

Article

Assessing Differentiated Land Supply Performance Under China's Major Function-Oriented Zone Strategy: A Scale–Structure–Efficiency Perspective

Zelian Guo ^{1,2} , Yecui Hu ^{3,*}, Yang Zhang ^{1,2}  and Yinbing Zhao ^{1,2} 

¹ College of Geography and Planning, Chengdu University of Technology, Chengdu 610059, China; guozl@cdut.edu.cn (Z.G.); zhangyang2020@cdut.edu.cn (Y.Z.); zhaoyinbing06@cdut.edu.cn (Y.Z.)

² Research Center for Human Geography of the Qinghai Tibet Plateau and Its Eastern Slope, Chengdu University of Technology, Chengdu 610059, China

³ School of Land Science and Technology, China University of Geosciences, Beijing 100083, China

* Correspondence: huyc@cugb.edu.cn; Tel.: +86-15010524960

Abstract

China launched the major function-oriented zone planning (MFZP) strategy in 2010 to address regional imbalances and resource–environment pressures through differentiated regulation. Using county-level data from 2010 to 2020, this study develops a “scale–structure–efficiency” framework and applies a self-organizing feature map (SOFM) model to examine construction land supply across four functional zones. The findings show that: (1) Key development zones provide the largest supply, while optimized zones supply the smallest but at the highest intensity, and restricted zones generally meet control targets. (2) Optimized zones record the highest incremental–stock supply index (ISSI), yet incremental supply still dominates; urbanized zones have balanced functional structures, whereas agricultural and ecological zones are more concentrated. (3) Supply efficiency in urbanized zones exceeds that of agricultural and ecological zones. (4) SOFM clustering identifies four distinct supply modes, reflecting regional heterogeneity in policy alignment. Overall, China's differentiated land supply strategy broadly matches national goals, though some regions face excessive intensity and low efficiency, calling for tailored optimization measures.

Keywords: major function-oriented zone planning (MFZP); land supply; scale–structure–efficiency framework; SOFM model; China



Academic Editors: Xidong Chen,
Xiao Zhang and Yuan Gao

Received: 3 July 2026

Revised: 30 July 2026

Accepted: 3 August 2026

Published: 7 August 2026

Copyright: © 2026 by the authors.
Licensee MDPI, Basel, Switzerland.
This article is an open access article
distributed under the terms and
conditions of the [Creative Commons
Attribution \(CC BY\)](https://creativecommons.org/licenses/by/4.0/) license.

1. Introduction

In recent years, countries worldwide have encountered overlapping challenges of uneven regional development, excessive land consumption, and intensifying ecological pressures. Reconciling economic growth with environmental protection has thus become a central issue on global policy agendas [1,2]. In response, governments have increasingly adopted differentiated management, applying region-specific regulatory measures. In the United States, growth management policies and urban growth boundaries are employed to contain sprawl [3], complemented by transferable development rights that redistribute land-use capacity across jurisdictions [4]. Within the European Union, the commitment to achieve “no net land take” by 2050 is accompanied by policies that prioritize land recycling and reuse, restrict urban expansion, encourage compact development, and restore natural landscapes [5]. Germany integrates municipal land banks with the principle of “inward

development first [6,7].” Japan monitors densely populated districts to guide zoning, promoting redevelopment in core areas while maintaining strict controls in low-density zones [8]. Singapore employs Concept Plans and Master Plans, reinforcing commercial and service functions in central areas and allocating ecological and residential uses to peripheral areas, thereby shaping a tiered pattern of differentiated land utilization [9,10]. These international experiences demonstrate that differentiated management is not only an effective mechanism for reconciling development and protection but also a growing global consensus on the efficient and sustainable use of land resources.

In comparison, China faces even more acute challenges of regional imbalance and resource–environment pressures. Over the past two decades, the urbanization rate has risen from 36.2% in 2000 to 65.2% in 2022, placing enormous pressure on farmland protection and ecological security [11]. To address these issues, the major function-oriented zone planning (MFZP) was launched in 2010, dividing national territory into four categories: optimized development zones (ODZs), key development zones (KDZs), restricted development zones (RDZs), and prohibited development zones (PDZs). Within this system, land supply is regarded as a critical instrument for linking strategic goals with spatial regulation [12,13].

Since the introduction of the MFZP, scholars have conducted extensive research on its implementation effects, optimization pathways, and supporting policies. Studies indicate that the MFZP has effectively curbed the expansion of construction land in restricted development zones and fostered more balanced human–land relationships [14,15]. Differentiated land-use rules have also produced positive shifts in land-use patterns and improvements in ecosystem services across functional zones [16–18]. Given the varying land development intensities across zones, significant differences have emerged in land values and the benefits derived from land use [19]. In response, a growing body of research has explored policies on interregional ecological compensation [20–22] and farmer welfare compensation [23].

However, research on land supply policy evaluation still lacks a systematic theoretical framework, which constrains efforts to optimize land supply. First, research on the sources of land supply has mainly focused on urban expansion and its encroachment upon farmland and ecological land [24–26], as well as on urban land redevelopment [27]. Comparative analyses of the “increment–stock” dual-track supply pattern are still insufficient. Second, in terms of land-use functions, existing studies have emphasized the supply and impacts of single-use categories, such as industrial land [28,29], residential land [30–32], commercial land [33], and transport land [34]. By contrast, limited attention has been paid to the supply structure of construction land subcategories. Finally, regarding supply efficiency, most studies have evaluated overall efficiency within built-up areas [28,35–37]. Few have measured efficiency from the perspective of “annual newly supplied land.”

To address these questions, this study constructs a land supply performance framework across three dimensions—scale, structure, and efficiency. Using data from 2713 counties nationwide as the basic research units, the analysis is aggregated to the “functional zone–province” level. We systematically evaluate land supply scale, incremental–stock structure, functional composition, and supply efficiency across the four types of functional zones. In addition, a self-organizing feature map (SOFM) clustering method is applied to identify multidimensional performance patterns, highlighting both typological characteristics and internal variations among zones. This study provides a comprehensive assessment of the performance and deviations of land supply policies under the MFZP. It further offers empirical evidence to refine differentiated supply strategies and to support the implementation of national strategic objectives.

2. Materials and Methods

2.1. Research Hypotheses

The National Plan for Major Function-Oriented Zones defines differentiated spatial governance targets for each zone type, serving as the policy benchmark for this study. Specifically, ODZs are located in areas with mature urban systems and high development intensity, where policies mandate controlling construction land intensity, reducing new land supply, and strengthening stock land redevelopment. KDZs serve as major growth poles that support economic expansion and represent the primary areas for future construction land supply. At the same time, policies promoting economical and intensive land use are strictly enforced. Industrial and population agglomeration is encouraged, together with the moderate expansion of industrial, transport, and residential land. Major Agricultural Production Zones (MAPZs) are tasked with ensuring food security while also supporting rural infrastructure development. These zones emphasize restrictions on high-intensity construction activities to safeguard county-level development space. Key Ecological Function Zones (KEFZs) are subject to the most stringent land-use constraints, only allowing ecological protection and the construction of public welfare facilities.

To rigorously examine the implementation effects of differentiated land supply policies under the MFZP, this study derives research hypotheses from the regional development goals and spatial governance requirements defined in the national plan.

(1) Land supply scale hypothesis:

H1a: *The scale of construction land supply in KDZs is higher than that in ODZs.*

H1b: *The scale of land supply in MAPZs and KEFZs is lower than that in urbanized areas.*

(2) Land supply structure hypothesis:

H2a: *The incremental–stock supply index (ISSI) of ODZs is higher than that of other zones, indicating greater reliance on the redevelopment of existing stock.*

H2b: *ODZs and KDZs tend to have a more balanced land supply structure with diversified functional types, whereas MAPZs and KEFZs exhibit a more concentrated supply structure, primarily serving their dominant regional functions, with other uses being significantly restricted.*

(3) Land supply efficiency hypothesis:

H3a: *Due to the positive effects of industrial and population agglomeration, the land supply efficiency of optimized zones and KDZs is higher than that of MAPZs and KEFZs.*

It should be noted that, since this study aims to assess the spatial alignment between actual land supply patterns and planning policy objectives, rather than to identify the net causal effects of policy interventions, the validation of each hypothesis adopts a “policy-consistency judgment” approach. That is, hypotheses are tested by comparing whether the magnitude and direction of the mean values of key indicators across different functional zones are consistent with planning orientations.

2.2. Analytical Framework and Technical Route

The technical route of this study is structured around the “scale–structure–efficiency” framework for evaluating land supply performance (Figure 1). For the scale dimension, both the quantity and intensity of construction land supply are measured, and cross-provincial comparisons are conducted. For the structure dimension, two indices are developed from the perspectives of sources and uses: the incremental–stock supply index

and the functional structure index. These indices are employed to examine land supply composition and allocation patterns. For the efficiency dimension, land supply efficiency is assessed based on the input–output relationship. Finally, drawing on the results of the three single dimensions, the SOFM model is applied to cluster land supply patterns across functional zones. For the detailed calculations, indicator definitions, and data sources of each component shown in the figure below, please refer to Sections 2.3 and 2.4.

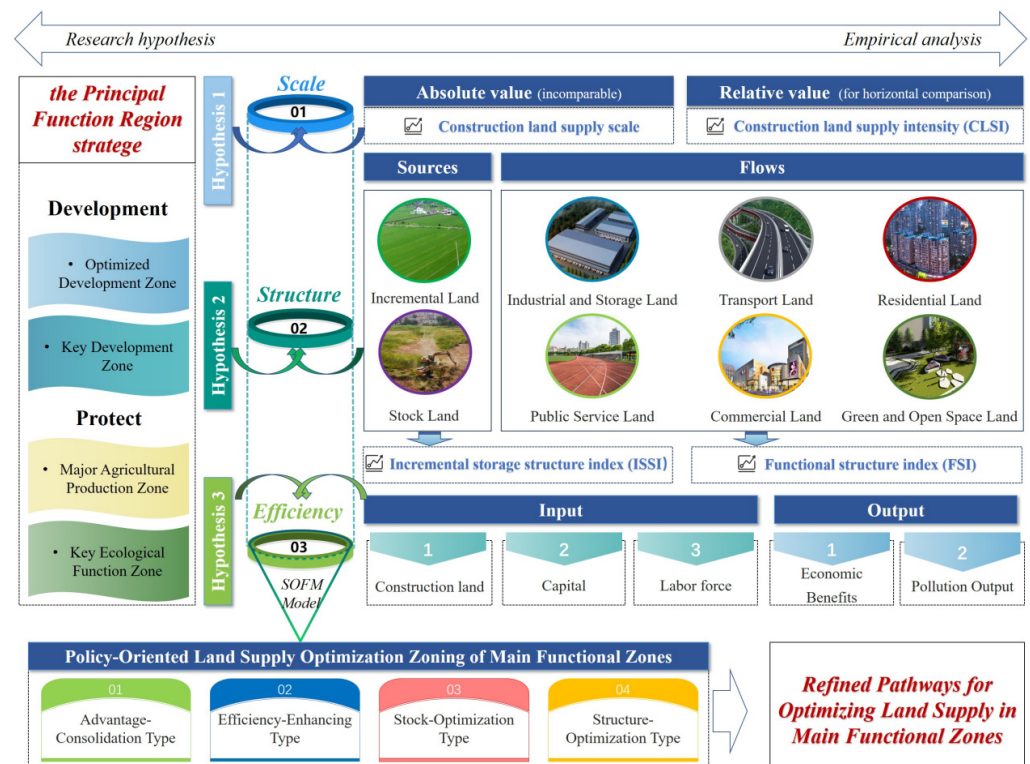


Figure 1. Technical roadmap.

2.3. Methodology

2.3.1. Land Supply Intensity Index

There are significant differences among provinces in terms of area, population, and the spatial distribution of functional zones. Using the total amount of land supply as a direct indicator for horizontal comparison may lead to a “scale trap,” thereby reducing the validity of cross-provincial comparisons. The Construction Land Supply Intensity (CLSI) is calculated to measure the level of construction land supply. For cross-provincial comparisons, the CLSI value for each functional zone type within a province is calculated by aggregating all county-level units belonging to that zone type within that province, ensuring statistical consistency. The calculation formula is as follows:

$$CLSI_{ij} = S_{ij} / A_{ij} \quad (1)$$

where $CLSI_{ij}$ represents the land supply intensity of functional zone type j in province i ; S_{ij} represents the total amount of construction land supplied in functional zone j of province i from 2010 to 2020; and A_{ij} represents the county-level area covered by functional zone j in province i .

2.3.2. Land Supply Structure Index Increment–Stock Supply Index (ISSI)

This index reflects the structural characteristics of the proportion between newly added land and redeveloped land in construction land supply. It serves as a key parameter for evaluating the degree of intensive land use and the mode of spatial expansion. The calculation formula is as follows:

$$ISSI_{ij} = \text{Stock}_{ij} / (\text{Stock}_{ij} + \text{Increment}_{ij}) \quad (2)$$

where Stock_{ij} represents the area of stock construction land supplied in functional zone j of province i and Increment_{ij} represents the area of newly added construction land supplied in the same period. A higher value of this index indicates a stronger tendency to utilize stock resources, whereas a lower value suggests a predominance of incremental expansion.

Functional Structure Index (FSI)

The index is used to measure the degree of concentration of land uses among different land-use subcategories within construction land, indicating whether land supply tends toward functional diversity or uniformity. The Gini coefficient, originally developed in economics to assess income inequality, is applied in this study to capture the concentration of the land supply structure. Land-use subcategories within construction land serve as the basic variables for analysis [38]. The calculation formula is as follows:

$$G = 1/2n^2\mu \sum_{i=1}^n \sum_{j=1}^n |x_i - x_j| \quad (3)$$

where x_i and x_j denote the supply proportions of land-use categories i and j ; μ is the mean supply proportion across all land-use categories; and n is the number of land-use categories. The value of the Gini coefficient is in the range $[0, 1]$. According to the international classification of equilibrium levels of the Gini coefficient, the index is divided into five levels: highly balanced (<0.2), moderately balanced ($0.2\text{--}0.3$), critically balanced ($0.3\text{--}0.4$), moderately concentrated ($0.4\text{--}0.5$), and highly concentrated (>0.5) [39]. Critically, a higher Gini value in this context indicates a more concentrated supply structure—i.e., land supply is dominated by a limited number of use types—rather than serving as a direct judgment of structural “quality.”

For regions identified as concentrated, the land-use subcategory with the highest supply share is defined as the dominant orientation of the supply structure. This dual classification approach combines the degree of concentration with the dominant orientation of land use.

2.3.3. Land Supply Efficiency Evaluation

The super-efficiency SBM model overcomes two limitations of the conventional SBM. It enables comparison among multiple efficient decision-making units (DMUs) and allows ranking of DMUs with an efficiency score of 1 [40]. Based on the indicator data of the supply efficiency calculation for various types of construction land, the variable-return-to-scale super-efficiency SBM model is applied in Matlab R2022a (9.12) to calculate land supply efficiency.

When applying the super-efficiency SBM model to measure land supply efficiency at the provincial level, both input and output indicators are selected with reference to the classical Cobb–Douglas production function [40,41]. Input factors relevant to urban land supply efficiency are proxied by land, capital, and labor. These are represented by the scale of construction land supply, total urban fixed-asset investment, and employment in the secondary and tertiary sectors, respectively [42,43]. Output indicators include desirable

and undesirable components. The desirable output is measured by the value added in the secondary and tertiary industries, whereas the undesirable output is proxied by industrial sulfur dioxide (SO₂) emissions, which are closely associated with industrial land expansion and energy consumption, making them a valid proxy for the environmental costs of land development [44,45]. The variables are listed in Table 1.

Table 1. Input–output indicator system for calculating land supply efficiency.

Indicator Type	Element	Indicator Description	Unit
Input	Land	Scale of construction land supply	10 ⁴ hm ²
	Capital	Total urban fixed-asset investment	10 ⁸ yuan
	Labor	Employment in the secondary and tertiary sectors	10 ⁴ persons
Output	Desirable output	Value added in the secondary and tertiary industries	10 ⁸ yuan
	Undesirable output	SO ₂ emissions	t

Using province-level panel data from 2010 to 2020, all input–output variables are log-transformed and then min-max-normalized to the [0, 1] range. No zero or negative values were observed in the dataset, so no adjustment for log-transformation of non-positive values was needed. Variance inflation factor tests confirm VIF values below 10, indicating no severe multicollinearity.

2.3.4. Land Supply Pattern Recognition

This study applies an SOFM model to cluster multidimensional land supply performance across MFZP functional zones. Compared with conventional clustering methods, SOFM preserves topological relationships in the data, making it suitable for planning performance classification [46].

Prior to training, all input indicators—scale, structure, and efficiency—are standardized. The SOFM algorithm is implemented in R (v4.4.2) using a hexagonal grid with a two-phase training process: rough-tuning followed by fine-tuning. Optimal cluster numbers are determined by minimizing the Davies–Bouldin Index (DBI) while maximizing the silhouette coefficient. To ensure robustness to random initialization, training is repeated 100 times with different random seeds, and the final typology is based on the most frequent clustering structure. Stability is further assessed through subsampling (80% of samples, 50 repetitions), yielding an average adjusted Rand index (ARI) above 0.80, confirming structural stability.

Each cluster is labeled according to the “most salient deficiency” rule relative to zone-specific policy expectations. For each cluster, we identify the indicator—CLSI, ISSI, FSI, or EI—that deviates most negatively from the national average or the zone’s policy target. Labels are assigned accordingly: “efficiency enhancement” (EI shortfall), “stock optimization” (ISSI weakness), or “structure optimization” (FSI concern). Clusters with no significant deficiencies are labeled “advantage consolidation.” This deficiency-based labeling directly informs targeted policy recommendations.

2.4. Data Sources and Preprocessing

2.4.1. Research Area

The boundaries of China’s major function-oriented zones were primarily derived from the National Major Function-Oriented Zone Plan and the China Major Function Zoning scheme (V1.0) [47]. Subsequent revisions were based on officially published provincial classifications of zone types (Figure 2). PDZs are excluded for two reasons: they overlap with other categories—most notably KEFZs—and account for only about 2% of national territory; more importantly, construction is strictly forbidden in PDZs, meaning they gener-

ate no land supply data. Since our dependent variables are land supply scale, structure, and efficiency, their exclusion does not introduce systematic bias. The analysis focuses on four zone types: ODZ, KDZ, MAPZ, and KEFZ. Excluding Tibet, Hong Kong, Macao, and Taiwan, 2773 county-level units were assigned to these categories, with 239, 926, 802, and 806 units respectively, accounting for 1.61%, 13.03%, 26.34%, and 59.02% of the national land area. For comparability, zones of the same type at the national and provincial levels were integrated for evaluation.

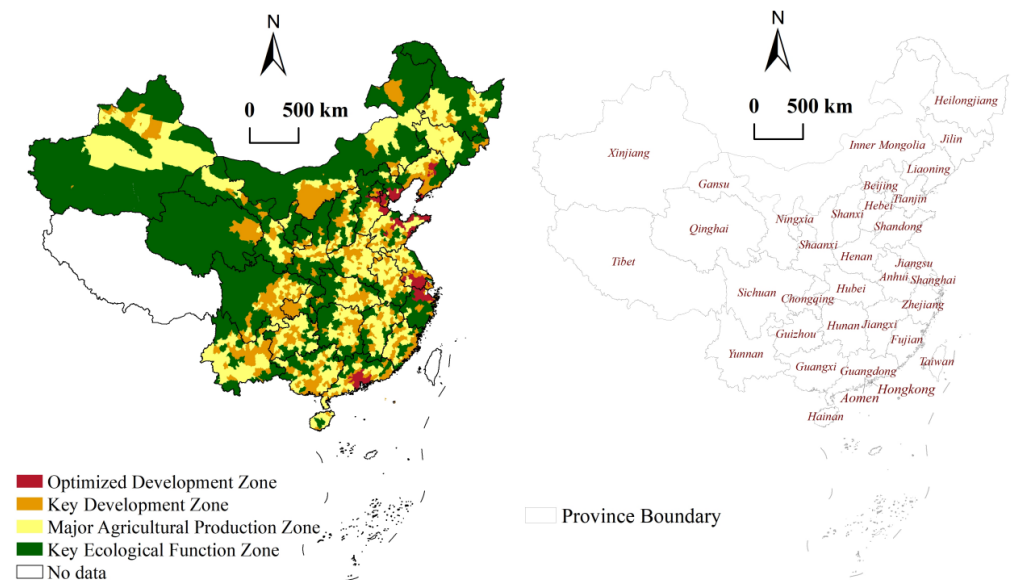


Figure 2. Classification of major function-oriented zones.

2.4.2. Data Sources

The construction land supply data were obtained from the China land market (<https://landchina.com/>). This platform serves as the information dissemination portal for the land market dynamic monitoring and supervision system established by the Ministry of Natural Resources (formerly the Ministry of Land and Resources). Since the launch of its new version in 2006, it has been required for all stages of land supply across the country to be fully disclosed on this website. This ensures that the data are officially mandatory and publicly accessible, making it one of the most systematic and authoritative micro-level data sources for land market research in China.

Using Python (v3.10) scripts, 2,261,249 records from 2010 to 2020 were scraped. After removing duplicates, 2,108,495 unique records were retained. The dataset contains over forty fields, including total supplied area, mode of supply, land use, and land source. The land-use field listed 114 fine-grained categories, which were consolidated into six classes following national guidelines: industrial and storage land, transport land, residential land, public service land, commercial land, and green and open-space land. Socioeconomic and environmental data were drawn from the China City Statistical Yearbook (2011–2021), provincial statistical yearbooks, and statistical communiqués.

3. Results

3.1. Characteristics of Construction Land Supply Scale

This study analyzes both the total construction land supplied and the supply intensity across the four MFZP zone types in China's provincial-level regions during 2010–2020. At the national level, three high-value belts are evident: the eastern coastal region, the Yangtze River Basin, and the northwestern sector (Figure 3a). By zone type, the total supply ranks as KDZ (2.80 Mha) > MAPZ (1.75 Mha) > KEFZ (1.43 Mha) > ODZ (0.87 Mha).

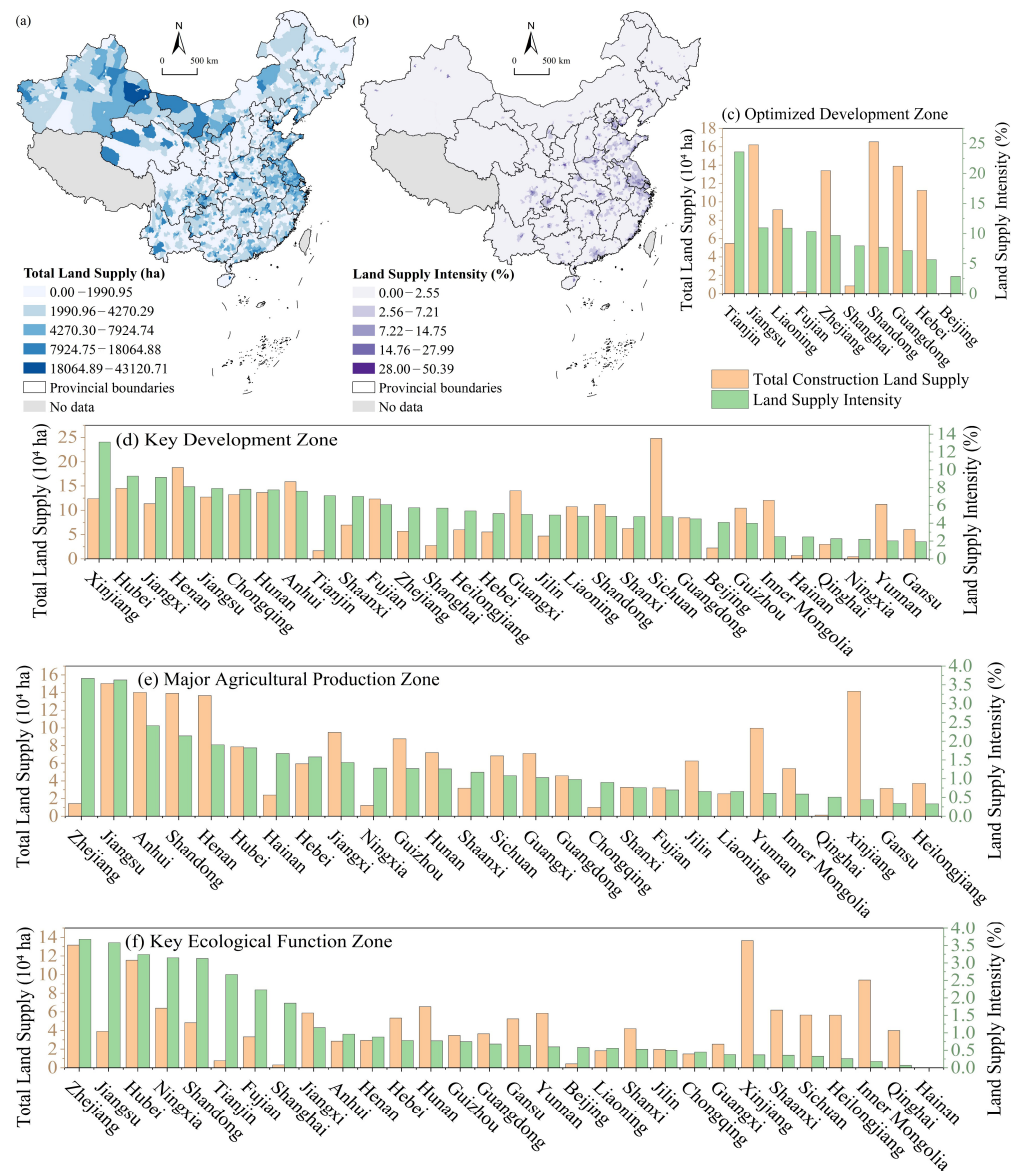


Figure 3. Spatial distribution and interprovincial comparisons of construction land supply scale and intensity across functional zones. (a) Spatial distribution of land supply scale; (b) Spatial distribution of land supply intensity; (c–f) Interprovincial comparisons for the four types of major functional zones.

The spatial distribution of supply intensity differs from that of total supply, showing a clear east–west gradient characterized by higher values in the east and lower values in the west, with distinct local clusters. High-value areas in eastern China are extensive and contiguous, whereas those in the central and western regions are mainly concentrated around municipalities directly administered by the central government and provincial capitals, forming a point-like distribution (Figure 3b). Quantitatively, supply intensity ranks as ODZ (9.68%) > KDZ (5.59%) > MAPZ (1.29%) > KEFZ (1.18%). Although ODZs have the smallest total land supply, their supply pressure per unit area is the highest. The two restricted zone types, MAPZ and KEFZ, exhibit substantially lower supply intensities, which is consistent with the strategic requirement of strictly controlling large-scale industrial expansion in these areas.

A provincial comparison of supply scale and intensity within each zone type reveals pronounced spatial heterogeneity. Within ODZs (Figure 3c), Shandong, Jiangsu, Guangdong, Zhejiang, and Hebei each supplied more than 0.10 Mha. Tianjin exhibits the highest

supply intensity at approximately 25%, whereas most provinces remain below 10%. Beijing records the lowest values nationwide in both total supply and intensity. Within KDZs (Figure 3d), sixteen provinces exceed 0.10 Mha in total supply, with Sichuan reaching approximately 0.25 Mha—substantially higher than other provinces. The Xinjiang Uygur Autonomous Region registers the highest intensity at 13.11%, being the only province above the 10% threshold.

Within MAPZs (Figure 3e), Jiangsu, Xinjiang, Anhui, Shandong, and Henan each supplied more than 0.10 Mha. In KEFZs (Figure 3f), Xinjiang, Zhejiang, and Hubei also exceed this threshold. The supply intensity of MAPZs in Zhejiang, Jiangsu, Anhui, and Shandong exceeds 2%, whereas that of KEFZs in Zhejiang, Jiangsu, Hubei, Ningxia, and Shandong surpasses 3%. These values are substantially higher than those in other provinces. Taken together, MAPZs in Jiangsu, Anhui, and Shandong, along with KEFZs in Zhejiang and Hubei, demonstrate both larger supply scales and higher intensities, which may warrant closer policy attention, as these patterns deviate from the typical low-supply profile expected for restricted zones.

3.2. Characteristics of Construction Land Supply Structure

3.2.1. Increment–Stock Structure

At the national scale, the ISSI displays a distinct east–west gradient, with higher values in the east and lower values in the west (Figure 4a). High-value clusters are concentrated in Northeast China, the eastern coastal region, and the Yangtze River Basin, where many counties record ISSI values greater than 0.5 (crossing the 0.5 threshold signifies a qualitative transition from incremental-driven to stock-driven land supply). In contrast, most parts of central and western China exhibit low values, with numerous counties registering ISSI values below 0.25. By zone type, mean ISSI values rank as ODZ (0.445) > KDZ (0.298) > MAPZ (0.227) > KEFZ (0.204), indicating that all four zone types remain predominantly dependent on incremental land supply (Figure 4b).

Provincial comparisons within each zone (Figure 4c–f) reveal that only Beijing’s ODZ (0.719), Tianjin’s KDZ (0.548), and Jiangsu’s KEFZ (0.506) exceed 0.5, reaching a stock-dominant level. In all other provinces, incremental land supply continues to prevail.

3.2.2. Functional Structure and Dominant Land-Use Categories

Figure 5 illustrates the spatial distribution of the functional structure of land supply across the four zone types. At the national scale (Figure 5a), areas west of the Hu Line (Hu Huanyong Line) exhibit a pronounced structural imbalance. Comparison of the FSI across zone types reveals that ODZs and KDZs generally maintain a more balanced land supply composition (Figure 5b,c). Only Hebei’s ODZ and Tianjin’s KDZ show a moderate concentration, dominated by industrial–mining–storage land.

By contrast, MAPZs and KEFZs exhibit broader patterns of concentration. Within MAPZs, six provinces show moderate concentration, with ISL dominating in Inner Mongolia, Ningxia, and Hubei, and TL prevailing in Gansu, Guangdong, and Fujian (Figure 5d). In MAPZs, concentrated supply does not indicate structural inefficiency; rather, it reflects the zones’ designated function of safeguarding agricultural production, where land supply is intentionally channeled toward a limited range of agricultural and rural infrastructure uses. In KEFZs, ten provinces are moderately or highly concentrated. TL dominates in Inner Mongolia, Qinghai, Hainan, Shaanxi, Guangdong, Guangxi, and Tianjin. GOSL prevails in Sichuan and Hubei, while ISL dominates in Jiangsu (Figure 5e). For KEFZs, high concentration is a direct outcome of the strict use restrictions imposed by policy—construction activities are largely limited to ecological protection and public welfare facilities, leaving little room for diversified land-use types.

3.3. Characteristics of Construction Land Supply Efficiency

Systematic assessment of land supply efficiency provides a basis for identifying spatial differences in land-use performance and reflects the extent to which the functional zoning strategy has been implemented. In ArcGIS 10.3, county-level land supply efficiency was categorized into four levels using the Jenks natural breaks method: low, lower-middle, upper-middle, and high. As illustrated in Figure 6a, efficiency levels alternate across the country, forming an uneven spatial pattern. High-efficiency belts occur in the eastern, central, and western regions, whereas the intervening areas show relatively low efficiency. Areas of relatively high efficiency are observable in the eastern, central, and western regions, though these should be interpreted as localized clusters rather than as persistent “belts” of high performance.

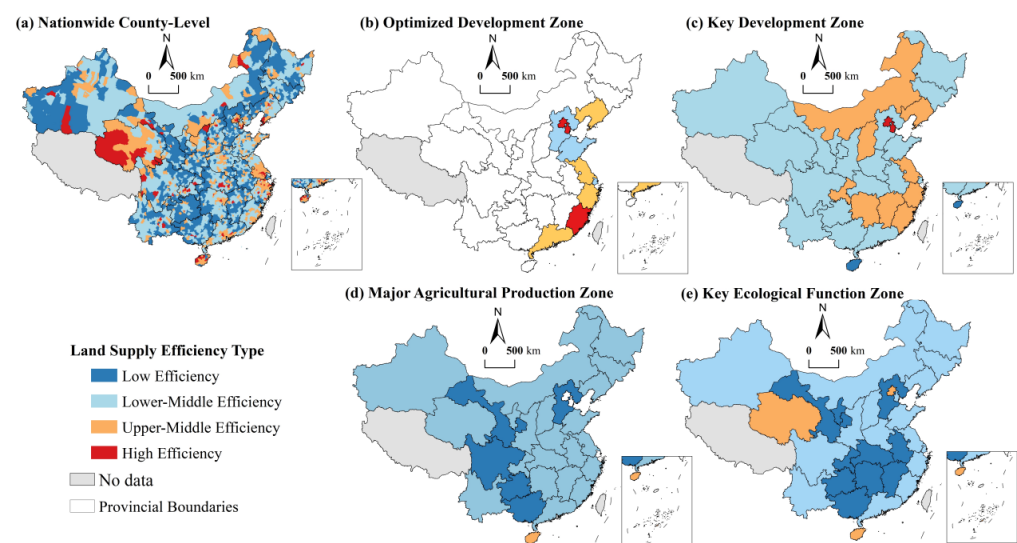


Figure 6. Land supply efficiency classes and spatial distribution in the functional zones.

Based on these data, land supply efficiency was calculated for the four zone types across all provinces. As shown in Figure 6b–e, ODZs and KDZs generally exhibit higher efficiency than MAPZs and KEFZs, reflecting distinct performance differences consistent with their functional orientations. Across provinces, approximately 70% of ODZs fall within the upper-middle or high categories, while the corresponding share for KDZs is 36.7%. In contrast, MAPZs and KEFZs account for only 3.7% and 10%, respectively.

Significant heterogeneity is observed across provinces within each zone type. In ODZs, southern provinces generally demonstrate higher land supply efficiency than northern ones, while in Hebei, Shandong, and Shanghai, it is notably lower than the national average. In KDZs, most provinces fall into the lower-middle or upper-middle categories. Developed eastern provinces such as Jiangsu and Guangdong generally exhibit higher efficiency than western provinces such as Guizhou and Gansu. In MAPZs, only Hainan reaches the upper-middle category. Gansu, Sichuan, Guizhou, and Guangxi form a contiguous low-efficiency belt across the central–western region, while lower-middle provinces dominate, accounting for 81.48%. KEFZs display a similar pattern, with lower-middle provinces constituting the majority. The proportions of upper-middle, lower-middle, and low efficiency are 10%, 56.67%, and 33.33%, respectively, at the national level.

It should be noted, however, that the provincial-level aggregation used here smooths out within-province heterogeneity at the county level. Some counties within a province may deviate substantially from the provincial average, and the reported efficiency values should therefore be interpreted as general tendencies rather than precise estimates for individual counties.

3.4. Construction Land Supply Modes

Building on the single-dimension results, an SOFM neural network was applied to cluster provincial indicators: CLSI, ISSI, FSI, and EI. The efficiency-enhancement type accounts for the largest share across all zones, indicating that EI remains the most widespread bottleneck. The stock-optimization and structure-optimization types reveal zone-specific weaknesses, providing an empirical basis for refining differentiated policies.

Within ODZs, three land supply types are identified (Figures 7a–c and 8a). The advantage-consolidation type appears only in Beijing (CLSI: 0.029; ISSI: 0.719; EI: 1.033), with very low supply intensity, stock-dominated supply, and frontier-level efficiency, closely aligning with the ODZ policy ideal. The efficiency-enhancement type occurs in eight provinces (e.g., Fujian and Guangdong), featuring a balanced stock-increment structure (ISSI: 0.431) but moderate efficiency (EI: 0.614), with efficiency improvement as the main priority. The stock-optimization type is found exclusively in Tianjin (CLSI: 0.236; ISSI: 0.204; EI: 0.724), characterized by high-intensity, increment-driven supply. The high CLSI reflects land pressure in a densely built-up municipality rather than inefficiency; the low ISSI (0.204) indicates excessive reliance on incremental supply, warranting policy attention under the ODZ mandate.

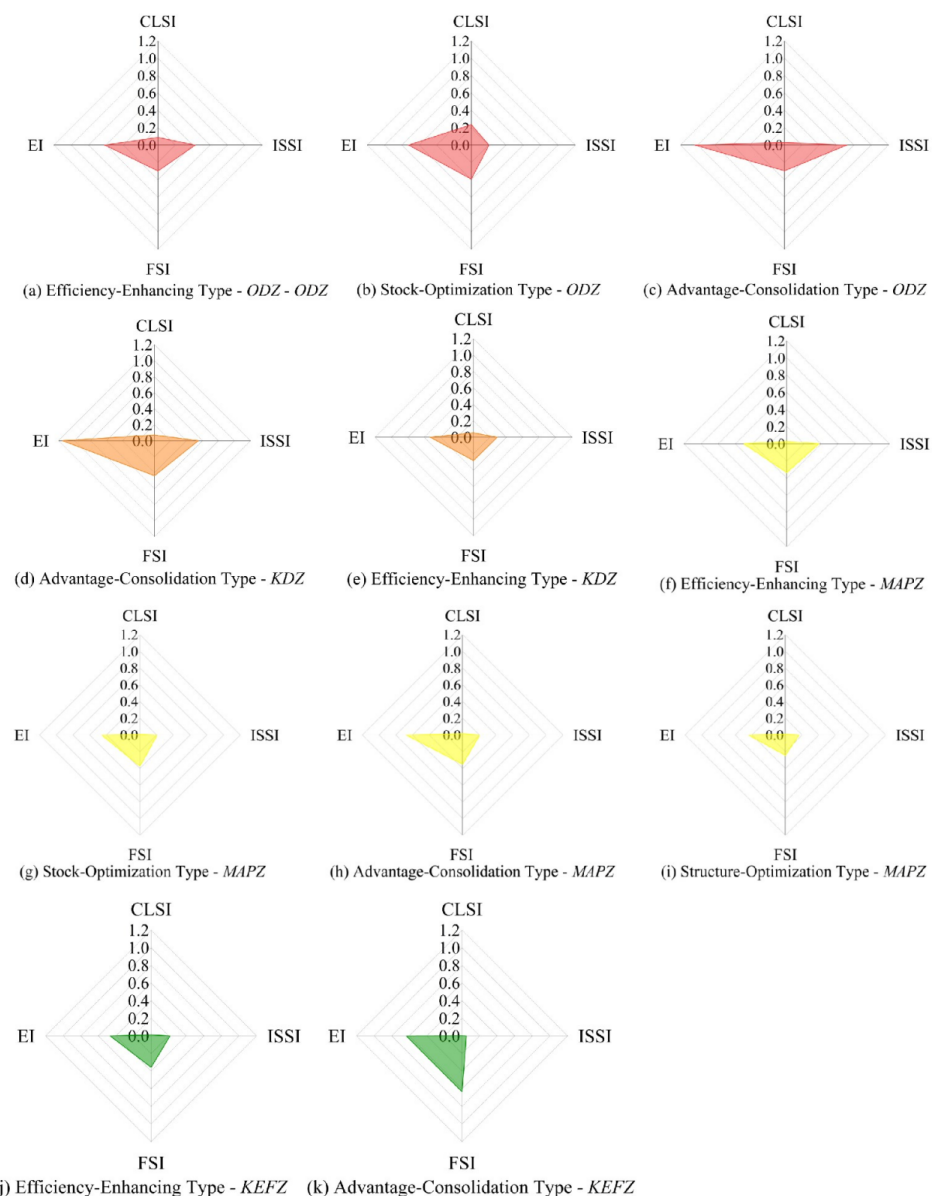


Figure 7. SOFM-based mean values of the subsystems across the functional zones.

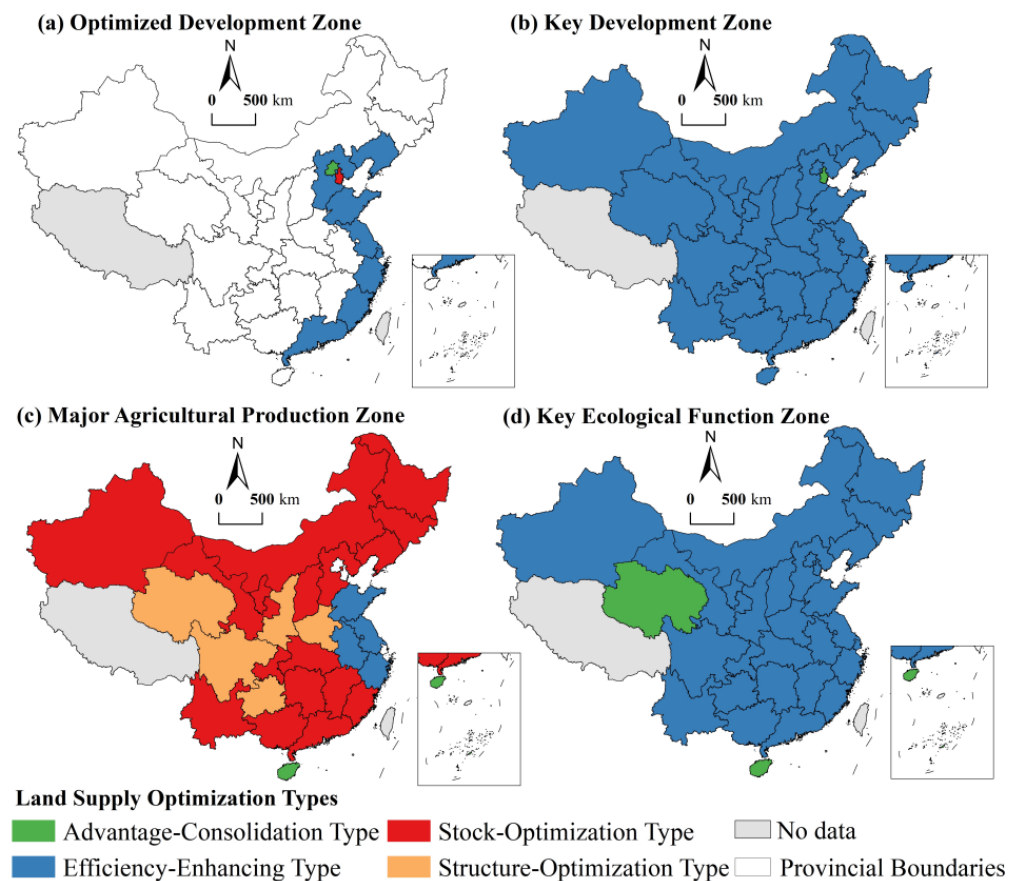


Figure 8. Policy-oriented zoning types for land supply optimization across the functional zones.

Within KDZs, two land supply types are identified (Figures 7d,e and 8b). The efficiency-enhancement type predominates, covering 29 provinces, while only Tianjin falls into the advantage-consolidation type. The efficiency-enhancement type shows moderate supply intensity (CLSI: 0.055) and a relatively balanced functional structure (FSI: 0.283), but low efficiency (EI: 0.527), making efficiency improvement the primary challenge. The advantage-consolidation type exhibits higher intensity (CLSI: 0.071), a balanced increment-stock structure (ISSI: 0.548), and a more concentrated functional structure (FSI: 0.439), with efficiency reaching 1.151—well above average—suggesting this configuration aligns well with the KDZ’s role as a growth pole.

Within MAPZs, four land supply types are identified (Figures 7f–i and 8c). The stock-optimization type predominates, covering 17 provinces (e.g., Fujian and Henan), with strong dependence on incremental supply (ISSI: 0.207) and the lowest efficiency (EI: 0.459). The structure-optimization type includes five provinces (Guizhou, Qinghai, Sichuan), characterized by a dispersed functional structure (FSI: 0.243) and low efficiency (EI: 0.442). The efficiency-enhancement type occurs in provinces such as Anhui, Jiangsu, and Shandong, featuring low supply intensity (CLSI: 0.030) and a relatively balanced structure (FSI: 0.335), but weak efficiency (EI: 0.501). The advantage-consolidation type appears only in Hainan, with a more concentrated structure (FSI: 0.351) and the highest efficiency within MAPZs (EI: 0.678), reflecting moderate alignment with the zone’s restricted development mandate.

Within KEFZs, two land supply types are identified (Figures 7j,k and 8d): efficiency enhancement and advantage consolidation. The efficiency-enhancement type predominates, covering 28 provinces, with extremely low intensity (CLSI: 0.013), a concentrated structure (FSI: 0.357), and low efficiency (EI: 0.466). The advantage-consolidation type appears only in Hainan and Qinghai, with the lowest intensity (CLSI: 0.002), a highly concentrated structure

(FSI: 0.634), and relatively high efficiency (EI: 0.634). This pattern reflects compliance with KEFZ's ecological conservation mandate rather than inherent superiority. This pattern is not inherently superior, but rather reflects compliance with the zone's ecological conservation mandate. The relatively higher efficiency here indicates that the limited construction activities permitted are concentrated in the most functionally appropriate uses.

These patterns should be interpreted with reference to each zone's designated function: a high EI combined with either high or low CLSI does not automatically signify "better" or "worse" land allocation; rather, it reflects the degree to which the supply pattern aligns with the zone's specific development or protection mandate.

4. Discussion

4.1. Alignment of Land Supply Outcomes with Strategic Goals

The results indicate that since the implementation of the MFZP, land supply patterns across the four functional zones have generally aligned with policy objectives, although localized deviations have emerged. Examining these discrepancies helps clarify the logic of regional land-use change and highlights the mismatches between strategic planning goals and local development incentives.

In terms of scale and intensity, the construction land supply in KDZs during 2010–2020 was significantly higher than that of other zones, consistent with their strategic role as the primary carriers of industrial and population growth. In contrast, ODZs recorded the lowest total supply but the highest supply intensity, reflecting the intensity of development under limited spatial capacity. MAPZs and KEFZs maintained generally low supply scales and intensities, consistent with their restrictive development orientation. However, exceptions occur in the MAPZs of Jiangsu, Anhui, and Shandong, and in the KEFZs of Zhejiang and Hubei, which display simultaneously high values of scale and intensity. These cases likely reflect fiscal land dependence or industrial spillover pressures in policy implementation [48–50]. Overall, the alignment between supply scale and intensity remains strong, but localized deviations confirm the spatial gradient pattern of "urban agglomeration–development axis–growth node" emphasized in spatial economics, underscoring persistent unevenness in regional policy implementation [51,52].

In terms of land supply structure, the ISSI shows a distinct "high in the east, low in the west" pattern, indicating that eastern regions—particularly ODZs—are more reliant on stock revitalization. This pattern is consistent with the national policy orientation of "prioritizing stock and promoting reuse." Nevertheless, the national mean remains below 0.5, implying that incremental supply continues to dominate. This outcome reflects the path dependence of local governments during the transformation process [53,54]. At the functional structure level, the relatively balanced configurations of ODZs and KDZs suggest that their integrated functional positioning is being effectively realized. In contrast, MAPZs and KEFZs demonstrate a more concentrated functional structure. Notably, neither has shifted toward residential or commercial uses, underscoring consistency with their restrictive development mandates. Much of their land supply is allocated to industrial and storage land or transport land, reflecting the practical need for facilities that support agricultural production, logistics, and ecological functions. However, in some provinces, this reliance has become relatively high, revealing persistent structural path dependence in land allocation that may limit the extent to which their designated functional roles are fully achieved [55,56].

In terms of efficiency, ODZs and KDZs generally outperform the restricted zones, yet notable internal disparities remain. ODZs display a "higher in the south, lower in the north" pattern, whereas KDZs follow a "stronger in the east, weaker in the west" gradient. This spatial differentiation indicates that efficiency is influenced not only by supply scale

and intensity but also by industrial structure, factor allocation, and market accessibility [57]. These results are consistent with studies on factor misallocation and efficiency divergence, which suggest that when land supply continues to rely on incremental expansion and fails to align with industrial upgrading or improvements in human capital, structural contradictions arise—manifested as rising intensity but lagging efficiency [58,59].

Finally, the four land supply modes identified through SOFM clustering reveal distinct differences. Regions of the advantage-consolidation type achieve high efficiency under low-intensity constraints, suggesting a balanced approach to stock utilization and functional optimization within policy boundaries. In contrast, stock-optimization regions combine intensive expansion with limited efficiency, reflecting a persistent reliance on extensive development. Structure-optimization regions, concentrated mainly in MAPZs, face the dual challenge of fragmented land-use structures and low efficiency. Efficiency-enhancing regions predominant nationwide, indicating that efficiency remains the most widespread bottleneck relative to policy targets. Overall, these patterns indicate that when scale and intensity are not well coordinated with structural optimization and efficiency improvement, strategic coherence tends to be weaker—producing configurations such as “high intensity–low efficiency” or “structural concentration–limited output.” These observations should be understood as empirical characterizations of the current land supply landscape rather than normative judgments of policy failure.

4.2. Pathways for Optimizing Differentiated Land Supply

Building on the above findings, the overall consistency between land supply patterns and the MFZP is evident, though localized deviations call for targeted refinement. Optimization should be guided by the four land supply modes identified in this study and adapted to each zone’s spatial and developmental context. The recommendations in this section are presented in two tiers. The first tier consists of policy directions that follow directly from the observed land supply patterns—these are empirical implications derived from the clustering results. The second tier comprises extended policy considerations that are logically consistent with the identified problems but have not been directly tested by our data; these are offered as potential directions for further exploration rather than as definitive conclusions.

ODZs exhibit a “low scale–high intensity” pattern with lagging efficiency, particularly in stock-optimization and efficiency-enhancing regions. Policy should focus on controlling new construction land, redeveloping inefficient parcels, and shifting from expansion-driven to performance-oriented land use. Advantage-consolidation areas such as Beijing should remain benchmarks for intensive development. In contrast, high-intensity regions such as Tianjin need stricter quota management and urban renewal. Efficiency-enhancing regions require industrial upgrading and technological innovation to improve land productivity.

KDZs face a “large scale–low efficiency” challenge, reflecting a persistent mismatch between land inputs and output performance. An “efficiency-first, coordinated-support” approach is needed. In the eastern developed provinces, land use should be more closely aligned with innovation-driven industries and advanced manufacturing to maximize land productivity. By contrast, KDZs in central and western regions need to strengthen the coordination between land expansion, population growth, and industrial agglomeration through improved industrial-chain integration and factor mobility.

MAPZs must balance food security with efficiency improvement. Stock-optimization regions should strictly limit incremental supply and prioritize redevelopment for agro-processing and agricultural infrastructure. Structure-optimization regions need to reduce excessive industrial and transport land shares and reallocate to agricultural-supporting industries and rural services. Efficiency-enhancing regions should integrate agriculture

with secondary and tertiary industries through technology and value-chain extension. Advantage-consolidation regions, such as Hainan, should sustain their “low-scale–high-efficiency” pattern while exploring policy mechanisms that link land-use performance with grain subsidies and fiscal incentives as a potential direction for coordination.

The primary mandate of KEFZs is to safeguard ecological security. In efficiency-enhancing regions, one possible instrument is the adoption of a strict negative-list system, with new construction land directed primarily toward ecological restoration, green industries, and eco-tourism to ensure consistency with ecological objectives. Advantage-consolidation regions, such as Hainan and Qinghai, should sustain their “low-intensity–high-efficiency” development path, supported by fiscal transfers and ecological compensation mechanisms, and serve as national benchmarks. Structure-optimization regions need to rebalance functional land allocations to prevent overreliance on any single land-use type and to foster synergy among ecological protection, green industries, and public services. Stock-optimization regions should prioritize ecological redevelopment of idle land to achieve “increment reduction and ecological expansion.”

4.3. Contributions and Limitations

The contributions of this study are threefold. Theoretically, it develops a “scale–structure–efficiency” evaluation framework for differentiated land supply under the MFZP, establishing a new analytical basis for assessing policy implementation. Methodologically, it introduces the increment–stock supply index and the functional structure index to capture differentiated supply patterns, and applies SOFM clustering to identify four typical supply modes—advantage consolidation, stock optimization, structure optimization, and efficiency enhancement—overcoming the limitations of single-indicator or macro-level analyses. Practically, it proposes targeted optimization pathways to strengthen functional zone roles and advance high-quality land development.

This study has several limitations. First, while it provides a comprehensive descriptive and comparative evaluation, it does not establish causal linkages between policy and land supply patterns. Future research should employ causal identification strategies—such as difference-in-differences, spatial econometrics, or quasi-natural experiments—to quantify policy effects and uncover underlying mechanisms. Second, the provincial-level analysis may mask intra-provincial variations, and the land supply data may be subject to reporting bias, as local officials have incentives to report favorable figures. Finer-scale spatial analyses could better capture localized responses and spatial spillover effects, while cross-checking records against alternative datasets—such as land-transfer fee revenues, approved construction quotas, or satellite-based land-use change data—could help to assess data consistency and completeness. Third, the “scale–structure–efficiency” framework does not fully address the complex interactions between land supply and broader socioeconomic and ecological systems. Future studies should adopt a more holistic approach—combining econometric analysis, spatial simulation, and system dynamics—to capture these interactive mechanisms.

5. Conclusions

This study finds that land supply practices are broadly aligned with strategic objectives, yet notable local deviations persist. ODZs exhibit a “low scale–high intensity” pattern with lagging efficiency; KDZs show large-scale expansion without corresponding performance gains; MAPZs face low efficiency due to trade-offs between farmland protection and fiscal dependence; and KEFZs remain predominantly “low intensity–low efficiency,” though some provinces deviate from restrictive mandates.

These findings indicate that the MFZP strategy has effectively promoted spatial differentiation, while also revealing tensions between top-down policy design and local implementation. Based on SOFM clustering, four differentiated optimization pathways are identified. Future policy should emphasize integrated coordination within a “scale regulation–structural optimization–efficiency enhancement” framework to better align national objectives with local capacity. Future research may refine these descriptive findings using finer-scale spatial data and causal identification methods to capture the dynamic linkages among land supply, industrial upgrading, population agglomeration, and ecological protection.

Author Contributions: Conceptualization, Z.G. and Y.H.; methodology, Z.G.; software, Z.G.; validation, Z.G. and Y.Z. (Yang Zhang); formal analysis, Z.G.; investigation, Z.G. and Y.H.; resources, Y.H. and Y.Z. (Yang Zhang); data curation, Z.G.; writing—original draft preparation, Z.G.; writing—review and editing, Y.Z. (Yinbing Zhao) and Y.Z. (Yang Zhang); visualization, Z.G.; supervision, Y.H.; project administration, Y.H.; funding acquisition, Y.H. and Y.Z. (Yang Zhang). All authors have read and agreed to the published version of the manuscript.

Funding: This research was supported by the National Natural Science Foundation of China (Grant Nos. 72374185, U23A2014 and 42501258).

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

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

Abbreviations

The following abbreviations are used in this manuscript:

MFZP	Major function-oriented zone planning
ODZs	Optimized development zones
KDZs	Key development zones
RDZs	Restricted development zones
PDZs	Prohibited development zones
MAPZs	Major Agricultural Production Zones
KEFZs	Key Ecological Function Zones

References

1. BenDor, T.K.; Branham, J.; Whittemore, A.; Linkous, E.; Timmerman, D. A national inventory and analysis of US transfer of development rights programs. *J. Environ. Plan. Manag.* **2022**, *65*, 2276–2296. [\[CrossRef\]](#)
2. Cao, K.; Deng, Y.; Wang, W.; Liu, S. The spatial heterogeneity and dynamics of land redevelopment: Evidence from 287 Chinese cities. *Land Use Policy* **2023**, *132*, 106760. [\[CrossRef\]](#)
3. Chakraborty, S.; Maity, I.; Dadashpoor, H.; Novotný, J.; Banerji, S. Building in or out? Examining urban expansion patterns and land use efficiency across the global sample of 466 cities with million+ inhabitants. *Habitat Int.* **2022**, *120*, 102503. [\[CrossRef\]](#)
4. Chang, S.; Su, K.; Jiang, X.; You, Y.; Li, C.; Wang, L. Impacts and Predictions of Urban Expansion on Habitat Connectivity Networks: A Multi-Scenario Simulation Approach. *Forests* **2023**, *14*, 2187. [\[CrossRef\]](#)
5. Chen, W.; Chen, W.; Ning, S.; Liu, E.; Zhou, X.; Wang, Y.; Zhao, M. Exploring the industrial land use efficiency of China’s resource-based cities. *Cities* **2019**, *93*, 215–223. [\[CrossRef\]](#)
6. Chen, Y.; Ge, H.; Chen, M. What drives urban land green use efficiency in China: A global meta-frontier Malmquist Index approach. *Ecol. Indic.* **2025**, *175*, 113550. [\[CrossRef\]](#)
7. Cheng, J. Analysis of commercial land leasing of the district governments of Beijing in China. *Land Use Policy* **2021**, *100*, 104881. [\[CrossRef\]](#)
8. Decoville, A.; Feltgen, V. Clarifying the EU objective of no net land take: A necessity to avoid the cure being worse than the disease. *Land Use Policy* **2023**, *131*, 106722. [\[CrossRef\]](#)
9. Du, L.; Wei, M.; Zhang, S.; Pan, J. Unveiling the policy intervention effects of natural resource regulation on firm-level pollution emissions: Evidence from China’s restrained land supply. *Resour. Policy* **2023**, *86*, 104081. [\[CrossRef\]](#)

10. Estoque, R.C.; Ooba, M.; Togawa, T.; Hijioka, Y.; Murayama, Y. Monitoring global land-use efficiency in the context of the UN 2030 Agenda for Sustainable Development. *Habitat Int.* **2021**, *115*, 102403. [[CrossRef](#)]
11. Fan, J. Draft of Major Function Oriented Zoning of China. *Acta Geogr. Sin.* **2015**, *70*, 186–201. (In Chinese) [[CrossRef](#)]
12. Fan, J.; Sun, W.; Zhou, K.; Chen, D. Major Function Oriented Zone: New method of spatial regulation for reshaping regional development pattern in China. *Chin. Geogr. Sci.* **2012**, *22*, 196–209. [[CrossRef](#)]
13. Fan, J.; Zhou, L.; Yu, X.; Zhang, Y. Impact of land quota and land supply structure on China's housing prices: Quasi-natural experiment based on land quota policy adjustment. *Land Use Policy* **2021**, *106*, 105452. [[CrossRef](#)]
14. Fan, X.; Qiu, S.; Sun, Y. Land finance dependence and urban land marketization in China: The perspective of strategic choice of local governments on land transfer. *Land Use Policy* **2020**, *99*, 105023. [[CrossRef](#)]
15. Fang, C.; Yu, D. Urban agglomeration: An evolving concept of an emerging phenomenon. *Landsc. Urban Plan.* **2017**, *162*, 126–136. [[CrossRef](#)]
16. Frolking, S.; Mahtta, R.; Milliman, T.; Esch, T.; Seto, K.C. Global urban structural growth shows a profound shift from spreading out to building up. *Nat. Cities* **2024**, *1*, 555–566. [[CrossRef](#)]
17. Hamacher, H. Flächenverbrauch im Recht: 30-Hektar-Ziel und Flächenzertifikatehandel. *NuR* **2020**, *42*, 388–394. [[CrossRef](#)]
18. He, M.; Li, W.; Wang, P.; Yao, C. Allocation equity of regulating ecosystem services from blue-green infrastructures: A case study of street blocks in Wuhan central city. *Ecol. Indic.* **2022**, *138*, 108853. [[CrossRef](#)]
19. He, Q.; Du, J. The impact of urban land misallocation on inclusive green growth efficiency: Evidence from China. *Environ. Sci. Pollut. Res.* **2022**, *29*, 3575–3586. [[CrossRef](#)] [[PubMed](#)]
20. He, Z.; Zhao, C.; Fürst, C.; Hersperger, A.M. Closer to causality: How effective is spatial planning in governing built-up land expansion in Fujian Province, China? *Land Use Policy* **2021**, *108*, 105562. [[CrossRef](#)]
21. Jia, K.; Zhong, S.; Huang, X. Unpacking Outcomes: A quasi-experimental study on the effectiveness of China's major function-oriented zone planning. *Landsc. Urban Plan.* **2025**, *264*, 105482. [[CrossRef](#)]
22. Jin, G.; Shi, X.; He, D.; Guo, B.; Li, Z.; Shi, X. Designing a spatial pattern to rebalance the orientation of development and protection in Wuhan. *J. Geogr. Sci.* **2020**, *30*, 569–582. [[CrossRef](#)]
23. Koroso, N.H.; Zevenbergen, J.A. Urban land management under rapid urbanization: Exploring the link between urban land policies and urban land use efficiency in Ethiopia. *Cities* **2024**, *153*, 105269. [[CrossRef](#)]
24. Li, F.; Wu, S.; Liu, H.; Yan, D. Biodiversity loss through cropland displacement for urban expansion in China. *Sci. Total Environ.* **2024**, *907*, 167988. [[CrossRef](#)] [[PubMed](#)]
25. Li, Q.; Wei, J.; Gao, W. Spatial differentiation and influencing factors of land eco-efficiency based on low carbon perspective: A case of 287 prefecture-level cities in China. *Environ. Chall.* **2023**, *10*, 100681. [[CrossRef](#)]
26. Li, W.; Cai, Z.; Jin, L. Urban green land use efficiency of resource-based cities in China: Multidimensional measurements, spatial-temporal changes, and driving factors. *Sustain. Cities Soc.* **2024**, *104*, 105299. [[CrossRef](#)]
27. Li, Z.; Hu, B.; Ren, Y. The Supply–Demand Budgets of Ecosystem Service Response to Urbanization: Insights from Urban–Rural Gradient and Major Function-Oriented Areas. *Remote Sens.* **2022**, *14*, 5670. [[CrossRef](#)]
28. Liu, S.; Tong, Z.; Liu, Y.; Chen, H.; Liu, Y. What is the quality of urban expansion under different expansion patterns? A study of Chinese cities. *Cities* **2026**, *168*, 106409. [[CrossRef](#)]
29. Liu, W.; Liu, J.; Kuang, W.; Ning, J. Examining the influence of the implementation of Major Function-oriented Zones on built-up area expansion in China. *J. Geogr. Sci.* **2017**, *27*, 643–660. [[CrossRef](#)]
30. Liu, X.; Wei, Y.; Jin, X.; Luo, X.; Zhou, Y. County-level carbon compensation zoning based on China's major function-oriented zones. *J. Environ. Manag.* **2024**, *367*, 121988. [[CrossRef](#)] [[PubMed](#)]
31. Long, H.; Qu, Y. Land use transitions and land management: A mutual feedback perspective. *Land Use Policy* **2018**, *74*, 111–120. [[CrossRef](#)]
32. Lönnroth, T.; Krigsholm, P.; Falkenbach, H.; Oikarinen, E. Advancing understanding of the linkages between local land policy interventions and the responsiveness of housing supply: Intervention mechanisms in the Finnish context. *Land Use Policy* **2024**, *141*, 107157. [[CrossRef](#)]
33. Ma, D.; Zhang, J.; An, B.; Guo, Z.; Zhang, F.; Yan, Y.; Peng, G. Research on urban land green use efficiency and influencing factors based on DEA and ESTDA models: Taking 284 cities in China as an example. *Ecol. Indic.* **2024**, *160*, 111824. [[CrossRef](#)]
34. Ma, J.; Shibuya, Y.; Pang, Y.; Omata, H.; Sekimoto, Y. A cost-and-effect simulation model for compact city approaches: A case study in Japan. *Cities* **2024**, *152*, 105212. [[CrossRef](#)]
35. Martin, A.J.F.; Conway, T.M. Using the Gini Index to quantify urban green inequality: A systematic review and recommended reporting standards. *Landsc. Urban Plan.* **2025**, *254*, 105231. [[CrossRef](#)]
36. McManamay, R.A.; Vernon, C.R.; Chen, M.; Thompson, I.; Khan, Z.; Narayan, K.B. Dynamic urban land extensification is projected to lead to imbalances in the global land-carbon equilibrium. *Commun. Earth Environ.* **2024**, *5*, 70. [[CrossRef](#)]

37. Nie, X.; Lu, B.; Chen, Z.; Yang, Y.; Chen, S.; Chen, Z.; Wang, H. Increase or decrease? Integrating the CLUMondo and InVEST models to assess the impact of the implementation of the Major Function Oriented Zone planning on carbon storage. *Ecol. Indic.* **2020**, *118*, 106708. [\[CrossRef\]](#)
38. Oertel, E.; Vickery, C.E.; Quinn, J.E. Linked spatial and temporal success of urban growth boundaries to preserve ecosystem services. *Landsc. Urban Plan.* **2024**, *250*, 105134. [\[CrossRef\]](#)
39. Sun, M.; Yang, R.; Li, X.; Zhang, L.; Liu, Q. Designing a path for the sustainable development of key ecological function zones: A case study of southwest China. *Glob. Ecol. Conserv.* **2021**, *31*, e01840. [\[CrossRef\]](#)
40. Tan, B.A.; Gaw, L.Y.-F.; Masoudi, M.; Richards, D.R. Nature-Based Solutions for Urban Sustainability: An Ecosystem Services Assessment of Plans for Singapore's First "Forest Town". *Front. Environ. Sci.* **2021**, *9*, 610155. [\[CrossRef\]](#)
41. Tong, D.; Chu, J.; Han, Q.; Liu, X. How Land Finance Drives Urban Expansion under Fiscal Pressure: Evidence from Chinese Cities. *Land* **2022**, *11*, 253. [\[CrossRef\]](#)
42. Vesanto, J.; Alhoniemi, E. Clustering of the self-organizing map. *IEEE Trans. Neural Netw.* **2000**, *11*, 586–600. [\[CrossRef\]](#) [\[PubMed\]](#)
43. Wang, H.; Cheng, P.; Liang, P.; Liu, K.; Nie, X. Invisible windfalls and wipeouts: What is the impact of spatial regulation on the welfare of land-lost farmers? *Habitat Int.* **2020**, *99*, 102159. [\[CrossRef\]](#)
44. Wang, L.; Zhou, J.; Chen, K.; Zhang, W. The impacts of housing purchase restriction policy on residential land supply in China. *Habitat Int.* **2024**, *153*, 103175. [\[CrossRef\]](#)
45. Wang, W.; Wang, W.; Xie, P.; Zhao, D. Spatial and temporal disparities of carbon emissions and interregional carbon compensation in major function-oriented zones: A case study of Guangdong province. *J. Clean. Prod.* **2020**, *245*, 118873. [\[CrossRef\]](#)
46. Wen, X.; Yang, F.; Chen, J.; Tu, Y.; Wang, H.; Chen, Z.; Dong, T.; Xu, G. Spatial patterns of urban expansion and cropland loss during 2017–2022 in Guangdong, China. *Heliyon* **2024**, *10*, e30548. [\[CrossRef\]](#) [\[PubMed\]](#)
47. Wu, C.; Wang, M.; Wang, J.; Smith, D.; Kraak, M.-J. 'Local Hubs and Global Gateways': Understanding the impact of Singapore's master plan on urban polycentricity. *Environ. Plan. B Urban Anal. City Sci.* **2025**, *52*, 789–803. [\[CrossRef\]](#)
48. Xi, Q.; Mei, L. How did development zones affect China's land transfers? The scale, marketization, and resource allocation effect. *Land Use Policy* **2022**, *119*, 106181. [\[CrossRef\]](#)
49. Xie, R.; Yao, S.; Han, F.; Zhang, Q. Does misallocation of land resources reduce urban green total factor productivity? An analysis of city-level panel data in China. *Land Use Policy* **2022**, *122*, 106353. [\[CrossRef\]](#)
50. Xu, G.; Geng, M.; Schwarz, P.; Dong, H.; Gong, Y.; Yang, H.; Thomas, M. The effect of industrial relocations to central and Western China on urban construction land expansion. *J. Land Use Sci.* **2021**, *16*, 339–357. [\[CrossRef\]](#)
51. Yan, S.; Grove, A. Regional Planning, Land-Use Management, and Governance in German Metropolitan Regions—The Case of Rhine–Neckar Metropolitan Region. *Land* **2022**, *11*, 2088. [\[CrossRef\]](#)
52. Yang, L.; Wang, J.; Feng, Y.; Wu, Q. The Impact of the Regional Differentiation of Land Supply on Total Factor Productivity in China: From the Perspective of Total Factor Productivity Decomposition. *Land* **2022**, *11*, 1859. [\[CrossRef\]](#)
53. Zheng, L.; Wu, S. Remote high-speed rail stations, urban land supply, and the emergence of new economic activities. *Transp. Res. Part A Policy Pract.* **2024**, *189*, 104226. [\[CrossRef\]](#)
54. Zhong, C.; Chen, J.; Yi, B.; Li, H. Examining the reliable trend of global urban land use efficiency from 1985 to 2020 using robust indicators and analysis tools. *Habitat Int.* **2025**, *163*, 103477. [\[CrossRef\]](#)
55. Zhou, K.; Zhang, X.; Xia, Y.; Zhang, R.; Zeng, P. Optimizing major function-oriented zone of Hunan Province from the perspective of population-land coordination. *Resour. Sci.* **2024**, *46*, 421–433. [\[CrossRef\]](#)
56. Zhou, L.; Tian, L.; Cao, Y.; Yang, L. Industrial land supply at different technological intensities and its contribution to economic growth in China: A case study of the Beijing-Tianjin-Hebei region. *Land Use Policy* **2021**, *101*, 105087. [\[CrossRef\]](#)
57. Zhou, M. An interval fuzzy chance-constrained programming model for sustainable urban land-use planning and land use policy analysis. *Land Use Policy* **2015**, *42*, 479–491. [\[CrossRef\]](#)
58. Zhu, J.; Li, X.; Huang, H.; Yin, X.; Yao, J.; Liu, T.; Wu, J.; Chen, Z. Spatiotemporal Evolution of Carbon Emissions According to Major Function-Oriented Zones: A Case Study of Guangdong Province, China. *IJERPH* **2023**, *20*, 2075. [\[CrossRef\]](#) [\[PubMed\]](#)
59. Zhu, X.; Li, Y.; Zhang, P.; Wei, Y.; Zheng, X.; Xie, L. Temporal-spatial characteristics of urban land use efficiency of China's 35mega cities based on DEA: Decomposing technology and scale efficiency. *Land Use Policy* **2019**, *88*, 104083. [\[CrossRef\]](#)

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.