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Strategies for Enhancing Rural Vitality from the Perspective of Comprehensive Land Consolidation: Integrating Production, Living, Ecology, and Efficiency Enhancement

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Abstract: This study examines the relationship between the space vitality of rural production, living, and ecology (SVRPLE) and comprehensive land consolidation (CLC), establishing a theoretical foundation for improving SVRPLE in rural areas. Building on this theoretical framework, we employed double-constraint spatial clustering and the three-dimensional magic cube method to zone the study area at the village level, facilitating the determination of CLC objectives and scheduling. We then applied an obstacle diagnosis model to identify key challenges within each zone for enhancing rural space vitality. The results indicate the following: (1) Theoretical analysis reveals the mutually reinforcing relationship between CLC and rural vitality. Efficiency-driven CLC enhances the vitality of rural spaces by optimizing the synergistic interactions between production, living, and ecological spaces. Rural vitality is both the core objective of and the guiding principle for the implementation of CLC. (2) The case study validates the proposed framework—"Vitality Status Evaluation—Vitality Enhancement Zoning—Land Consolidation Guidelines"—as a feasible approach for CLC strategy development based on SVRPLE. The zoning outcomes accurately reflect the unique conditions of different rural villages within the study area, providing a scientific and logical methodology for constructing a context-specific CLC strategy. (3) The zoning results, which incorporate CLC objectives and scheduling, yield differentiated CLC sub-strategies aimed at enhancing SVRPLE, offering both theoretical and practical support for CLC implementation in China, particularly in the ecologically fragile Qinghai Plateau. Overall, our research deepens the understanding of rural vitality enhancement pathways, supplements existing studies on rural vitality, and provides practical guidance for CLC.

Keywords: comprehensive land consolidation; space vitality; production–living–ecological space; degree of obstruction; sustainable rural development; Qinghai Plateau

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1. Introduction

Rural areas are essential for ensuring food security, providing ecological services, and maintaining social stability [1]. However, many rural villages—especially in developing countries like China—are currently facing serious challenges such as depopulation, aging populations, land abandonment, and deteriorating living conditions [2]. Addressing these issues requires integrated solutions, as tackling them individually does not effectively enhance rural vitality. As urbanization advances, rural revitalization in China increasingly necessitates the adoption of urban functions in rural areas to foster integrated urban–rural development [3]. Traditional governance approaches have proven inadequate, necessitating comprehensive strategies that address these challenges in a more coordinated and

integrated manner [4]. Given the complex challenges facing China's rural areas and their redefined role in integrated urban–rural development, stimulating rural vitality has become a key strategy to address these difficulties [5].

Rural vitality refers to the dynamic and integrated capacity of rural areas to sustain social, economic, and environmental well-being. It is characterized by sustainable development, community resilience, and a high quality of life, underpinned by factors such as population stability, employment opportunities, access to services, social cohesion, and the preservation of local cultures and ecosystems. As a multidimensional concept, rural vitality depends on the harmonious interaction between production, living, and ecological spaces, which are the core areas targeted by comprehensive land consolidation [6]. Research on rural vitality in China began relatively late, often in connection with themes of rural revitalization and sustainable development [7,8]. Scholars generally agree that labor outflow from rural areas is a fundamental cause of declining rural vitality [9], that a weak industrial base is a primary bottleneck in improvement [10], and that outdated infrastructure further restricts the potential of rural vitality. In contrast, research on rural vitality originated in Germany and has since accumulated substantial theoretical and empirical advancements in Europe, the United States, and Japan. In these regions, studies have identified changes in population structure, higher education quality, and local policies as key drivers of rural vitality [11,12]. The development of cultural and landscape heritage eco-villages enhances rural vitality. In Italy, preserving historic village landscapes supports sustainable lifestyles and green development, creating opportunities for rural revitalization [13]. In the Netherlands, eco-villages foster self-sufficiency, reducing resource use while maintaining well-being, thus promoting long-term sustainability [14]. Recently, scholars have found that smart villages boost rural vitality, offering new momentum for sustainable development in eastern Poland, despite challenges like uneven technology and inadequate infrastructure [15].

Historically, studies of rural vitality have tended to focus on individual factors—such as local resources, economic diversification, or community engagement—rather than adopt a comprehensive approach. Consequently, significant gaps remain in the understanding of how to holistically enhance the vitality of rural production, living, and ecological spaces. Addressing rural revitalization thus requires integrated and practical strategies that consider the interplay among these dimensions [16].

Comprehensive land consolidation (CLC) is an integrated approach to land management aimed at optimizing land use, improving agricultural productivity, and promoting sustainable rural development. In China, CLC has emerged as a critical measure to unlock rural potential, advance overall rural vitality, and promote rural revitalization [17,18]. Scholars have analyzed the relationship between comprehensive land consolidation and the space vitality of rural production, living, and ecology (SVRPLE) from various perspectives. From a dynamic development standpoint, Rao et al. examined the long-term correlation between CLC and urban–rural development, revealing that CLC significantly enhances rural economies, improves land use efficiency, and promotes industrial development [19]. From the perspective of multidimensional integration, Yin et al. highlighted that against the backdrop of global rural vitality decline, CLC leverages spatial restructuring as a material foundation and vehicle to drive economic restructuring, transitioning from traditional agricultural practices to modern agriculture and industrial integration [20]. Simultaneously, it facilitates social restructuring, transforming rural societies toward urbanization, community-based living, and multiculturalism.

Delving deeper into rural development elements, researchers have identified that CLC, guided by the goal of activating key rural development factors, optimizes land resource allocation and effectively balances the supply and demand of land use functions [21]. This aligns with the theory of land multifunctionality, which posits that land serves as a multidimensional resource offering diverse social, economic, and environmental functions, thereby contributing significantly to population aggregation, industrial growth, and resource support [22]. Notably, some scholars have analyzed the practical implications

of CLC and observed that the reconstruction of production, living, and ecological spaces can be both mutually reinforcing and constraining, with certain negative impacts on the ecological environment [23]. Given that CLC differs from traditional land consolidation by shifting from a production-oriented focus on economic benefits to a holistic measurement that considers social, economic, and environmental benefits in tandem. It is imperative, especially in the context of increasing ecological concerns, to emphasize the comprehensive revitalization of rural production, living, and ecological spaces [24].

The essence of this comprehensive revitalization concept is to create an efficient and intensive production space, a comfortable and moderate living space, and a beautiful and sustainable ecological space [25]. Specifically, in production space, economic revitalization is targeted through land reorganization, infrastructure improvements, and industrial upgrading, which together boost productivity and mitigate labor outflow. These initiatives aim to transform agricultural practices and encourage economic diversification, establishing a strong economic foundation in rural areas. The revitalization of living space focuses on improving residents' quality of life by enhancing essential infrastructure and community services. Such improvements elevate living standards and foster social cohesion, which are vital for population retention and overall community stability.

Meanwhile, the revitalization of ecological space emphasizes environmental protection and restoration to ensure long-term sustainability. Efforts like reforestation, soil and water conservation, and pollution control contribute to a more resilient and balanced ecosystem, aligning human activity with environmental stewardship. The interconnected nature of rural production, living, and ecological spaces is fundamental to the vitality of rural areas. Enhancing production space not only boosts economic resources but also creates a foundation for improvements in living and ecological spaces. For example, higher agricultural productivity can generate resources that support better living conditions and ecological restoration. Likewise, improving living space through infrastructure development and community services attracts residents and businesses, fostering a sustainable human–environment relationship. A healthy ecological environment, in turn, supports agricultural productivity and livability, completing the virtuous cycle that underpins rural vitality. This integrated approach is at the core of CLC, which seeks to optimize these interdependencies for holistic rural revitalization [26]. The ultimate goal of CLC is not the isolated improvement of individual elements such as production or living spaces, but rather the integrated enhancement of overall rural vitality. When these three types of spaces are placed within the same CLC framework, CLC can ensure that improvements in one domain contribute to improvements in other domains through the synergistic positive feedback effects among production, living, and ecological spaces, thereby forming a coherent strategy for sustainable and balanced rural development.

However, despite the potential of CLC, current studies on the interaction between SVRPLE and CLC need to be supplemented, and existing CLC strategies tend to focus on isolated objectives and lack a comprehensive framework for integrating multiple objectives to enhance SVRPLE. Addressing these gaps requires a more holistic and integrated approach to CLCS that fully considers the interlinked dimensions of rural spaces to promote balanced and sustainable rural revitalization [27].

Furthermore, as rural villages are basic units of rural governance in China, they exhibit significant heterogeneity in production, living, and ecological space and elements due to varying factors such as geographic location, resource endowment, economic foundation, and socio-cultural environment [28]. This heterogeneity results in vastly different challenges for villages, making the choice of appropriate CLC strategies with distinct goals complex, in varying levels of difficulty for land consolidation, and in different outcomes in terms of benefits [29]. Limited resources and increasing ecological pressures further underscore the need to maximize internal efficiency while aligning with sustainable development goals. Thus, it is essential to establish CLC strategies with appropriate land consolidation goals, measures, and temporal sequencing. This necessitates that CLC strategy construction accurately evaluate the current state of SVRPLE, carefully investigate the challenges

and benefits of land consolidation measures, identify key issues, and formulate targeted strategies to achieve the synergistic enhancement of SVRPLE.

Therefore, this study aims to reveal the interactive relationship between SVRPLE and CLC and explore pathways and strategies for revitalizing rural vitality. By analyzing the intrinsic need for enhancing SVRPLE, this study proposes a systematic "Vitality Status Evaluation—Vitality Enhancement Zoning—Land Consolidation Guidelines" framework to design CLC strategies. Using Datong County in Qinghai Province as the study area, our research seeks to verify the feasibility and effectiveness of the new framework for CLC strategy construction. This study will enrich the theoretical framework of CLC strategy construction, providing both theoretical support and practical references for rural governance and promoting rural revitalization.

2. Interaction Between Rural Vitality and Comprehensive Land Consolidation

2.1. Rural Vitality

From a perspective that treats rural areas as living organisms, scholars argue that village vitality is demonstrated through the interaction between internal elements—such as location, resource endowment, spatial structure, and culture—and the external environment. This interaction drives the development, expansion, stabilization, and reorganization of villages [30,31]. In the field of land science, scholars generally agree that the production, living, and ecological spaces of villages serve as carriers of rural vitality, which is generated through the dynamic interplay between space, people, and their activities [32]. A vibrant space can meet the diverse needs of its dwellers and generate positive feedback effects through their rational activities, thereby promoting sustainable development [33].

In this study, rural vitality is understood as the capacity of rural areas to sustain production, living, and ecological activities through the coordinated interaction between spatial elements and rural residents. This vitality reflects the resilience and long-term sustainability of rural communities, which are directly shaped by the optimization of interactions and synergies between spaces through integrated land management strategies, particularly CLC. CLC plays a central role in enhancing rural vitality by optimizing these key spaces and fostering their interconnected development. Rural spaces in China can be categorized into three types: production, living, and ecological spaces [34]. Accordingly, the vitality of rural areas in China can be understood in terms of active economic activities and a stable growth trend in production, a strong population attraction and accommodation capacity in the context of living, and a stable supply of ecological products and services. These factors collectively contribute to forming sustainable relationships among people, land, industry, and the environment.

2.2. How CLC Enhances the Vitality of Rural Production, Living, and Ecological Spaces

CLC is rooted in territorial spatial planning and utilizes a combination of policy tools, such as the cultivated land requisition–compensation balance, the linking of urban and rural construction land adjustments, and land trading, to optimize land use structures and facilitate a resource nexus between urban and rural areas [35]. For example, rural construction land indices released through land adjustments can be traded in the land market, allowing rural areas access to capital. This process creates new channels for capital to flow into rural areas during the early stages of CLC, facilitating land and capital exchange between urban and rural areas, and providing financial support to enhance rural vitality [36].

Regarding rural production space, CLC focuses on improving agricultural production conditions [37]. It achieves this by both increasing the quantity and quality of cultivated land and optimizing the structure and layout of rural industrial space [38]. Additionally, it promotes the mixed use of agricultural and ecological construction land, supporting the development of rural primary, secondary, and tertiary industries, thus ensuring the sustainable development and growth of rural industries [39]. This mixed use may involve practices such as integrated agroforestry systems, where crops are grown alongside trees,

or the establishment of buffer zones between agricultural fields to balance agricultural production with ecosystem restoration and enhance biodiversity. These practices not only yield agricultural products but also provide significant ecological benefits, including windbreaks, reduced soil erosion, and improved soil fertility [40].

In terms of living space, CLC follows a "people-oriented" approach, addressing the living and livelihood needs of farmers while actively adapting to rural modernization processes [41]. First, land use optimization is achieved through the remediation of inefficient land use and the repurposing of unused rural residential land, meeting spatial needs for public service facilities for villagers such as pension and childcare services [42]. Second, by focusing on improving rural habitats and preserving traditional culture, CLC creates distinctive rural landscapes and enhances the quality of rural life through the integration of natural, historical, cultural, and agricultural landscape resources [43].

Regarding ecological space, CLC plays a key role in implementing territorial ecological restoration, facilitating the comprehensive remediation of water resources and soil pollution, forest and grassland protection, and the restoration of abandoned mines in rural areas. This not only enhances the functionality of rural ecosystems but also promotes the value realization of ecological products, balancing ecological protection with economic development and boosting the ecological vitality of rural areas [44].

2.3. How the Space Vitality of Rural Production, Living, and Ecology Guides a Comprehensive Land Consolidation Strategy

China's villages have long supported urbanization and industrial development, which has resulted in space–time mismatches of resources between urban and rural areas, leading to inadequate resource supply for rural development. Moreover, some rural villages have indiscriminately adopted inappropriate development strategies that target urbanization and industrialization, which has caused functional disorder and further accelerated the decline of space vitality in rural areas [45]. Specifically, agriculture and the ecological space are seriously degenerated. Simultaneously, unmanaged development activities in villages have highly fragmented construction and cultivated land, which has obviously reduced their utilization efficacy. Traditional development strategies have become a critical obstacle to improvements in land use efficiency in rural villages [46]. Moreover, for villages that are situated in areas with restrictions on development, it is challenging to provide local residents with enough space for living and working; for example, their housing demands are usually difficult to meet, and space for the development of industries that are suited to local conditions is also largely limited.

In recent years, rapid technological advancements and social transformations have accelerated the shift of many rural areas into a non-agricultural state. These socio-economic changes have compelled many rural villages to adopt highly differentiated development strategies, such as becoming industry- or tourism-oriented. However, not all villages have succeeded in this wave of socio-economic transformation. Many have become hollowed out due to population loss, while some have experienced a resurgence with a wave of population returns [47]. These variations in rural transformation pathways highlight significant regional differences in rural spaces and the underlying causes of declining space vitality [48]. The issues surrounding vitality decline in rural China are complex and multifaceted [49]. A primary factor contributing to this decline is the conflict between the utilization of PLES and the resulting functional imbalances. The lack or decline of vitality is an external manifestation of these conflicts, making it difficult to improve rural vitality through the optimization of a single space [50]. Therefore, CLC strategies must adopt a comprehensive and differentiated approach, taking into account the unique characteristics and interdependencies of each rural area's production, living, and ecological spaces. In conducting a thorough assessment of the current state of these spaces and their vitality, CLC can be tailored to address specific challenges and opportunities. This ensures that improvements in one space—whether production, living, or ecological—will generate

positive feedback effects that enhance the other spaces, ultimately contributing to the overall vitality and sustainable development of rural areas.

To effectively enhance rural vitality, CLC strategies must move beyond a focus on individual spaces and adopt an integrated approach that optimizes the synergy between production, living, and ecological spaces. By addressing the dynamic interrelations between these spaces, CLC can promote the balanced and sustainable revitalization of rural areas. For example, improving the vitality of production space by increasing agricultural productivity can lead to higher living standards, which in turn support the retention of population and local community stability. Similarly, strengthening ecological space through restoration efforts can enhance both agricultural productivity and quality of life, creating a harmonious relationship between the environment and rural development. This creates a mutually reinforcing cycle of vitality between these spaces, and this integrated approach is key to achieving sustainable rural development, as it emphasizes the interconnectedness of these spaces rather than focusing on isolated interventions. Moreover, land consolidation measures should be arranged and scheduled in an orderly manner through zoning, classification, and time scheduling based on the local, natural, and socio-economic conditions of individual villages. First, the primary objective of land consolidation should be determined based on the local conditions of a village. Objectives can be production-oriented, living-oriented, or ecological protection-oriented. The objective of a specific village should give full consideration to the advantages of regional functions, thus further promoting the main function of this village in local development. For example, for villages with a relatively better basis for economic development, CLC strategies should mainly aim to improve the vitality of production space, whereas for villages with relatively better living conditions, CLC strategies should focus on improving the vitality of living space. This strategy is employed to trigger the positive feedback effect during the implementation of CLC measures. In turn, improvements in the vitality of space that represents the main function of a village will continuously exert a positive influence on the vitality of other spaces, both of the same kind and in surrounding areas [51]. For the non-primary objectives of land consolidation, complementary measures should be taken to address the most critical issues that hinder rural vitality.

Second, CLC strategies should prioritize villages with better natural or socio-economic conditions in order to promote their development with less human, resource, and financial investment. The purpose of this is to establish representative villages of rural resurgence in the initial period of CLC. These villages will play an igniting role in motivating other villages to accept and implement CLC measures [52]. By implementing easily executable measures and strategically investing limited human and financial resources in these representative villages, feasible land consolidation policies and experiments can be quickly established, facilitating the implementation process of CLC strategies from simple to complex across more villages [53]. This goal can be achieved by carefully scheduling and organizing a sequence of villages where CLC projects will be implemented. Zones based on the scheduling of CLC implementation in villages can be categorized into three groups: prioritized, reserved, and restricted [54].

Finally, practitioners should consider the scale effect of benefits from CLC measures. Therefore, it is important to promote the spatial clustering of measurements in the implementation of CLC in order to maximize the scale and spillover effects of various rural elements [55]. That is to say, villages that have the same CLC objectives and measures should be spatially aggregated.

The interaction between SVRPLE and CLC is shown in Figure 1.

2.4. Framework for Constructing CLC Strategies Based on Space Vitality of Rural Production, Living, and Ecology

Based on the analysis of the relationship between rural vitality and CLC, we proposed a framework for constructing CLC strategies based on the space vitality of rural production, living, and ecology. First, the framework includes an indicator system to assess SVRPLE

in the study area. The indicator system allowed for the calculation of vitality indices for production, living, and ecology spaces in each village. Second, based on these three vitality indices, a spatially constrained multivariate clustering algorithm was applied to zone villages in terms of land consolidation objectives. Third, based on the different types of combinations of the three vitality indices for each village, the three-dimensional magic cube model was employed to schedule the implementation sequence for CLC in each village. Fourth, critical obstacles to the enhancement of SVRPLE in villages with different CLC objectives and scheduling sequences were identified. Measures of CLC to address these obstacles were proposed based on the local conditions of each village. Finally, systematic CLC strategies with tailored measures for the differentiated problems of different villages were constructed. The framework for the construction of CLC strategies is shown in Figure 2.

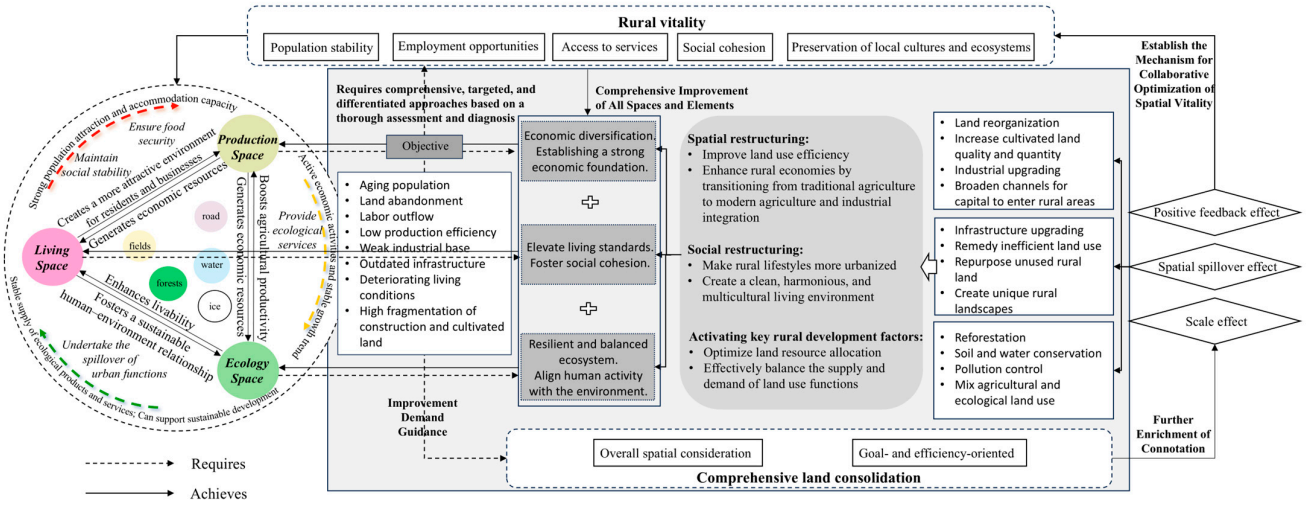


Figure 1. Interactive relationship between rural vitality and comprehensive land consolidation.

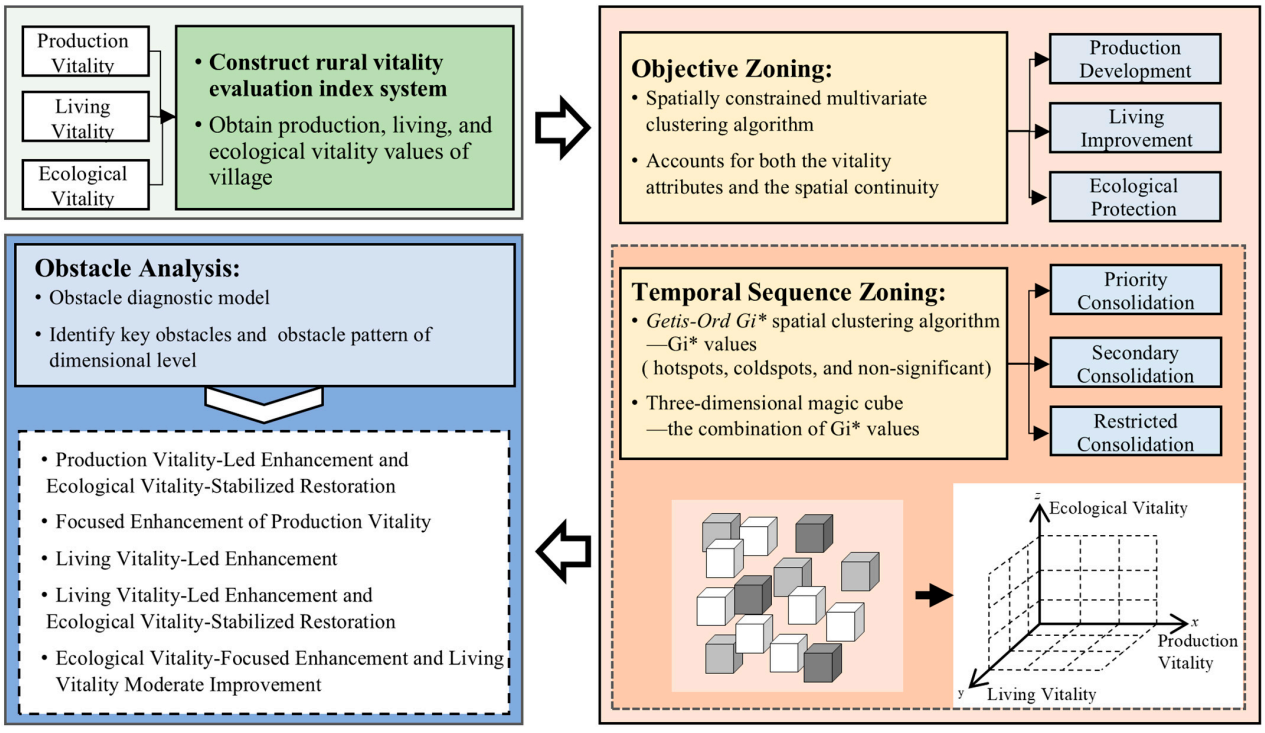


Figure 2. Framework for the construction of comprehensive land consolidation strategies based on the space vitality of rural production, living, and ecology.

3. Materials and Methods

3.1. Study Area

Datong County, part of Xining City in Qinghai Plateau, is located in Northwest China, positioned between latitude 36°43′–37°23′ N and longitude 100°51′–101°56′ E. In 2020, the county had a population of approximately 383,800, distributed across 289 administrative villages, covering a total area of 3159.97 km^2, which accounts for 42.58% of Xining's total area. (Areas such as pastures, forests, and chemical plants were excluded from this study due to their large size and single-function nature, which could impact the accuracy of data for individual study units.)

As shown in Figure 3, the county's terrain is predominantly characterized by plateaus and mountainous regions, serving as a transitional zone between the Qinghai–Tibet Plateau and the Loess Plateau. The county is rich in ecological resources, which provide water conservation, windbreak and sand fixation, and biodiversity preservation functions. Consequently, it serves as a crucial ecological barrier to the north of Xining, the capital city of Qinghai province. At the same time, the region's fragile plateau ecosystem, coupled with the difficulty of restoration after ecological degradation, places Datong County under the dual pressures of resource protection and economic development. Similar challenges are faced by other highland areas globally, such as the Deccan Plateau in India, the Anatolian Plateau in Turkey, the Andes in South America, and the Ethiopian Highlands in Africa. These regions share the common issue of balancing ecological protection with economic development in ecologically fragile environments. Therefore, the study of Datong County offers valuable insights that can be applied to address similar challenges in other regions across Asia, South America, and Africa, particularly in maintaining sustainable agricultural productivity.

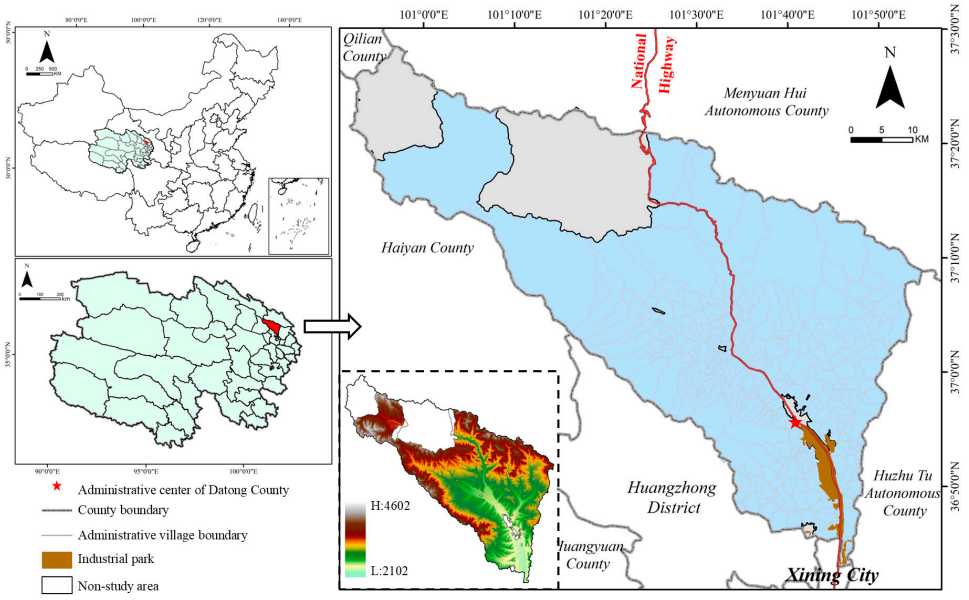


Figure 3. Locator map for Datong County.

The cultivated land area of Datong County ranks third in the province, positioning it as a critical agricultural production area within Qinghai. Due to its unique ecological role and land use structure, Datong County faces challenges in multipurpose land use, particularly in the Qinghai Plateau region, where demand for rural land is notably tight. Additionally, Datong County possesses a robust industrial base, with a secondary industry output value of CNY 5.972 billion in 2020, including key industrial zones such as the Beichuan Industrial Park and the Qinghai Comprehensive Bonded Zone. Effective land resource allocation is essential for sustaining both regional agricultural and industrial development.

However, in recent years, rapid urbanization has led to a significant decline in rural vitality, characterized by a shortage of cultivated land reserves, localized forest and grass-

land degradation, and the inefficient use of construction land. This phenomenon of rural vitality decline, coupled with the increasing scarcity of cultivable land, is a pressing issue not only in Datong County but also in many other parts of China's western regions. As the first national modern agricultural demonstration zone in Qinghai, Datong County is a microcosm of the broader challenges faced by many agricultural counties in China's western regions. These regions are characterized by resource constraints, ecological fragility, and the need for sustainable agricultural development. For example, areas like Gansu, Inner Mongolia, and the northwest of Xinjiang, where rapid urbanization and land use pressures are similar, are faced with challenges such as land abandonment, inefficient agricultural land use, and the degradation of natural resources. To address these challenges, the application of CLC is essential to enhance land adaptability and facilitate resource integration, thereby restoring sustainable rural vitality. In response to these challenges, Datong County is actively implementing measures to enhance rural vitality through comprehensive land consolidation, providing essential data and insights for our research.

This study focuses on Datong County and aims to develop a CLC strategy that enhances the vitality of rural production, living, and ecological spaces. The strategy not only addresses the challenges faced by the region but also contributes to the broader discourse on rural revitalization and CLC in areas with similar geographical and ecological conditions.

3.2. Data Sources and Preprocessing

The data used in this study include socio-economic data and spatial data in both vector and raster formats (Table 1). The socio-economic data include the following: (1) population data, encompassing the total population, the young and working-age population (15–60 years), and the elderly population (60 years and above); (2) per capita annual income; and (3) the number of characteristic factories in rural villages. Data related to village infrastructure include the following: (1) the types of infrastructure; (2) the number of public service facilities; and (3) the number of facilities for ecological and environmental protection. Additionally, the area of each land type was extracted from data from the third national land survey of the study area.

Table 1. Data used to evaluate space vitality in the study area.

Data Type	Data Name	Time Section	Data Resolution	Data Source
Socio-economic Data	Socio-economic statistical data	August 2020	—	Administrative village-level statistics, Survey data
	Facility deployment data	August 2020	—	Administrative village-level statistics, Survey data
Vector Data	Administrative division data	August 2020	—	Datong County Natural Resources Bureau
	Land use data	2020	—	The third national land survey of Datong County
	Location and boundary data of Beichuan Industrial Park	2020	—	Datong County Natural Resources Bureau
	Location and boundary data of permanent basic farmland protection area and ecological protection red line	2020	—	Datong County Natural Resources Bureau
	Road distribution in Qinghai Province	2020	—	Resource and Environmental Science and Data Center, Chinese Academy of Sciences https://www.resdc.cn/Default.aspx accessed on 10 September 2023

Table 1. *Cont.*

Data Type	Data Name	Time Section	Data Resolution	Data Source
Raster Data	DEM	—	30 m × 30 m	Geospatial Data Cloud Platform https://www.gscloud.cn accessed on 10 September 2023
	NDVI	2010, 2020	500 m × 500 m	Resource and Environmental Science and Data Center, Chinese Academy of Sciences https://www.resdc.cn/Default.aspx accessed on 10 September 2023
	NPP/VIIRS	September 2020	500 m × 500 m	Resource and Environmental Science and Data Center, Chinese Academy of Sciences https://www.resdc.cn/Default.aspx accessed on 10 September 2023
	Total ecosystem service value	2018	1 km	Resource and Environmental Science and Data Center, Chinese Academy of Sciences https://www.resdc.cn/Default.aspx accessed on 10 September 2023

For data with values presented in interval ranges, new values were assigned based on a hierarchical classification method. All raster data underwent projection transformation (UTM projection) and resampling (30 m × 30 m) to generate raster surfaces that met the requirements. The shortest distance from the village center (expressed as the center of mass) to the administrative center of Datong County, as well as to the nearest river and industrial park, was calculated using the cost distance tool in ArcGIS 10.2. This tool is used to assign different resistance values to different levels of traffic networks (e.g., highways, railways, national, provincial, county, and other roads), gradients, terrain, and river systems, resulting in a cost grid.

3.3. Methods

3.3.1. Evaluation of Space Vitality of Rural Production, Living, and Ecology

To evaluate the vitality of rural production, living, and ecological spaces, a hierarchical analysis method was applied to assign weights to each indicator in the constructed evaluation system. Next, an extreme value standardization method was used to normalize the indicators. Finally, a composite index method was employed to calculate the vitality indices for village production, living, and ecology [56].

3.3.2. Zoning Villages to Identify CLC Objectives

We used the "spatially constrained multivariate clustering" tool in ArcGIS to zone villages based on the evaluated vitality indicators for rural production, living, and ecological space [57]. Then, CLC objectives for each zone were identified by analyzing the values of the vitality indicators of villages in each zone. This tool uses unsupervised machine learning to group spatial data based on specified attributes, while ensuring geographic contiguity. It constructs a connectivity graph, such as a Delaunay triangulation or minimum spanning tree, and applies methods like the SKATER algorithm to create clusters that are homogeneous within groups and distinct between groups [58]. Clustering performance is evaluated using metrics like R^2 and the Calinski–Harabasz pseudo-F-statistic. This tool can include spatial constraints, cluster size constraints, and membership probabilities to assess cluster quality. The optimal number of zones was determined using AIC values from different clustering results [59]. The objective zones delineated using this method exhibited minimal differences in SVRPLE indices within each zone, while maximizing disparities

between zones. More detailed information, including specific steps performed in ArcGIS, is provided in Supplementary Materials S1.

3.3.3. Schedule of Villages for CLC

A local spatial autocorrelation analysis was conducted using the *Getis-Ord* G_i^* spatial clustering algorithm to calculate the G_i^* values for the production, living, and ecological vitality indices of each village [60]. A larger positive G_i^* value of space vitality indicates more significant clustering of villages with high vitality in that space, while a smaller negative G_i^* value indicates more significant clustering of low-vitality villages. If the G_i^* value approaches 0, the clustering is considered non-significant. Accordingly, the villages were classified into three categories: hotspots, coldspots, and non-significant. The formula for G_i^* is as follows:

$$G_i^* = \frac{\sum_{j=1}^{n} w_{ij} \cdot x_j - \overline{x} \cdot \sum_{j=1}^{n} w_{ij}}{s \cdot \sqrt{\frac{\sum_{j=1}^{n} w_{ij}^2 - \left(\sum_{j=1}^{n} w_{ij}\right)^2 / n}{n-1}}} \quad (1)$$

where G_i^* represents the *Getis-Ord* G_i^* statistic for location i, x_j represents the observed value at location j, $\overline{x}$ represents the mean of all observations, s represents the standard deviation of all observations, w_{ij} represents the spatial weight between locations i and j, and n represents the total number of observations.

After the G_i^* was calculated, the three-dimensional magic cube model was applied to determine the schedule of CLC based on the combination of G_i^* values for production, living, and ecology in each village. The construction process of this three-dimensional magic cube model is as follows: in a three-dimensional Cartesian coordinate system, the G_i^* values of production, living, and ecological vitality were represented on the x, y, and z axes. From the origin, the maximum G_i^* values of hotspots, coldspots, and non-significant areas were used to define the nodes, and a $3 \times 3 \times 3$ magic square was constructed, divided into 27 spatial units. This abstracts the real spatial entity into a three-dimensional cube cut by a grade scale, enabling researchers to clearly identify the levels of production, living, and ecological vitality for each research unit and the combination of these three by observing the spatial distribution of the research units in the cube. Extending from the origin to the three-dimensional high-value region, the spatial unit gradually demonstrates improved resource endowment characteristics and a better combination of vitality across the production, living, and ecological spaces. Then, a schedule of CLC for each village is determined based on its position in the coordinate system.

3.3.4. Identification of Obstacles to Vitality Enhancement

After villages are zoned based on their CLC objectives and schedules, the key obstacle factors and patterns of obstacles to the enhancement of SVRPLE in each zone are identified through the obstacle degree diagnosis model. The formula is as follows:

$$O_{ij} = \begin{cases} 1 - P_{ij} & P_{ij} \leq 1 \\ 0 & P_{ij} > 1 \end{cases} \quad (2)$$

$$V_{ij} = \frac{F_{ij} \times O_{ij}}{\sum_{i=1}^{m} \left(F_{ij} \times O_{ij}\right)} \quad (3)$$

where O_{ij} represents the degree of deviation for each evaluation indicator of the research unit, P_{ij} represents the standard value of each evaluation indicator of the research unit, F_{ij} represents the contribution degree of the evaluation indicators (expressed by the weight of each indicator), and V_{ij} represents the degree of obstruction for each indicator of the research unit.

4. Results

4.1. Vitality Evaluation Indicators for CLC

In this study, 18 indicators were selected for the evaluation of village space vitality, as shown in Table 2. The selection of indicators was inspired by prior research regarding rural vitality and was tailored to reflect the goals of PLES in CLC, while also accounting for the unique characteristics of the study area [61]. Furthermore, the data used for quantifying these indicators were chosen based on their accessibility and relevance. After vitality indicators were selected and quantified, their weights were calculated using a hierarchical analysis method, as shown in Table 2.

Table 2. Indicators and weights for the assessment of production, living, and ecological vitality in the study area.

Dimension Level	Indicator Level	Attribute **	Weight	Calculation Method
Production Vitality	Per capita cultivated land area	+	0.0319	Ratio of cultivated land area to total population
	Proportion of permanent basic farmland	+	0.0125	Ratio of permanent basic farmland area to cultivated land area
	Proportion of grassland area	+	0.0188	Ratio of total area of natural and artificial grassland to area of administrative village
	Distance to industrial park	−	0.059	Minimum cumulative resistance value from administrative village center to industrial park *
	Development status of characteristic rural industries	+	0.1401	Total number of types of characteristic industries in administrative villages
	Per capita income level	+	0.0711	Per capita income of each administrative village obtained by survey
Living Vitality	Total population	+	0.0164	Number of permanent residents of each administrative village obtained by survey
	Ratio of young and working-age population to elderly population	+	0.0199	Ratio of population aged 15–60 years to population aged 60 years and above
	Potential for land reclamation of construction land	+	0.0318	Ratio of area of abandoned and idle rural construction land to area of administrative village
	Distance to administration of Datong County	−	0.0477	Minimum cumulative resistance value from administrative village center to administrative center of Datong County *
	Intensity of human activities	+	0.1035	Extracted from finished raster data of night light
	Completeness of infrastructure	+	0.1141	Total number of types of infrastructure and public service facilities in administrative villages
Ecological Vitality	Distance to river	−	0.0325	Minimum cumulative resistance from center of administrative village to nearest river *
	Proportion of forest coverage	+	0.1315	Ratio of forest area to administrative village area
	Value of ecosystem services	+	0.0417	Extracted from finished raster data of total ecological service value
	Completeness of ecological and environmental protection facilities	+	0.0296	Total number of facilities for ecological and environmental protection in administrative villages
	Proportion of ecological red line area to administrative area	+	0.0138	Ratio of ecological protection line area to administrative village area
	Vegetation degradation status	−	0.0843	Extracted from NDVI data

** The cost grid generation process is described in "Section 3.2". ** "+" represents a positive indicator: a higher value means greater vitality; "−" represents a negative indicator: a higher value indicates lower vitality.*

The vitality of rural production space is largely shaped by the stakeholders of rural production. The responsiveness of villagers to land use policies and their enthusiasm for

agricultural activities are crucial internal factors in enhancing production vitality. This responsiveness is represented by "per capita income level", as income levels can indicate economic incentives to engage in agricultural work [62]. Moreover, the richness of unique natural resources and the ability to monetize these resources are crucial factors in assessing the growth potential and vitality of rural production space, which can be reflected in the indicator of "status of characteristic rural industries". Indicators such as "per capita cultivated land area", "proportion of permanent basic farmland", and "proportion of grassland" were chosen to represent land availability and land protection efforts, respectively, which are essential for assessing the agricultural productivity and sustainability of rural regions. Additionally, the "distance to industrial park" highlights the spatial economic connectivity and potential for industrial–agricultural integration, a factor that significantly influences local economic development [63].

Living space vitality is primarily reflected by the population structure and human activity in a village. "Total population" was selected to represent the overall demographic strength of a village, a key factor in evaluating social vitality. The "ratio of young and working-age population to elderly population" is crucial because a younger, active population is often associated with higher levels of productivity and innovation [64]. The "intensity of human activities" reflects the engagement of the community in various daily and economic activities, indicating the vibrancy of village life. The "potential for land reclamation of construction land" was chosen to capture opportunities for revitalizing and expanding rural settlements, thereby improving living conditions [65]. The "quality of infrastructure" is a vital indicator, as the presence of well-developed public facilities supports both economic activities and the quality of rural life. Finally, the "distance to urban center" was included to reflect the accessibility of urban services and markets, which are essential for fostering rural–urban integration [66].

The ecological vitality of rural areas depends on the presence of high-quality natural resources and effective ecological services. The "distance to river" was selected as it indicates the availability of water resources, which are fundamental to sustaining local ecosystems. The "proportion of forest coverage" was chosen because forests play a key role in biodiversity conservation and climate regulation, directly impacting the health of the rural environment. The "value of ecosystem services" reflects the economic and ecological benefits provided by natural systems, emphasizing the importance of maintaining these resources [67]. Meanwhile, to ensure the sustainability of a local ecosystem, the protection of the ecosystem is crucial. In order to evaluate ecological protection efforts, the "ecological red line area ratio" was included to highlight the commitment to the protection of important ecological areas. In addition, the "vegetation degradation index" was selected to evaluate the impact of land use on vegetation health, which is a key factor in ensuring long-term ecological stability [68]. Finally, the countryside's role in ecological guidance is reflected in the "completeness of ecological and environmental protection facilities", highlighting efforts in promoting positive ecological succession [69]. To ensure that explanation remains concise within the main text, a detailed description of the reasons for the selection of each indicator has been provided in Supplementary Materials S2.

To ensure the comprehensiveness and rationality of the evaluation framework, the determination of indicator weights took into account Datong County's resource endowment, the development of its primary, secondary, and tertiary sectors, current land use patterns, and specific challenges related to rural vitality loss. Special attention was given to the objectives of CLC activities, ensuring that the indicator weights align with the local government's needs and development goals. For indicators like distance to rivers, which cannot be directly influenced by CLC, their weights were based on their indirect impact on CLC effectiveness. An expert scoring method, involving local government officials, regional planning professionals with extensive experience in Qinghai, and university professors, helped ensure that the selected indicators and their weights aligned with both the practical realities of the region and the strategic goals of CLC, thus providing a more targeted and context-specific framework for evaluation.

4.2. Pattern of Space Vitality of Production, Living, and Ecology in Villages

The natural break method was applied to classify the production, living, and ecological vitality index values in the study area into three categories: high, medium, and low. In addition, hotspot analysis was used to visualize the spatial pattern of rural vitality, as shown in Figure 4.

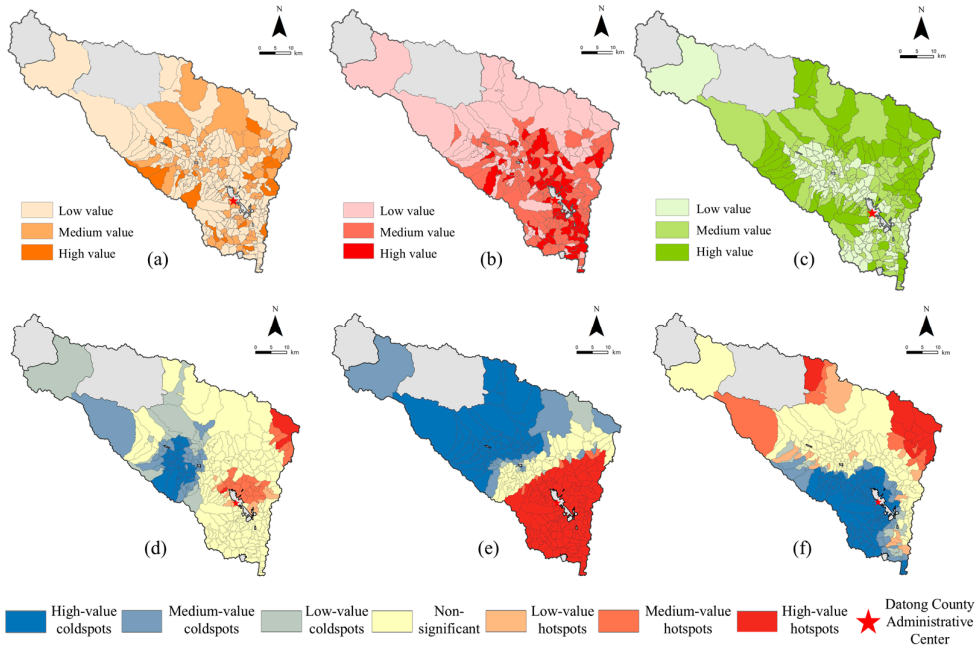


Figure 4. Distribution of production, living, and ecological vitality values and their coldspots and hotspots in Datong County. (**a**) Production vitality value; (**b**) living vitality value; (**c**) Ecological vitality value; (**d**) hotspots and coldspots of production vitality; (**e**) hotspots and coldspots of living vitality; and (**f**) hotspots and coldspots of ecological vitality.

The high, medium, and low production vitality areas account for 7.67%, 26.29%, and 66.04% of the study area, respectively (Figure 4a). Villages in the three categories vary significantly in size and show an interspersed distribution pattern in the study area, with most villages showing low production vitality. Specifically, villages with high production vitality form two clusters, due to richness in cultivated and pasture land resources. Villages with moderate production vitality are generally located around high-vitality villages and are sparsely distributed from southeast to northwest, following the river's course. This pattern suggests a connection between water availability and production vitality. Villages with low production vitality are widely dispersed in the study area. These villages often face challenges stemming from a weaker industrial foundation. Two production vitality hotspots are prominent in the study area (Figure 4d): the Beichuan Industrial Park, which benefits from industrial development, and densely populated village areas with strong agricultural vitality, driven by the availability of abundant cultivated land. In contrast, the western and northwestern regions are identified as coldspots of production vitality, characterized by limited cultivated land, inadequate transportation infrastructure, and minimal external economic influence, which collectively result in relatively disadvantaged production conditions.

Villages with high, medium, and low levels of spatial living vitality account for 13.36%, 27.23%, and 59.41% of the total area, respectively (Figure 4b). The spatial distribution of living vitality exhibits a distinct difference between the north and south regions of the study area. Low-vitality villages are predominantly concentrated in the northern region, with only a few scattered in the south. Conversely, villages with medium and high living vitality are mainly found in the central and southern regions. High-vitality areas are primarily situated along major transportation routes, due to dense road networks and flat terrain,

which collectively contribute to a higher quality of rural life. Medium-vitality areas tend to surround high-vitality regions, due to their relatively well-developed infrastructure and transportation. Low-vitality areas, in contrast, are distant from the county's urban center and thus face limited accessibility to and convenience of public services. Overall, the spatial distribution of living vitality in the study area is characterized by hotspots in the southeast and coldspots in the northwest, with densely distributed villages in both areas (Figure 4e). This pattern is shaped by multiple factors, including topography and transportation. Moreover, the preference for high-quality settlements, combined with the better location conditions and industrial advantages of the southeast, attracts a larger population and more public facilities to these regions, thereby exacerbating the north–south disparity in living space vitality.

Villages with high, medium, and low ecological space vitality account for 34.20%, 40.87%, and 24.92% of the total area, respectively (Figure 4c). Regions with low ecological vitality are primarily concentrated in the central and southwestern parts of the study area, where flat terrain, dense populations, and intense human activities place significant pressure on the environment, resulting in coldspots of ecological vitality (Figure 4f). In contrast, villages with medium and high ecological vitality are distributed across the western, northern, and eastern parts of the county, forming a ring around the low-vitality zones. These regions demonstrate relatively high ecological function and services due to abundant water resources and extensive forest and grassland cover, thereby creating hotspots of ecological vitality. The distribution of these hotspots aligns with the spatial layout of woodlands and grasslands, whereas the coldspots are predominantly a consequence of limited ecological land and intensified human activity.

4.3. The Zoning of Comprehensive Land Consolidation in the Study Area

Based on AIC index analysis, the villages were classified into three zones according to the objectives of comprehensive land consolidation. The dominant objectives for the different zones are defined as production development, living improvement, and ecological protection (Figure 5a). The production development zone includes 183 villages in the southern part of the study area, which encompasses the administrative center and industrial park. Its favorable location, adjacent to Xining, provides significant economic, political, and transportation advantages, thereby supporting industrial growth. The living improvement zone consists of 58 villages in the central area of the study area. Although its economic development is lower than that of the production development zone, it benefits from good transportation infrastructure, public services, and a relatively dense population, making it well suited for an enhancement of living standards. The ecological protection zone, which includes 48 villages in the northern area, features lush vegetation and well-preserved ecosystems. However, it faces challenges related to limited transportation infrastructure and an underdeveloped economy.

Temporal sequence zoning for consolidation is divided into three categories—priority, secondary, and restricted—based on the three-dimensional magic cube model (Figure 5b). Each category occupies nine spatial units in the three-dimensional magic cube model (Figure 6). The priority consolidation zone, consisting of 105 villages mainly located in the east, is designated to lead the consolidation efforts. The secondary consolidation zone includes 100 villages spread across the southwest, north, and northeast, serving as a reserve for future consolidation. The restricted consolidation zone, comprising 84 villages primarily in the northwest, faces limitations due to poor resource endowment and unfavorable location conditions. Notably, these three consolidation zones are integrated within each objective zone. The priority and secondary consolidation zones within the production development zone cover larger areas, reflecting a strong push for economic growth. In contrast, the living improvement zone and ecological protection zone are largely categorized as restricted consolidation zones, emphasizing conservation and gradual enhancement.

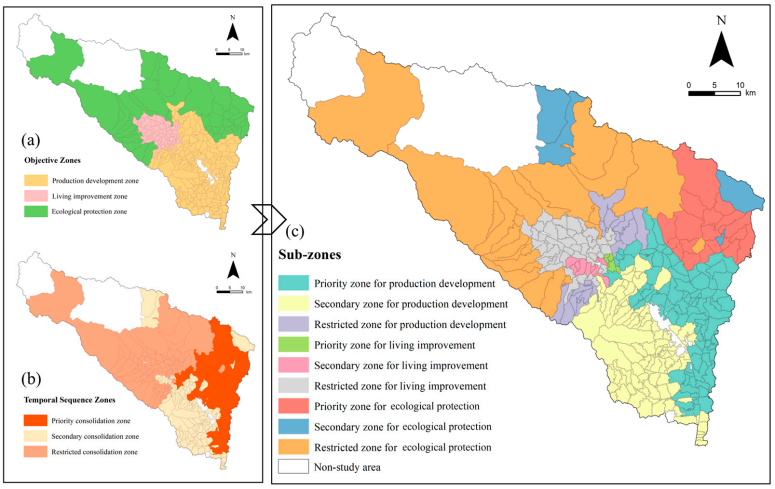


Figure 5. Objective zoning, temporal sequence zoning, and the sub-zones formed by their overlap in comprehensive land consolidation. (**a**) Objective zones; (**b**) temporal sequence zones; (**c**) sub-zones.

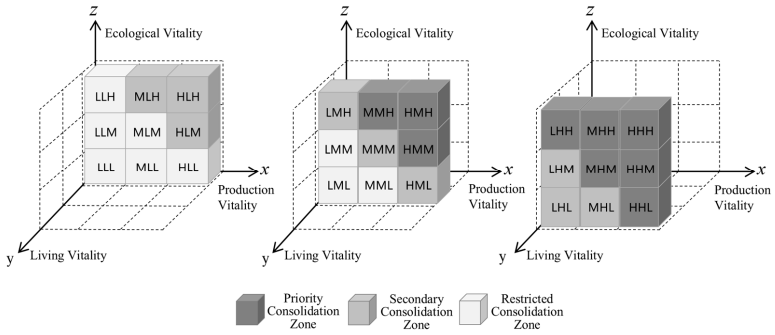


Figure 6. Three-dimensional magic cube model for temporal sequence zoning.

Nine consolidation sub-zones are formed by overlaying the objective zones with the temporal schedule zones (Figure 5c). These sub-zones are as follows: the priority zone for production development (PP), the secondary zone for production development (SP), the restricted zone for production development (RP), the priority zone for living improvement (PL), the secondary zone for living improvement (SL), the restricted zone for living improvement (RL), the priority zone for ecological protection (PE), the secondary zone for ecological protection (SE), and the restricted zone for ecological protection (RE).

4.4. Obstacles to Vitality Enhancement in Different Zones

Both the PP and SP sub-zones exhibit the same pattern of obstacles across the three dimensions: ecology > production > living. The primary challenge arises from the decline in ecosystem services and the scarcity of water resources, creating significant obstacles to enhancing regional ecological vitality. Ecological vulnerability, combined with continuous pressure from human activities, restricts the self-recovery capacity of the plateau ecosystem, further exacerbating the decline in ecological vitality. While both sub-zones benefit from transportation and locational advantages that enhance living and production convenience, these factors also contribute to resource depletion, increased ecological degradation, and threats to ecological vitality. Additionally, competition between ecological conservation and production is becoming increasingly prominent in regional development. Striking a balance between these two aspects for long-term, harmonious coexistence has thus become a pressing concern.

The obstacle pattern for the RP sub-zone follows the order of production > living > ecology. A key factor limiting local production vitality is the lack of characteristic industries, which weakens the region's competitiveness and attractiveness, thereby diminishing its internal

economic momentum. The RP region is divided into two main clusters—central and western—with a relatively small area. Despite having geographic advantages, such as national highways and flat terrain, the central cluster faces significant disadvantages in infrastructure and geographic positioning compared to the PP and SP sub-zones. These limitations increase production costs and hinder economic connectivity. Additionally, the low intensity of human activity suggests a risk of potential population outflow.

The obstacle pattern in the PL sub-zone follows the order of living > ecology > production. On one hand, convenient transport links to Datong County's center and nearby industrial parks offer great potential for enhancing production vitality, thereby minimizing production-related obstacles. On the other hand, the river valley plains and well-developed road network in this region create favorable conditions for settlement. However, the lack of basic public services limits the potential benefits for the improvement of living conditions. Additionally, the absence of characteristic rural industries weakens internal development momentum, while increasing demand for cultivated land poses a threat to ecological health.

The SL and RL sub-zones face significant ecological challenges in improving overall vitality, primarily due to forest and grassland degradation. Situated between river valleys and mountains, these regions benefit from favorable terrain and a climate with more moisture and higher accumulated temperatures compared to mountainous areas, creating a more livable plateau environment for residents. However, human activities significantly disturb the fragile ecosystem, with the expansion of production and residential areas continuously eroding forests and grasslands, thereby threatening ecological stability. Additionally, poor transportation conditions in certain areas are a major barrier to achieving livability goals.

The dimensional obstacle patterns for the PE, SE, and RE sub-zones are all in the order of living > production > ecology. The remote location and complex terrain of these regions hinder transportation and limit basic public services, reducing convenience and resident satisfaction. The limited human activity, combined with inadequate public service facilities, weakens living vitality, resulting in outward migration. Furthermore, strict ecological protection policies and a homogenous industrial structure constrain the potential for productive development.

The obstacle patterns for various factors affecting vitality enhancement across the sub-zones are illustrated in Figure 7.

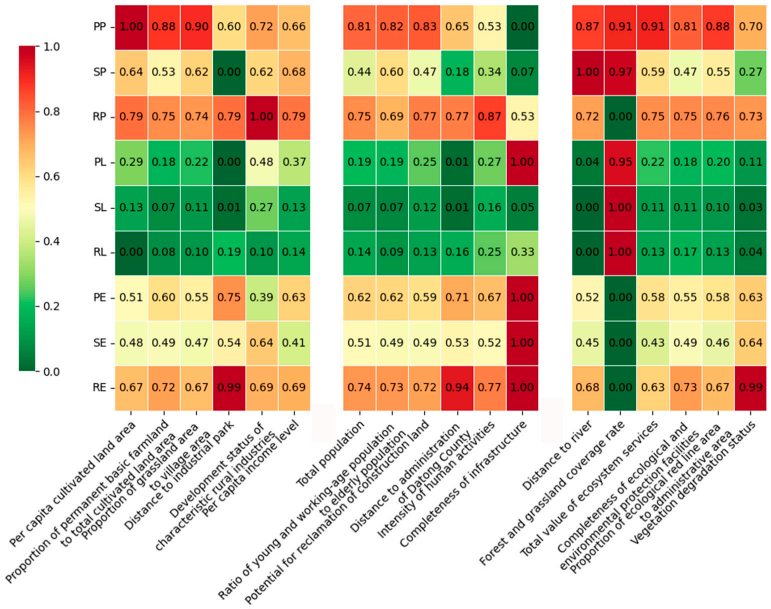


Figure 7. Obstacle patterns for various factors affecting vitality enhancement of different sub-zones.

4.5. Comprehensive Land Consolidation Strategy for the Study Area

Based on the obstacles faced in enhancing vitality across various sub-zones, this study identifies key points for land consolidation in each sub-zone to formulate targeted measures and constructs a comprehensive land consolidation (CLC) strategy consisting of five sub-strategies.

(1) Enhancing Production Vitality and Preserving Ecological Vitality

The PP and SP sub-zones aim to achieve sustainable production development but face significant challenges in enhancing ecological vitality. Therefore, this sub-strategy aims to enhance rural production vitality by optimizing land use and implementing sustainable ecosystem development measures. The goal is to establish a strong foundation for rural industries while ensuring the effective protection and sustainable management of ecological resources. By improving infrastructure and enhancing the quality of cultivated land, this strategy seeks to create a balanced system that supports both agricultural productivity and ecological preservation.

To enhance production vitality, it is essential to implement the cultivated land requisition–compensation balance policy to prevent imbalances in farmland utilization. Furthermore, the rational expansion and efficient use of construction land should be promoted, while particular emphasis is placed on improving the quality and concentration of cultivated land. In addition, accelerating the development of rural roads and infrastructure is vital to establish a solid foundation for rural production and to ensure the sustainable growth of both upstream and downstream industries. To restore ecological vitality, optimizing land use and coordinating efforts for sustainable ecological development are crucial. In addition, strengthening environmental monitoring can help prevent environmental damage from production activities, and polluted land should be gradually restored. Moreover, efforts should be directed toward realizing the value of ecological products and promoting the formation and development of local ecological industries by integrating and leveraging rural resources.

(2) Production Vitality-Oriented Land Consolidation

The primary objective for the RP sub-zone is production development, yet its greatest challenge in enhancing overall vitality lies in the limitations of its production capacity. Therefore, the focus of this sub-strategy is to stimulate economic vitality in rural production spaces by fostering the development of characteristic industries and leveraging regional advantages. The goal of this process is to establish a competitive and sustainable industrial system that utilizes local resources efficiently. By promoting an ecological resource-based economy and attracting talent, this strategy aims to drive regional economic growth and improve overall productivity.

To significantly boost production vitality, this area should leverage its regional advantages to foster an ecological resource-based economy. By taking advantage of rural revitalization policies, the region should promote the development of characteristic industries, build ecological brands, and attract skilled talent to support village revitalization. Additionally, public services must be improved to facilitate industrial growth and create channels for capital investment.

(3) Living Vitality-Oriented Land Consolidation

The primary objective for the PL sub-zone is to enhance living conditions, with the main challenge being the improvement of living vitality itself. Thus, this sub-strategy seeks to improve the quality of rural living spaces by enhancing infrastructure and public services, thereby strengthening social cohesion and creating an environment that attracts and retains residents. The goal is to foster a livable, well-connected community that supports the long-term stability and development of rural populations, contributing to the overall sustainability of rural areas.

To achieve substantial progress in living vitality, it is essential to capitalize on policy opportunities, such as the reallocation of permanent basic farmland, to optimize residential

land use patterns, attract industrial investment, secure financing, and expand the influence of industrial parks. Improving supportive infrastructure, providing convenient residential services, fostering village development hubs, and mitigating the risk of labor outflow are also crucial for this area's sustainable development.

(4) Enhancing Living Vitality and Preserving Ecological Vitality

The SL and RL sub-zones seek to improve living conditions, with the greatest challenge being ecological restoration. Therefore, this sub-strategy focuses on improving living conditions while simultaneously protecting and restoring ecological systems. The goal is to create a sustainable living environment through ecological restoration and comprehensive land use planning, minimizing human impact and ensuring the stability of ecosystems. By coordinating agricultural and ecological efforts, this strategy aims to establish a development model that meets the demand for high-quality living conditions and safeguards ecological health.

To enhance living vitality, industrial transformation should be employed as a strategic measure to facilitate improvements in living standards. Comprehensive agricultural consolidation, along with integrated planning for fields, water, roads, and forests, can significantly improve the suitability of the living environment through more efficient land use structures. Additionally, enhancing the rural landscape and optimizing infrastructure and public services are essential to meeting the growing demand for high-quality living conditions. For stable restoration of ecological vitality, it is critical to prevent environmental degradation, minimize human interference, and avoid encroaching on ecological land. Strengthening ecological monitoring to assess restoration potential, identify key issues and critical factors, and implement appropriate remedial actions after thorough evaluation is a vital measure that should be taken.

(5) Enhancing Ecological Vitality and Living Vitality

The PE, SE, and RE sub-zones serve as ecological barriers for Datong County, where the primary focus is on ecological protection, while improving living conditions presents the most significant challenge. Therefore, this sub-strategy emphasizes the protection of key ecological barriers while improving rural living conditions in an environmentally sustainable manner. The goal of this process is to restore and preserve ecosystem integrity, increase the production capacity of ecological products, and balance ecological and economic objectives. For populated ecological villages, this strategy seeks to enhance infrastructure while developing eco-tourism and resource-based industries, ensuring a harmonious integration of ecological and human activities.

To enhance ecological vitality, it is imperative to preserve ecosystem integrity by adhering to conservation principles and natural restoration processes to promote ecological recovery and reconstruction. Improving the production capacity of ecological products is also crucial to balancing ecological and economic objectives, such as developing and protecting ecological resources and scenic environments, forming distinctive advantages, and fostering integrated ecological industries. In terms of improving living vitality, ecological village consolidation should be implemented in more populated areas, with upgrades to infrastructure such as roads, power supply, communication networks, and water environment protection systems. For villages with fragile ecological environments and ongoing population outflows, relocation plans should be considered.

5. Discussion

Our research presents the "Vitality Status Evaluation—Vitality Enhancement Zoning—Land Consolidation Guidelines" framework as an effective and structured approach for developing CLC strategies. By incorporating goal-oriented and efficiency-driven zoning, this framework enhances the scientific rigor of CLC processes. Unlike previous research that primarily focuses on comparing the benefits of CLC strategies before and after implementation, or is limited to analyzing single elements or spaces, our approach integrates multiple dimensions [70]. By combining scenario assessment with integrated zoning adaptable to

diverse social and economic contexts, our framework addresses the unique challenges faced by different regions. The framework is further refined by deconstructing components longitudinally, enabling the development of tailored sub-strategies to meet the long-term needs of various regions.

Compared to previous studies, this research refines the intrinsic relationship between SVRPLE and CLC, aligning CLC objectives with broader rural development goals that emphasize balanced progress across production, living, and ecological spaces [71]. This alignment is critical for achieving China's integrated development vision, particularly in the context of urban–rural integration and shared prosperity [72]. Additionally, we also explore the interactive mechanisms between SVRPLE and CLC. Past research has demonstrated the role of CLC in optimizing resource allocation and fostering bi-directional flow between urban and rural areas, thereby enhancing rural vitality [73]. For instance, CLC has been shown to facilitate the movement of production factors and consumers into rural areas, while enabling the flow of rural products and services to urban markets, creating a pathway for rural revitalization. However, there remains a lack of policy coordination addressing the complex interdependencies between CLC's long-term development and the production, living, and ecological dimensions of rural systems. Balancing economic benefits with ecological sustainability continues to be a significant challenge.

Despite the potential of CLC, some scholars argue that ecological constraints may limit its effectiveness. In contrast to this view, other researchers have found that the retention of or withdrawal from CLC pilot areas is primarily influenced by land use and economic factors, with economic considerations being particularly decisive in determining whether an area continues as a pilot site [74]. Thus, the future development of CLC requires not only active participation from various stakeholders but also a strong emphasis on optimizing efficiency and benefits.

The three consolidation objective zones identified in this study, namely the production development zone, living improvement zone, and ecological protection zone, are distributed from southeast to northwest, covering 33.73%, 6.84%, and 59.42% of the total area, respectively. This zoning pattern aligns well with the socio-economic and environmental characteristics of the study area, where the economic and social centers are concentrated in the southeast near Xining, the capital of Qinghai Province, and reduce in proportion with the transition to high-altitude regions in the northwest, which are dominated by extensive forests and grasslands. This arrangement corresponds to the functional roles designated for different villages in the territorial spatial planning of the area. Moreover, the priority, secondary, and restricted consolidation zones account for 22.69%, 22.00%, and 54.31% of the total area, respectively. The production development zone contains extensive areas designated as priority and secondary consolidation zones, whereas the living improvement and ecological protection zones are primarily classified as restricted consolidation zones. This arrangement facilitates a gradual progression of consolidation efforts, starting with simpler tasks and advancing to more complex ones, with the priority zone serving as a pilot area to lay the groundwork for CLC. This validation confirms that the proposed CLC framework ensures rational zoning and facilitates the efficient implementation of CLC efforts. By incorporating an obstacle analysis model, the framework enhances spatial balance and provides precise, targeted guidance for rural revitalization.

It is worth noting that the rural vitality evaluation indicator system developed in this study, which is oriented toward CLC, still has room for further refinement. We recognize that certain important indicators, such as land use efficiency, cultural heritage preservation, and the level of community engagement, are crucial in providing a more comprehensive representation of rural vitality and can be effectively improved through relevant CLC measures. For instance, CLC can improve land use efficiency through land optimization and rational planning; promote cultural heritage preservation and restoration projects to support cultural continuity; and enhance community engagement by involving villagers in land consolidation and decision-making processes. However, due to challenges in obtaining village-level data, these indicators were not fully incorporated into the current

study. Therefore, future studies will focus on gathering more extensive data to further enhance this evaluation system. At the same time, we advocate for greater attention to the establishment and management of rural data systems in future rural management and land consolidation practices. We also suggest that scholars, when adopting the indicator system presented in this study, consider adjusting it based on the specific context of their research areas to better align with local needs.

Building on this, future research will deepen the study of this topic in terms of several key areas. First, future work will focus on collecting more data from rural areas to refine and enhance the proposed CLC rural vitality evaluation framework. This may involve incorporating factors such as land use efficiency, community participation, historical landscape preservation, and cultural heritage protection, all of which are crucial for strengthening rural vitality. By integrating these elements, we aim to further optimize the implementation of CLC and deepen our understanding of social and cultural contributions to sustainable rural development. Second, we will explore how rural vitality can be enhanced by balancing production, living, and ecological functions. This includes studying the coupling and coordination of these aspects under different CLC strategies, with particular emphasis on achieving synergy between economic growth and ecological sustainability. On the methodological level, future work should also explore ways to further integrate resources, enhance the efficiency and effectiveness of CLC, and strengthen research on rural vitality evaluation methods in China, thereby contributing to the refinement of CLC strategic practices.

Based on the key findings of this study, we propose the following policy recommendations. It is crucial to develop region-specific comprehensive land consolidation guidelines that address varying ecological, agricultural, and urbanization needs. By adjusting the allocation of spatial units within the three-dimensional cube model, zoning outcomes can be optimized for each region. Additionally, enhancing the regional adaptability of the CLC framework can be achieved by refining the rural vitality evaluation system through the addition or removal of indicators and the adjustment of their weights in response to the specific conditions of different regions. For example, in areas with intensive agricultural activities and high population density, prioritizing land optimization and sustainable farming practices is essential. In contrast, for regions with fragile ecosystems and lower population density, land consolidation efforts should focus on promoting ecological restoration and ensuring balanced resource utilization. Beyond this, to ensure that these strategies are effectively implemented and achieve the desired outcomes, it is equally important to establish a comprehensive monitoring and evaluation system. This system should track the progress of strategy implementation at the village level, encourage innovation and experimentation within CLC practices, and use the achievement of key indicators as performance metrics. Regular evaluations of CLC implementation will facilitate ongoing improvements and enhance its overall effectiveness.

The findings of this study can inform international rural development policies by offering an adaptable CLC strategy and a robust vitality assessment framework. Additionally, adjusting the proposed CLC framework to align with the ecological and economic conditions of different regions reinforces the global emphasis on balancing economic development and ecological conservation, thereby fostering sustainable, context-specific rural revitalization.

6. Conclusions

The main conclusions of this study are as follows: (1) CLC and rural vitality are mutually reinforcing. As a key strategy for activating the vitality of rural spaces and their elements, CLC reshapes rural areas by optimizing the synergistic interactions between production, living, and ecological spaces. This creates a positive feedback loop that enhances vitality, addresses development bottlenecks, stimulates endogenous growth, and fosters sustainable development. (2) The goal-oriented and chronologically classified CLC strategy provides a clear temporal sequence and hierarchical structure for zoning, achieving not only a reasonable division of consolidation zones but also enhancing the scientific and

logical rigor of the CLC zoning process, offering a more systematic planning framework for CLC. (3) The CLC strategy, designed to enhance SVRPLE, integrates the evaluation of current vitality status, goal setting, implementation sequencing, and the identification of potential obstacles, fully embodying the concept of comprehensive consolidation across all regions and elements. This strategy helps fully stimulate the intrinsic vitality of rural areas, enhancing the quality and optimizing the efficiency of rural production, living, and ecological spaces. It provides strong support for the acceleration of rural revitalization and holds significant practical guidance value. At the same time, it enriches research on the construction of an indicator system for rural vitality and is a beneficial supplement to research on rural vitality in China. (4) We advocate for future CLC policies to place greater emphasis on balancing production, living, and ecological spaces, with improvement in efficiency as a core priority. Tailoring the CLC framework to regional characteristics by flexibly adjusting the parameters of its components, along with the innovative rural vitality evaluation system proposed in this study, can integrate the CLC framework with region-specific considerations. Furthermore, it is essential to establish a long-term, comprehensive monitoring and evaluation system aimed at enhancing rural vitality.

China is currently undergoing a critical period of transformation in agricultural and rural development, creating an urgent need to establish a reliable and efficient development path for rural areas through CLC. Enhancing SVRPLE and promoting rural revitalization are the core purpose and historical mission of CLC. In summary, this paper explores the intrinsic relationship between CLC and SVRPLE, explaining the mechanism of interaction between the two. By proposing a phased and zoned CLC strategy, our research addresses critical challenges in rural development and provides a systematic framework to enhance implementation efficiency while balancing economic productivity, social well-being, and ecological sustainability. This integrated approach not only contributes to the theoretical understanding of rural vitality enhancement but also provides practical guidance for future comprehensive land consolidation and rural revitalization efforts.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/land13122092/s1, S1: A detailed description of using the spatially constrained multivariate clustering algorithm to delineate consolidation objective zones; S2: A detailed explanation of why this study selected these 18 indicators to evaluate rural vitality. References [57,58,75,76] are cited in the Supplementary Materials.

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