M.G. and Z.P.; validation, Y.Q.; formal analysis, S.W. and M.G.; investigation, Z.P.; resources, Y.Q.; data curation, M.G. and Z.P.; writing—original draft preparation, S.W. and M.G.; writing—review and editing, S.W., Y.Q. and M.G.; visualization, W.Z.; supervision, Y.Q. and M.G.; funding acquisition, Y.Q. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the National Natural Science Foundation of China, grant number 42077434; the National Natural Science Foundation of China, grant number 41771560; and the Shandong Provincial Institutions of Higher Learning "Youth Innovation Team Development Plan" Project, grant number 2019RWG016.

Institutional Review Board Statement: Not applicable for studies not involving humans or animals.

Informed Consent Statement: Not applicable for studies not involving humans.

Data Availability Statement: The administrative area and river surface data were obtained from the National Catalogue Service for Geographic Information (https://www.webmap.cn (accessed on 3 September 2021)). The DEM data were derived from Geospatial Data Clouds (http://www.gscloud.cn (accessed on 3 September 2021)), while road traffic data were obtained from the OpenStreetMap. Land-use remote sensing instances in 2000, 2005, 2010, 2015, and 2020 were gathered from the Resources and Environment Science and Data Center (http://www.resdc.cn (accessed on 3 September 2021)). Socio-economic data were obtained from the Statistical Yearbook of Shandong Province and the Statistical Yearbooks of counties, cities, and districts under its jurisdiction.

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

References

1. Waters, C.N.; Zalasiewicz, J.; Summerhayes, C.; Barnosky, A.D.; Poirier, C.; Galuszka, A.; Cearreta, A.; Edgeworth, M.; Ellis, E.C.; Ellis, M.; et al. The Anthropocene is functionally and stratigraphically distinct from the Holocene. *Science* **2016**, *351*, 137. [CrossRef] [PubMed]
2. Liu, Y.; Fang, F.; Li, Y. Key issues of land use in China and implications for policy making. *Land Use Policy* **2014**, *40*, 6–12. [CrossRef]
3. Fu, B.; Liu, Y.; Li, Y.; Wang, C.; Li, C.; Jiang, W.; Hua, T.; Zhao, W. The research priorities of Resources and Environmental Sciences. *Geogr. Sustain.* **2021**, *2*, 87–94. [CrossRef]
4. Song, X.; Hansen, M.C.; Stehman, S.V.; Potapov, P.V.; Tyukavina, A.; Vermote, E.F.; Townshend, J.R. Global land change from 1982 to 2016. *Nature* **2018**, *560*, 7720. [CrossRef] [PubMed]
5. Abd El-Kawy, O.R.; Rod, J.K.; Ismail, H.A.; Suliman, A.S. Land use and land cover change detection in the western Nile delta of Egypt using remote sensing data. *Appl. Geogr.* **2011**, *31*, 483–494. [CrossRef]
6. Liu, J.; Kuang, W.; Zhang, Z.; Xu, X.; Qin, Y.; Ning, J.; Zhou, W.; Zhang, S.; Li, R.; Yan, C.; et al. Spatiotemporal characteristics, patterns, and causes of land-use changes in China since the late 1980s. *J. Clean. Prod.* **2014**, *24*, 195–210. [CrossRef]
7. Wang, J.; Chen, Y.; Shao, X.; Zhang, Y.; Cao, Y. Land-use changes and policy dimension driving forces in China: Present, trend and future. *Land Use Policy* **2012**, *29*, 737–749. [CrossRef]
8. Halmy, M.W.A.; Gessler, P.E.; Hicke, J.A.; Salem, B.B. Land use/land cover change detection and prediction in the north-western coastal desert of Egypt using Markov-CA. *Appl. Geogr.* **2015**, *63*, 101–112. [CrossRef]
9. Jiang, P.; Chen, D.; Li, M. Farmland landscape fragmentation evolution and its driving mechanism from rural to urban: A case study of Changzhou City. *J. Rural Stud.* **2021**, *82*, 1–18.

10. Sandro, L.S.; Ana Carolina, F.V.; Michelle, B.; Stefan, S.; Alexandre, S.; Marcos, L. Agricultural land use dynamics in the Brazilian part of La Plata Basin: Fromdriving forces to societal responses. *Land Use Policy* **2021**, *107*, 105519.
11. Bai, Y.; Ochuodho, T.O.; Yang, J. Impact of land use and climate change on water-related ecosystem services in Kentucky, USA. *Ecol. Indic.* **2019**, *102*, 51–64. [CrossRef]
12. Song, W.; Deng, X. Land-use/land-cover change and ecosystem service provision in China. *Sci. Total Environ.* **2017**, *576*, 705–719. [CrossRef]
13. Qu, Y.; Jiang, G.; Li, Z.; Tian, Y.; Wei, S. Understanding rural land use transition and regional consolidation implications in China. *Land Use Policy* **2019**, *82*, 742–753. [CrossRef]
14. Yang, Y.; Bao, W.; Li, Y.; Wang, Y.; Chen, Z. Land use transition and its eco-environmental effects in the Beijing–Tianjin–Hebei urban agglomeration: A production–living–ecological Perspective. *Land* **2020**, *9*, 285. [CrossRef]
15. Wolch, J.R.; Byrne, J.; Newell, J.P. Urban green space, public health, and environmental justice: The challenge of making cities 'just green enough'. *Landsc. Urban Plan.* **2014**, *125*, 234–244. [CrossRef]
16. Duan, Y.; Wang, H.; Huang, A.; Xu, Y.; Lu, L.; Ji, Z. Identification and spatial-temporal evolution of rural "production-living-ecological" space from the perspective of villagers' behavior—A case study of Ertai Town, Zhangjiakou City. *Land Use Policy* **2021**, *106*, 105457. [CrossRef]
17. Fu, B. Geography: From knowledge, science to decision making support. *Acta Geogr. Sin.* **2017**, *72*, 1923–1932.
18. Zhao, X.; Li, S.; Pu, J.; Miao, P.; Wang, Q.; Tan, K. Optimization of the national land space based on the coordination of urban-agricultural-ecological functions in the Karst Areas of Southwest China. *Sustainability* **2019**, *11*, 6752. [CrossRef]
19. Erb, K.H.; Haberl, H.; Jepsen, M.R.; Kuemmerle, T.; Lindner, M.; Muller, D.; Verburg, P.H.; Reenberg, A. A conceptual framework for analysing and measuring land-use intensity. *Curr. Opin. Environ. Sustain.* **2013**, *5*, 464–470. [CrossRef]
20. Aldwaik, S.Z.; Pontius, R.G. Map errors that could account for deviations from a uniform intensity of land change. *Int. J. Geogr. Inf. Sci.* **2013**, *27*, 1717–1739. [CrossRef]
21. Searchinger, T.D.; Wirsenius, S.; Beringer, T.; Dumas, P. Assessing the efficiency of changes in land use for mitigating climate change. *Nature* **2019**, *56*, 249–253. [CrossRef] [PubMed]
22. Newbold, T. Future effects of climate and land-use change on terrestrial vertebrate community diversity under different scenarios. *Proc. R. Soc. B-Biol. Sci.* **2018**, *285*, 1881. [CrossRef] [PubMed]
23. Powers, R.P.; Jetz, W. Global habitat loss and extinction risk of terrestrial vertebrates under future land-use-change scenarios. *Nat. Clim. Chang.* **2019**, *9*, 1. [CrossRef]
24. Lai, L.; Huang, X.; Yang, H.; Chuai, X.; Zhang, M.; Zhong, T.; Chen, Z.; Chen, Y.; Wang, X.; Thompson, J. Carbon emissions from land-use change and management in China between 1990 and 2010. *Sci. Adv.* **2016**, *2*, e1601063. [CrossRef]
25. Arsanjani, J.J.; Helbich, M.; Kainz, W.; Boloorani, A.D. Integration of logistic regression, Markov chain and cellular automata models to simulate urban expansion. *Int. J. Appl. Earth Obs. Geoinf.* **2013**, *21*, 265–275. [CrossRef]
26. Aspinall, R.; Staiano, M. A conceptual model for land system dynamics as a coupled human-environment system. *Land* **2017**, *6*, 4. [CrossRef]
27. Zhang, G.; Zhang, N.; Liao, W. How do population and land urbanization affect CO2 emissions under gravity center change? A spatial econometric analysis. *J. Clean. Prod.* **2018**, *202*, 510–523. [CrossRef]
28. Wang, J.; Xu, C. Geodetector: Principle and prospective. *Acta Geogr. Sin.* **2017**, *72*, 116–134.
29. Ju, R.; Zhang, Z.; Zuo, L.; Wang, J.; Zhang, S.; Wang, X.; Zhao, X. Driving forces and their interactions of built- up land expansion based on the geographical detector: A case study of Beijing, China. *Int. J. Geogr. Inf. Sci.* **2016**, *30*, 2188–2207. [CrossRef]
30. Huang, J.; Wang, J.; Bo, Y.; Xu, C.; Hu, M.; Huang, D. Identification of Health Risks of Hand, Foot and Mouth Disease in China Using the Geographical Detector Technique. *Int. J. Environ. Res. Public Health* **2014**, *11*, 3407–3423. [CrossRef] [PubMed]
31. Yang, R.; Xu, Q.; Long, H. Spatial distribution characteristics and optimized reconstruction analysis of China's rural settlements during the process of rapid urbanization. *J. Rural Stud.* **2016**, *47*, 413–424. [CrossRef]
32. Yang, X.; Zheng, X.; Chen, R. A land use change model: Integrating landscape pattern indexes and Markov-CA. *Ecol. Model.* **2014**, *283*, 1–7. [CrossRef]
33. Verburg, P.H.; Soepboer, W.; Veldkamp, A.; Limpiada, R.; Espaldon, V.; Mastura, S.S.A. Modeling the spatial dynamics of regional land use: The CLUE-S model. *Environ. Manag.* **2002**, *30*, 391–405. [CrossRef] [PubMed]
34. Liu, X.; Liang, X.; Li, X.; Xu, X.; Ou, J.; Chen, Y.; Li, S.; Wang, S.; Pei, F. A future land use simulation model(FLUS) for simulating multiple land use scenarios by coupling human and natural effects. *J. Clean. Prod.* **2017**, *168*, 94–116. [CrossRef]
35. Wang, Z.; Ya, S.; Pu, H.; Mofakkarul, I.; Ou, L. Simulation of spatiotemporal variation of land use in mountainous-urban fringes based on improved CA-Markov model. *Trans. Chin. Soc. Agric. Eng.* **2020**, *36*, 239–248.
36. Odum, E.P. The Strategy of Ecosystem Development. *Science* **1969**, *164*, 262–270. [CrossRef]
37. Green, R.E.; Cornell, S.J.; Scharlemann, J.P.W.; Balmford, A. Farming and the fate of wild nature. *Science* **2005**, *307*, 550–555. [CrossRef]
38. Angelstam, P.; Manton, M.; Green, M.; Jonsson, B.G.; Sabatini, F.M. Sweden does not meet agreed national and international forest biodiversity targets: A call for adaptive landscape planning. *Landsc. Urban Plan.* **2020**, *202*, 103838. [CrossRef]
39. Li, S.; Zhao, X.; Pu, J.; Miao, P.; Tan, K. Optimize and control territorial spatial functional areas to improve the ecological stability and total environment in karst areas of southwest china. *Land Use Policy* **2021**, *100*, 104940. [CrossRef]

40. Pontius, R.G.; Huang, J.; Jiang, W.; Khallaghi, S.; Lin, Y.; Liu, J.; Quan, B.; Ye, S. Rules to write mathematics to clarify metrics such as the land use dynamic degrees. *Landsc. Ecol.* **2017**, *32*, 2249–2260. [CrossRef]
41. Ian, E.; Kevin, T.; Susan, E.; Mandar, T. Modelling Deforestation and Land Cover Transitions of Tropical Peatlands in Sumatra, Indonesia Using Remote Sensed Land Cover Data Sets. *Land* **2015**, *4*, 670–687.
42. Fan, C.; Myint, S. A comparison of spatial autocorrelation indices and landscape metrics in measuring urban landscape fragmentation. *Landsc. Urban Plan.* **2014**, *121*, 117–128. [CrossRef]
43. Pontius, R.G.; Peethambaram, S.; Castella, J.C. Comparison of three maps at multiple resolutions: A case study of land Change simulation in Cho Don District, Vietnam. *Ann. Assoc. Am. Geogr.* **2011**, *101*, 45–62. [CrossRef]
44. Varga, O.G.; Pontius, R.G.; Singh, S.K.; Szabo, S. Intensity Analysis and the Figure of Merit's components for assessment of a Cellular Automata—Markov simulation model. *Ecol. Indic.* **2019**, *101*, 933–942. [CrossRef]
45. Mas, J.F.; Perez-Vega, A.; Clarke, K.C. Assessing simulated land use/cover maps using similarity and fragmentation indices. *Ecol. Complex.* **2012**, *11*, 38–45. [CrossRef]
46. Mcdonagh, B. Property, land and territory. *J. Hist. Geogr.* **2015**, *50*, 112–113.
47. Feng, Y.; Wang, X.; Du, W.; Liu, J.; Li, Y. Spatiotemporal characteristics and driving forces of urban sprawl in China during 2003–2017. *J. Clean. Prod.* **2019**, *241*, 118061. [CrossRef]
48. Zhu, G.; Qiu, D.; Zhang, Z.; Sang, L.; Liu, Y.; Wang, L.; Zhao, K.; Ma, H.; Xu, Y.; Wan, Q. Land-use changes lead to a decrease in carbon storage inarid region, China. *Ecol. Indic.* **2021**, *127*, 107770. [CrossRef]
49. Liu, Y.; Zhou, Y. Reflections on China's food security and land use policy under rapid urbanization. *Land Use Policy* **2021**, *109*, 105699. [CrossRef]
50. Su, Y.; Qian, K.; Lin, L.; Ke, W.; Tao, G.; Mg, A. Identifying the driving forces of non-grain production expansion in rural China and its implications for policies on cultivated land protection. *Land Use Policy* **2020**, *92*, 104435. [CrossRef]
51. Wang, J.; He, T.; Lin, Y. Changes in ecological, agricultural, and urban land space in 1984-2012 in China: Land policies and regional social-economical drivers. *Habitat. Int.* **2018**, *71*, 1–13. [CrossRef]
52. Zhao, X.; Li, S.; Tan, K.; Miao, P.; Pu, J.; Lu, F.; Wang, Q. Land use optimization of plateau lake basin based on town-agriculture-ecological spatial coordination. *Trans. Chin. Soc. Agric. Eng.* **2019**, *35*, 296–307.
53. Kong, Y.; Zhen, F.; Zhang, S.; Liu, J.; Li, Z. Evaluation on high-quality utilization of territorial space based on multi-source data. *China Land Sci.* **2020**, *34*, 115–124.
54. Wu, X.; Wang, S.; Fu, B.; Liu, Y.; Zhu, Y. Land use optimization based on ecosystem service assessment: A case study in the Yanhe watershed. *Land Use Policy* **2018**, *72*, 303–312. [CrossRef]
55. Marull, J.; Pino, J.; Tello, E.; Cordobilla, M.J. Social metabolism, landscape change and land-use planning in the Barcelona Metropolitan Region. *Land Use Policy* **2010**, *27*, 497–510. [CrossRef]
56. Barredo, J.I.; Kasanko, M.; Mccormick, N.; Lavalle, C. Modelling dynamic spatial processes: Simulation of urban future scenarios through cellular automata. *Landsc. Urban Plan.* **2003**, *64*, 145–160. [CrossRef]
57. Jones, K.R.; Venter, O.; Fuller, R.A.; Allan, J.R.; Maxwell, S.L.; Negret, P.J.; Watson, J.E.M. One-third of global protected land is under intense human pressure. *Science* **2018**, *360*, 788–791. [CrossRef] [PubMed]
58. Liang, X.; Guan, Q.; Clarke, K.C.; Liu, S.; Wang, B.; Yao, Y. Understanding the drivers of sustainable land expansion using a patch-generating land use simulation (PLUS) model: A case study in Wuhan, China. *Comput. Environ. Urban Syst.* **2021**, *85*, 101569. [CrossRef]