

Article

An Integrated Framework for the Effectiveness Assessment of Major Function-Oriented Zoning Based on the Dynamic Supply–Demand Relationship of Ecological Resources: A Case Study of Hunan Province, China

Yinghang Yang ¹, Huimin Yan ^{2,3}, Tian He ¹, Xiaozhi Xiang ¹, Zhiqi Yang ^{4,*}  and Wenpeng Du ^{1,*} 

¹ Institute of Geography and Resources Science, Sichuan Normal University, Chengdu 610101, China; yangyh@stu.sicnu.edu.cn (Y.Y.); hetian2014@163.com (T.H.); xiangxz@sicnu.edu.cn (X.X.)

² Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China; yanhm@igsrr.ac.cn

³ University of Chinese Academy of Sciences, Beijing 100049, China

⁴ School of Politics and Public Administration, Soochow University, Suzhou 215123, China

* Correspondence: zqyang@suda.edu.cn (Z.Y.); duwp@sicnu.edu.cn (W.D.)

Abstract

Major function-oriented zoning is a comprehensive policy designed to promote coordinated development through rational resource flows between regions in China. However, previous effectiveness assessments of major function-oriented zones have largely neglected the inter-relationships and complementarity among different functional zones. To address this gap, this study developed a framework for assessing the effectiveness of major function-oriented zoning by identifying the dynamic supply–demand characteristics of ecological resources and matching major targeted functions with these characteristics to formulate differentiated assessment standards. Empirical results from Hunan Province showed that 62 counties achieved their goals in 2020 (accounting for 50.82%), an increase of 10 counties since 2010. The number of urbanized regions achieving their goals nearly tripled during 2010–2020, indicating that urbanized regions approached their expected functional characteristics markedly faster than the other two zone types. However, the goal-achievement status of key ecological functional regions and main agricultural production regions remained relatively stable over the same period. Most importantly, statistically significant differences existed between goal-achieving and non-achieving counties in the traditional indicators reflecting their major functions; for example, the urbanization rate of goal-achieving urbanized regions was significantly higher than that of non-achieving ones, indirectly verifying the validity and practicality of the proposed framework.

Keywords: major function-oriented zoning; natural resource flows; effectiveness assessment; supply–demand relationship; Hunan Province



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1. Introduction

In 2015, the Sustainable Development Goals (SDGs) were formally proposed at the United Nations Sustainable Development Summit [1,2], emphasizing the importance of strengthening intergovernmental cooperation to address global and regional challenges, such as global warming, biodiversity loss, poverty, and inequality [3–5]. Although the current progress towards achieving the SDGs has fallen behind expectations because of factors such as the COVID-19 pandemic and the Russia–Ukraine conflict, it cannot be

ignored that most countries have contributed to advancing the SDGs over the past decade by formulating relevant policies [6,7]. Numerous previous studies have suggested that policy is one of the crucial factors in promoting the achievement of the SDGs [8–10].

China, which is the largest developing country, is both a participant in SDG formation and a contributor to implementation [11]. China's SDG score has increased from 59.1 in 2016 to 74.4 in 2025, with a global ranking increase of 17 places [12]. This could be attributed to intergovernmental cooperation agreements, such as the Belt and Road Initiative [13], and domestic policies related to ecological civilization construction [14,15]. In recent years, assessing the effectiveness of policy implementation in China has become a focus of academic attention. Among these policies, ecological governance and restoration policies, such as the Grain-for-Green Program [16], the Three-North Shelterbelt Program [17], and rocky desertification control [18], have attracted the most attention. Studies have shown that ecological governance and restoration policies not only directly improve regional eco-environmental protection but also indirectly drive regional economic development and increase human well-being [14,19]. The effectiveness of social-economic policies, such as ecological compensation and targeted poverty alleviation, has also drawn significant attention. The former has played a positive role in narrowing development gaps between regions [20,21], while the latter has effectively reduced the poverty rate by 94.4% in China, contributing to over 70% of the reduction in global poverty and to reaching the SDGs [22].

Major function-oriented zoning has all the regional advantages for increasing the average sustainable development level in China, with comprehensive consideration of regional economic, social, and ecological factors. Moreover, it promotes the free flow and rational allocation of natural resources to achieve coordinated development among regions [23,24]. Compared with widely recognized single-dimensional policies, the effectiveness assessment of the comprehensive policies represented by major function-oriented zoning is insufficient in terms of scope and depth. At this stage, relevant studies on major function-oriented zoning focus mainly on exploring its impact on urban development [25], land use efficiency [26], and eco-environmental benefits [27,28]. These studies have not evaluated whether different major function-oriented zones are progressing towards their intended functions. Studies on implementation effectiveness from the perspective of the main functions of a region that has strengthened or weakened can be divided into two categories: (1) those based on spatiotemporal changes in cultivated land, construction land, and ecological land [29]; (2) those based on an indicator system that reflects differences in major function-oriented zones [30,31]. These approaches share a common limitation: each major function-oriented zone is evaluated in isolation. Indicator-based systems rely on arbitrarily weighted scores that rank regions only against one another. Land use change assessments describe the areal redistribution of functions but cannot quantify resource use intensity or interregional flows. Therefore, neither can reflect the interrelationships and complementarity among different major function-oriented zones that form the inherent logic of this policy.

Ecological resources constitute the material basis for human survival and development, as well as for the generation and maintenance of ecosystem services [32]. Ecological resources are developed into ecological products (e.g., agricultural, forestry, and livestock products) through agricultural production activities, primarily exerting the provisioning services of ecosystems [33,34]. Meanwhile, the remaining ecological resources in ecosystems mainly perform regulation services and support services [35]. Major function-oriented zoning assigns differentiated functional orientations to different regions [36,37]. This functional differentiation leads to a mismatch between the supply and demand of ecological resources within each region, characterized by a specific direction and degree of disparity [37,38]. This implies that, through the interregional flow and allocation of ecological

resources, the scale at which supply–demand balance is achieved needs to be expanded from closed regions to the interregional level, thereby realizing an overall dynamic equilibrium on a larger scale [39]. In summary, the intraregional supply–demand mismatch is a fundamental characteristic of regional spatial functional differentiation, and its direction and degree can conversely serve as indicators for assessing the effectiveness of major function-oriented zoning.

To address this gap, this study develops a supply–production–demand framework for assessing the effectiveness of major function-oriented zoning. Pairwise comparison of the ecological resource supply capacity, production intensity, and demand level yields three indicators: self-sufficiency degree (SE), external dependence (ED), and ecological carrying pressure (EP). These indicators measure ecological resources in net primary productivity (NPP), a physically commensurable quantity rather than an arbitrarily weighted score, enabling two assessments unattainable with existing approaches: goal achievement can be judged for each county against absolute, zone-specific criteria; inter-zonal complementarity becomes observable, because the supply–demand identity underlying ED and EP is closed across regions. Taking Hunan Province as a case, an empirical analysis is conducted to reveal the implementation effectiveness and key constraint factors during the first phase of the policy (2010–2020). Spatially differentiated management policies that rely on interregional resource flows pose the same challenge worldwide. The framework therefore provides a scientific basis for optimizing major function-oriented zoning in China and extends to comparable policies in other countries.

2. Materials and Methods

2.1. Assessment Framework Construction

This study constructs the assessment framework in three stages: (1) From the perspective of the dynamic supply–demand relationship of ecological resources, the supply capacity, production intensity, and demand level are calculated at the county level, and then a three-dimensional indicator system that quantitatively reveals this relationship is constructed through pairwise comparisons. (2) According to the key functional objectives of urbanized regions, main agricultural production regions, and key ecological functional regions, the expected supply–demand characteristics of ecological resources in each region are analyzed, thereby establishing corresponding effectiveness assessment standards. (3) Referencing the classification idea used in the SDG effectiveness assessment, the categories that can reflect the achievement status and trends of the effectiveness of major function-oriented zoning are determined.

2.1.1. Assessing the Dynamic Supply–Demand Relationship of Ecological Resources

Ecological resources in a narrower sense refer to biomass resources present in ecosystems, such as farmland, grassland, forestland, wetland, and aquatic ecosystems [40]. Net primary productivity (NPP) refers to the amount of solar energy converted into biomass by vegetation through photosynthesis in terrestrial ecosystems; it is also the fundamental resource that sustains human life and heterotrophic organisms [41]. Therefore, NPP is often regarded as the fundamental physical form for the quantitative assessment of ecological resources, serving as a key indicator of supply capacity, flow characteristics, and ecological carrying pressure [42–44]. NPP has been reported to integrate several planetary boundaries, including land-system change, freshwater use, biosphere integrity, and global nitrogen and phosphorus flows [45], and to vary synergistically with soil conservation and water yield [46]. The significant correlation between NPP and biodiversity, as well as the strong dependency between ecosystem services and biodiversity, has been confirmed in relevant

studies [47,48], indicating that NPP serves as an integrated indicator to quantify the supply capacity of various ecosystem services.

Human Appropriation of Net Primary Production (HANPP) is an important framework for measuring the extent to which human activities utilize biomass in terrestrial ecosystems. In the HANPP framework, the current biomass provided by ecosystems (NPP_{act}) consists of two components: harvested biomass consumption ($HANPP_{harv}$) and the remaining biomass of ecosystems (NPP_{eco}) [44]. $HANPP_{harv}$ represents the ecological resources developed by agricultural production activities that enter the social system from the ecosystem. This component plays the role of ecosystem supply services and corresponds to the functions of the main agricultural production regions. NPP_{eco} mainly plays the role of ecosystem regulation services and support services, which corresponds to the functions of key ecological functional regions.

Consequently, this study utilizes the NPP to characterize the supply capacity of ecological resources ($SNPP_S$) and calculates the $HANPP_{harv}$ based on data from both the production and consumption sides to quantify the production intensity of ecological resources ($CNPP_P$) and the demand level of ecological resources ($CNPP_L$). The assumptions for calculating the three quantities are as follows: For $SNPP_S$, the terrestrial ecosystem is assumed to remain intact in structure and function, and all NPP provided by the ecosystem is assumed to be available for human utilization. For $CNPP_P$, harvested biomass is assumed to originate from local NPP of the same year, with physical outputs converted through fixed harvest and biomass coefficients. For $CNPP_L$, residents' consumption is converted into NPP-equivalent demand using dietary coefficients specific to urban and rural populations. By comparing the ecological resource supply capacity, production intensity, and demand level in pairs, the three-dimensional indicators are obtained that quantitatively characterize the supply–demand characteristics of ecological resources: self-sufficiency degree (SE), external dependence (ED), and ecological carrying pressure (EP) (Figure 1a, Table 1).

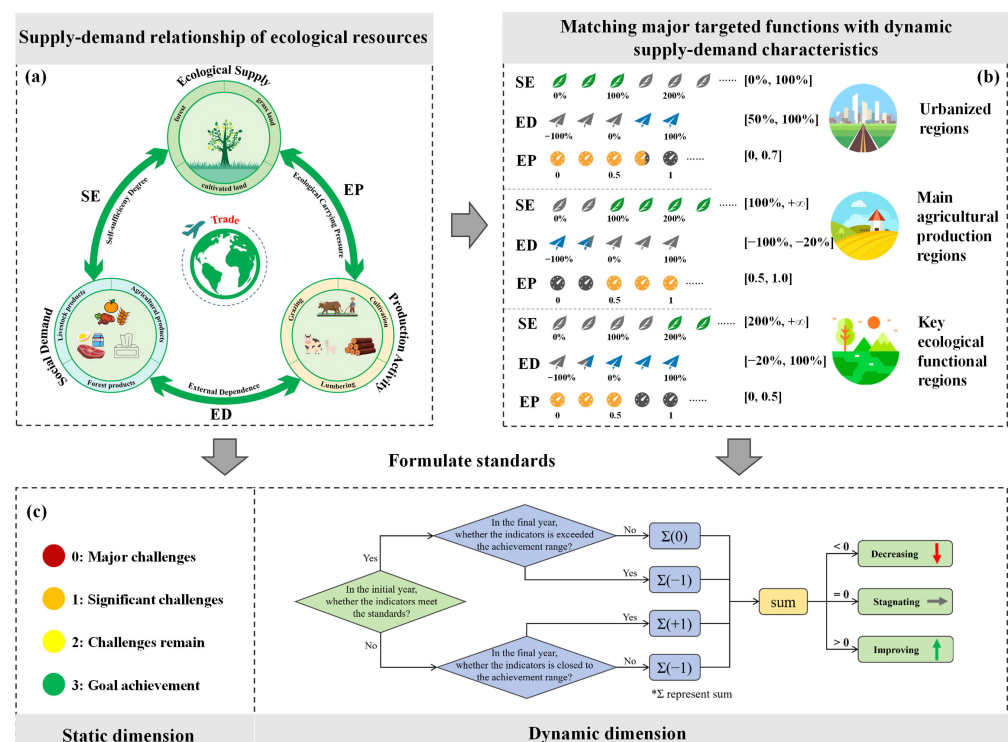


Figure 1. (a–c) An integrated framework for assessing the effectiveness of major function-oriented zoning.

Table 1. Algorithm for social–ecological system sustainability assessment.

Dimension	Definition	Algorithm	Explanation
Self-sufficiency degree (SE)	Reflects the carrying capacity of the local ecosystem without relying on external ecological resources.	The self-sufficiency degree is obtained by comparing the supply capacity with the social demand level of ecological resources: $SE = \frac{SNPP_S}{CNPP_L} * 100\%$	SE < 100%, indicates that the ecological resources in this region are not able to meet local demands. SE > 100%, indicates that the ecological resources in this region are able to meet local demands.
External dependence (ED)	Reflects to the dependence degree of regional social system demands on external ecological resources given the current production intensity of local ecological resources.	The external dependence is obtained by comparing the social demand level with the production intensity: $ED = \frac{CNPP_L - CNPP_P}{\max(CNPP_L, CNPP_P)} * 100\%$	ED < 0, indicates that the region is export-dependent (ED < −50%, with the ecological resources it produced mainly used for export); ED > 0, indicates that the region is import-dependent (ED > 50%, with the ecological resources it demands mainly dependent on imports).
Ecological carrying pressure (EP)	Reflects the actual pressure exerted on ecosystems by local human activities in the regions.	The ecological carrying pressure is obtained by comparing the production intensity with the supply capacity of ecological resources: $EP = \frac{CNPP_P}{SNPP_S}$	EP < 1, indicates that the ecosystem in the region is in surplus; EP > 1, indicates that the ecosystem in the region is in overloaded.

Notes: (1) SNPP_S denotes ecological resource supply capacity: the maximum of ecological resources that terrestrial ecosystems can sustainably supply to the social system for production and utilization while ensuring the integrity of ecosystem structure and function. (2) CNPP_P denotes ecological resource production intensity: the degree of consumption and appropriation of ecological resources provided by local terrestrial ecosystem in regional production activities. (3) CNPP_L denotes the ecological resource demand level: the actual consumption of ecological resources by regional social systems to meet the needs of residents' livelihoods and economic development. (4) The specific calculation methods for SNPP_S, CNPP_P, and CNPP_L are detailed in the Supplementary Materials (Tables S1–S6).

2.1.2. Matching Major Targeted Functions with Dynamic Supply–Demand Characteristics of Ecological Resources

The county is the basic unit for major function-oriented zoning in China. In accordance with the differences in development orientation, in this study, the achievement range of the self-sufficiency degree, external dependence, and ecological carrying pressure for each major function-oriented zone were determined by analyzing the relationships among the supply, production, and demand of ecological resources in urbanized regions, main agricultural production regions, and key ecological functional regions (Figure 1b).

Urbanized regions are the core of economic development in China [36,49]. Population aggregation in these regions leads to a shortage of ecological resources (demand > supply), so that ecological resources are unable to achieve self-sufficiency (SE < 100%). Moreover, agricultural production is not their major function and large amounts of ecological resources must be imported to meet residents' living demands, corresponding to external dependence above 50%. According to the biodiversity conservation target [50], the 30% ecological protection target is set as the constraint on the production intensity (the ecological resources

consumed by production activities cannot exceed 70% of the supply) for urbanized regions, which means that the ecological carrying pressure should be less than 0.70.

Key ecological functional regions serve as critical barriers to ecological security, whose primary functions are to provide regulating and support services such as water conservation, climate regulation, and biodiversity protection [23]. On the basis of this positioning, sufficient residual biomass should be retained within their ecosystems, so these regions must prioritize the 50% ecological conservation target, meaning that ecological carrying pressure remains below 0.50. Abundant ecological resources, together with ecological migration and labour transfer, generally lead to an oversupply in these regions [51,52]; as only half of the NPP supply is available for utilization under the 50% target, meeting local demands requires a gross supply at least twice the demand, that is, a self-sufficiency degree no lower than 200%. Small-scale restricted development zones are also contained in these regions, where ecological resources can be exploited to meet residents' living demands or moderately exported [53,54]. Accordingly, external dependence is bounded at -20% , that is, the exported amount cannot exceed 20% of the amount produced, following the observed export pattern in China's major ecological regions [51].

Main agricultural production regions are strategic regions that ensure national food security, whose primary function is to provide provisioning services such as grain, vegetables, fruits, meat, eggs, and dairy products [36]. Self-sufficiency in these regions is a prerequisite for supplying ecological resources to the living demands of residents in other functional regions, so the self-sufficiency degree is required to be no lower than 100%. Given their role as net suppliers of ecological resources, with ecological products produced by agricultural activities primarily consumed in external regions [55,56], the external dependence threshold is set at -20% or below, meaning that the export standard is no lower than that of key ecological functional regions. The upper limit of the production intensity is defined as the consumption of all ecological resources provided by the ecosystem in the current year, that is, ecological carrying pressure ≤ 1 ; in this scenario, these regions can at least enjoy the regulating and support services generated by the accumulated ecological resources of previous years and the spillover ecosystem services from surrounding key ecological functional regions [57]. Additionally, the ecological carrying pressure in these regions should be higher than that in key ecological functional regions (the ecological carrying pressure should be above 0.50) reflecting their role in ensuring food security through agricultural production activities.

The above thresholds are anchored in three ways. Target-based values derive from the staged conservation goals: $EP < 0.70$ in urbanized regions and $EP < 0.50$ in key ecological functional regions correspond to the 30% and 50% conservation targets [50]. Empirically patterned values derive from observed interregional flows, in which exports rarely exceed 20% of the exploited amount in major ecological regions [51]; hence, $ED \geq -20\%$ is set for key ecological functional regions and $ED \leq -20\%$ for main agricultural production regions. Definitional values derive from functional positioning: $SE < 100\%$ reflects the demand–supply gap induced by population aggregation, and $0.50 < EP \leq 1$ requires higher production intensity in agricultural regions than in ecological regions, while the current-year NPP is not over-appropriated. A sensitivity analysis that systematically varies the principal thresholds within reasonable ranges is reported in Section 4.3.

2.1.3. Formulating Standards for the Effectiveness of Major Function-Oriented Zoning

In this study, the implementation effectiveness of major function-oriented zoning is assessed from both static and dynamic perspectives, with the results presented in a format that references Sustainable Development Reports [12]. In the static dimension, according to the number of socio-ecological sustainability indicators within a given major function-

oriented zone that fall within their corresponding achievement ranges in a specific year, the achievement status of major function-oriented zones is divided into four levels: major challenges, significant challenges, challenges remain, and goal achievement (Figure 1c).

In the dynamic dimension, the effectiveness of major function-oriented zoning is judged by comparing the closeness of a region's socio-ecological sustainability indicators to the achievement range between two years. The specific process is as follows (Figure 1c): For indicators that were already within the achievement range at the initial stage, whether the indicator exceeded the achievement range at the final stage was determined. If the indicator exceeds the achievement range, it is assigned a value of -1 ; otherwise, it is assigned a value of 0 . For indicators that were not in the achievement range at the initial stage, whether the indicator is closer to the achievement range at the final stage was determined. If the indicator is closer to the achievement range (including within the achievement range), it is assigned a value of 1 ; otherwise, it is assigned a value of -1 . The values of the three indicators are summed and the implementation effectiveness of major function-oriented zoning is determined (sum > 0 : improving; sum $= 0$: stagnating; sum < 0 : decreasing).

It should be noted that SE, ED, and EP are given equal weights in the dynamic classification for three reasons. First, they are pairwise ratios within one closed supply–demand–production cycle, so they are mutually constrained rather than independent, and no relation should be privileged over the others. Second, the differences among zone types are already captured by their zone-specific achievement ranges (Section 2.1.2) and a uniform scoring rule keeps the trajectories comparable. Third, in the absence of a clear prior for differential importance, equal weighting is the least-assumption choice and avoids the arbitrary weighting typical of indicator-based assessments.

2.2. Study Area

Hunan Province is located in central China ($108^{\circ}47'$ E– $114^{\circ}15'$ E, $24^{\circ}38'$ N– $30^{\circ}08'$ N; Figure 2a) and plays important roles in urban economic development, food security, and eco-environmental protection in China. The Chang–Zhu–Tan urban agglomeration, designated as a key development region in the *Development Plan for Urban Agglomerations in the Middle Reaches of the Yangtze River* (2015), is the core of economic growth for central China and a representative region for integrated urban agglomeration development [58]. Hunan Province is a major agricultural production province in China and a key province for the construction of high-standard farmland. As of 2021, Hunan Province had a reserve of 2.41 million hectares of high-standard farmland and a total grain output of 30.745 million tons [59]. Moreover, Hunan Province plays an important role in the ecological safety of the middle reaches of the Yangtze River, relying on its abundant forest resources and complex water ecological networks formed by Dongting Lake, the Xiang River, the Zi River, the Yuan River, and the Li River [60]. Therefore, in this study, Hunan Province was selected as a case study to assess the effectiveness of major function-oriented zoning.

The *National Territorial Spatial Plan for Hunan Province (2010–2020)*, published in 2012, divided the 122 counties in Hunan into 43 urbanized regions, 44 key ecological functional regions, and 35 main agricultural production regions (Figure 2c). Among these, urbanized regions are primarily distributed around the Chang–Zhu–Tan urban agglomeration, covering an area of approximately 40,200 km²; key ecological functional regions are located mainly in the western and southern regions, spanning approximately 100,000 km²; and the main agricultural production regions are distributed primarily in the surroundings of the Chang–Zhu–Tan region and the Dongting Lake region, covering approximately 71,400 km². In 2023, the *National Territorial Spatial Plan for Hunan Province (2021–2035)* was approved, in which the major function-oriented zoning remained essentially consistent with the previous version. In this study, the implementation effectiveness of major function-oriented

zoning in Hunan Province from 2010 to 2020 was assessed. Hunan Province has nearly balanced numbers of counties across the three types of major function-oriented zones, making it a suitable case for testing the applicability of the framework to each zone type simultaneously under the same provincial zoning plan and for evaluating its transferability to other provinces implementing major function-oriented zoning.

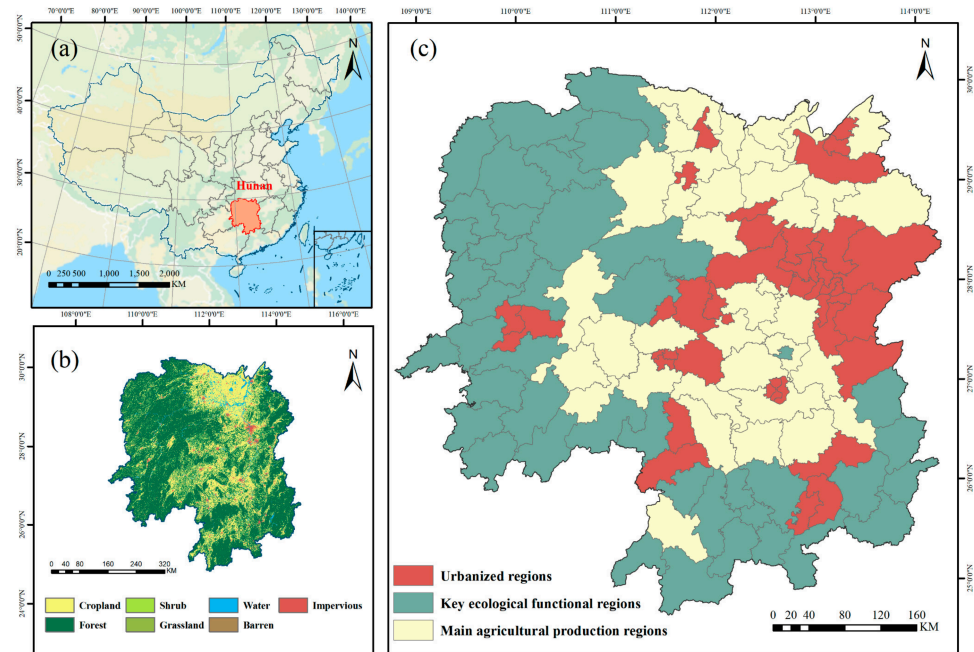


Figure 2. Location (a), land use in 2020 (b), and major function-oriented zoning in 2012 (c) in Hunan Province.

2.3. Data Sources

The basic data used in this study mainly includes the following four aspects:

- (1) Net primary productivity (NPP) data were sourced from the MODIS satellite product (MOD17A3H) developed by the National Aeronautics and Space Administration (NASA). Land-use and land-cover change (LUCC) data were sourced from the China Land Cover Dataset (CLCD) developed by Wuhan University [61]. These data were primarily used to calculate the ecological resource supply capacity in Hunan Province. The spatial resolution of the NPP data is 500 m, while the spatial resolution of the CLCD is 30 m. Before calculation, the CLCD was resampled to 500 m using the nearest method. Lastly, the data were aggregated at county level using Zonal Statistics tools in ArcGIS 10.8.
- (2) Agricultural, forestry, and livestock production (yield and output values) data, per capita consumption of major foods for urban and rural residents, and population data were sourced from the Hunan Province Statistical Yearbook and the Hunan Province Rural Statistical Yearbook. These data were used to calculate ecological resource production intensity and demand levels in Hunan Province.
- (3) The major function-oriented zoning data of Hunan Province were sourced from the document The National Territorial Spatial Plan for Hunan Province (2010–2020), and the county-level administrative division data were sourced from the Resource and Environment Data Platform.
- (4) The urbanization rate and GDP data were sourced from the Hunan Statistical Yearbook, the labor force structure data were sourced from the China Population Census County-Level Data, and the normalized difference vegetation index (NDVI) data were sourced from the National Ecosystem Science Data Center (spatial resolution: 30 m;

aggregated by county using Zonal Statistics tools in ArcGIS). The above data were primarily used for the cross-verification of the results.

This study assessed the effectiveness of major function-oriented zoning in Hunan Province in 2010 and 2020, using data from the corresponding years.

3. Results

3.1. Achievement Status of Major Function-Oriented Zones

In 2020, 62 major function-oriented zones (counties) in Hunan Province attained goal-achievement status (accounting for 50.82%), an increase of 10 counties compared with 2010. Among them, 44 counties attained this status twice (counties that achieved their goals in both 2010 and 2020) (Figure 3). The number of counties with statuses of challenges remain, significant challenges, and major challenges were 35, 15, and 10 in 2020, showing a decrease of 12, an increase of 1, and a decrease of 1 compared with results in 2010, respectively. This indicates that more counties had moved toward the expected functional characteristics in 2020.

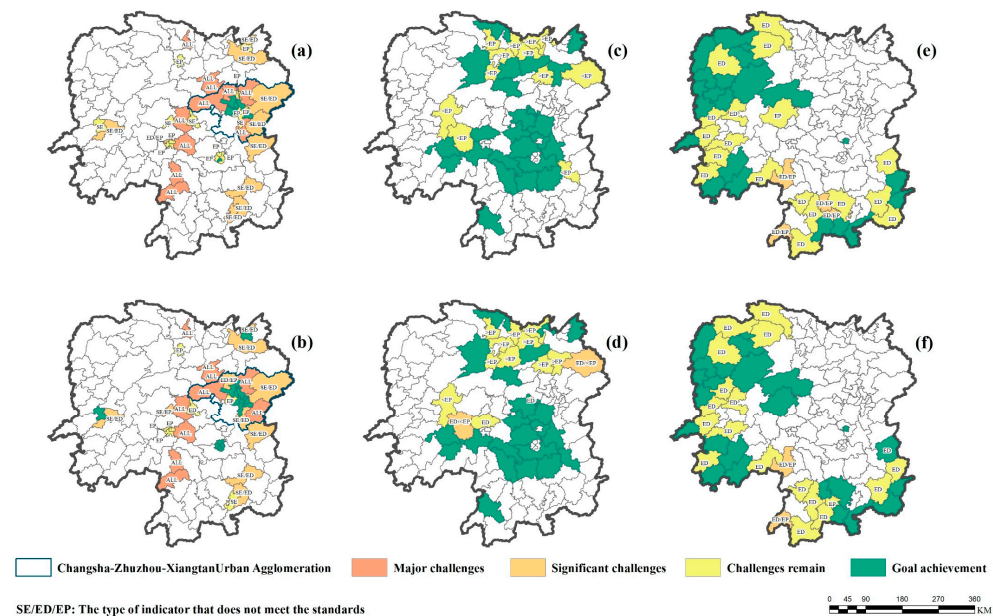


Figure 3. Status of major function-oriented zones in Hunan Province (urbanized regions in 2010 (a) and 2020 (b), main agricultural production regions in 2010 (c) and 2020 (d), and key ecological functional regions in 2010 (e) and 2020 (f)). Note: In the figure, ALL indicates that all three indicators (SE, ED, and EP) fail to meet the qualification standard.

Goal-achievement patterns differed clearly across the three types of major function-oriented zones in Hunan Province. In 2020, 16 urbanized regions attained goal-achievement status, accounting for 37.21% (Figure 3a,b). These regions were mainly concentrated in the Chang–Zhu–Tan urban agglomeration. Compared with that in 2010, the number of regions that attained goal-achievement status increased nearly threefold in 2020, indicating that urbanized regions approached their expected functional characteristics markedly faster than the other two zone types. The number and spatial distribution of main agricultural production regions and key ecological functional regions with goal-achievement status remained relatively stable. In 2020, 23 main agricultural production regions attained goal-achievement status (accounting for 65.71%), which were 1 fewer than in 2010. Specifically, 21 of them attained this status twice, making up over 90% (Figure 3c,d). There were 23 key ecological functional regions with goal-achievement status (accounting for 52.27%) in 2020,

an increase of 1 compared with 2010. Among them, 18 counties attained the status twice, accounting for nearly 80% (Figure 3e,f).

3.2. Implementation Effectiveness of Major Function-Oriented Zoning

This section describes an evaluation of the effectiveness of major function-oriented zoning in the 78 counties that did not attain goal-achievement status twice. The results reveal that, from 2010 to 2020, 47 counties, 6 counties, and 25 counties experienced improving, stagnating, and decreasing functions, respectively (Figure 4). With respect to urbanized regions, among the 38 counties that failed to achieve their goals in both 2010 and 2020, 30 experienced improvements, accounting for nearly 80%. Specifically, their SE decreased by an average of 34.37%, their ED increased by an average of 16.69%, and their EP declined by an average of 0.18 (Table S7). Moreover, 15 of these 30 counties showed positive changes in goal-achievement grades: 2 counties changed from major challenges to significant challenges, 2 counties changed from significant challenges to challenges remain, and 11 counties changed from challenges remain to goal achievement (Figure 4).

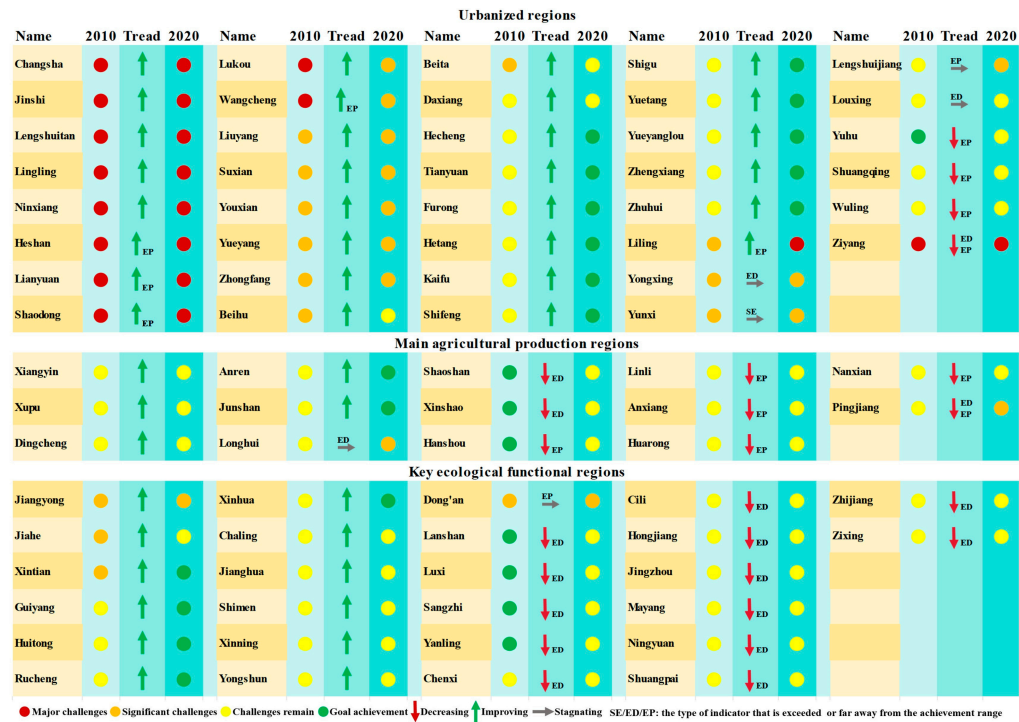


Figure 4. Implementation effectiveness of major function-oriented zoning in Hunan Province from 2010 to 2020.

In the main agricultural production regions, there were eight counties with decreasing functions and one county with stagnating functions, which was slightly higher than the number of counties with improving functions (five counties). Of the 14 counties that did not attain goal-achievement status twice, 2 changed from challenges remain to goal achievement, while 3 changed in the opposite direction (Figure 4). Among the key ecological functional regions, 12 counties improved (SE decreased by an average of 132.22%, ED increased by an average of 9.92%, and EP decreased by an average of 0.03), including 5 counties that changed from significant challenges or challenges remain to goal achievement, and 13 counties decreased, including 4 counties that changed from goal achievement to challenges remain (Figure 4).

3.3. Constraints on Goal Achievement

In 2020, the counties among urbanized regions that did not achieve their goals were constrained by a mixture of indicators. Specifically, 20 urbanized regions were constrained by two or more factors, accounting for 74.07% of urbanized regions. The self-sufficiency degree (SE), external dependence (ED), and ecological carrying pressure (EP) hindered goal achievement in 20, 20, and 16 urbanized regions, respectively (Figure 3b). EP was the most frequently observed limiting indicator for urbanized regions from 2010 to 2020. Among the eight urbanized regions with stagnating or decreasing functions, five counties were affected by increased EP (increased by an average of 0.29) (Figure 4).

For the main agricultural production regions, ED and EP were the most frequently observed limiting indicators for goal non-achievement in 2020 and for decreasing functions from 2010 to 2020 (Figures 3d and 4). In 2020, 33.3% of the counties that did not attain goal-achievement status had an external dependence greater than -20% , which meant their export standards were lower than those of key ecological functional regions—contrary to the desirable level for main agricultural production regions. In addition, seven counties did not attain goal-achievement status due to excessive EP and three counties due to insufficient EP. Among the nine counties whose functions were stagnating or decreasing, four counties were also affected by increased ED (increased by an average of 8.95%), leading to changes in two counties from goal achievement to challenges remain (Figure 4).

As in the main agricultural production regions, ED was also the most frequently observed limiting indicator in key ecological functional regions not attaining goal-achievement status by 2020 and among those that experienced decreasing functions from 2010 to 2020 (Figures 3f and 4). In 2020, 20 counties did not attain goal-achievement status due to their ED being less than -20% , accounting for 95.24% (Figure 3f). There were 13 counties that experienced a decrease in ED (decreased by an average of 7.68%), among which 4 counties directly shifted from goal achievement to challenges remain (Figure 4). In these counties, ED fell below the -20% threshold, indicating that exports of ecological resources exceeded the level consistent with their designated ecological function.

4. Discussion

4.1. Cross-Verification

Previous studies have selected indicators according to functional differences to construct an evaluation system of the effectiveness of major function-oriented zoning. The propensity score matching (PSM) method was used to calculate the functional scores. The results revealed that the major function-oriented zoning in Hunan Province enhanced the urban development function of urbanized regions but did not have a positive effect on the function of the main agricultural production regions or key ecological functional regions from 2009 to 2018 [30]. Considering all the counties in each major function-oriented zone of Hunan Province, the results of this study also show that the three-dimensional indicators of urbanized regions were closer to the achievement range, whereas the achievement status of the main agricultural production regions and key ecological functional regions remained relatively stable from 2010 to 2020 (Figure 5a–c). The findings of this study are essentially consistent with those of previous studies.

To further verify the reliability of the idea and standard for assessing the implementation effectiveness of the major function-oriented zoning proposed in this study, we selected representative indicators that reflect the functions of each major function-oriented zone with reference to previous studies [30,62,63]. Differences in these indicators between goal-achieving and non-achieving counties were tested using the two-sided Mann–Whitney U test.

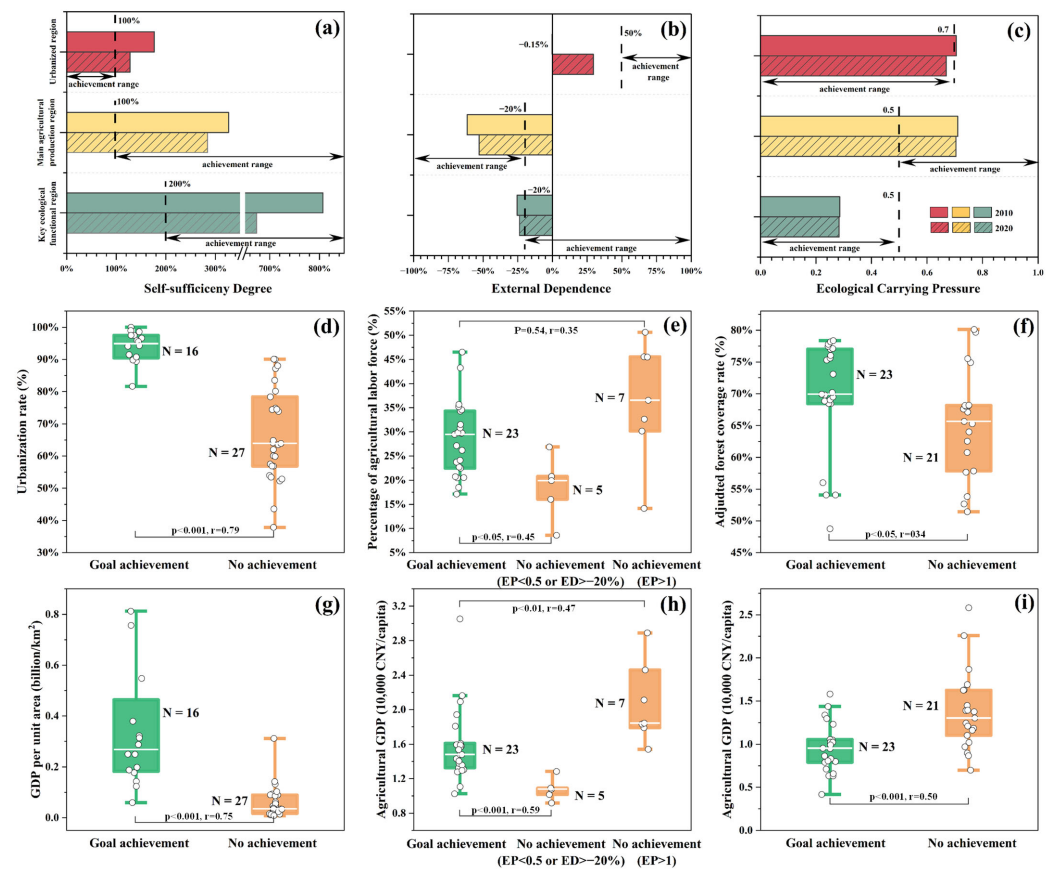


Figure 5. Changes in the three-dimensional assessment of urbanized regions, main agricultural production regions, and key ecological functional regions in Hunan Province from 2010 to 2020 ((a): self-sufficiency degree; (b): external dependence; (c): ecological carrying pressure), and cross-verification for the effectiveness assessment of major function-oriented zoning in Hunan Province ((d,g): urbanized regions; (e,h): main agricultural production regions; (f,i): key ecological functional regions; compared using two-sided Mann–Whitney U tests, $r = |Z| / \sqrt{N}$).

In urbanized regions, the urbanization rate ($p < 0.001$, $r = 0.79$) and GDP per unit area ($p < 0.001$, $r = 0.75$) of goal-achieving counties were significantly higher than those of non-achieving counties (Figure 5d,g). Additionally, in key ecological functional regions, per capita agricultural GDP (as a reverse indicator) ($p < 0.001$, $r = 0.50$) and the forest coverage rate ($p < 0.05$, $r = 0.34$) differed significantly between the two groups (Figure 5f,i).

The major agricultural production regions that did not achieve goals were divided into two categories (Figure 5e,h): those with excessive agricultural function leading to ecological overload ($EP > 1$) and those with insufficient agricultural function ($EP < 0.5$ or $ED > -20\%$). For main agricultural production regions, significant differences in per capita agricultural GDP were observed between counties that attained goal-achievement status and both categories of non-achieving counties ($p < 0.001$, $r = 0.59$; $p < 0.01$, $r = 0.47$), and the difference in the percentage of the agricultural labor force was significant for counties with insufficient agricultural function ($p < 0.05$, $r = 0.45$), whereas for counties with agricultural overload it was marginally non-significant ($p = 0.054$, $r = 0.35$), which may be attributable to the limited number of counties in this category ($N = 7$) (Figure 5e,h).

4.2. Reasons for the Implementation Effectiveness of Major Function-Oriented Zoning

Civil cultivation is the foundation of China's origin and development. Under the dual influence of regional functional evolution and government spatial control, agricultural production regions have gradually differentiated into three major function-oriented

zones [37,64]. Hunan Province, as a traditional agricultural province in China [65], has only begun to formally differentiate its regional functions since the implementation of the national territorial spatial plan centered on major function-oriented zoning in 2012. Owing to the relatively short period since agricultural regions were transformed into urbanized regions or key ecological functional regions, their functional development is still immature. Therefore, only 50.82% of the counties in Hunan Province achieved their major functional goals in 2020 (Figure 3).

In recent years, urbanization in Hunan Province, represented by the Chang–Zhu–Tan urban agglomeration, has developed rapidly [66]. From 2010 to 2020, with the support of urban development policies, such as the Hunan Province Outline for Promoting New Urbanization (2014–2020), the goal-achievement rate in urbanized regions nearly tripled from 13.95% to 37.21% (Figure 3). As early as 2007, Hunan Province established a development framework for the “integration of three cities” by formulating the Chang–Zhu–Tan Urban Agglomeration Regional Planning, focusing on developing the agglomeration into a national-level reform pilot region. As a result, the goal-achievement rate in the Chang–Zhu–Tan urban agglomeration reached 58.82%, which was higher than the average level of urbanized regions in Hunan.

From 2010 to 2020, nearly 90% (31) of the main agricultural production regions experienced an increasing trend in their external dependence (ED), leading to functional stagnating or decreasing in four counties (Figure 4). From the perspective of the ED algorithm (Table 1), the faster growth rate of the ecological resource demand level to production intensity is the direct cause of the increase in ED. At present, agricultural production and its associated industries in Hunan Province remain labor-intensive [67], which may have kept a large population continuing to reside in rural areas. Moreover, during the 21st century, rising demand in developing countries has replaced population growth as the primary driver of increased ecological resource consumption [68,69]. In this scenario, rising local consumption would absorb an increasing share of regional production, crowding out the surplus available for export [70]. These findings in previous studies [67–70] offer a possible explanation for the increase in external dependence (ED) in most of the main agricultural production regions in Hunan Province.

Key ecological functional regions need to adopt measures such as labor transfer, ecological migration, and national transfer payment policies to achieve ecological protection goals while not sacrificing human well-being [71–73]. In 2020, more than 70% of the key ecological functional regions experienced a decrease in the permanent population compared with that in 2010, which contributed to the realization of their ecological protection functions. However, the transfer payment standards for key ecological functional regions in China were relatively low. For Hunan Province, the national transfer payment funds for key ecological functional regions in 2020 totaled approximately 4.534 billion CNY, with an average of approximately 273.32 CNY per capita. The ecological compensation funds received by key ecological functional regions in Hunan remain insufficient, with relatively low standards and largely homogeneous payment measures [74,75]. Such limited payments may not be enough to offset the returns from agricultural expansion. This may have sustained agricultural production intensity and hindered the achievement of their ecological protection functions.

4.3. Contributions, Sensitivity Analysis, and Limitations

(1) Contributions

Major function-oriented zoning is a comprehensive policy that leverages regional advantages to enhance overall sustainable development and promote the rational allocation of national resources between regions to achieve coordinated development [23]. In this study,

the ecological resource flow perspective [76] was incorporated to develop a framework for assessing the effectiveness of major function-oriented zoning, which compensates for the shortcomings of traditional indicator systems that fail to reflect interregional relationships. Additionally, traditional indicator systems evaluate implementation effectiveness on the basis of changes in indicators reflecting regional main functions (such as urbanization rates in urbanized regions) [30]. However, they cannot evaluate whether the corresponding main functions of a region have been achieved. This study evaluated the effectiveness of major function-oriented zoning in Hunan Province and revealed significant differences in traditional indicators between regions that attained or did not attain goal-achievement status (Figure 5), providing a threshold reference for traditional indicator systems to judge whether regional major functional goals have been achieved.

(2) Sensitivity analysis

Since the achievement thresholds directly determine whether a county is classified as goal-achieving, it is necessary to examine whether the above conclusions depend on the specific threshold values. Thus, a sensitivity analysis was conducted by perturbing all thresholds simultaneously by $\pm 10\%$. The results show that relaxing or tightening the threshold criteria altered the proportion of goal-achieving counties in Hunan Province by no more than 10%, and, for each of the three types of major function-oriented zones, the number of goal-achieving counties changed by no more than four (Table 2). This indicates that the findings in this study are robust across reasonable threshold settings.

Table 2. Number of goal-achieving counties and goal-achievement rate for each type of major function-oriented zone under different achievement-threshold settings.

Year	Threshold Setting	Urbanized Regions		Main Agricultural Production Regions		Key Ecological Functional Regions		Total	
		Count	Rate (%)	Count	Rate (%)	Count	Rate (%)	Count	Rate (%)
2010	Original	6	13.95	24	68.57	22	50.00	52	42.62
	Tightened	4	9.30	21	60.00	19	43.18	44	36.07
	Relaxed	9	20.93	28	80.00	26	59.09	63	51.64
2020	Original	16	37.21	23	65.71	23	52.27	62	50.82
	Tightened	13	30.23	21	60.00	20	45.45	54	44.26
	Relaxed	16	37.21	25	71.43	24	54.55	65	53.28

Note: The tightened and relaxed settings correspond to narrowing and widening the achievement range of each threshold by 10%.

(3) Limitations

The NPP data are derived from a remote-sensing model product whose accuracy depends on meteorological inputs and light-use efficiency parameters, and the harvest, biomass, and dietary conversion coefficients are fixed values; together with possible reporting errors in statistical yearbook data, these introduce uncertainty into the county-level values of SE, ED, and EP, although the use of consistent data sources and coefficients across 2010 and 2020 limits its influence on the comparison between the two years. Moreover, county-level aggregation masks spatial heterogeneity within counties and results at other scales may differ; this unit was nonetheless retained because the county is the basic implementation unit of major function-oriented zoning in China. Additionally, the assessment compares conditions in 2010 and 2020, so intermediate fluctuations remain unobserved; in particular, NPP is sensitive to annual climate variability and a two-point comparison cannot fully distinguish long-term trends from short-term fluctuations. Most importantly, the assessment rules do not evaluate changes in indicators that are already within the achievement range, because moving further toward the theoretical extreme is not meaningful—only bare land, whose ecological supply is zero, can reach a self-sufficiency

degree of 0—so the stability of indicators within the achievement range still requires benchmarks.

Major function-oriented zoning is one of the most important spatial planning policies in China, and a wide range of subsequent regional policies have been formulated to serve and support its implementation. Nevertheless, several contemporaneous regional and provincial-level plans have also shaped territorial functional differentiation. For Hunan, the Development Plan for Urban Agglomeration in the Middle Reaches of the Yangtze River (2015) and the Plan for the Dongting Lake Eco-Economic Zone (2014) are two such examples, and the findings of this study therefore cannot be attributed solely to major function-oriented zoning. Future work could employ a difference-in-differences (DID) design to isolate its net effect more cleanly. This study takes Hunan Province, where the three types of major function-oriented zones are present in relatively balanced numbers, as the study area. Its assessment results have passed both cross-verification and sensitivity analysis, indicating that the proposed framework and its thresholds are broadly adaptable to regions of this type, though targeted adjustments would be required for special regions: a stricter ecological-protection threshold ($EP < 0.5$) in the ecologically fragile Qinghai–Tibet Plateau, and a higher resource-export ratio ($ED < -20\%$) in the vast and sparsely populated main agricultural production zones of Northeast China.

5. Conclusions

In this study, an integrated framework for assessing the effectiveness of major function-oriented zoning was developed from the perspective of the dynamic supply–demand relationship of ecological resources. This highlights the policy’s original intention (to promote rational resource flows between regions to achieve coordinated development) and reflects targeted differences in three major function-oriented zones. The empirical results show that there were 62 major function-oriented zones (counties) in Hunan Province that attained goal-achievement status (accounting for 50.82%) in 2020, an increase of 10 counties compared with 2010. From 2010 to 2020, the three types of major function-oriented zones in Hunan Province showed different goal-achievement trajectories following the implementation of this policy. The number of urbanized regions attaining goal-achievement status nearly tripled, while main agricultural production regions and key ecological functional regions remained essentially unchanged. External dependence and ecological carrying pressure were the most frequently observed limiting indicators for goal non-achievement in the latter two zone types. The statistically significant differences between the regions that attained or did not attain goal-achievement status in terms of traditional indicators reflecting the major functions confirm the applicability of the framework proposed in this study. This study not only provides a new perspective for assessing the effectiveness of major function-oriented zoning, but also offers a generalizable approach for assessing spatially differentiated management policies by translating the policy objective of coordinated regional development into a quantifiable supply–production–demand framework.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/land15091718/s1>, Table S1: The ratio of aboveground biomass of different vegetation types. Table S2: The harvest index, moisture, and loss rate of each crop. Table S3: The harvest index, moisture, and loss rate of each crop. Table S4: The conversion coefficient table of standard sheep unit. Table S5: The feed conversion ratio and loss rate of the beef, mutton, milk. Table S6: The conversion coefficient, moisture content, harvest index and loss rate. Table S7: Changes in the self-sufficiency degree (SE), external dependence (ED), and ecological carrying pressure (EP) from 2010 to 2020 for counties that failed to achieve their goals in at least one of 2010 and 2020. Table S8: Changes in the self-sufficiency degree (SE), external dependence (ED), and ecological

carrying pressure (EP) from 2010 to 2020 for counties that achieved their goals in both 2010 and 2020. References [77–106] are cited in the Supplementary Materials.

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