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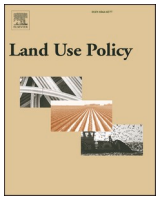

Socio-economic impacts, challenges, and strategies for whole-region comprehensive land consolidation in China

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ABSTRACT

Amid increasingly complex challenges of unsustainable rural development, China introduced the whole-region comprehensive land consolidation (WCLC) policy in late 2019. The WCLC aims to address issues such as farmland fragmentation, inefficient construction land use, disorganized village layouts, and ecological degradation. Building on the WCLC socio-economic and ecological benefits analysis framework, this study takes Dudu village in central Anhui Province, China, as a case study to assess its socio-economic benefits through cost-benefit analysis. Results indicate that WCLC represents a progressive phase in land consolidation, integrating a bottom-up approach with extensive collaboration across departments and stakeholders. Despite its high cost, WCLC proves economically viable and yields substantial socio-economic benefits, including enhanced land utilization efficiency, reduced costs, increased gain yields, improved agricultural conditions, and strengthened community cohesion. WCLC has indeed played a significant role in optimizing rural production-living-ecological spaces. However, challenges persist, encompassing an inadequate and underdeveloped mechanism for diversified funding inputs, limited societal engagement, insufficient impetus from local governments for implementation, a lack of comprehensive systemic consideration, and the absence of well-defined performance evaluation criteria for the project. Addressing these issues through innovative policies and institutional reforms is essential to enhance WCLC's effectiveness, contributing to rural revitalization and sustainable development. These findings provide valuable insights for China and other nations seeking to refine land use policies for optimal resource allocation and regional sustainability.

1. Introduction

Land is the foundation of socio-economic activities and essential for human survival (Long et al., 2019). Increasing demands from population growth, urbanization, and industrialization have intensified the reliance on land resources, while unsustainable practices have led to degradation, salinization, and desertification (Zhou et al., 2020a). The scarcity and deteriorating quality of cultivated land pose significant constraints on sustainable development (Gomiero, 2016). Land consolidation, originating in Western Europe, has become a key strategy to address these challenges by increasing arable land (Pašakarnis et al., 2021). In regions like Spain and Germany (Bavaria), it has boosted agricultural productivity and restructured rural land ownership (Bronstert et al., 1995; Van Dijk, 2007; Crecente et al., 2002). Initially focused on compensating for lost farmland, land consolidation has evolved to into a critical tool for promoting rural development (Crecente et al., 2002; Pašakarnis and Maliene, 2010; Jiang et al., 2021).

China, facing tense human-nature relationships, has designated land consolidation as a pivotal strategy for addressing rural development challenges. While land consolidation practices data China date back to 1066 BC, modern initiatives began in the 1950s, only becoming widespread in the late 1990s (Wang, 1997; Huang et al., 2011). Over the past two decades, land consolidation has proven essential for increasing the quantity and quality of cultivated land (Jin et al., 2017; Jiang et al., 2017; Du et al., 2018), enhancing farmers' incomes (Wang et al., 2021), and supporting poverty alleviation and rural revitalization (Zhou et al., 2019; 2020a; Li et al., 2023). It also enhanced land-use efficiency (He et al., 2019), driven rural industrial growth (Wang et al., 2023), and

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prevented land degradation (Molnárová et al., 2023). These efforts play a critical role in maintaining arable land balance, ensuring food security, and optimizing rural land resources (Rao, 2022). Land consolidation is also regarded as an important institutional arrangement in China for optimizing land resource allocation and promoting urban-rural space governance (Yue et al., 2024). Land consolidation has been widely regarded as yielding significant socio-economic and ecological benefits, providing crucial insights for shaping land use policies and practices in China (Jin et al., 2016; Duan et al., 2021; Zhong et al., 2020).

However, challenges persist, including land fragmentation, non-agricultural land use (Liu et al., 2019, 2023a; Deng et al., 2024), disorganized settlement expansion (Liu et al., 2023b), inefficient construction land use (Liu et al., 2022; Zhou et al., 2023a), and ecological degradation (Han, 2020). In 2017, the average land operated per household was just 0.5 ha in China, with over 85 % managing less than 0.67 ha, limiting large-scale farming and reducing production efficiency (Lu et al., 2018; Du and Xiao, 2019; Lai et al., 2020). From 2009 to 2019, China's village settlement land increased by 34 % despite a 38 % rural population decline (Xinhua Agency, 2021). The shortage of industrial land, driven by strict land-use controls, further complicates rural development (Zhou et al., 2023a). These issues underscore the limitations of traditional land consolidation in address the element shortages, structural imbalances, and functional declines in rural areas (Liu et al., 2023; Wang et al., 2023).

In response, the Ministry of Natural Resources of China (MNR), inspired by pilot projects in Zhejiang province, proposed the Whole-Region Comprehensive Land Consolidation (WCLC) initiative in 2019, designating 446 national pilots in 2021 to integrate the consolidation of agricultural, construction, and ecological lands at the township level (Ministry of National Resources of China MNR, 2019; Pan et al., 2023). This holistic approach addresses issues such as arable land fragmentation, disorganized rural settlements, and inefficient land use, while promoting ecological preservation and rural revitalization (Fan et al., 2021). WCLC seeks to optimize rural production-living-ecological spaces, improving land utilization efficiency and supporting sustainable development (Fan et al., 2021; Guo and Wang, 2023). The spatial distribution of WCLC national pilot projects exhibits significant heterogeneity, primarily influenced by the combined effects of natural geographic conditions, agricultural production factors, and economic development conditions (Kuang et al., 2023). By the end of 2023, 1304 pilot projects had been launched across China nationwide, with an investment of RMB 448.8 billion. These projects consolidated of 252, 000 ha of land, added 31,000 ha of arable land, and reduced construction land by 8000 ha (Wang and Zhong, 2024).

Existing research has primarily focused on the developmental trajectory (Fan et al., 2021; Guo and Wang, 2023), underlying logic (Jin et al., 2022), and implementation pathways (Liu et al., 2021) of WCLC, with some studies addressing the key challenges encountered during the implementation process (Zhou, 2020; Jin et al., 2022). For example, Yan and Cai (2022) systematically elaborated on the strategic background, significance, objectives, and implications of WCLC. Ying et al. (2022) developed a WCLC performance evaluation method that integrates Actor-Network Theory with the Structure-Process-Outcome framework. WCLC is a process involving multiple stakeholders and diverse participants, in which village-level organizations play a crucial role (Pan et al., 2023). Implementing WCLC in metropolitan peripheries helps enhance the multifunctionality of arable land (Zhou et al., 2021; Liu et al., 2023). He et al. (2022) argue that WCLC can significantly drive the transformation of agricultural management models, operational scale, and production methods. WCLC, especially through nature-based initiatives, can contribute to energy conservation and emission reduction goals by transforming land use practices and optimizing land use structures (Lv et al., 2022). WCLC can promote the urban-rural integrated development by optimizing the spatial configuration of urban and rural areas (Luo et al., 2024). WCLC promotes rural industrial upgrading and integration by optimizing land resource allocation, driving multi-channel investment, and achieving multi-dimensional hollowing governance (Ying et al., 2023). Unlike conventional land consolidation, WCLC integrates engineering, managerial, and social elements, targeting multifaced challenges in rural development (Jin et al., 2022; Jin and Ying, 2023).

Existing studies have provided valuable insights for China's WCLC decision-making and practice. However, most of them focuses on qualitative descriptions of WCLC's theoretical framework, implementation pathways, and practical value, with limited investigation into its socioeconomic and ecological effects, which deserves further exploration. To bridge this significant knowledge gap, this study develops an analytical framework for evaluating the socioeconomic benefits of WCLC. It further examines the socio-economic impacts of WCLC through a case study of Dudu village in Anhui Province, central China. The marginal contribution of this study lies in utilizing a typical case study and cost-benefit analysis to systematically deconstruct the socioeconomic benefits of China's WCLC. It seeks to answer the critical question of whether WCLC is economically viable, while proposing a comprehensive framework for assessing the socioeconomic benefits of the initiative. Through this research, we aim to provide a scientific foundation and practical insights to support the comprehensive evaluation of WCLC's socioeconomic impacts across China.

2. Theoretical Framework

2.1. WCLC: An advanced form of land consolidation

Since the implementation of the reform and opening-up policy in 1978, China's land consolidation has undergone four distinct stages to meet different development needs, i.e., land rearrangement, land consolidation, comprehensive land consolidation, and WCLC (Guo and Wang, 2023). Over time, the objectives, definitions, functions, and practices of land consolidation have progressively expanded and diversified, reflecting an enriched understanding and application of this strategy (Table 1). Initially focused on agricultural land, it now encompasses village construction land, industrial and mining land, and ecological and residential areas. The goal has broadened from merely increasing the quantity of arable land to enhancing both its quantity and quality, boosting agricultural productivity, protecting ecosystems, and optimizing national spatial planning to support targeted poverty alleviation and rural revitalization (Zhou et al., 2020b). The socioeconomic characteristics of land resources highlight the multifunctional role of land consolidation (Hartvigsen, 2014).

Driven by China's national priorities such as rural revitalization, ecological civilization construction, and newly-type urbanization, the functions of land consolidation have evolved from singular goals, such as increasing farmland quantity and quality, to multifaceted objectives (Zhou et al., 2020b; Liu et al., 2023). These now encompass enhancing agricultural productivity, safeguarding food security, optimizing land use at both the village and national levels, protecting and restoring ecosystems, improving living conditions, promoting modern agriculture, and boosting farmers' income (Guo and Wang, 2023). The methods have progressed from simple plot arrangements to integrated land consolidation projects and large-scale engineering initiatives that prioritize the harmonious integration of biological, agronomic, and engineering measures (Han et al., 2022). This transition from spontaneous, unorganized efforts to systematic, large-scale operations highlights a shift towards balancing quantity with quality, while integrating land management with ecological and environmental considerations. It reflects a more ecologically-oriented approach to land consolidation.

WCLC represents an innovative evolution in comprehensive land consolidation, signifying an advanced stage in its development (Sun and Lu, 2023). Its value lies in a holistic approach to managing and consolidating a region's natural, economic, social, and ecological components across all sectors, factors, and life cycles (Fan et al., 2021). WCLC targets land within specific areas requiring renovation,

Table 1
The evolution of land consolidation policies in China since 1978.

Stage	Objects	Goals	Measures	Main features
Land arrangement (early stage of exploration, 1982–1997)	Farmland	Supply farmland	Individual land consolidation project	• Spontaneous and disorderly land consolidation • Preliminary exploration of land consolidation for farmland protection • Linking farmland occupation and supplement
Land consolidation (Extensive and orderly stage, 1998–2007)	• Farmland • Village construction land	• Increase farmland quantity • Improve farmland quality	• Combining projects and engineering • Combining farmland consolidation and village renovation	Orderly land consolidation
Comprehensive land consolidation (Quality improvement stage, 2008–2018)	• Farmland • Village construction land • Urban industrial and mining land	• Increasing farmland- improving farmland quality-protecting ecology • Supporting targeted poverty alleviation	Major land consolidation projects	• Large-scale land consolidation • Quantity-Quality-Ecology Trinity
Whole-region comprehensive land consolidation (Efficient innovation stage, since 2019)	• Agricultural land • Construction land • Ecological land • Living environment • Others	• Optimize land space • Support rural revitalization • Protect the ecosystem	• Nature-based land consolidation • Combining biological, agronomic and engineering measures	• Whole-region and all elements comprehensive land consolidation • Resource-Environment-Ecology Trinity

Notes: The table is compiled by the authors.

addressing the region's entire natural, economic, social, and ecological systems. Key stakeholders—governments, village collectives, farmers, and enterprises—play crucial roles. The WCLC's goal is to optimize the flow of energy, materials, and information to improve the efficiency and balance of natural, social, and economic systems, promoting coordinated development.

This approach is long-term, complex, and dynamic, requiring a comprehensive management mechanism that encompasses resource assessment, planning, implementation, monitoring, and feedback to ensure sustainability (Yan and Cai, 2022). WCLC integrates principles of sustainable rural development and ecological protection, significantly influencing the distribution of production factors such as labor, capital, land, information, and technology. It would play a key role in restructuring rural production-living-ecology spaces—and recalibrating the human-land relationship (Sun and Lu, 2023). Compared to traditional methods, WCLC is more intricate, covers larger areas, demands greater technical proficiency, and is expected to have a profound impact on the socio-economic and ecological landscapes of rural regions.

2.2. The evaluation framework for WCLC impacts

Over the past four decades, China has made remarkable achievements in agricultural and rural development (Han, 2020). However, alongside changes in the rural depopulation, the optimization of land resource allocation in rural areas faces significant challenges, particularly manifested in the discoordination of the rural production-living-ecological (three-life) spaces (Liu et al., 2010 ; Long et al., 2016). Production space problems include fragmented farmland, urban encroachment on prime agricultural areas, limited integration space for rural industries, and a lack of production facilities (Song et al., 2023; Robinson, 2024). Challenges in living space involve disorganized village layouts, degraded living environments, inadequate rural infrastructure, and village hollowing (Li et al., 2014; Yang et al., 2015). Ecological space is threatened by construction on protected lands, fragmented landscapes, and ecological degradation (Cao et al., 2020; Zou et al., 2022). These issues largely stem from imbalanced resource flows between urban and rural settings and historical policies that favored urban and industrial interests over rural and agricultural ones (Zhou et al., 2023b).

In response to sustainable development strategies, the Chinese government has leveraged the WCLC since 2019 as a key tool for optimizing the "three-life" spaces in rural areas. The main objective of WCLC is to optimize the allocation of rural production-living-ecological spaces by consolidating agricultural, construction, and ecological lands, as well as preserving historical and cultural heritage (Zhang et al., 2022). This approach aims to enhance agricultural productivity, improve rural living conditions, support rural revitalization, and facilitate urban-rural integration (Fig. 1). WCLC effectively addresses systemic challenges such as farmland fragmentation, disorganized village layouts, inefficient use of construction land, and environmental degradation (Ao et al., 2020; Zhong et al., 2024). It promotes a balanced allocation of urban and rural resources, adjusts urban-rural spatial structures, and enhances the functional value of both urban and rural areas (Sun and Lu, 2023). Additionally, WCLC fosters the deep integration of rural production-living-ecological spaces (Liang and Li, 2024) and significantly improves the appeal of rural tourism, making rural areas more comfortable and attractive (He et al., 2024). WCLC acts as a spatial framework that enhances sustainable rural growth by refining spatial structures, bolstering organizational effectiveness, and reinforcing spatial functions (Liu et al., 2020). It addresses rural development's systemic challenges by integrating the management of agricultural, construction, and ecological lands, as well as living environments, on a comprehensive regional scale (Liu et al., 2023a).

WCLC typically involves comprehensive consolidation of agricultural land, construction land, and arable land in rural areas, and human settlement improvement as well as historical and cultural heritage protection. For agricultural land consolidation, its focus includes fragmented farmland, polluted or degraded land, inefficiently utilized farmland, and reserve arable land resources. Consolidation measures include farmland quality improvement projects, arable land supplementation projects, and high-standard farmland construction projects. The consolidation of construction land targets the unused homesteads, abandoned industrial and mining sites, and inefficient unused land (such as pits and ditches). The primary measure for construction land consolidation is land reclamation. For ecological land, the focus is on degraded or polluted ecosystems, with ecological restoration and protection projects being the key measures. The remediation of human settlements and cultural protection targets living environments, infrastructure, public services, and traditional ancient villages. The corresponding measures include residential environment improvement projects and cultural heritage protection projects.

The benefits of WCLC encompass socioeconomic and ecological

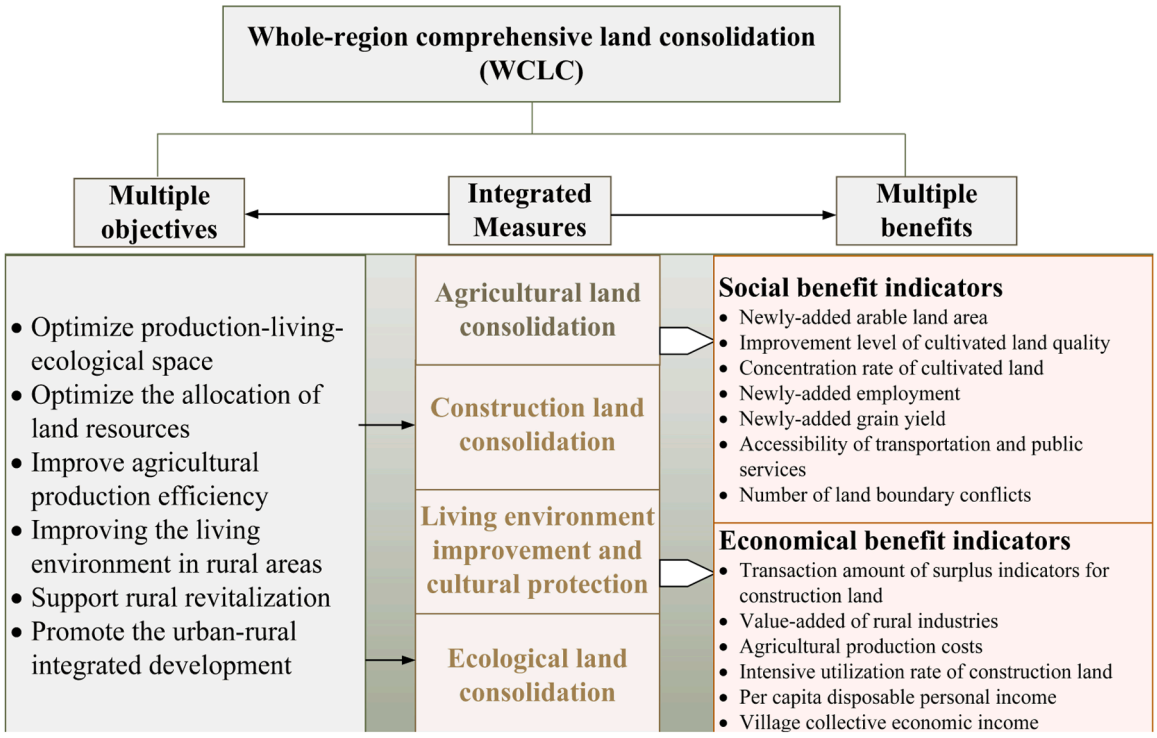

Fig. 1. The evaluation framework for the socioeconomic benefits of WCLC.

effects. Social effects can be measured through specific indicators such as the amount of newly added arable land, the grade improvement of arable land quality, the arable land consolidation rate (the number of land parcels), the number of new jobs created, the increase in grain production, the accessibility of transportation infrastructure and public services, and improvements in public health. Economic benefits can be assessed by indicators such as collective village economic income, per capita net income of villagers, added industrial value, and the transaction value of surplus construction land quotas. It is important to note that WCLC benefits include both long-term and short-term effects. Long-term benefits, such as improvements in human health and most ecological benefits, may not be immediately observable and require long-term monitoring to fully assess.

3. Data and methods

3.1. Study area and data sources

This study selects Dudu village in Wuwei City, Anhui Province, located in central China, as a typical case to investigate the socio-economic benefits of WCLC. Dudu village is located in the western part of Wuwei City, covering a total land area of 950 ha, with 341 ha of arable land (Fig. 2). In 2022, the village had 970 households and a population of 3813, with 15 % of the population aged 65 and above. In 2019, the per capita net income of villagers was RMB 22,887, and the village's economy primarily relied on farming and animal husbandry.

Like many mountainous regions in China, Dudu village's sustainable development is challenged by fragmented farmland, dispersed village layouts, village hollowing, and ecosystem degradation. Dudu village is located in a hilly and undulating terrain, where the land is scattered and fragmented, with a low degree of contiguous land parcels. This fragmented land structure severely limits the potential for land consolidation, transfer, and large-scale agricultural operations. The village's residential buildings, primarily self-built by villagers, vary widely in quality—some are aging and potentially unsafe. The layout of housing is scattered, marked by illegal constructions and frequent instances of oversized residences, which contradicts the 'one household, one residence' rule mandated by Chinese Land Management Laws. Despite the high demand from young adults for new housing, the village faces a critical shortage of land allocation indicators. This challenge is exacerbated by an aging population and significant out-migration, resulting in underused farmland and contributing to village depopulation and land inefficiency. In addition, the village's agricultural infrastructure is underdeveloped, with poor roads and network systems, hindering farmland productivity. Moreover, the integration of village construction with the natural landscape is lacking, leading to a suboptimal living environment. As one of the national pilot projects, Dudu village implemented the WCLC initiative from 2021 to 2023 to address the challenges faced in rural development.

The WCLC project in Dudu village encompasses key initiatives in agricultural land consolidation, construction land remediation, living environment enhancement, and rural historical and cultural preservation. Agricultural land consolidation includes the conversion of dryland to paddy fields (2 projects, 4.0041 ha) and the development of arable land reserve resources (24 projects, 13.9238 ha). Construction land remediation involves the reclamation of old residential sites in four natural villages, covering 318 households (17.8513 ha). The living environment enhancement projects comprise the construction of resettlement areas, including resettlement housing, infrastructure, and public service facilities (7.0675 ha), along with road improvement and upgrading projects (7.5 km). The rural historical and cultural preservation efforts primarily focus on the ecological remediation of river channels (3.0446 ha).

The WCLC initiative necessitates adjustments in land ownership, including the rights to residential land, collective construction land, and the contracted management rights of agricultural land. Specifically, the residential land use rights of 318 households (17.8513 ha, 37 parcels) have been reclassified as arable land, with an additional 8 parcels (6.9343 ha) of collective operational construction land being added, primarily from previously unused land. The adjustment of agricultural land contracting rights involves 24.5703 ha (55 parcels). These land ownership adjustments were conducted through village representative

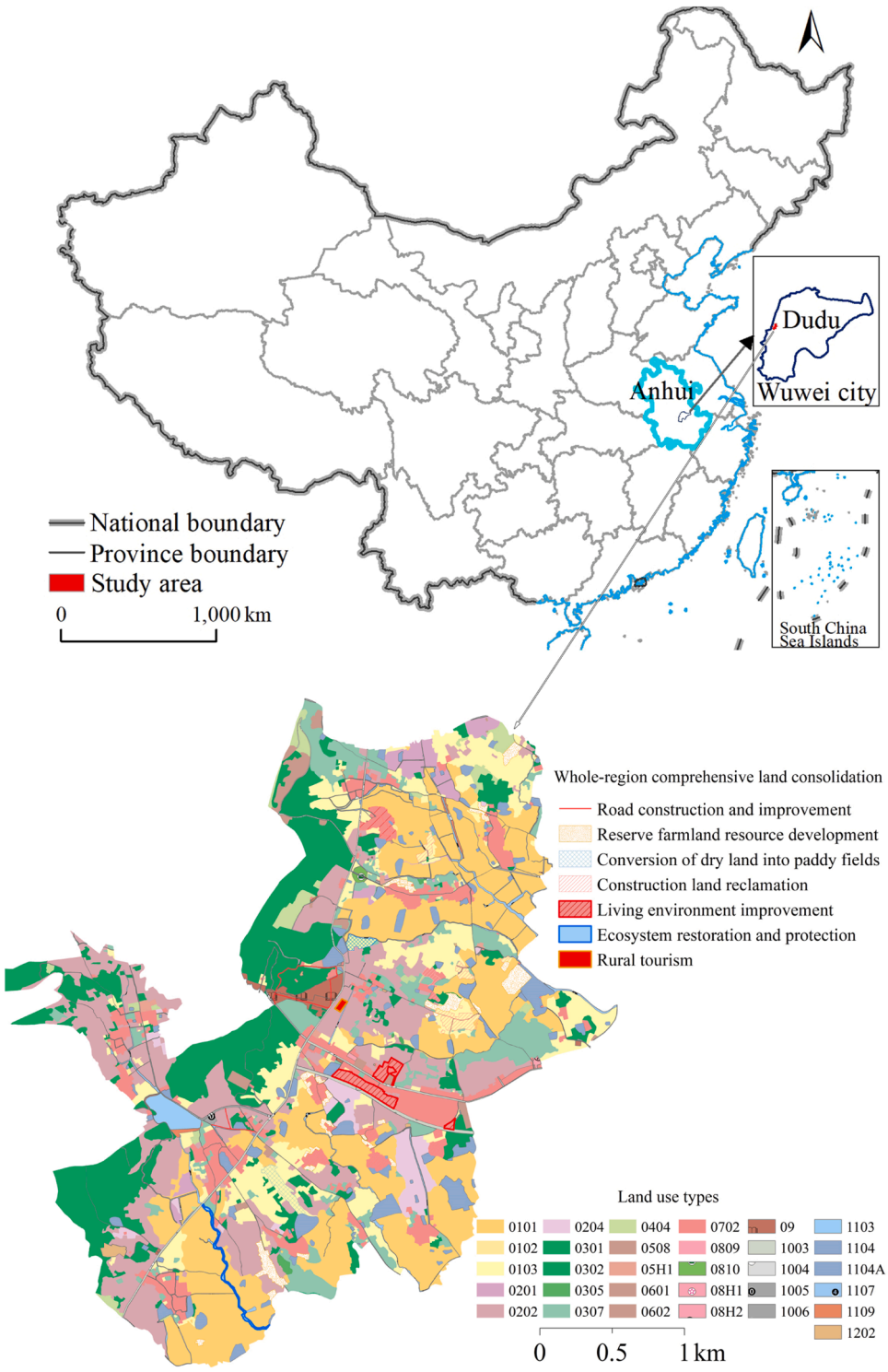

Fig. 2. Study area and its whole-region comprehensive land consolidation. Notes: The codes for specific land classes are listed below: 0101 (paddy field), 0102 (irrigated land), 0103 (dry land), 0201 (orchard), 0202 (tea garden), 0204 (other garden land), 0301 (arbor woodland), 0302 (bamboo woodland), 0305 (shrub woodland), 0307 (other forest land), 0404 (other grassland), 0508 (logistics and warehousing land), 05H1 (commercial service industry facility land), 0601 (industrial land), 0602 (mining land), 0702 (rural homestead), 0809 (Land for public facilities), 0810 (parks and green spaces), 08H1 (other land), 08H2 (land for science, education, culture and health), 09 (other), 1003 (road land), 1004 (urban and village road land), 1005 (traffic service places) Land), 1006 (rural road), 1103 (reservoir water surface), 1104 (pond water surface), 1104 A (breeding pond), 1107 (ditch), 1109 (hydraulic construction land), 1202 (facilitated agricultural land).

meetings, public notices within the village, and approvals from the county-level government, with no disputes reported.

In addition, in the context of arable land quality enhancement, Dudu village implemented several key measures during the WCLC process, including topsoil replenishment, deep plowing and loosening, and soil fertility optimization. The topsoil replenishment involved selecting high-quality external arable soil, which was stripped and transported to the project area for backfilling. It was essential to ensure that the thickness of the cultivated layer exceeded 20 cm after the backfilling process. The deep plowing and loosening aimed to maintain an optimal

balance of soil compaction and moisture retention, with specific methods tailored according to the soil's maturity, profile structure, and crop planting requirements. The depth of plowing was generally kept within 20 cm. For soil fertility optimization, two primary strategies were employed. First, the use of commercial organic fertilizers, farmyard manure, green manure cultivation, and straw returning to the field helped increase the organic matter content in the soil, improving its permeability and enhancing the cation exchange capacity. Second, the application of limestone powder or superphosphate was used to adjust and improve soil pH, making it more conducive to crop growth. These measures effectively contribute to the improvement of arable land quality.

The data utilized in this study encompass the input-output metrics of the WCLC project in Dudu village, Wuwei City, Anhui Province, alongside the villagers' perceptions of the WCLC policy. These data were gathered during field research conducted by our team in Dudu village in July 2023. Specific data sets include Dudu village's land use data for 2020 and WCLC planning maps obtained from the Wuwei City Natural Resources and Planning Bureau. This study also surveyed villagers' satisfaction with the WCLC in terms of improving production conditions, living environments, and ecological spaces. We designed a questionnaire using a Likert 5-point scale to assess villagers' perceptions and attitudes towards the WCLC project, particularly regarding their understanding of land utilization efficiency, labor costs, irrigation costs, crop yields, landscape types, and ecological environmental changes before and after the project implementation. In July 2023, our team conducted face-to-face interviews and a questionnaire survey in Wuwei City to gather villagers' views and attitudes toward the WCLC project. A total of 139 villagers participated in the survey. The designed questionnaire is shown in Table 2.

Table 2
Villager attitude questionnaire on the WCLC project.

No.	Question	1	2	3	4	5
1	Do you think the WCLC project has improved land utilization efficiency?	☐	☐	☐	☐	☐
2	Do you think the WCLC project has reduced labor costs?	☐	☐	☐	☐	☐
3	Do you think the WCLC project has reduced irrigation costs?	☐	☐	☐	☐	☐
4	Do you think the WCLC project has increased crop yields?	☐	☐	☐	☐	☐
5	Do you think the WCLC project has diversified landscape types?	☐	☐	☐	☐	☐
6	Do you think the WCLC project has optimized landscape patterns?	☐	☐	☐	☐	☐
7	Do you think the WCLC project has improved the ecological environment?	☐	☐	☐	☐	☐
8	Do you think the WCLC project has reduced boundary conflicts?	☐	☐	☐	☐	☐
9	Do you think the WCLC project has reduced agricultural production conflicts?	☐	☐	☐	☐	☐
10	Do you think the WCLC project has increased village collective cohesion?	☐	☐	☐	☐	☐
11	How do your relatives and neighbors feel about your participation in the WCLC project?	☐	☐	☐	☐	☐
12	How does the village committee feel about your participation in the WCLC project?	☐	☐	☐	☐	☐
13	How does the township government feel about your participation in the WCLC project?	☐	☐	☐	☐	☐
14	Are your relatives and neighbors actively participating in the WCLC project?	☐	☐	☐	☐	☐
15	Is the village collective organization actively promoting the WCLC project?	☐	☐	☐	☐	☐
16	Is the local government actively promoting the WCLC project?	☐	☐	☐	☐	☐
17	How difficult do you think it is to participate in the WCLC project?	☐	☐	☐	☐	☐
18	Do you think the WCLC project will achieve the expected economic benefits?	☐	☐	☐	☐	☐
19	Can you access information about the WCLC project through multiple channels?	☐	☐	☐	☐	☐
20	Do you think you have the necessary knowledge and skills for the WCLC project?	☐	☐	☐	☐	☐
21	Do you think you have enough time to participate in the WCLC project?	☐	☐	☐	☐	☐
22	Do you think you can afford the costs associated with participating in the WCLC project if necessary?	☐	☐	☐	☐	☐

Notes: This questionnaire aims to understand villagers' perceptions and attitudes towards the WCLC project. The scale is as follows: 1 - Strongly Disagree; 2 - Disagree; 3 - Neutral; 4 - Agree; 5 - Strongly Agree.

3.2. Methods

3.2.1. Cost-benefit accounting

3.2.1.1. (1) Cost investment. Due to the involvement of WCLC in Dudu village, which encompasses the rectification of residential land, agricultural land, ecological land, and the improvement of the living environment, the cost input includes compensation for the demolition of farmers' old houses, investment in land consolidation projects (including agricultural land consolidation and the reclamation of construction land), investment in improving the living environment, and ecological restoration projects. Therefore, the total cost (C) of WCLC in Dudu village can be expressed by the following formula:

$$\boldsymbol{C} = \boldsymbol{C_1} + \boldsymbol{C_2} + \boldsymbol{C_3} \quad (1)$$

In this formula, C represents the total cost, C_1 denotes the demolition compensation fee, C_2 refers to the cost of land consolidation projects (including the consolidation of agricultural land and construction land), and C_3 represents the investment in improving the living environment and ecological restoration projects.

Among them, the WCLC demolition compensation (C_1) in Dudu village involves 318 households, with a total demolition area of 30,280.72 m^2. Among these, 18,171.36 m^2 are brick-tile structures, and 12,109.36 m^2 are brick-concrete structures. According to the demolition compensation standards of Wuwei City, the compensation rates for brick-tile and brick-concrete structures are RMB 1345 and RMB 1350 per m^2, respectively. The land consolidation project (C_2) involves a dryland-to-irrigated land conversion project (2 parcels covering a total of 4.0041 ha), an arable land reserve resource development project (24 parcels covering a total of 13.9238 ha), and a construction land reclamation project (37 parcels covering a total of 17.8513 ha). According to estimates by the Wuwei City government, the investment per ha for the dryland-to-irrigated land conversion, arable land reserve development, and construction land reclamation projects is RMB 1334, RMB 800, and RMB 1000 per ha, respectively. Additionally, the investment in improving the living environment and ecological restoration projects (C_3) includes expenditures for the construction of resettlement areas, the construction or renovation of infrastructure and public service facilities, as well as comprehensive river environment management.

3.2.1.2. (2) Benefit accounting. The total revenue (B) from WCLC in Dudu village primarily comes from transactions of surplus quotas under the urban-rural construction land linkage policy (B_1), transactions of newly added arable land quotas (B_2), dryland-to-irrigated land conversion revenue (B_3), rural tourism revenue (B_4), and grain production revenue from newly-added arable land (B_5). The formula for calculating these revenues can be outlined as follows:

$$\boldsymbol{B} = \boldsymbol{B_1} + \boldsymbol{B_2} + \boldsymbol{B_3} + \boldsymbol{B_4} + \boldsymbol{B_5} \quad (2)$$

Through the construction land reclamation project under WCLC, Dudu village obtained 12.61 ha of surplus urban-rural construction land quotas. According to the WCLC Implementation Plan for Dudu village in Kaicheng Town, Wuwei City (People's Government of Kaicheng Town, Anhui Province (PGKT), 2021), and interview data with the Natural Resources and Planning Bureau and Dudu village director of Wuwei City

Table 3
Cost-benefit of WCLC in Dudu village, Anhui Province.

WCLC project	Sub-items	Area or size (Price: million RMB/ha)	Cost (Million yuan)	Benefit (Million yuan)
Demolition compensation	Demolition of old houses (ha)	Brick-tile structure: 1.817 (10.45) Brick-concrete structure: 1.2109 (13.5)	35.3367	—
Land consolidation	Conversion of dry land into paddy fields (ha)	4.0041 (0.75)	1.2012	3.0031
	Development of reserve cultivated land resources for paddy fields (ha)	9.6993(1.80)	2.5063	17.4587
	Development of reserve cultivated land resources for drylands (ha)	2.2146 (0.45)		0.9966
	Construction land reclamation (ha)	12.9372 (4.50)	39.3532	58.2175
Living environment improvement and eco-environmental restoration	Resettlement area construction (ha)	6.7201 (1.429)	9.6000	—
	Construction of rural tourism facilities (ha)	0.1878 (10.65)	2.0000	—
	Rural road improvement and reconstruction (km)	7.5 (0.667)	5.0000	—
	River and pond management (ha)	3.0446 (3.022)	9.2000	——
Others	Annual operating expenses		0.5509	
	Newly-added arable benefit			0.4467
	Rural tourism revenue			0.9680

Notes: In this cost-benefit analysis, we only considered the direct economic benefits derived from the newly-added farmland, the transfer of surplus construction land indicators, and the development of rural tourism. However, the analysis currently excludes potential benefits related to land reclamation, such as enhancements in human health, the residential environment, and employment opportunities due to limitations in data availability. The values in parentheses within the third column indicate the specific prices associated with each type of expenditure.

in July 2023, the transaction price for the urban-rural construction land quota is RMB 4.5 million per ha (approximately RMB 0.3 million per mu) (B_1). According to the implementation plan of WCLC in Dudu village, Wuwei City, the reserve arable land resource development project includes two categories: the development of paddy fields and drylands, with transaction prices of RMB 1.8 million per ha for paddy fields and RMB 0.45 million per ha for drylands (B_2) (People's Government of Kaicheng Town, Anhui Province (PGKT), 2021). The dryland-to-irrigated land conversion project (4.0041 ha) receives a government subsidy of RMB 0.75 million per ha (B_3). Rural tourism generates an annual revenue of approximately RMB 0.968 million (B_4). The newly-added farmland from the construction land reclamation project is used for planting sweet potatoes, with an estimated yield of RMB 0.4467 million (B_5). All pricing parameters were obtained through field surveys and interviews conducted by author team in July 2023 at the National Resources and Planning Bureau and Dudu village in Wuwei City, Anhui Province. Some parameters also refer to the historical transaction prices of Anhui Provincial Land and Resources Reserve and Development Center (https://zrzyt.ah.gov.cn/ztlm/ahsgtzycbfzzx/index.html).

3.2.2. Cost-benefit analysis

This study uses cost-benefit analysis to explore the dynamic economic benefits of the WCLC program in a Dudu village. Cost-benefit analysis has been widely used to assess the cumulative economic value of a project (Asimeh et al., 2020; Callesen et al., 2022; Valtiala et al., 2023). This study presents the benefits (B) and costs (C) of WCLC in the form of net present value (NPV) to analyze its dynamic economic benefits. The calculation formula can be presented as follows:

$$\boldsymbol{NPV} = \sum_{t=1}^{n} (\boldsymbol{B} - \boldsymbol{C})_t (\mathbf{1} + \boldsymbol{i})^{-t} \tag{3}$$

Where NPV represents the net present value; C and B represent the cost and benefit of the project respectively, and B-C represents the net cash flow; t represents the project implementation time, and i is the social discount rate. According to China's economic development level, the social discount rate (i) in this study is 8 %. In this study, according to local planning, the implementation period of the Dudu village's WCLC project is 3 years (2021–2023), and the operation period is 17 years (2023–2040), that is, the entire project period is 20 years ($t = 1, \ldots\ldots, 20$).

We further calculated the benefit-to-cost ratio (BCR) and internal rate of return (IRR) for the WCLC in Dudu village. The calculation formula for the BCR is as follows:

$$\boldsymbol{BCR} = \frac{\sum_{t=1}^{n} \boldsymbol{B_t}(\mathbf{1} + \boldsymbol{r})^{-t}}{\sum_{t=1}^{n} \boldsymbol{C_t}(\mathbf{1} + \boldsymbol{r})^{-t}} \tag{4}$$

Where $\boldsymbol{BCR}$ represents the benefit-to-cost ratio; $\boldsymbol{B_t}$ represents the economic benefit in period t; $\boldsymbol{C_t}$ represents the cost in period t; i is the social discount rate, here we assume it is 8 % (Du et al., 2019). Generally, if the benefit-to-cost ratio is equal to or greater than 1, it indicates that the economic efficiency of the WCLC project has reached an acceptable level.

The internal rate of return (IRR) embodies a critical financial metric for gauging the efficacy of investment in a given project. It is defined as the discount rate that renders the net present value (NPV) of all future cash flows from the project equal to zero, serving as a cornerstone in the arsenal of tools employed for capital budgeting decisions. The mathematical representation of IRR is derived through the equation:

$$\boldsymbol{NPV} = \sum\nolimits_{t=0}^{n} \frac{\boldsymbol{CF_t}}{(\mathbf{1} + \boldsymbol{IRR})^t} = \mathbf{0} \tag{5}$$

Where NPV denotes the Net Present Value; $\boldsymbol{CF_t}$ represents the cash flow at time t, with $\boldsymbol{CF_0}$typically indicating the initial outlay, thereby assuming a negative value; IRR signifies the Internal Rate of Return; t spans the lifecycle of the project from inception (0) to conclusion (n).

The elucidation of IRR necessitates the resolution of the aforementioned formula to pinpoint the rate (IRR) that neutralizes the NPV of anticipated cash flows. Given the complex nature of this equation, which often precludes a straightforward analytical solution, the determination of IRR usually involves sophisticated numerical methodologies, including the Newton-Raphson method or iterative trial-and-error approaches.

The Payback Period (PP) is defined as the duration required for an investment to recover its initial costs, beginning from the start of the investment period (Wojewodzic et al., 2021). This metric is straightforward and offers an intuitive gauge of an investment's efficiency, primarily used to assess the associated risk and the speed at with which capital is recovered. Given the variable annual cash flows generated by the WCLC project in Dudu village, the payback period is calculated using the following formula:

$$PP = N + \frac{I - \sum_{i=1}^{N} CF_i}{CF_{N+1}} \quad (6)$$

Where PP is the payback period (years); I is the initial investment; CF_i is the net cash flow in the i-th year; N is the number accumulated until $\sum_{i=1}^{N} CF_i$ approaches but does not exceed I. The shorter the PP, the faster the project recovers the investment, indicating relatively lower investment risk.

4. Results

4.1. The cost of the WCLC

WCLC is a complex livelihood project that requires substantial financial investment. The WCLC project in Dudu village represented a significant investment totaling RMB 68.86 million, not including additional funds for farmers' self-built houses and demolition compensation (C_1). Including the demolition compensation for villagers, the total investment in the WCLC project in Dudu village reached RMB 1.042 trillion (People's Government of Kaicheng Town, Anhui Province (PGKT), 2021). Of this, government financial funds contributed RMB 59.66 million, while integrated agricultural-related funds added another RMB 9.2 million. The investment in WCLC project amounted to RMB 43.0608 million. The WCLC project comprised three key initiatives: conversion of 4.0041 ha of dryland to paddy fields with an investment of RMB 1.2012 million, reclamation of 17.8513 ha of construction land costing RMB 39.35 million, development of 13.9238 ha of reserve arable land with a RMB 2.51 million investment. The investment in improving the living environment and ecological restoration projects totaled RMB 25.8 million. Of this, RMB 16.6 million was allocated for enhancing the living environment, including the construction of resettlement areas, road infrastructure, public service facilities, road quality improvements, and rural tourism infrastructure. Additionally, RMB 9.2 million was invested in river eco-environment management, which received support from special funding (Table 3).

From the perspective of cost allocation, the reclamation of construction land (residential land) into farmland incurs the highest cost, accounting for approximately 38 % of the total WCLC cost, followed by the compensation for residential demolition, which accounts for 34 %. The total cost of WCLC in Dudu village alone exceeds RMB 100 million, which is about 3.4 % of Wuwei City's fiscal revenue in 2022. Such high costs, if borne solely by the local government without the participation of social capital, would pose a significant challenge to local finances. Under the current policies in China, WCLC lacks direct financial support from the central government, and the involvement of social capital is insufficient. As a result, local governments show limited willingness to implement WCLC projects.

4.2. The socio-economic benefits of the WCLC

4.2.1. Great socio-economic benefits

WCLC has yielded multiple social benefits, including enhanced land utilization efficiency, reduced labor and irrigation costs, increased grain output, and fewer land boundary conflicts. WCLC has increased the effective cultivated land area in the project area, improved the quality of farmland, enhanced agricultural production conditions, and boosted overall agricultural productivity. By reclaiming and utilizing agricultural land, abandoned ponds, grasslands, and construction land within the restoration area, the project has added 29.79 ha of arable land (an 8.73 % increase in the original cultivated land area). After the WCLC, the orchard area in Dudu village decreased to 6.79 ha, a reduction of 3.75 %, primarily due to the decrease in tea gardens and other orchards. The forest area also decreased by 6.77 ha, mainly due to the reduction in other forest lands. Grassland area saw a reduction of 14.45 % (approximately 2.29 ha). In contrast, land used for transportation increased by 1.99 %, while water bodies and water conservancy facility areas decreased by 4.9 %, and other unused land decreased by 2.87 % (Table 4). Through the construction of high-standard farmland and the implementation of optimized field roads, production roads, and new drainage projects, WCLC has better supported rural production and living conditions, ultimately improving the comprehensive agricultural productivity of the consolidation area. Our survey of 139 households in the WCLC area of Wuwei City revealed significant positive perceptions: 89.21 % of respondents noted improved arable land utilization efficiency, 78.42 % reported a reduction in labor costs, 77.69 % observed decreased irrigation expenses, and 76.98 % anticipated higher grain yields. Furthermore, 77.70 % of the farmers expected more diversified landscape types, and an equal percentage perceived improved ecological condition. Additionally, the implementation of WCLC has fully utilized the leadership role and coordination capabilities of grassroots organizations. This has helped to strengthen the cohesion and combat effectiveness of these organizations, improve grassroots governance, and better serve the people. More than 80 % of respondents believed that WCLC had helped reduce land boundary conflicts, and 71.94 % believed it strengthened village collective cohesion.

Table 4
Changes in land use types before and after the WCLC in Dudu village, Anhui Province.

First-level land type	Second-level land type	Before consolidation (ha)	After consolidation (ha)	Increased or decreased rate (%)
Cultivated land	Paddy field	235.75	261.18	10.79
	Irrigated land	0.22	0.22	0.00
	Dry land	105.04	109.4	4.15
Garden land	Garden land	2.38	2.38	0.00
	Tea garden	159.84	154.05	−3.62
	Other gardens	18.81	17.81	−5.32
Woodland	Arboreal woodland	173.45	171.54	−1.10
	Shrubland	0.79	0.79	0.00
	Other forest land	51.17	46.31	−9.50
Grassland	Grassland	15.85	13.56	−14.45
Residential land	Rural homestead	78.55	67.19	−14.46
Commercial service industry land	—	1.53	1.86	21.57
Industrial and mining land	—	9.37	9.37	0.00
Transportation land	—	23.22	23.68	1.99
Land for water bodies and water conservancy facilities	—	64.6912	61.52	−4.90
Other land	—	6.7532	6.5593	−2.87

Notes: The data comes from the Natural Resources and Planning Bureau of Wuwei City, Anhui Province.

WCLC has facilitated the deep integration of the primary, secondary, and tertiary industries in Dudu village. By leveraging local resource advantages, the village has developed rural tourism while integrating agricultural funds to attract agricultural product processing enterprises. Through WCLC, development space for these enterprises has been provided, further extending the sweet potato cultivation industry chain. Statistics from Dudu village show that from 2019 to 2023, its collective

Table 5
Cost-benefit results of WCLC project in Dudu village, Anhui Province.

Year	C_t (10^4 RMB)	B_t (10^4 RMB)	*NCF* (10^4 RMB)	*SDF*	*NPV* (10^4 RMB)
2021	2886.09	0	−2886.09	0.93	−2684
2022	2000	0	−2000	0.86	−4404
2023	2000	0	−2000	0.79	−5984
2024	55.09	8109.06	8053.97	0.74	−24
2025	55.09	141.47	86.38	0.68	35
2026	55.09	141.47	86.38	0.63	89
2027	55.09	141.47	86.38	0.58	139
2028	55.09	141.47	86.38	0.54	186
2029	55.09	141.47	86.38	0.5	229
2030	55.09	141.47	86.38	0.46	269
2031	55.09	141.47	86.38	0.43	306
2032	55.09	141.47	86.38	0.4	340
2033	55.09	141.47	86.38	0.37	372
2034	55.09	141.47	86.38	0.34	402
2035	55.09	141.47	86.38	0.32	429
2036	55.09	141.47	86.38	0.29	454
2037	55.09	141.47	86.38	0.27	478
2038	55.09	141.47	86.38	0.25	499
2039	55.09	141.47	86.38	0.23	519
2040	55.09	141.47	86.38	0.21	538

Notes: C_t symbolizes the project's capital investment, B_t denotes the project income, *NCF* represents the net cash flow (C_t- B_t), *SDF* stands for the social discount rate (assumed to be 8 %), and *NPV* indicates the cumulative Net Present Value.

economic income increased from RMB 0.5 million to 3.1 RMB million, while the per capita net income of villagers rose from RMB 22,887 to RMB 31,025.[1] Through the WCLC project, Dudu village transformed its dormant land resources into equity in enterprises, thereby increasing property-based income. Additionally, the project boosted villagers' incomes by facilitating land transfer and promoting non-agricultural employment.

WCLC has also generated huge economic benefits. Dudu village's WCLC project spans an execution period of three years (2021–2023), with an operational lifespan of 17 years and a financial analysis horizon of 20 years. Assuming a social discount rate of 8 %, the discount calculations commence at the beginning of the first construction year, with all costs and benefits accounted for at the year-end. Project revenues include: RMB 58.2175 million from surplus construction land indicator transfers, RMB 18.4553 million from adjustments to supplementary arable land indicators, and RMB 3.0031 million from dry-to-wet water transaction indicators. Additionally, 0.443 ha of newly-reclaimed land dedicated to rural tourism development are projected to generate annual revenues of RMB 0.9680 million. The 29.78 ha of arable land added through construction land reclamation, now managed by the village collective, are expected to produce a steady land transfer income of RMB 0.4467 million annually (Table 2). The results indicate that in 2024, the WCLC project in Dudu village can generate an economic benefit of RMB 81.0906 million, with a total investment of RMB 69.4118 million since its implementation in 2021 (excluding compensation for the demolition and resettlement of farmers' houses). According to formulas 1–6 above, it can be calculated that the economic net present value (*ENPV*) of the WCLC project in Dudu village is estimated at RMB 5.38 million, with a benefit-to-cost ratio (*BCR*) of 1.078, an economic internal rate of return (*EIRR*) of 10 %—surpassing the applied social discount rate—and a dynamic investment payback period (*PP*) of 3.85 years (Table 5). These results demonstrate that the WCLC in Dudu village is economically feasible and has significant economic benefits.

4.2.2. *Optimization of production-living-ecological spaces*

The WCLC project in Dudu village has increased the arable land area in the project-implemented area, improved the quality of arable land, raised the level of land intensive utilization, and optimized the structure and layout of village construction land. WCLC has achieved the goal of optimizing the production-living-ecological spaces in Dudu village. This is reflected in the following three aspects.

First, WCLC has improved land use efficiency in Dudu village and promoted the development of the agricultural industry. Our survey results indicate that, through the WCLC initiative, Dudu village consolidated fragmented farmland, improving both the layout and conditions of agricultural fields, resulting in the establishment of 66.7 ha of high-standard farmland. Key achievements include an increase in arable land by 29.78 ha (8.73 % of the original arable land area) and an improvement in land quality by 0.13 grades. The WCLC also enhanced comprehensive agricultural production capacity through optimization of field and production roadways and updates to irrigation and drainage systems. These improvements have not only optimized farmland texture but also reshaped the rural landscape, integrating 6.49 ha of poor-quality, scattered woodland and 2.76 ha of land with degraded irrigation in the remediation zone, which also included abandoned ponds and ditches, along with 2.41 ha of underutilized orchard land. It has enhanced the scale and efficiency of land use, creating better conditions for the development of modern agriculture. Specifically, WCLC has also facilitated land transfer, with the land transfer rate in the village exceeding 90 % in 2023, an increase of 20 % compared to 2020. This attracted numerous newly-type agricultural entities, including over 10 new businesses such as a 40-ha plum orchard, a 20-ha vineyard, and a 13.33-ha strawberry farm. This diversification of the local agricultural industry not only fostered the development of agriculture but also provided more than 300 stable jobs annually for local villagers, increasing their income by over RMB 10 million.[2] Furthermore, WCLC has increased collective economic income by generating surplus quotas and additional farmland during the land consolidation process, greatly enhancing the revenue from collective resource leasing. In 2023, the collective economic income of Dudu village exceeded RMB 3 million, representing nearly a fourfold increase compared to 2020.

Second, through the demolition of old housing and centralized resettlement, the living space in the village has been optimized. Dudu village relocated scattered villagers into centralized resettlement areas, constructing uniform housing along with supporting infrastructure such as roads, water, electricity, and public service facilities. This improved travel conditions, enhanced the quality of life for residents, and increased livelihood capital (Fig. 3). WCLC has successfully reduced the area of construction land by 11.22 ha (a 10 % reduction), including a 14.46 % decrease in rural residential land, leading to a reduction in per capita residential land from 206 m^2 to 175 m^2 (Table 2). The village collective facilitated land ownership adjustments by enabling the withdrawal of rural residents from their original homesteads. Furthermore, centralized resettlement provided villagers with sufficient economic resources and need for residential land to purchase homes, thereby addressing the shortage of residential land in old houses.

Third, WCLC undertook the enhancement and renovation of two rivers in the restoration area, Shichonggou and Maogongshangou, improving water quality. Through river channel management, levee reinforcement, and the implementation of riverside greening, a total area of 3.0446 ha was restored. Additionally, waterside spaces were created, forming a beautiful aquatic ecological environment and charming rural landscapes. This supported the development of eco-tourism and rural tourism routes, attracting visitors for sightseeing and tourism, promoting a positive interaction between ecological protection and economic development. At the same time, through land leveling, water conservancy facility construction, and other efforts, the area's capacity for water and soil conservation was enhanced, improving the ecological landscape and effectively restoring the environment.

[1] The data was provided by the Dudu Village Committee on November 30, 2024.

[2] http://ww.whxf.gov.cn/Home/Content/?Id= 1236752&ClassId= 6721.

Fig. 3. Changes in the living environment of residents in Dudu village before and after WCLC. Notes: The image was taken by the authors.

5. Discussion

5.1. Anticipated and unexpected outcomes of the WCLC

WCLC is a crucial tool in modern China for optimizing land use, improving rural eco-environments, enhancing the living and production conditions of farmers, and promoting the integration of primary, secondary, and tertiary industries in rural areas. It has also contributed to reshaping the supply of key factors such as population, land, capital, and information between urban and rural areas, while helping to rebuild the relationship between cities and villages and between humans and the land. Our findings indicate that WCLC has increased arable land area in the consolidation zones, improved land quality, reduced fragmentation, optimized village layouts, and enhanced both living conditions and the eco-environment, yielding significant socioeconomic and ecological benefits. This is consistent with a previous study, which found that WCLC reduced farmland fragmentation by 64 %, increased the concentration of construction land by 34 %, and expanded arable land by 14 % in the Sichuan Basin, thereby improving land use efficiency (Ao et al., 2020). In Zhejiang, a pioneer region for WCLC, 22,011 ha of high-standard farmland were established, and 933.8 ha of unused construction land were revitalized between 2018 and 2020 (Yue et al., 2023). These efforts significantly improved the eco-environment in the project areas and helped narrow the income gap between urban and rural residents.

WCLC has produced a range of expected outcomes in the pilot areas, such as optimizing land use, enhancing farmland protection, promoting efficient and intensive land use, strengthening rural governance, and advancing the integration of rural industries (Zhong et al., 2024). WCLC strengthened the cohesion of villagers by enhancing infrastructure, optimizing public spaces, promoting land transfer, and fostering industrial development, which in turn facilitates increased interaction and cooperation among villagers (Yin et al., 2022; Jiang et al., 2024). Particularly, infrastructure upgrades and the development of public spaces have enhanced communication and social activities, fostering emotional bonds among villagers. Additionally, through industrial development and land transfer, the close economic cooperation among villagers has deepened their collective sense of identity. Throughout the process, the close communication between the village committees and villagers has promoted collaborative participation in both planning and implementation, allowing villagers to feel a sense of ownership, which in turn bolsters the internal cohesion and social stability of the village (Yang et al., 2023). Our survey of 139 farmers participating in WCLC in the study area also shows that 93.53 % of respondents believe that WCLC has enhanced their sense of cohesion.

The WCLC project not only optimizes the allocation of land resources but also promotes the appropriate scale of agricultural production. According to China's Land Administration Law, "A household is entitled to only one homestead," meaning that when a family's minors reach marriageable age and need to build a new house, they must apply to the village collective organization for a homestead (Zhou et al., 2020b). However, in reality, unused homesteads are rarely relinquished, even if the family no longer resides in the old house. This has led to a scarcity of land available for new housing in villages, making it difficult for younger generations to obtain homesteads when they need to build homes (Zhou et al., 2023b). This issue is particularly challenging in our study area, Dudu village. Through the WCLC project, Dudu village has consolidated scattered residents and freed up abandoned homesteads, which not only improves the utilization efficiency of construction land but also allows families with housing needs and economic capability to purchase new homes. This approach meets the national legal requirement of "one homestead per household" and addresses the practical housing needs of farmers. Furthermore, WCLC's investment in agricultural water conservancy facilities and the consolidation of fragmented farmland have facilitated land transfer and promoted the scale of agricultural production. This result is consistent with previous studies (Do et al., 2023; Wang et al., 2023).

The main purpose of implementing WCLC has obvious regional differences. In China's economically advanced regions, the WCLC initiative promotes integrated urban-rural development, revitalizing industrial land, securing spaces for emerging rural industries, and managing spatial evolution. Rapid industrial growth has exacerbated land shortages and industrial zone fragmentation in economically developed areas, but the WCLC has facilitated the development of industrial parks, residential communities, and ecological improvements, optimizing spaces for production, living, and ecological balance. In central agricultural regions, WCLC focuses on correcting inefficient land use, revitalizing depopulated villages, improving ecological land quality, and consolidating agricultural areas to enable large-scale farming and modern agricultural practices. It also emphasizes expanding land for infrastructure and optimizing residential layouts. In the mountainous and hilly western regions, WCLC aims to revitalize depopulated villages, improve inefficient land use, and enhance rural living conditions, addressing the land scarcity hindering infrastructure development and industrial growth.

WCLC may also lead to some negative effects. First, there is a potential risk of ecological damage. If construction is poorly executed or planning is inadequate, the land consolidation process may cause harm to the environment, such as the destruction of natural vegetation, loss of biodiversity, or increased soil erosion (Yang et al., 2024). Second, WCLC may also disrupt traditional rural lifestyles and folk cultures, breaking existing social networks. Moreover, concentrated resettlement poses challenges for villagers in adapting to modern living conditions, manifesting in increased living costs and greater distances or costs associated with accessing original agricultural production land. Furthermore, WCLC may exacerbate the financial burden on local governments. The project requires significant funding, including costs for initial planning, construction, and ongoing maintenance. If funding channels are insufficient or resources are not efficiently managed, the project may face delays or become unsustainable in the long run. For example, by the end of 2023, 90 out of the 446 national WCLC pilot projects in China had applied to withdraw due to factors such as funding shortages, land-use adjustment restrictions, and insufficient farmer willingness (Wang and Zhong, 2024).

5.2. Key challenges in advancing WCLC

Since the MNR initiated the WCLC pilot policy in 2019, its implementation has progressed slowly despite its significant socio-economic and ecological impacts. This slow advancement can be attributed to numerous practical challenges (Fig. 4):

Financial Constraints. WCLC, as a large-scale foundational project, demands significant investment and is heavily reliant on government fiscal support (Lu and Liu, 2024). For individual villages, financial requirements often surpass hundreds of millions of RMB, placing substantial pressure on local government budgets. For instance, in this study, all WCLC funding in Dudu village was solely provided by the local government, with no involvement of social capital. As these fiscal constraints intensify, sustaining long-term and adequate funding for the WCLC becomes increasingly challenging. Although China's central government encourages private capital participation in WCLC, extended project timelines, low returns on investment, and high risks deter investors, resulting in limited private sector involvement. This reliance on traditional government funding alone has proven inadequate, compounded by a lack of innovative market-driven financing mechanisms (Li and Qu, 2020; Xiao et al., 2022). Moreover, the implementation of WCLC often depends on the off-site transfer of land-use indicators linked to the balance between increased urban and rural construction land during consolidation (Xiao et al., 2022). However, the reliance on such mechanisms, amid a downturn in the real estate market and unfavorable economic conditions, has diminished the appeal for social capital involvement in these projects (Li et al., 2024).

Social Participation Deficit. WCLC is essentially a rural collective action that involves coordinated governance by stakeholders such as local government, villagers, and enterprises (Pan et al., 2023; Li et al., 2024). However, the current WCLC is still more government-led, and the participation of various social entities is still far from enough (Li et al., 2024). Our survey results show that 56 % of respondents believe that the implementation of WCLC is complex and primarily the responsibility of the government, with little personal involvement. This indicates a significant lack of participation from social entities. This is primarily due to the current "top-down" government-led model of advancing WCLC, where the motivation for participation from village collectives and farmers remains insufficient. During the planning, implementation, and evaluation phases of these projects, asymmetrical information and a lack of transparency may result in a limited understanding of WCLC among the local population, thereby affecting their willingness to engage. When communities lack clarity or harbor doubts about key aspects such as project objectives, implementation plans, and expected outcomes, it becomes difficult to foster meaningful participation. Moreover, there is a lack of skilled professionals and management personnel capable of carrying out WCLC projects (Li et al., 2021). For example, our survey data reveals that nearly 30 % of respondents feel they have little to no knowledge or skills related to WCLC.

Policy and Planning Gaps. WCLC involves multiple departments, including land, water resources, housing and construction, environmental protection, agriculture, etc., and faces challenges in organizing and implementing. Due to the lack of special financial support from the central government, it hopes to use the WCLC as a platform to integrate funds related to agriculture from various departments. Coordination among various departments such as land, water resources, and environmental protection is weak, and the situation of each department acting independently has not changed (Xiao et al., 2022), complicating the integration of funds and policies necessary for effective WCLC implementation. The absence of strong leadership from county and city leaders exacerbates these coordination challenges (Guo and Wang, 2023). At the same time, in some regions, conflicts have arisen between WCLC planning and village planning during the implementation process. These challenges include breakdowns in the communication and

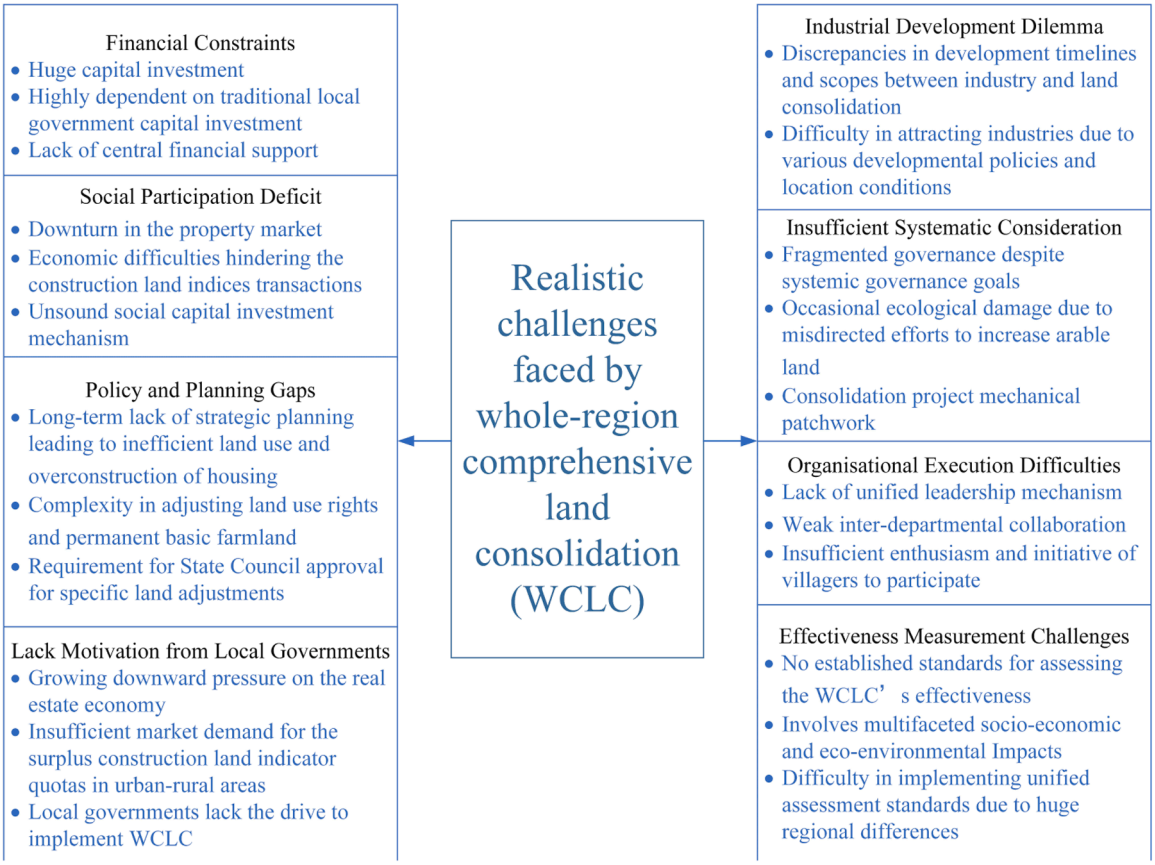

Fig. 4. Realistic challenges in promoting the whole-region comprehensive land consolidation (WCLC). Notes: The figure is drawn by the authors.

transmission of plans, misalignment of objectives, inconsistencies between the planning and implementation processes, and discrepancies between performance metrics and the goals of preserving local culture (Shi et al., 2024). Such issues underscore the need for greater coherence and integration between WCLC and village-level planning to address these practical conflicts effectively.

Industrial Development Dilemma. The land consolidation area needs industrial development to support it, but faces the dilemma of difficulty in introducing industries. One of the goals of implementing the WCLC is to promote regional economic and social development, which requires the development of industries for support. Industrial development and WCLC are complementary. However, in reality, industrial development needs to consider the layout of the entire county, while WCLC can only be carried out within the scope of townships. Industrial development is a long-term process, while WCLC has only about three years. However, WCLC's short operational timeline and the specific locational requirements limit effective industry introduction, affecting the project's sustainability and economic viability.

Inefficient Systematic Consolidation. The systematic consideration of WCLC projects is still insufficient. Traditional land consolidation methods do not align with the WCLC's more integrated approach, which aims to manage land, water, and ecological resources holistically (Xiao et al., 2022). Through the comprehensive use of engineering technology, agronomy, and biotechnology, identifying limiting factors, and promoting efficient flow between elements, it achieves comprehensive and coordinated governance throughout the process. Current practices often result in fragmented governance that fails to reflect the systemic governance concept necessary for regional development (Xiao et al., 2022). More importantly, although the Chinese government mandates that the WCLC be implemented at the township level, the enormous financial demands have led local governments to adopt a more pragmatic approach by limiting implementation to a few or even just one administrative village within pilot townships. For instance, in this study, Kaicheng Township in Wuwei City is a national-level pilot (MNR, 2019), but WCLC was only carried out in Duduo village within the township. This deviates from the original design of the WCLC policy by the Chinese government, making it difficult to achieve the goal of overall spatial optimization.

Lack of Motivation among Local Governments. The purpose of local governments implementing WCLC is to obtain surplus indicators from the urban-rural construction land transfer, which can be traded for substantial land-based fiscal revenue. However, in recent years, the downturn in China's real estate market, with falling housing prices and increasing pressure on land-based finance, has made it difficult to trade surplus indicators. This has led to insufficient motivation for local governments to advance WCLC projects.

Challenges in Measuring Effectiveness. The effects of WCLC are complex and multifaceted, involving various aspects such as society, economy, ecology, and the environment. There is a lack of a comprehensive evaluative framework to assess the outcomes of WCLC effectively (Li and Qu, 2020). This deficiency in supervision, management, and evaluation mechanisms hampers the ability to gauge the WCLC's impact accurately across different regions, which vary significantly in their needs and conditions (Guo and Wang, 2023).

5.3. Countermeasures

To ensure the sustainability of the WCLC, innovative mechanisms are essential to expand funding sources and engage private capital. Crucially, the establishment of a robust policy environment and regulatory framework is imperative. First, the promotion of WCLC should respond to and even serve China's rural revitalization strategy and the grand goal of ecological civilization construction. WCLC should be incorporated into the national major strategy of coping with the rapid decline of rural population and optimizing rural production-living-ecological space. Second, the Chinese central government should implement preferential policies, offer subsides for construction and operational costs, and provide incentives such as low-interest loans, tax exemptions, and risk compensation to attract private investment. Providing land or other assets could further enhance private sector engagement. Third, it is vital to assist eligible areas secure local government bonds and encourage development and policy-oriented financial institutions to offer medium-to-long-term credit support. Local governments should fully encourage the participation of financial and social capital in the WCLC, establish a diversified input and return mechanism, and broaden funding sources. Expanding and refining market mechanisms would also be critical in increasing social capital involvement in land consolidation.

The urgency of implementing multi-target, locally adapted land consolidation is paramount. Human-land relationships and developmental needs differ across regions, requiring targeted approaches tailored to specific village types. Effective village planning, grounded in rational, scientific principles, is vital for the WCLC's success. As outlined by the Chinese Rural Revitalization Strategy, WCLC should progress systematically, addressing the needs of urban-rural integration, agglomeration, relocation, and characteristic protection (Liu et al., 2021). In urban-rural integration villages, efforts should optimize land use, renew industrial areas, and integrate rural industries with the tertiary sector. For villages requiring relocation, WCLC focus should be on revitalizing underpopulated areas, consolidating farmland, and addressing ecological challenges. Agglomeration villages should prioritize reorganization of construction land and farmland protection to support large-scale farming. In characteristic protection villages, addressing farmland fragmentation while preserving cultural heritage is key.

Institutional innovation is crucial to developing a governance system aligned with current agricultural and rural needs. This requires coordinated policies across finance, agriculture, water, land, and construction, fostering a mechanism led by government and supported by interdepartmental collaboration and public engagement. A robust supervisory and evaluation system, ensuring regular inspections and addressing issues systematically, will help maintain progress towards set objectives.

In response to the issue of local governments lacking motivation to promote WCLC due to the sluggish real estate market, it is urgent to establish a WCLC mechanism based on market demand and grounded in nature. Encouraging social capital investment is essential for overcoming funding constraints. Tailored, market-oriented mechanisms, such as value realization frameworks based on construction land and carbon emission indicators, can boost investment. Exploring public-private partnerships (PPP) in eco-environment-oriented developments (EOD) or using engineering-procurement-construction (EPC) models, where contractors take full responsibility, will further advance these goals. More importantly, it may be advisable to establish a mechanism linking the performance of the WCLC project to the promotion of local government officials, given the strategic importance of WCLC in optimizing rural production-living-ecological spaces and supporting rural revitalization.

5.4. Limitations and future outlook

WCLC represents a complex systemic initiative that signifies a profound human intervention in nature, with the potential to significantly influence rural socio-economic and ecological systems. WCLC, as a new initiative designed to adapt to China's socio-economic development, has rarely been subject to quantitative assessments of its socio-economic and ecological effects. This study innovatively develops an analytical framework for assessing the socio-economic impacts of WCLC, using a typical case and cost-benefit analysis to evaluate its socio-economic benefits. However, due to the relatively short implementation period of WCLC and the lack of available data, it is currently difficult to quantitatively measure its ecological effects. Future research must

urgently expand its scope to include WCLC's impact on optimizing land resource allocation, adjusting land ownership, and reorganizing rural factors such as population, land, capital, labor, technology, and information. Additionally, studies should also explore its impact on the restructuring of rural production-living-ecological spaces and the deepening of rural land system reforms. Whether WCLC promotes the non-agricultural transfer of agricultural labor, large-scale operation of agricultural land and increase of farmers's income deserves further in-depth investigation and exploration.

The impact of WCLC on rural ecosystem, as well as its contribution to rural revitalization, warrants further investigation. Leveraging tools such as artificial intelligence and geographical big data, including high-resolution remote sensing imagery and mobile phone signaling data, would enable a more comprehensive analysis of WCLC's socio-economic and ecological effects. Moreover, since the WCLC national pilot has been underway since 2019, it is crucial to scientifically evaluate its socio-economic and ecological impacts using widely accepted policy evaluation models like the Difference-in-Differences (DID) model. The ecological impact assessment can focus on several dimensions before and after the implementation of the WCLC project, including species diversity, habitat quality, landscape diversity, landscape fragmentation, ecosystem service value, vegetation cover, and changes in the soil and water environment. Additionally, it can also address changes in agricultural carbon emissions and agricultural non-point source pollution. Whether the WCLC pilot is worth promoting nationwide is a question that urgently requires scientific support from relevant research.

6. Conclusions

WCLC represents an advanced stage of land consolidation and is a crucial tool for promoting rural development. In China, WCLC aims to optimize national territorial space by addressing key issues such as fragmentation arable land, inefficient use of construction land, disorganized village layouts, and ecological degradation. Despite the high cost of WCLC, its socio-economic benefits are evident. These benefits include increasing farmland quantity and quality, boosting agricultural production efficiency, improving the living environment, supporting rural revitalization, and promoting integrated urban-rural development. WCLC indeed optimizes rural production-living-ecological spaces, enhancing the efficiency of land resource allocation in the project area. Economically, the WCLC projects are viable, with a dynamic payback period of 3.88 years in this study. These findings demonstrate that rapid urbanization and industrialization have led to the decline and unsustainability of rural development. However, well-planned human intervention can mitigate these negative effects, as demonstrated by the successful implementation of the Dudu's village WCLC project, emphasizing the importance of the concepts of sustainable development and ecological protection.

While WCLC is a promising initiative for promoting sustainable development in rural China, its implementation faces several challenges, including insufficient funding, limited social capital involvement, inadequate societal participation, and weak coordination across departments. The complexity of these projects requires innovative financial mechanisms, broader social engagement, comprehensive process monitoring, and rigorous effectiveness evaluations. Future research should focus on further assessing WCLC's socio-economic and ecological impacts, employing advanced tools like artificial intelligence, deep learning, DID models, cost-effectiveness analysis, and geospatial big data to enhance understanding and improve implementation strategies.

CRediT authorship contribution statement

Yang Zhou: Writing – review & editing, Writing – original draft, Software, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Peixuan Li:** Writing – review & editing, Software, Resources, Methodology, Investigation, Formal analysis, Data curation. **Qi Zhang:** Writing – review & editing, Writing – original draft, Validation, Methodology, Formal analysis. **Guoqiang Cheng:** Writing – review & editing, Writing – original draft, Supervision, Funding acquisition, Conceptualization.

Declaration of Competing Interest

No conflict of interest exits in the submission of this manuscript, and manuscript is approved by all authors for publication. The work described was original research that has not been published previously, and not under consideration for publication elsewhere, in whole or in part. All the authors listed have approved the manuscript that is enclosed.

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Data availability

Data will be made available on request.

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