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How should rural development be chosen? The mechanism narration of rural regional function: A case study of Gansu Province, China

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ABSTRACT

Several major changes in China's land policy, economic system, and development strategy have contributed to the continuous transformation of rural patterns and urban-rural relations. The deepening of urban-rural interaction has led to an increasing complexity of rural territorial functions, and the importance of territorial multifunctional mechanisms in the dynamic process of rural development in China has been highlighted. However, the current choice of a rural development model lacks comprehensive thinking that combines the functional mechanisms of rural areas with the elements of the development environment. In this paper, we define and identify the functions of rural areas in Gansu Province, China, and analyze and construct a rural development model by analyzing the interaction between the mechanisms of rural regional functions and the "rural revitalization" strategy. We find that under the control of "rural revitalization," a sustainable development tool, the countryside is constantly developing into a multifunctional complex, and its development mode should be dynamically adjusted according to functional changes. Finally, we summarize the general evolutionary cycle of the multifunctional system of rural regions and attempt to extrapolate the dynamic developmental village type classification process of "rural revitalization" from the perspective of rural regional functions in China.

1. Introduction

As the original foundation and important carrier of socioeconomic activities [1,2], rural territorial space is constantly transforming into a multifunctional system with obvious spatial heterogeneity and temporal dynamics in the context of rapid urbanization [3,4]. Reasonable use of the multifunctionality and multiple values of the countryside and its revitalization is a major strategy in solving the "three rural issues" of the new era [5]. Many countries in the world have experience exploring rural development, including rural governance models that emphasize land production and ecological integration (French 'family farms') [6]; paying attention to the construction of public facilities for farmers' life happiness and sense of belonging (the New Village Movement in South Korea) [7]; fully tapping local resources and rural brand building of the production association organization development (Japan's 'One Village One Product') [8]; and the planning principle system of highlighting rural carrying capacity and coordinating suburban relations (the new

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town construction in the United States) [9]. Although these rural development studies and practices started earlier, they all focus on exploring the objective functional attributes of the countryside and strengthening the interaction of regional elements, which shows the importance of the regional functions of the countryside. As the interaction between urban and rural regional systems deepens, the agglomeration of urban elements has led to the development of rural regional space with multiple business modes, enriching the connotation of the multiplicity of rural regional functions [10]. At the same time, it also brings a lot of development problems. The concept of multifunctional agriculture has been proposed in response to rapid urbanization, environmental degradation, poverty and food insecurity [11]. More attention has been paid to agricultural activities that are not directly related to food production and to the multifunctional development of rural areas [12]. Originating from the theory of multifunctional agriculture, Holmes (2006) systematically expounded the theory of rural multifunctional transformation, pointing out that in the process of social development, the changes in human's needs for production, life, ecology and other functions in rural areas drive the continuous evolution of rural areas [13]. The focus of rural development has shifted from a production and stability-oriented approach to the realizing multifunctional goals, which aims at promoting comprehensive rural development.

The multifunctional characteristics of rural regions involve the multiple goals of urban-rural interaction and rural development, providing a new theoretical understanding of the pathway of rural development [14]. The multifunctional character of the countryside is the product of specific socioeconomic development stage and the attributes of the stable existence of the countryside in the interaction between urban and rural relations [2]. In the view of multifunctional theory, the countryside is not limited to the agricultural system, multifunctionality is originally a reflection of the overall attributes of the countryside [13]. Its functional complexity develops dynamically over time, and the complex interactions between the functions of living, production, and ecology involve various types of human-land system actors [15]. The diversification of rural areas is conducive to moving away from over-dependence on agriculture and the single production approach [16,17], narrowing the urban-rural gap and optimizing the internal structure and function of rural areas [12]. Furthermore, the coordinated development of rural multifunction focuses on ecological and economic sustainability, which is an important way of sustaining rural development [18]. Rural regional multifunction has significant spatio-temporal characteristics, showing strong heterogeneity and dynamics, and evolving in accordance with a certain mechanism, which means that different villages have corresponding personalized multifunctional development patterns. Therefore, exploring the coupling mechanism of rural regional multifunction is of great significance for formulating a reasonable rural sustainable development model and promoting China's "rural revitalization" strategy.

The rural regional function has been extensively discussed in recent years, the topics of which range from the connotation and the meaning of rural regional multifunctionality, evolution characteristics, functional relations to evaluation identification and application path [19–22]. These studies mainly focused on Europe and Australia [23], and then gradually transferred to China [24]. The use of the multifunctionality of rural regions in China's "rural revitalization" model is mainly reflected in the rural reconstruction and land transformation guided by the policy system [25,26]. However, the existing related research still has shortcomings. First of all, in terms of research scales, the county scale is the main one [27], and the county has become an important focus point for promoting "rural revitalization" [28], ignoring the targeted analysis of county non-urban areas and rural regions. From the perspective of research, scholars pay more attention to a certain function of the countryside and are good at using theoretical intervention to explain the micro and meso perspective [29,30]. In these studies, the various functions of rural development are often viewed as relatively independent components, and are seldom analyzed from an integrated and unified perspective, neglecting the inter-relations among different functions [31]. Finally, in terms of research content, mathematical methods are used to explore the evolution of rural regional functions, classification, and evaluation, as well as the coordination of the "sansheng" [32,33], but less research is conducted on the interaction mechanism within regional multifunctionality. In relation to the evaluation of rural regional multifunctionality, Rudolfde (2006) paid attention to the rural ecosystem function, which was divided into five categories: regulation, habitat, production, information and carrier [34]. Wilson (2008) found that rural areas combine the important functions of natural environment protection and human resources development [35]. Gulickx (2013) believed that rural areas also assume the cultural inheritance function of protecting cultural heritage diversity, inheriting and carrying forward traditional history and culture [36]. However, these evaluations are applicable to different research perspectives and do not pay attention to the integrity of rural regional multifunctionality. In addition, multiple regional functions interact with each other driven by various forces, which leads to tradeoffs and synergies between multifunctions [37]. Analysis of the interactions between multifunctions can help to explore the coupling mechanisms of multifunctionality in rural regions and help rural development choices. However, most studies have not identified tradeoffs and synergies between multifunctions.

Gansu Province of China has almost all regional functional environments except sea areas, with obvious regional differences, forming the complexity and diversity of rural regional functions. At the same time, as an underdeveloped region in China, the rural areas in Gansu are in urgent need of development guidance. Therefore, how to scientifically diagnose and identify the functional types of rural areas in different regions, reveal the evolution characteristics of their spatial and temporal patterns, and explore the mutual coupling mechanism among various functions has become an important issue. Therefore, this study takes 65 counties in nonurban built-up areas of Gansu Province as the basic research unit, based on the value orientation and target orientation of improving economic efficiency, maintaining social equity, protecting the ecological environment, and achieving the sustainable use of resources [38], and intends to quantitatively evaluate six categories of geographical functions, namely, life residence, life security, agricultural production, nonagricultural production, ecological environment, and ecological conservation, and then to analyze the functional differentiation characteristics and coupling mechanism of rural geographical space in each district and county. The remainder of this paper is organized as follows: Section 2 builds the theoretical basis and defines the functional structure of rural regions. Then, this paper describes the research methods and data, and constructs a multifunctional spatial evaluation index system in rural regions. In section 4, the results and analysis are presented, and an interactive coupled system of rural regional multifunctionality is constructed to

quantitatively identify the functional mechanisms and development cycles of rural regional multifunctionality. Discussions are provided in Section 5. The last part presents and concludes our findings. This paper aims to enrich the identification tools of "rural revitalization" in China, expand the perspective of rural regional multifunctionality research, provide a scientific basis for the future rural functional orientation and development direction of all districts and counties in Gansu Province, and stimulate the vitality of rural development. This study aims to promote the sustainable development of Chinese countryside and enrich the research content of rural geography.

2. Theoretical basis

2.1. Rural regional function

2.1.1. Understanding rural regional function

In the man-land relationship system based on a certain region of the land surface, human activities are dependent on the natural geographical environment, and the regional differences of man-land relationship must coordinate the land use mode according to the regional function type [39]. Regional function refers to the functions and roles performed by the man-land relationship system in a certain region in the sustainable development of the background region [40]. Therefore, the rural regional function refers to the comprehensive characteristics of the rural regional system that produce beneficial effects on nature or human development by playing its attributes together with other systems at a certain stage of social development, including both the development guarantee of the rural region's own needs and the interaction promotion with the urban system [41]. The countryside encompasses all areas outside of cities and has multiple functions, such as residence, vacation, economic development, civilization, and social transmission [42]. Three major basic functions can be summarized for rural regions: first, to provide healthy resource goods in perpetuity through agricultural production space; second, to maintain the human living environment system through ecological space; and third, to provide ideal habitat conditions through settlement space [42]. As social and economic development continues, China's demand for a wide range of products and services produced in rural regions is also changing. From agricultural products, capital, and labor to some industrial products and construction land to the current livable space, consumption space, and ecological services, the functions of rural regions are constantly enriched and upgraded. The driving forces for the development and evolution of these rural regional functions include both internal and external forces, such as agricultural overcapacity, equal rights systems for agricultural land, the market economy, and urban-rural interactions [13].

2.1.2. Evolution of rural regional function in China

From the perspective of the endogenous dynamics of the development of rural regional functions, in traditional "Rural China," the land was the only means of survival and production for farmers, and for a long time, farmers took "cultivators having their own farmland" [43] as the goal of gaining benefits. Although the basic completion of land reform in 1953 eliminated landlordism and realized the idea of equal rights to land, it remained a private land system, and the functional use of the territory was always limited to housing and agricultural production [44]. The weak industrial base on the subsequent industrial development path forced China's industrialization to draw resources from the countryside [45]. To give enough support to industry, the communal economy of the people's commune was always maintained after 1956 under the guidance of the ideology of socialist collectivization, and the construction of farmland infrastructure was greatly improved, but the nonagricultural production functions were neglected, which seriously affected the integrity of the rural economic system [44]. In the parallel development of the agricultural economy and land resource constraints, "rural China" has achieved "growth without development" [46]by establishing itself on the land and being bound by it. In addition, the relationship between people and land, which was created by the peasants during the "rural China" period, is not only reflected in the economic form but also rooted in the political system and cultural concepts [26]. The formal establishment of the household contract responsibility system in 1983 largely separated the ownership and management rights of agricultural land and gave farmers the rights of market subjects, which brought fundamental changes to the rural economic organization, optimized the original characteristics of household management, effectively restrained the externalities of agricultural production [47], and improved the efficiency of agricultural economic production. Agricultural production could provide more employment opportunities and secure capital, which provided a great boost to the diversified development of rural regional functions [44]. During this period, the rise of rural enterprises caused development problems such as the loss of rural characteristics and environmental pollution [48]. Second, the urbanization-led development strategy has led to the expansion of towns and cities that continue to occupy arable land, the influx of surplus agricultural population into cities, the increase in the proportion of wage income, and the intensification of occupational differentiation [49]. At the same time, marketization has led to rural infrastructure construction and social service expenditures being self-financed by villagers, with serious problems of infrastructure inequality [50]. By 2005, the introduction of the new socialist countryside construction led to a significant improvement in the appearance of the countryside and a rapid rise in the welfare of farmers [51]. Through the "urban and rural coordination" approach, the state will integrate resources to allocate as much as possible to the countryside and activate the inner dynamics of the countryside. The industry feeds agriculture and supports the countryside with cities [51]. Through the development of industry and cities, the state will support and guide the diversification of the geographical functions of the countryside [44]. With the spatial change of rural living entities, the problem of hollowing out has led to increasingly serious spatial idleness and land abandonment in rural areas, coupled with the land transfer promoted by large-scale production and industrial chain extension, which has enhanced the interaction between regional production and ecological functions [1]. Therefore, the current strategy of "rural revitalization," which is dedicated to enhancing the interaction between urban and rural functions, strengthening the development of rural functions, and respecting farmers' wishes, has become a new starting point for China's rural

development and a new stage for the coordinated development of rural regional functions into multifunctional ones.

In terms of the external dynamics of the interaction between urban and rural areas, in the early days, the rural regional function was limited to the internal system of the countryside, with agricultural production as the core to build the rural development structure. The combination of Western shocks and industrialization led to the emergence of an urban structure born out of the countryside, while collectivization and the household registration system created a unique urban-rural duality in China [52], and the regional function of the countryside was to some extent dependent on the needs of urban development. Later, the opening of rural land use rights, centered on the reform of the land system, led to the transformation of the peasant's tied relationship with the land and a shift towards a revival of the village economy and institutions [26]. Rural development has entered the stage of "urban-rural China," where traditional farmers have become the second generation of farmers, and the economic, cultural, and social characteristics of this group have become more urban-oriented [53,54] The density of farmers and villages has decreased, the differentiation of village types has increased, and the public and private order of villages has been reconstructed [55,56]. Urban-rural interaction has been strengthened, and urban-rural integration has become a new form of urban-rural relations, emphasizing urban-rural factor interaction, institutional equity, and equality in the quality of life [57]. As a result, rural regional functions have manifested as nondependent urban-rural demand interactions that continue to diversify and develop with social needs.

In general, geographical factors plays a fundamental role in the formation and evolution of rural regional functions, but rural development is dominated by internal self-development capabilities combined with increasingly strong external rural socioeconomic drivers [42]. At the present stage, external forces play a decisive role in the evolution of rural functions. Rural regional multifunction emphasizes the coordination and unification of multiple functions, which provides a new research perspective and theoretical paradigm for rural development [58]. In-depth understanding of the law of the evolution of rural regional functions and exploration of the interaction between regional multifunctionalities can enhance rural development dynamics and promote coordinated urban-rural development. It has important theoretical and practical significance [36].

2.2. Main dimensions of rural regional function

In the process of regional function evolution in China's countryside, regional functions have changed from single to multiple based on the changes in the relationship between rural people and land and urban-rural relations, and the types of functions have been continuously enriched and differentiated. However, in general, there has always been a regional function structure with agricultural production, residential life, economy and employment, ecological services and other functions as the core development [44]. The theory of sustainable development seeks for coordination and compromise between the concepts of development and protection [59]. As an important producer of natural commodities, rural areas should reasonably use their multi-functional attributes to promote sustainable land use and meet human beings' long-term ecological needs and services [34]. Therefore, rural areas not only provide sufficient resources for urban and rural residents through production space but also serve as a place to maintain the livelihood of farmers and traditional cultural preservation and maintain the security of urban and rural ecosystems through ecological space, with multiple functions of production, living, ecology, and culture [60–62]. Scholars hold different views on the classification of rural multifunction. The functions of rural landscape can be divided into seven categories, including cultural heritage, residence, intensive animal husbandry, arable production, tourism, plant habitat and leisure cycling [63]. The important components of rural multifunction include socio-cultural value, aesthetic landscape value, cultural heritage and ecological conservation value [64]. From the perspective of land use space, rural regional function can be divided into three categories: production, living, and ecological "sansheng space" [65]. From the perspective of regional functions, it can be divided into four categories: economic, food, social, and ecological.

Combined with the above contents, based on the basic functions of production, life, and ecology in rural regions, and taking into account the characteristics of social development and the transformation of human needs, this paper further summarizes the functions of rural areas into six major functions: residence, security, agriculture, nonagriculture, environment, and conservation. These functions interact and relate to each other and jointly construct the multifunctional structure of rural areas (Fig. 1).

Among them, the rural region, as the settlement collection space of rural residents, has as its residential function the traditional

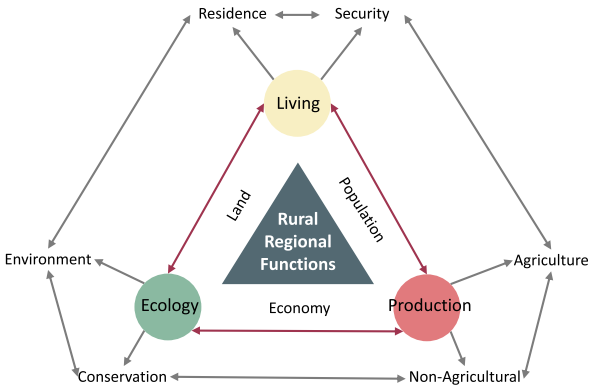

Fig. 1. Multifunctional structure of rural region.

expression of the spatial dependence of humans and land [66]. Regardless of the early coercion of natural environmental elements on the spatial scale and density of settlements or the current dominant drive of human factors such as economic policy and culture on the development of villages, the LRF (life residential functions) have always been the basic building blocks of the functional system of rural regions. The LSF (life security function) refers to the self-regulating ability of the rural regional life function system when the life supply capacity reaches a certain stage [67], and the quality of rural regional life is closely related to it. In addition to providing leisure, aesthetic and educational values for people, it also assumes the functions of maintaining the original lifestyle, protecting the diversity of cultural heritage, and inheriting and carrying forward traditional history and culture [68]. The LSF aims to provide support for people living in the regional space and is an important guarantee of the rural regional function system.

Production creates conditions for life, APF (agricultural production function) takes farmland and other agricultural production space as a carrier, providing sufficient agricultural products and laying a primitive foundation for the development of the village [69]. The output of agricultural production activities guarantees national food security, provides employment for village farmers, and provides sustainable development momentum for village development [44]. Therefore, the APF is the traditional driving force of the functional system of the village region.

NAPF (nonagricultural production function) refers to the production capacity other than agricultural production for the purpose of increasing the income of rural laborers [70], and nonagricultural production is mainly manifested as related production away from but not separate from agriculture, such as deep processing of agricultural products or traditional mining and metallurgical industries and the current tourism industry that relies on environmental resources. Nonagricultural production can bring higher income-generating efficiency to rural territories, promote the occupational differentiation of farmers, and facilitate the diversification of rural production, and it serves as the main support in the functional system of rural regions [71].

The ecological environment is the substrate of the existence of rural areas, a unified collection of ecological landscapes. The EEF (ecological environment function) provides natural elements for rural life and production as a spatial carrier. The potential for sustainable development of rural regions is reflected in the merits of the EEF, which is the potential of the rural regional function system.

The ecological conservation function (ECF) refers to the ecological maintenance and natural regulation function that is carried out by the ecological environment of rural regions. On the one hand, it helps to repair and adjust rural life and the production system. On the other hand, it receives negative human outputs, such as waste garbage and chemical liquid gas. The ECF provides development tolerance and correct guidance for the rural regional space and is the public property of the rural regional function system.

2.3. Rural regional functions and "rural revitalization"

First, Rural regional function has positive significance for realizing "rural revitalization" and promoting the coordinated development of urban and rural society, economy and environment. China's "rural revitalization" in the context of urban-rural integration is not only the revival and development of the countryside but also the new type of urbanization to break the institutional barriers between urban and rural regions. In terms of strategic thinking, the key is to break the restrictions on the flow of resources between urban and rural areas and give rural areas opportunities for development. The coordination of rural regional multifunctionality helps to establish the urban-rural connection network and realize the interaction between different socio-economic sectors through the exchange of material, information and energy, to meet the diversified demand for rural development [72]. Therefore, under the framework of the urban-rural territorial system, it is necessary to unify the urban-rural development system and classify and grade the countryside to establish a connection between rural development and local policy differentiation [73]. To clearly identify the development potential of different villages and classify villages based on their resource advantages or future development goals, it is necessary to clearly grasp the characteristics and evolutionary mechanisms of rural regional functions. As the most basic and stable administrative unit in China [74,75], counties connect urban and rural areas and carry a variety of regional functions [76]. It is appropriate for this study to identify the pattern and type of rural regional functions and the countryside itself, using the county as the research unit.

Second, the diversified rural regional functions provide more options for rural development modes, contributes to optimizing the internal structure and function, and improving rural ability to cope with endogenous changes and external disturbances, thereby enhancing rural resilience [16]. Rural regional functions constitute a stable system of functional interaction mechanisms with distinct dynamics and stages, so that it can cope with changing challenges. In different development periods, the characteristics of the regional multifunctional system vary according to the functional needs of rural regions. For example, in the traditional production stage, there is a low level of coordination of agricultural functions. Similarly, the functions of rural territories have separated variability in different natural locations, such as rural gentrification territories dominated by residential and living functions, marginalized territories dominated by ecological security functions, and agricultural areas dominated by single crop or animal production [77,78]. The functions of rural areas interact with each other through the three major roles of people, places, and media to show the role of regional functions in promoting rural development. To provide more scientific decision support for rural development positioning and more accurate power injection for the development of rural revitalization, this study should build a rural regional function identification system and further analyze the interaction and coupling mechanism of rural regional multifunctional systems.

Finally, although the intrinsic connection between the rural regional multifunctional system and "rural revitalization" is complex, from the guiding significance of the rural development perspective, the specific mutual promotion of the two can be manifested in the following four points: ① From the perspective of dynamic commonality, the dynamic development of regional multifunctionalization makes the rural construction system more perfect and helps improve the resilience of "rural revitalization" [79]. ② From the perspective of diversification characteristics, the multifaceted rural regional functions provide richer production paths and economic access to "rural revitalization" [16]. ③ In terms of interactivity, the network between multifunctionalities can connect the interaction

and combination. ④ In terms of functional specificity, the combination of unique regional functions and rural development can form rural impressions and rural development orientation.

In general, although the relationship between function and development within the rural regional system is complex, these can be summarized as the essential human-territorial relationship between the infinity of human needs and the finiteness of regional space, the stages of social development and the heterogeneity of regional space, and the diversity of subjects of interest and the variability of regional elements. Due to this, relatively few studies on the coordination mechanism between multifunctional of rural region exist. In this paper, we take the identification of the mechanism of rural regional function as the main research idea, combine it with the development characteristics of "rural revitalization" in China, and judge and construct the dynamic development model of rural areas to better understand the relationship between rural development and regional function in China.

3. Data and methods

3.1. Data source

This study takes the spatial differences of multifunctional rural regions in Gansu Province as the research object, based on the representativeness and availability of data, and takes the period of 2014–2020 as the research period. There are 86 counties (cities and districts) in Gansu Province (Fig. 2), firstly, the 21 core urban areas that basically do not possess agriculture are removed, Second, it removes county town core areas based on Lighting image data (https://www.ngdc.noaa.gov/eog/dmsp/downloadV4composites.html), then extracts for rural regions, and finally arrives at 65 counties (rural regions) as the study unit. In addition, the land use data used in the calculation of the index were obtained from the Resource and Environment Data Center of Chinese Academy of Sciences (http://www.resdc.cn/), and the NDVI data were obtained from the Geospatial Data Cloud (http://www.gscloud.en/). The socioeconomic data were mainly obtained from the Gansu Rural Statistical Yearbook 2014–2020, Gansu Statistical Yearbook 2014–2020, China County Statistical Yearbook 2014–2020, and the statistical development bulletins of each study area and county in the China Yearbook Network Publishing Database (https://kns.cnki.net/kns/advsearch?dbcode=CYFD).

3.2. Multifunctional indicator system for rural regions

Based on the above systematic definition of rural regional functions and referencing the relevant literature [2], the three basic regional functions of living, production, and ecology are used to select comprehensive indicators by combining land, residence, population, economic, and construction indicators. At the same time, to reflect the internal coupling and evolution characteristics of rural regional functions, this paper uses the improved method of difference to eliminate the influence of the evaluation indices and normalize them, while superimposing the evolution ratio of the original indices to reflect the standard evolution level. We then combined it the entropy method and expert scoring method [80]to calculate the entropy value, variability coefficient, and the weights, then uses the weighted summation method to derive various functions. The weighted summation method is applied to obtain the scores of various functions, and the multifunctional spatial evaluation index system of rural regions (Table 1) is constructed for the multifunctional evaluation of rural regions.

In terms of indicator selection, considering that the LRF is analyzed comprehensively in terms of basic population, residence, income and expenditure, this paper uses four indicators for accounting: two indicators, r1 and r2, directly indicate the basic conditions of rural residents' residence, while r3 and r4 simply reflect the actual residence rate and agglomeration degree of living and living.

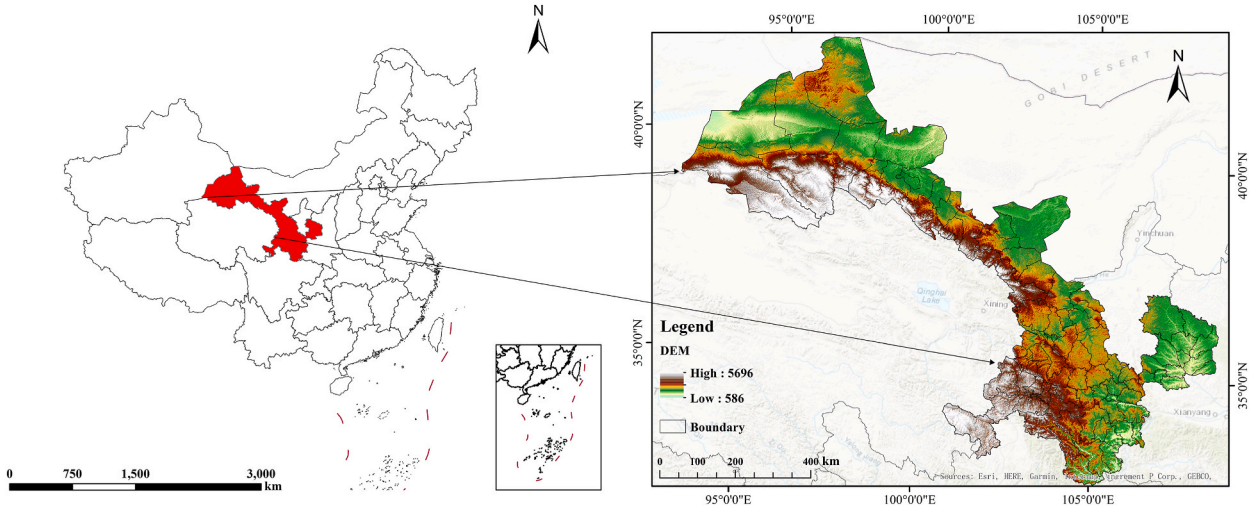

Fig. 2. Location map of Gansu Province.

Table 1
Multifunctional spatial evaluation index system of rural regions.

Target layer	Guideline layer	Indicator layer	Weights	Properties	Unit	Calculation Methodology and Interpretation of Indicators
Life Function (LF)	Life residence function (LRF)	Average per capita dwelling area r_1	0.1566	+	person/m^2	Rural residential area/agricultural household population
		Regional population density r_2	0.1354	+	person/hm^2	Permanent population in rural regions/area of rural regions
		Housing vacancy rate r_3	0.2970	–	%	Total idle houses/rural houses
		Residential concentration r_4	0.4111	+	–	Calculation of nearest neighbor index
	Life security function (LSF)	Road traffic density s_1	0.3892	+	km/km^2	Road mileage/county administrative area
		Number of beds in health establishments per million s_2	0.0155	+	number	Number of beds in health institutions/ permanent population in rural regions
		The old-age insurance participation rate of urban and rural residents s_3	0.3007	+	%	Number of people participating in pension insurance for urban and rural residents/ permanent population in rural regions
		Perfection of public service facilities s_4	0.2946	+	%	X = N/L/ (Rural Permanent population/ten thousand people) ， N is the total number of health facilities, schools, markets, savings institutions and cultural stations, and L is the type
Production function (PF)	Agricultural production function (APF)	Farmland areas per person a_1	0.1433	+	hm^2/ person	Farmland area/agricultural household population
		Grain yield a_2	0.3894	+	t/hm^2	Total food production/acreage of food crops
		Land reclamation rate a_3	0.1004	+	%	Cultivated land area/county administrative area
		Per capita output of grain a_4	0.0929	+	t/person	Total grain output/agricultural household population
		Vegetable yield per capita a_5	0.0731	+	t/person	Vegetable yield/agricultural household population
		Per capita oil production a_6	0.0577	+	t/person	Oilseeds production/agricultural household population
		Per capita output value of forestry, animal husbandry, and fishery a_7	0.1433	+	Yuan/ person	Gross output of forestry, animal husbandry and fishery/agricultural household population
	Nonagricultural production function (NAPF)	Proportion of nonagricultural population na_1	0.4833	+	%	Nonagricultural population/agricultural household population
		The proportion of output value of the second and third industries na_2	0.0531	+	%	(The sum of output value of secondary and tertiary industries × A × 100) / (GDP × A)
		Nonagricultural land area ratio na_3	0.2256	+	%	Industrial, commercial, service and other land area/county administrative area
		Investment in fixed assets per capita na_4	0.2379	+	Yuan/ person	(fixed investment × A) /Rural resident population
Ecological function (EF)	Ecological environment function (EEF)	The perfection of ecological facilities e_1	0.1523	+	%	X = N/3 ， N is whether the domestic sewage centralized treatment, garbage centralized treatment, toilet renovation; is: 1, no: 0.
		Average monthly household waste production e_2	0.3929	–	t	(domestic waste output × A) /12
		Per capita green area e_3	0.4547	+	m/ person	Green space area/agricultural household population
	Ecological conservation function (ECF)	Average use of chemical fertilizer c_1	0.2484	–	kg/hm^2	intensity of fertilization
		Average use of pesticides c_2	0.3077	–	kg/hm^2	intensity pesticide use
		Average film usage c_3	0.2071	–	kg/hm^2	Level of film use
		Percentage of forest cover c_4	0.3929	+	%	Forest area/county administrative area

Note: The stable light data of the 2013 Version 4 DMSP-OLS Nighttime Lights Time Series were used to extract the rural regional index data. The ratio A was obtained by dividing the sum of the gray value (DN value) of each pixel within the rural area by the sum of the gray value of each pixel within the district, county and administrative region, and then the index data of the rural region could be obtained by multiplying A with the corresponding index data. Lighting data source for https://www.ngdc.noaa.gov/eog/dmsp/downloadV4composites.html. Agricultural household population and rural resident population are directly obtained from district and county statistics. In addition, data such as cultivated land area, grain output, fertilizer and pesticide are almost produced in rural areas, considering that they belong to agricultural production, so the data directly use district and county statistics.

Drawing on relevant research results, the LSF is briefly determined to measure the level of life services in terms of infrastructure and public service support. s1 is more representative than water supply, drainage, electricity and heating in the representation of infrastructure conditions for rural regions. At the same time, in addition to using s4 to represent the level of public service facilities, we focus on measuring its s2 and s3 for the hollowed-out characteristics of rural areas. The indicators of APF were selected from the input–output perspective. a1 and a3 reflect the basic agricultural production conditions, while a2, a4, a5, and a6 reflect agricultural output from the overall and subcrop types, respectively. The NAPF is in a minority part of the traditional rural geographical production function. na1 and na3 represent the population resource-land resource base in terms of production conditions, and na2 and na4 characterize the proportion of the nonagricultural production structure to reflect the level of nonagricultural output efficiency. Considering the demand-supply relationship of ecological factors, the setting of accounting criteria is influenced by human factors [81, 82]. In the EEF index, e1 and e2 represent the capacity and pressure of ecological environment maintenance in rural regions, and e3 indicates the current ecological environment landscape status. The ECF was selected from a combination of natural self-regulation ability and the negative impact of agricultural production for four indicators c1, c2, c3, and c4 (Table 1). Among them, the standardized formulas for specific data are as follows:

$$y_{\theta ij} = \frac{x_{\theta ij} - \min\limits_{1<i<m} x_{\theta ij}}{\max\limits_{1<i<m} x_{\theta ij} - \min\limits_{1<i<m} x_{\theta ij}} \tag{1}$$

$$y_{\theta ij} = \frac{\max\limits_{1<i<m} x_{\theta ij} - x_{\theta ij}}{\max\limits_{1<i<m} x_{\theta ij} - \min\limits_{1<i<m} x_{\theta ij}} \tag{2}$$

In the equation: $x_{\theta ij}$ is the original indicator data, which represents the j th indicator data value of study area i in year θ; $y_{\theta ij}$ is the standardized indicator data value; m indicates the number of study areas; $\min\limits_{1<i<m} x_{\theta ij}$ and $\min\limits_{1<i<m} x_{\theta ij}$ denote the maximum and minimum values of the j th indicator in year θ, respectively. The positive standardization formula is formula (1) and the negative standardization formula is formula (2). The relative proportions between different study years are balanced by formula (3).

$$e_{\theta ij} = \frac{y_{\theta ij} \times x_{\theta ij}}{\sum\limits_{\theta=1}^{r} x_{\theta ij}} \tag{3}$$

In the equation: $e_{\theta ij}$ is the j th equilibrium standardized indicator of district i in year θ; r denotes the number of years, and in this study r is 4. The specific gravity of each indicator value is determined through equations formula (4) and formula (5).

$$e_{\theta j} = \sum_{i=1}^{n} e_{\theta ij} \tag{4}$$

$$f_{\theta j} = \frac{e_{\theta j}}{\sum\limits_{\theta=1}^{r} e_{\theta j}} \tag{5}$$

In the equation: $f_{\theta j}$ is the specific gravity of the data value of the j th indicator in the θ th year; n denotes the number of districts and counties, and a total of 65 districts and counties are selected in this study. The information entropy of the indicator is calculated by formula (6).

$$D_j = 1 + E_j \ , \ E_j = k \sum_{\theta=1}^{r} f_{\theta j} \ln f_{\theta j} \ , \ k = \frac{1}{\ln r} \tag{6}$$

In the equation: E_j is the indicator information entropy; D_j is the information entropy redundancy; k is a parameter. The objective weights of the indicators are determined by formula (7).

$$w_j = \frac{D_j}{\sum\limits_{j=1}^{m} D_j} \tag{7}$$

In the equation: w_j is the objective weight of indicator j; in combination with the subjective weight $w_j^{'}$ of each indicator derived from the expert scoring of the AHP, it is averaged and multiplied with the balanced standardized indicators to calculate the evaluation score of each function of the rural region according to formula (8).

$$P_{\theta i} = \sum_{j=1}^{m} \left(\frac{w_j + w_j^{'}}{2} \right) e_{\theta ij} \tag{8}$$

In the equation: $P_{\theta i}$ denotes the evaluation score of rural function P in year θ in district and county i; finally, we get the rural regional multifunctionality evaluation index system.

3.3. Research method

This section describes the material methods used to analyze the evolution characteristics and coupling mechanism of rural regional functions. Although this study has established a relatively complete functional evaluation system, the mechanism behind the regional function still needs to interpret its spatial characteristics and interaction. Specific methods and functions are as follows.

3.3.1. Global spatial autocorrelation

The global *Moran's I* I index [83] was used to measure the spatial relationship of each function in rural areas among neighboring counties, and then identify the global spatial differentiation characteristics of each function, with *Moran's I* close to 1 or -1, indicating the stronger spatial autocorrelation or the stronger agglomeration of the function scores in that category of rural areas.

3.3.2. Coupling coordination degree model

The coupling coordination model is applied to quantitatively evaluate the degree of interaction and coordination between rural geographical functions. The model characterizes the interactions between different functions as follows:

$$C = \sqrt{\frac{A \bullet B}{\frac{(A+B)}{2}}} \tag{9}$$

$$T = \alpha A + \beta B \tag{10}$$

$$D = \sqrt{C \bullet T} \tag{11}$$

In formula (9) and formula (10): C is the coupling degree, C ∈ [0, 1], T is the comprehensive development index of two different rural regional functions; A=(LRF, LSF, APF, NAPF, EEF, ECF), B=(LRF, LSF, APF, NAPF, EEF, ECF), A≠B; α, β are the coefficients to be determined, generally take α = β = 0.5. In formula (11), D is the coupling coordination degree.

3.3.3. Decoupling model

The coupling coordination degree model only portrays the coordination relationship between two different functions and cannot reflect the interaction relationship between them, while the Tapio decoupling model can be used to analyze the interaction relationship between the two systems. According to the positive and negative situation between the growth rate of different regional functions and the size of decoupling index, the decoupling status is classified into eight types with reference to the existing literature [84](Table 2).

$$DI_i = \frac{\frac{(A_i - A_{i-1})}{A_{i-1}}}{\frac{(B_i - B_{i-1})}{B_{i-1}}} = \frac{\Delta A}{\Delta B} \tag{12}$$

In formula (12): DI_i is the decoupling index; A_i and A_{i-1} are the regional function index of year i and year $i-1$, respectively. B_i and B_{i-1} are another regional function index in year i and year $i-1$ respectively, ΔA is the growth rate of regional function A, ΔB is the growth rate of regional function B.

4. Results and analysis

4.1. Multifunctional spatiotemporal characteristics of rural regions

4.1.1. Time characteristics

For the changes in rural regional functions in Gansu Province, we first observe its temporal variation characteristics from the global perspective, and use the global *Moran'sI* index to express the spatial autocorrelation of each rural geographical function. As seen from Table 3, all functions in the study area show a positive correlation with spatial aggregation characteristics that passes the significance test. In terms of pattern characteristics, the degree of concentration of each function changed, and the function with the highest degree of concentration changed from ECF to LRF, while EEF switched to the lowest. This shows that rural areas pay more attention to the

Table 2
Classification table of decoupling status.

Status		ΔA	ΔB	DI
decoupling status	Recession decoupling	0 <	0 <	$DI \geq 1.2$
	Strong decoupling	0 <	> 0	$DI < 0$
	Weak decoupling	> 0	> 0	$0 \leq DI < 0.8$
connection status	Growth link	> 0	> 0	$0.8 \leq DI < 1.2$
	Recession connection	0 <	0 <	$0.8 \leq DI < 1.2$
Negative decoupling status	Growth negative decoupling	> 0	> 0	$DI \geq 1.2$
	Strong negative decoupling	> 0	0 <	$DI < 0$
	Weak negative decoupling	0 <	0 <	$0 \leq DI < 0.8$

Table 3
Multifunctional global *Moran's I* for rural regions (Moran's I, Z-value, pseudo p-value).

Function	2014	2016	2018	2020	Changes in spatial correlation
LRF	0.399, 10.9373, 0.01	0.416, 11.2534, 0.01	0.357, 12.9457, 0.01	0.374, 14.0317, 0.01	−0.025
LSF	0.288, 9.3971, 0.01	0.392, 9.3042, 0.01	0.309, 10.6467, 0.01	0.276, 7.5034, 0.01	−0.012
APF	0.325, 11.1469, 0.01	0.426, 9.2237, 0.01	0.336, 14.8782, 0.01	0.354, 15.5281, 0.01	0.029
NAPF	0.314, 10.3091, 0.01	0.511, 12.8564, 0.01	0.331, 8.5648, 0.01	0.342, 7.9154, 0.01	0.028
EEF	0.301, 10.7519, 0.01	0.365, 9.2564, 0.01	0.285, 7.7704, 0.01	0.214, 8.6315, 0.01	−0.087
ECF	0.403, 13.9945, 0.01	0.360, 12.9009, 0.01	0.341, 14.3637, 0.01	0.352, 15.5111, 0.01	−0.051

ecological and green development of the whole area, the social characteristics of urban and rural areas begin to be integrated, and the residential function of the rural region is concentrated and becomes the first regional function. In terms of temporal changes, the degree of aggregation of all functions except APF and NAPF shows a decreasing trend, and there is a turning change in 2018 in general. The rural regional function gradually shifts from agglomeration development to regional diffusion development, and the quality of development is further improved (Fig. 3).

Specifically, policy guidance is the core force influencing the clustering characteristics of rural regions. LRF shows a fluctuating downward trend, which is attributed to Gansu Province's continuous promotion of the construction of security housing projects and the renovation of rural dilapidated houses since 2011. After 2014, the living quality of Gansu Province's districts and counties significantly improved, from pilot to promotion, showing the characteristics of first clustering and then scattering, with both local governments improving living conditions and raising basic security playing a leading role. In addition, policy has not always played a pioneering role in the process of rural development and has assumed the function of matching the changes in social characteristics. Subject to LRF synchronous changes in LSF, with policy regulation supporting the further development of the social security system in the context of improved living conditions, economic empowerment and population size.

Policy can provide clear guidelines for the development of rural regional functions in the form of global planning. Gansu Province mainly promotes full-film duopoly furrow sowing technology, efficient farmland water conservation technology (drip irrigation cultivation), and standardized cultivation technology; improves planting subsidies and agricultural machinery purchase subsidies policies; and strengthens the integration of projects and funds to invest, further stimulating the enthusiasm and efficiency of farmers in all districts and counties to grow food. The development quality of APF has improved, the planting scale has expanded, and the agglomeration characteristics have enhanced. In addition, NAPF's weakly rising spatial aggregation trend is also due to the influence of traditional industry and tourism and other industrial development plans. On the one hand, under Gansu Province's "13th five-years" for industrial transformation and upgrading, industrial capacity removal [85], industrial transformation and development, industrial quality development, and industrial relocation around nature reserves promote further concentration of industrial development in several districts and counties in Gansu Province. On the other hand, the implementation of programs such as rural tourism development and physical retail innovation and transformation has improved the level of infrastructure and public services, promoted the full opening of tourism industry elements to social capital, aided the overall development of the tertiary industry, and slowed down the spatial concentration of nonagricultural production functions.

Compared with urban space, the ecological function is the most advantageous regional function of rural areas. The policy serves as a link to balance protection and development, enabling better use of resources within the boundaries of development constraints. The Gansu Provincial Ecological Protection and Construction Plan (2014–2020) initially focused on Qilian Mountain, Gannan Plateau, (Bailong River, Baishui River, West Han River) basin, Ziwuling, and other water conservation areas. Later, the Gansu Province's ecological construction was carried out in terms of forest ecosystem protection and construction, grassland ecosystem protection and restoration, desert ecosystem deterioration trend containment, wetland ecosystem protection and restoration, and farmland ecosystem protection and improvement, so that EEF spatial aggregation characteristics showed a trend of first rising and then falling. The ECF continues to disperse because of the Gansu Province's 2014 major pollutant reduction plan and natural forest protection project, as well as the province's promotion of the policy of returning farmland to forest and grassland, which has led to an overall improvement of the environmental protection capacity in each county.

4.1.2. Spatial characteristics

For the different spatial pattern evolution characteristics of each function in rural regions of Gansu Province, this study divided the six types of rural regional function scores of the four study periods into five levels by the natural breakpoint method of comprehensive years. Functional strength from low to high was relatively divided into level I area, level II area, level III area, level IV area, and level V area and visualized and expressed using ArcGIS 10.2 software [86] (Fig. 4).

Among them, the LRF shows year-by-year overall improvement, and the core residential comfort zone is located in central Gansu Province and shows a trend of proliferation. In 2014, only four counties were in the LRF level IV area, and these counties have the characteristics of low population density and high per capita income and expenditure. With the increase in per capita living area, per capita income and expenditure in 2020, four counties, such as Guazhou, developed into LRF level V areas, and 17 counties in the whole area, such as Longxi County, were added. Poverty is an important constraint on rural development and a key component of

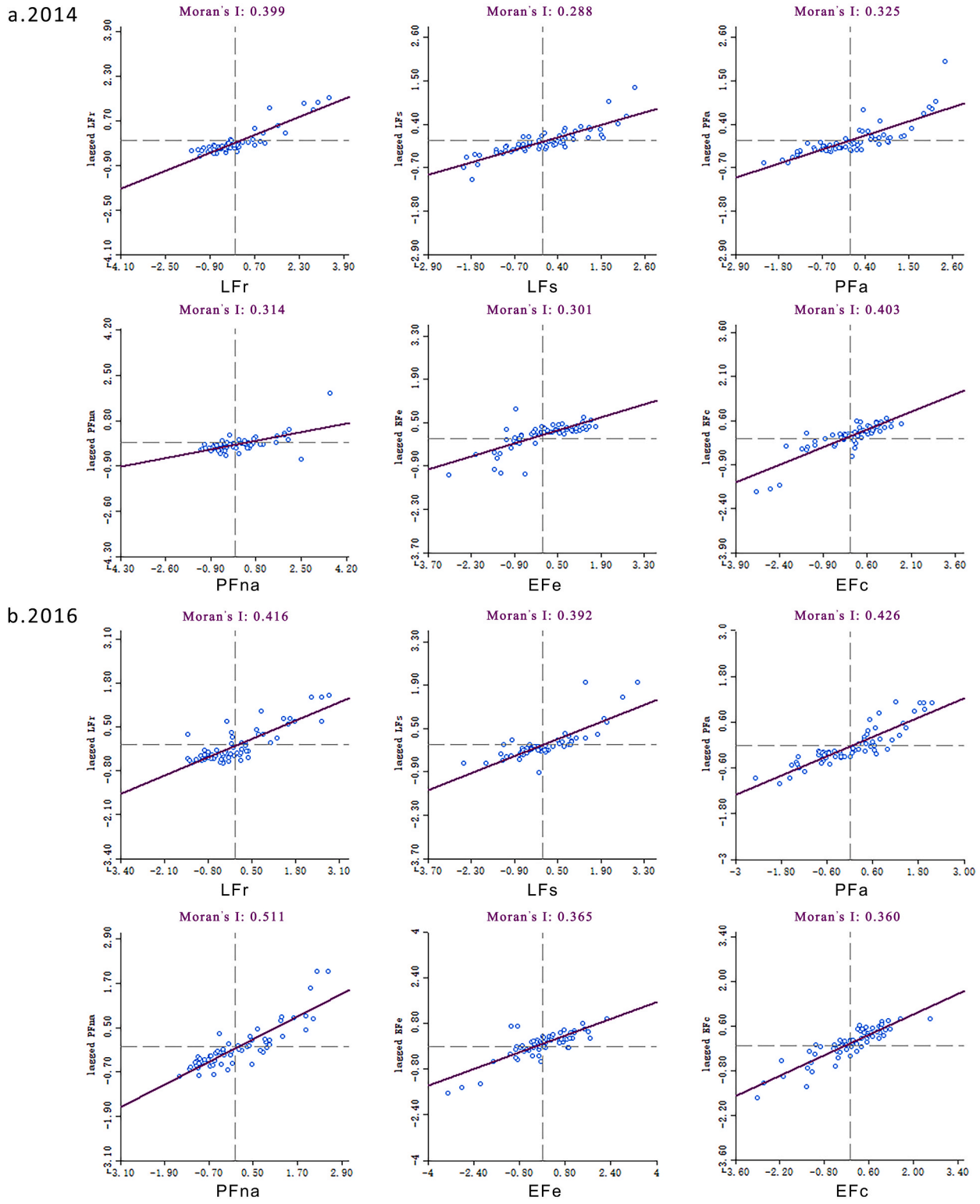

Fig. 3. Multifunctional global spatial autocorrelation changes of rural regions: a is the multifunctional global spatial autocorrelation for 2014, and b, c, d represent 2016, 2018, and 2020, respectively.

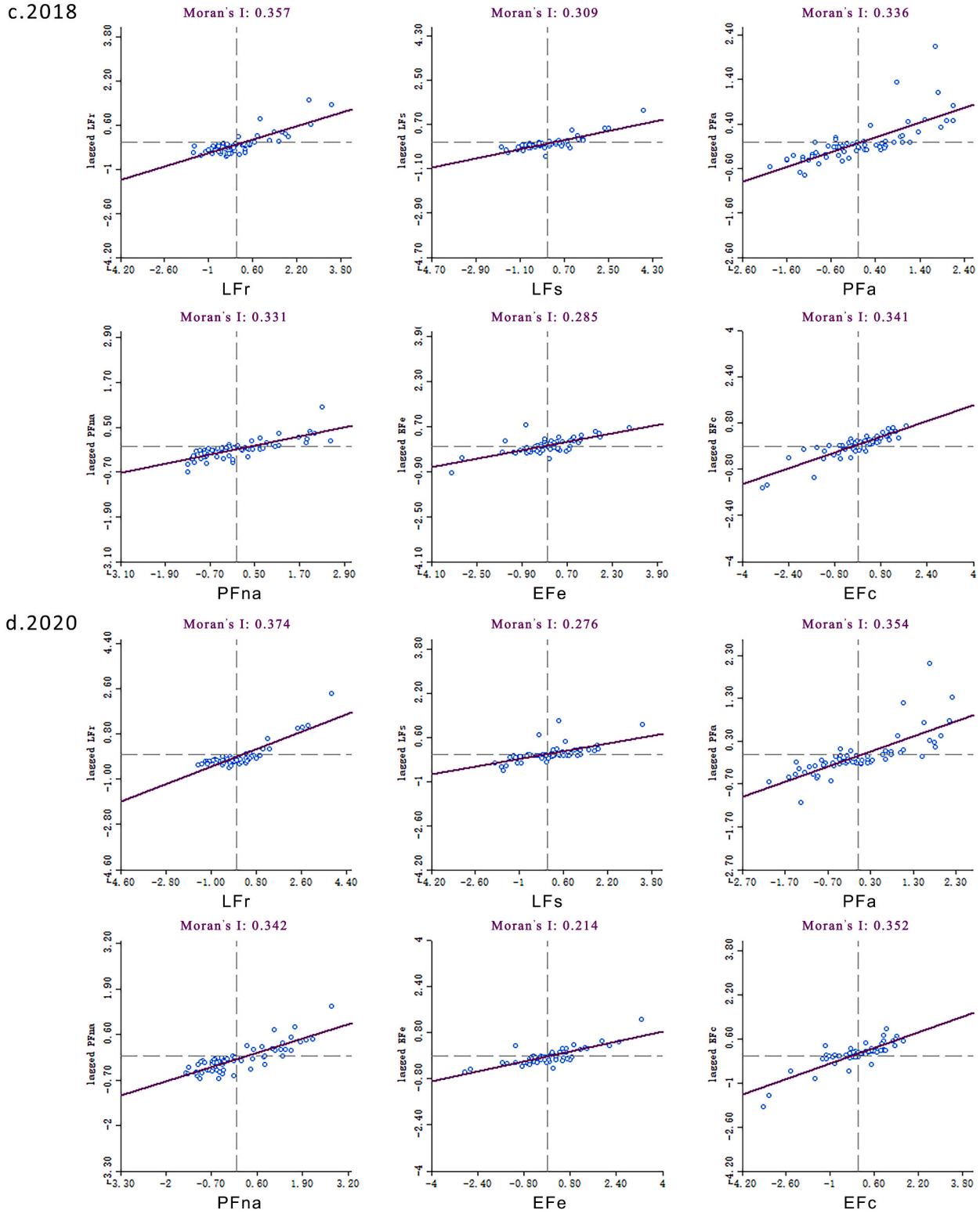

Fig. 3. (*continued*).

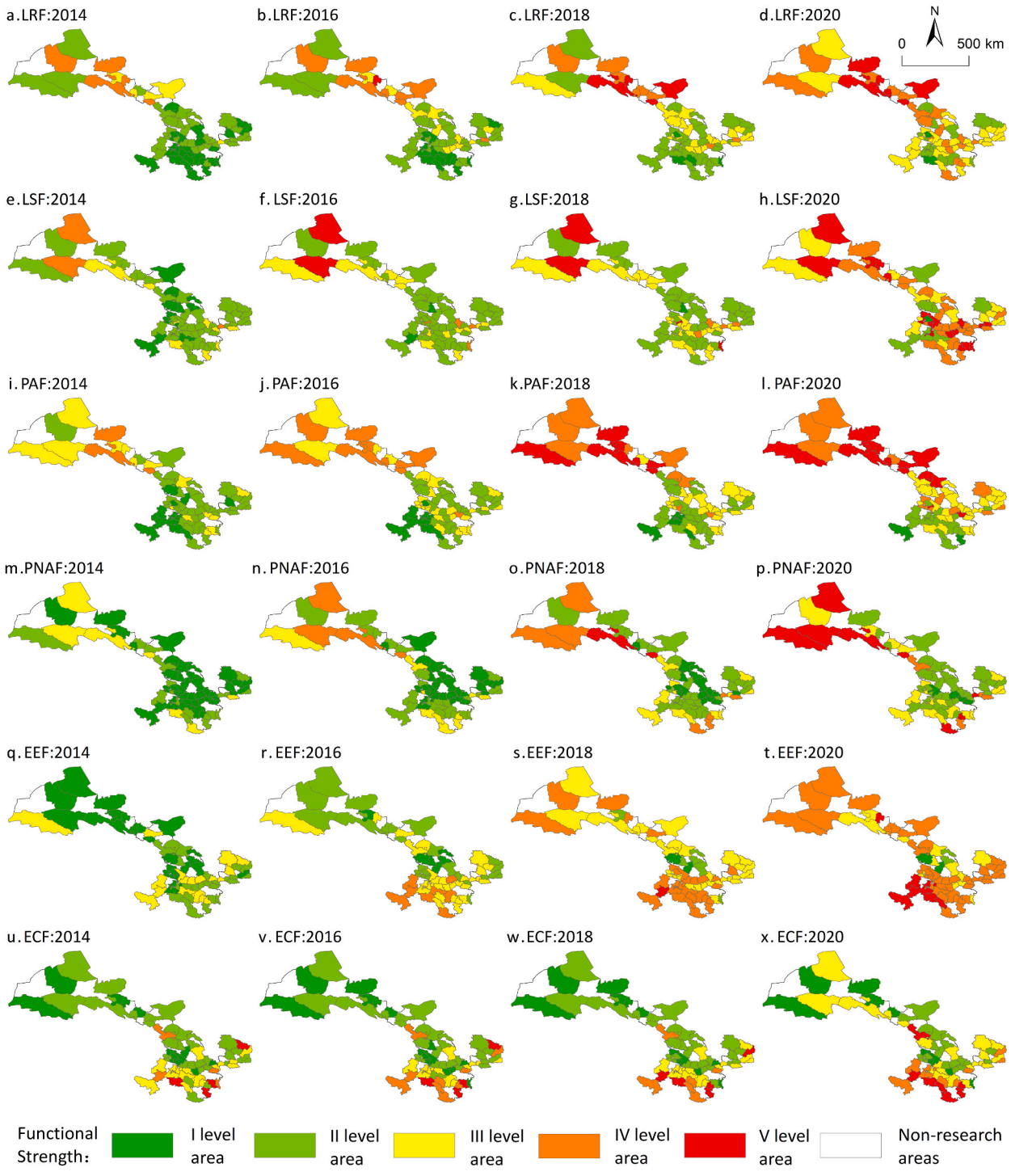

Fig. 4. Map of changes in functional intensity of rural regions: a-b are changes in LRF 2014–2020, e-h are changes in LSF 2014–2020, i-l are changes in PAF 2014–2020, m-p are changes in PNAF 2014–2020, q-t are changes in EEF 2014–2020 and u-x are changes in ECF 2014–2020.

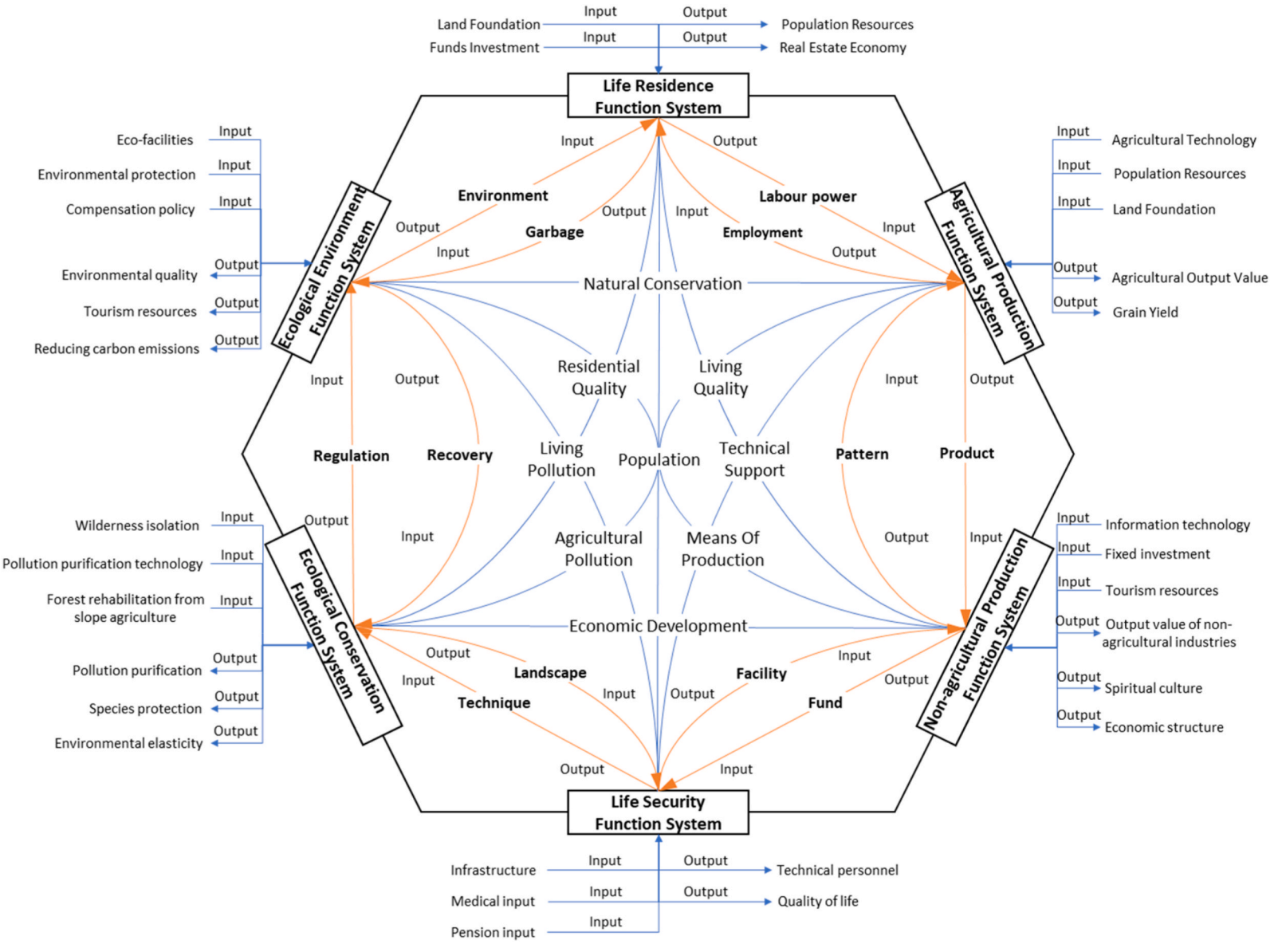

Fig. 5. Multifunctional interactive coupling system for rural regions.

disadvantaged rural communities and disadvantaged multifunctionality [87]. The enhancement of LRF in the period of 2014–2020 is mainly due to Gansu Province's full efforts to promote the province's 58 concentrated contiguous poor counties and 17 "insertion--type"[1] transformation of rural dilapidated housing, rather than simply being focuses on guiding its economic development out of poverty. The per capita living area has also increased significantly to LRF basic from the weak state. In addition, Gansu Province aims to crack the bottleneck regarding the economic development of small towns; to achieve a large concentration of small space; to achieve powerful improvement of the living environment; to adhere to the industry, culture, and tourism "trinity"; to constantly improve the quality of life and living; and to consolidate the development of LRF.

During the study period, LRF and LSF showed a mutually reinforcing effect. LSFs are mainly influenced by living facility conditions, while places with good living infrastructure conditions generally attract population concentration, leading to an increase in population density, which in turn affects the quality of living accommodation. Therefore, in 2014, the level IV areas of the life security function were Subei Mongolian Autonomous County and Huating County, and the overall life security level was relatively low. With the implementation of a series of development strategies, the life security function is gradually enhanced. The 2020 LSF level V areas increase to 17, the scope of the LSF high-level areas increases significantly from concentration to diffusion, and the spatial scope keeps moving southward.

The agricultural structure of Gansu Province has become more intensive, and production has become more large-scale. The scope of the core area has been expanded, but the trend of concentration in the north is obvious. In addition, APF and LRF also show partial spatial overlap in their distribution, which highlights the role of labor factors in promoting agricultural production. In 2014, the only agricultural production level IV areas were Sunan Yugu Autonomous County and Jinta County, which have a good agricultural production base. The two counties serve as production bases in the crop seed industry development plan, and APF keeps clustering and spreading around them. Together with the improvement to agricultural production technology and modernization levels, the province's agricultural production functions have been enhanced, incuding 12 functional level IV and level V areas each in 2020.

In 2014, the province's rural region NAPF was not strong. Due to Gansu Province's "13th national five-year plan" industrial transformation and planning upgrades [85], and through the transfer of industrial elimination, industrial development slowed in the short term. Following industrial bloodletting, the industrial base is deep, and its innovation ability is stronger in counties with a faster rate of industrial development. Coupled with the development of rural tourism, the nonagricultural economy of the countryside with superior natural resources can be further developed and strengthened. The 2020 NAPF level V area includes six counties, all of which have a better industrial base or tourism resources. Among them, Aksai Kazakh Autonomous County, Sunan Yugu Autonomous County, and Huating County are also agricultural production level V areas, which shows that the relationship between APF and NAPF is not simply linear.

The relationship between ecological resource protection and development is gradually harmonized, and the EEF is mainly concentrated in the south of Gansu Province, which to some extent promotes local economic development. In 2014, Gansu Province, to accelerate the construction of a national ecological security barrier comprehensive pilot area, protected the entire natural core area by classification [88]. The inland river area west of the river focuses on water connotation, wetland protection, and desertification control; the central area along the Yellow River focuses on soil erosion control and comprehensive watershed management; the plateau area south of Gansu focuses on water connotation, grassland management, and river, lake, and wetland protection; the mountain area south of Qinba focuses on biodiversity protection and water connotation; and the loess plateau area in Longdong-Longzhong focuses on soil and water conservation and comprehensive watershed management. In 2020, significant results were achieved.

The ECF area has a significant negative correlation with the production function area due to the hindrance of ecological conservation by polluting waste caused by the production process, but it has improved with the popularity of ecological agriculture methods. On the one hand, the province further promotes the plan to reduce major pollutants. On the other hand, with the continuous promotion of eco-environmental protection planning, the quality of the ecological environment has further improved, and the forest coverage rate has significantly increased to provide support for ecological conservation. The 2020 ECF V level areas are concentrated in the south, including 7 counties, such as Luqu and Diebe.

4.2. Analysis of multifunctional coupling mechanisms in rural regions

4.2.1. Multifunctional interactive coupling system for rural regions

Cross-coupling refers to the dynamic relationship between two or more system units interacting with each other, and this relationship can be seen as an open, nonequilibrium, dynamic up-and-down system with nonlinear interaction and self-organization capability [89]. In this study, the six rural regional functions summarized above are conceptualized as regional function subsystems and then characterized according to the coupling relationships between subsystems, such as one-to-one, one-to-many, positive and negative feedback, and constraint coercion. The interactive coupling mechanism of rural territorial multifunctional systems is explored from the perspective of human-land relationships, and the characteristics cycle of rural regional function development is derived. First, with reference to the research framework of the sansheng spaces and the "ecology-economy-society" system and combining the above spatial evolution characteristics of rural regions and research data, we construct a multifunctional interactive coupling system of rural regions. The system is an adaptive growth complex mega-system composed of six functional subsystems (life residence, life security, agricultural production, nonagricultural production, ecological environment, and ecological conservation),

[1] A plugged-in poverty county is called a plugged-in county if a county consists of a dozen villages, only a few of which are poor.

three major root causes (people, land, and media), and multiple external forces (Fig. 5).Among them, the LRF system refers to the basic man-made environmental conditions that are needed for man to live on the land for a long time, forming a dynamic organic whole through the flow of capital and land circulation. In this system, people and land are the most direct occupancy relationship. Architecture, as the main medium, connects land and capital in tandem, while other external forces, such as location and policy, intervene to make the system steadily produce population resources and a property economy. The LSF system refers to the survival guarantee conditions constituted by various types of service facilities, which become the support system of the LRF system through the input of resource elements such as transportation, education, medical care, and pension. In this system, people constitute the human-land transformation relationship by empowering the land. Management is the main medium to provide basic functions and public service functions for people, it also serves to improve the quality of life and to produce technical talent. The APF system refers to the value creation system based on agricultural production methods, which is the original way for rural residents to use the land to generate economic benefits, using traditional agricultural production methods to integrate labor, technology, and land resources to form a spiraling and steady development system. In this system, people and the land are in a direct utilization relationship, and plants and animals are used as the main medium to obtain food provided by nature for human beings and to carry out preliminary processing to become commodities to obtain an excess (beyond the edible value of the agricultural products themselves) economy. The NAPF system refers to the value creation system based on nonagricultural production methods such as secondary and tertiary industries, which can not only generate more than traditional APF economic value but also go further to generate nonmaterial values, such as culture and entertainment. Nonfarm production is rooted in the land and uses it indirectly for its resources, characteristics and laws. A system in which humans use natural consumptive resources, including minerals, gases, elements, etc., on the one hand, and the natural landscape and laws on the other hand, to develop art and science, creating higher economic value and the ability to explore and innovate; the EEF system is a natural balance system composed of nonman-made areas that are not subject to or little modification by human beings, which is the basic carrier to maintain ecological integrity and undertake biosphere functions. This system can provide green landscape space for human beings, which is beneficial to their physical and psychological health and is also a powerful engine for carbon neutral development. Science and technology as the main medium make this system an endogenous power guarantee for the sustainable development of human society; the ECF system refers to the feedback system that gives full play to the self-regulating ability of the natural system and maintains the stable operation of the ecosystem. Planning and policies serve as the main medium to protect the natural ecological environment from the negative impact of human activities by means of dividing ecological reserves, returning farmland to forest, and awakening ecological functions. The outputs of this system belong more to long-term invisible benefits, and environmental resilience protection and species integrity protection are the most valuable outputs.

4.2.2. Multifunctional coupling degree of rural regions

The multifunctional coupling coordination degree of rural regions can highlight the degree of interaction between the functions of each region. Referring to the relevant coupling degree type classification criteria [33], the frequency analysis method was used to group the proportion of each function coupling type in the same time period, and the frequency was multiplied by the corresponding median and divided by the number of study areas to obtain the average coupling coordination degree of that function in that year. The average coupling degree of each function in rural regions in 2014, 2016, 2018, and 2020 was measured, and the level of functional coupling coordination in rural regions of Gansu Province was classified into five categories with 0.2, 0.4, 0.6, and 0.8 as the

Functional relationship（A-B）	2014	2016	2018	2020	Mini figure
LRF-LSF	0.33 mild disorder	0.37 mild disorder	0.40 reluctant coordination	0.42 reluctant coordination	
LRF-APF	0.34 mild disorder	0.36 mild disorder	0.38 mild disorder	0.41 reluctant coordination	
LRF-NAPF	0.31 mild disorder	0.32 mild disorder	0.33 mild disorder	0.35 mild disorder	
LRF-EEF	0.38 mild disorder	0.41 reluctant coordination	0.44 reluctant coordination	0.45 reluctant coordination	
LRF-ECF	0.49 reluctant coordination	0.50 reluctant coordination	0.54 reluctant coordination	0.60 intermediate coordination	
LSF-APF	0.37 mild disorder	0.39 mild disorder	0.40 reluctant coordination	0.43 reluctant coordination	
LSF-NAPF	0.35 mild disorder	0.35 mild disorder	0.37 mild disorder	0.40 reluctant coordination	
LSF-EEF	0.43 reluctant coordination	0.51 reluctant coordination	0.54 reluctant coordination	0.61 intermediate coordination	
LSF-ECF	0.56 reluctant coordination	0.61 intermediate coordination	0.62 intermediate coordination	0.66 intermediate coordination	
APF-NAPF	0.35 mild disorder	0.38 mild disorder	0.39 mild disorder	0.41 reluctant coordination	
APF-EEF	0.49 reluctant coordination	0.51 reluctant coordination	0.55 reluctant coordination	0.62 intermediate coordination	
APF-ECF	0.61 intermediate coordination	0.62 intermediate coordination	0.63 intermediate coordination	0.64 intermediate coordination	
NAPF-EEF	0.42 reluctant coordination	0.42 reluctant coordination	0.51 reluctant coordination	0.55 reluctant coordination	
NAPF-ECF	0.52 reluctant coordination	0.54 reluctant coordination	0.57 reluctant coordination	0.60 intermediate coordination	
EEF-ECF	0.63 intermediate coordination	0.64 intermediate coordination	0.65 intermediate coordination	0.66 intermediate coordination	

Fig. 6. Evolution map of multifunctional coupling coordination degree in rural regions.

breakpoints, which corresponded to serious imbalance, mild disorder, reluctant coordination, intermediate coordination, and advanced coordination, respectively. The evolution matrix of the multifunctional coupling coordination degree (Fig. 6) was finally measured to make a functional relationship judgment.

Among them, LRF-LSF, LRF-APF, LRF-EEF, and APF-NAPF increased from mild disorder to reluctant coordination and entered the period of functional coordination coupling. LSF-APF and LSF-NAPF have obvious rate fluctuations when the coordination rises, and the functional coupling of LRF-NAPF is always in the mild disorder state. LRF-ECF, LSF-EEF, LSF-ECF, APF-EEF, APF-ECF, NAPF-ECF, and EEF-ECF all showed a yearly increase in coordination, rising to a period of intermediate coordination development. NAPF-EEF, although elevated within the reluctant coordination phase, was mainly focused on the explosive development during 2016–2018.

The decoupling analysis reflected the interaction relationship between the two functions (Table 4). During the study period, the LRF and LSF decoupling states showed fluctuating weak decoupling, both of which had positive growth rates, and the LRF grew relatively fast. The LRF and APF function showed a trend of decoupling, and the weak decoupling index gradually decreased; the LRF showed a fluctuating decoupling state with NAPF and EEF function, and from 2016 to 2018, during the weak decoupling development of the period, the LRF and both functions showed an expansionary connection, experiencing relatively synchronous growth. The LSF and APF showed growth negative decoupling during 2014–2016, with the latter growing faster in the case of both growth. In addition, the period 2016–2020 showed weak decoupling, with the former growing faster in the case of both growth types. The LSF to NAPF showed growth negative decoupling to growth link change, gradually changing from relatively faster growth of LSF to both remaining in sync, while LSF to EEF showed the exact opposite decoupling state change from that of NAPF. The decoupling state of APF to NAPF and EEF was similar to that of LSF to EEF, and the relative synchronization between the functions changed from relative synchronization to a relatively faster growth rate of APF. The decoupling state of NAPF and EEF changed from weak decoupling to a growth link, and the relatively faster growth rate of NAPF gradually kept synchronous growth with EEF. The five functions of LRF, LSF, APF,

Table 4
Multifunctional decoupling analysis table for rural regions.

Period	Function	Decoupling index		Type of decoupling	Function	Decoupling index		Type of decoupling
2014–2016	LRF—LSF	0.51514	$0 \leq DI <$	Weak decoupling	LRF—APF	0.66565	$0 \leq DI <$	Weak decoupling
2016–2018		0.74583	0.8	Weak decoupling		0.57024	0.8	Weak decoupling
2018–2020		0.63486	$0 \leq DI <$	Weak decoupling		0.45624	$0 \leq DI <$	Weak decoupling
			0.8				0.8	
			$0 \leq DI <$				$0 \leq DI <$	
			0.8				0.8	
2014–2016	LRF—NAPF	0.75008	$0 \leq DI <$	Weak decoupling	LRF—EEF	0.53269	$0 \leq DI <$	Weak decoupling
2016–2018		0.98655	0.8	Growth link		0.85502	0.8	Growth link
2018–2020		0.69856	$0.8 \leq DI <$	Weak decoupling		0.79872	$0.8 \leq DI <$	Weak decoupling
			1.2				1.2	
			$0 \leq DI <$				$0 \leq DI <$	
			0.8				0.8	
2014–2016	LRF—ECF	−0.0038	$DI < 0$	Strong decoupling	LSF—APF	1.29216	$DI \geq 1.2$	Growth negative
2016–2018		0.14680	$0 \leq DI <$	Weak decoupling		0.76456	$0 \leq DI <$	decoupling
2018–2020		0.16618	0.8	Weak decoupling		0.47216	0.8	Weak decoupling
			$0 \leq DI <$				$0 \leq DI <$	Weak decoupling
			0.8				0.8	
2014–2016	LSF—NAPF	1.45606	$DI \geq 1.2$	Growth negative	LSF—EEF	1.03405	$0.8 \leq DI <$	Growth link
2016–2018		1.32275	$DI \geq 1.2$	decoupling		1.14640	1.2	Growth link
2018–2020		1.10033	$0.8 \leq DI <$	Growth negative		1.25810	$0.8 \leq DI <$	Growth negative
			1.2	decoupling			1.2	decoupling
				Growth link			$DI \geq 1.2$	
2014–2016	LSF—ECF	−0.0075	$DI < 0$	Strong decoupling	APF—NAPF	1.12684	$0.8 \leq DI <$	Growth link
2016–2018		0.19683	$0 \leq DI <$	Weak decoupling		1.73006	1.2	Growth negative
2018–2020		0.26177	0.8	Weak decoupling		1.94198	$DI \geq 1.2$	decoupling
			$0 \leq DI <$				$DI \geq 1.2$	Growth negative
			0.8					decoupling
2014–2016	APF—EEF	0.80025	$0.8 \leq DI <$	Growth link	APF—ECF	−0.0058	$DI < 0$	Strong decoupling
2016–2018		1.49942	1.2	Growth negative		0.25744	$0 \leq DI <$	Weak decoupling
2018–2020		2.22043	$DI \geq 1.2$	decoupling		0.46200	0.8	Weak decoupling
			$DI \geq 1.2$	Growth negative			$0 \leq DI <$	
				decoupling			0.8	
2014–2016	NAPF—EEF	0.71017	$0 \leq DI <$	Weak decoupling	NAPF—ECF	−0.0051	$DI < 0$	Strong decoupling
2016–2018		0.86668	0.8	Growth link		0.14880	$0 \leq DI <$	Weak decoupling
2018–2020		1.14338	$0.8 \leq DI <$	Growth link		0.23790	0.8	Weak decoupling
			1.2				$0 \leq DI <$	
			$0.8 \leq DI <$				0.8	
			1.2					
2014–2016	EEF—ECF	−0.0072	$DI < 0$	Strong decoupling				
2016–2018		0.17170	$0 \leq DI <$	Weak decoupling				
2018–2020		0.20807	0.8	Weak decoupling				
			$0 \leq DI <$					
			0.8					

NAPF, and EEF to ECF showed the same decoupling state change characteristics. In 2014–2016, each function was strongly decoupled from ECF, and the enhancement of ecological conservation and other functions declined. From 2016 to 2018, the decoupling state changed to a growth trend of weak decoupling.

4.2.3. *Multifunctional coupling mechanism in rural regions*

Through the above data analysis, it is found that in the multifunctional system of rural regions in Gansu Province, LRF and LSF, APF, EEF, and ECF are constantly developing in a coordinated manner, and the relative development rate of the former is faster, but the growth rate is gradually converging. The growth rate of LRF and NAPF hovers in the synchronous range, and it is never able to get rid of the disorder status quo. LSF and other functions are also constantly converging, and their growth rate is accelerating while APF, NAPF, EEF, and ECF slow down; APF and other functions are also in the law of gradually coordinated development but have a faster development rate than NAPF and EEF; NAPF, relative to the faster development of EEF, gradually converged to synchronization; EEF in the growth of the same time and ECF growth rate slowed down. On this basis, combined with the spatial evolution characteristics of multifunctional rural regions in Gansu Province, with reference to various indicators and regional multifunctionality development drivers [67,90], and incorporated into the elemental factor analysis of the multifunctional interaction coupling model of rural regions, the functional development of rural regions under China's "rural revitalization" strategy can be divided into three periods: function-led, region-led, and structure-led (Fig. 7).

From the specific mechanism, in Gansu Province, of the rural multifunctional system, the interaction of the six functional subsystems influences the mechanism: the living and residential functions to provide living conditions for population growth, first, the increase in human resources to promote the development of industrial functions to enhance economic strength, and second, population growth brings the increase in population density but also through the reduction of residential area to limit the residential function. In addition, the pollution generation of domestic waste that accompanies population growth also destroys forest cover and affects the ecological conservation function. It can be seen that closed-loop interactions can be formed among the six systems, one-to-one or even one-to-many, to promote or inhibit the development of functional systems through relevant variables in different development periods to achieve coordinated coupling.

4.3. *Dynamic development of the countryside based on regional functions*

"Rural revitalization" should not start with full-line development. Village development is a dynamic process, and a classification model system should be established according to realistic needs, to explore the characteristic and advantageous attributes of villages, to determine development goals, to refine endogenous resources and core regional functions and to define indicators according to the actual situation, such as regional planning, and then to categorize and position development. At the theoretical level, a large number of studies have been conducted on the classification of villages, mainly based on different theoretical bases, such as industrial structure, natural elements, economic level, urban-rural relationships, and geographical space [91]. At the practical level, local governments at all levels also have working thoughts on rural classification according to local conditions.

Based on the above characteristics measurement and analysis, this paper compares in detail the intimate relationship between the functional mechanism of rural regions and the "rural revitalization" strategy and finds that China's rural development has entered the stage of urban-rural integration development, and the "rural revitalization" strategy under urban-rural Chinese society is a general

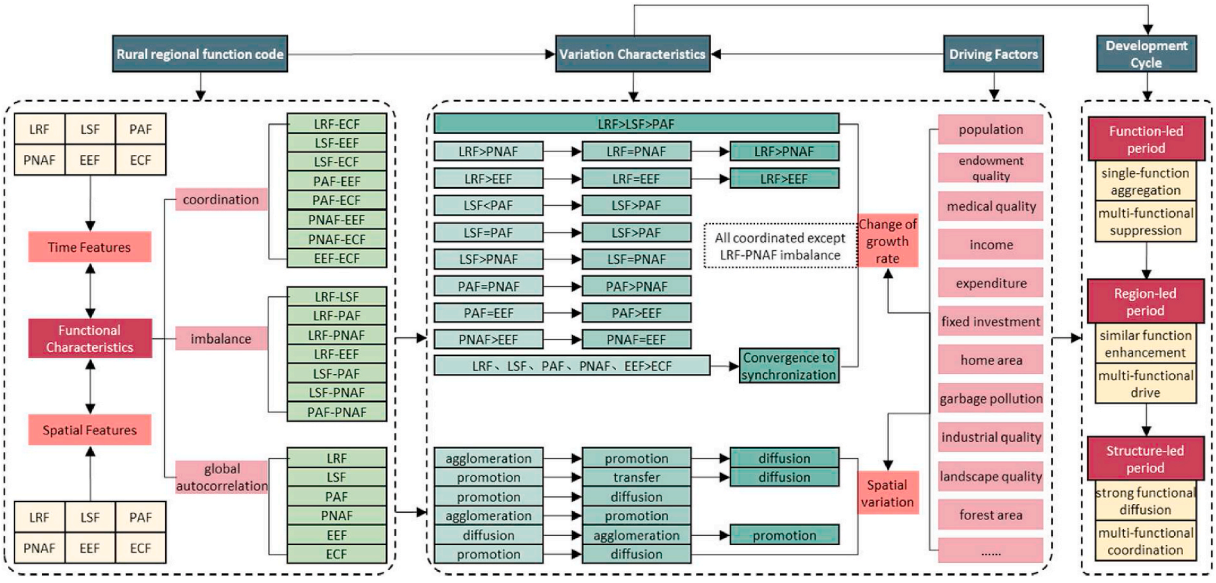

Fig. 7. Process of change of multifunctional system in rural regions.

strategy that cuts across the macro, meso, and micro levels. It is possible to stage, partition, and classify urban-rural integration, functional complexes and rural organisms in order from the region to the county to the village. First, at the macro level, we should abide by the twenty-word policy of "rural revitalization": "prosperous industry, pleasant ecology, civilized countryside, effective governance, and rich life" [92]. We will breakdown the barriers to the circulation of resources between urban and rural areas and build a unified urban and rural governance policy system. Second, at the meso level, we should grasp the development characteristics of rural functional systems and clarify the development cycle and the law of divergence, analyze the functional types of counties, determine their socioeconomic development directions and key areas, formulate scientific zoning schemes, and optimize functional interaction space. According to the characteristics of agricultural region and comprehensive production capacity, the non-comprehensive agricultural type can be divided into key agricultural area and general agricultural area. According to the level and scale of ecological protection areas, the ecological types were divided into core protected areas, important ecological areas and general ecological areas. The comprehensive area is divided into comprehensive service core, professional service center and general service point according to the main service type and scale. Finally, at the micro level, villages are integrated into the urban development system and divided into general villages, central villages, and evacuated villages. Based on the existing village classification criteria for rural revitalization, combined with the elements of interaction of the multifunctional mechanism of rural areas and from the perspective of both development and protection functions, and with modified evaluation, the types of villages for dynamic development of "rural revitalization" can be judged (Fig. 8). This is conducive to optimizing the zoning control of villages, realize the village main body function orientation. We will make effective arrangements for village development, land use, infrastructure construction, industrial development, and ecological and environmental protection, and promote the spatially concentrated development of rural areas and the coordinated development of urban and rural areas. In addition, it is conducive to the establishment and improvement of the national village basic information database, providing comprehensive and systematic data support for the continuous deepening of the national "rural revitalization" strategy [91].

5. Discussion

5.1. Reasons for the diversification of rural regional functions

Through the review of the evolution process of rural regional functions in China, we find that rural regions are developing into multifunctional complexes. These can be explained from the following perspectives:

First, the improvement of agricultural economic production efficiency is an important reason for the development of rural functions. The liberation of agricultural productivity promotes the increase of agricultural surplus products, and the working population gradually separates from the traditional agricultural production. By analyzing the common characteristics of counties with different functional types in Gansu Province, we find that natural resource endowment, location factors, social and economic basis, ecological environment, regional cultural environment, system reform, degree of marketization and government macro-control and other factors jointly determine the evolution trend of rural regional multifunction. On the one hand, the awakening of people's consciousness in the process of social development and the change of demand for multiple functions such as production, consumption and ecology in rural areas drive the continuous evolution of rural areas [21]. The added value of agriculture has improved people's quality of life, and the demand for landscape beautification and recreation has become increasingly vigorous. Rural regional scenery based on environmental advantages has become an important resource for the tertiary industry economy [93]. On the other hand, the improvement of infrastructure makes rural transportation and location conditions more convenient, stimulating residents' travel and consumption to a

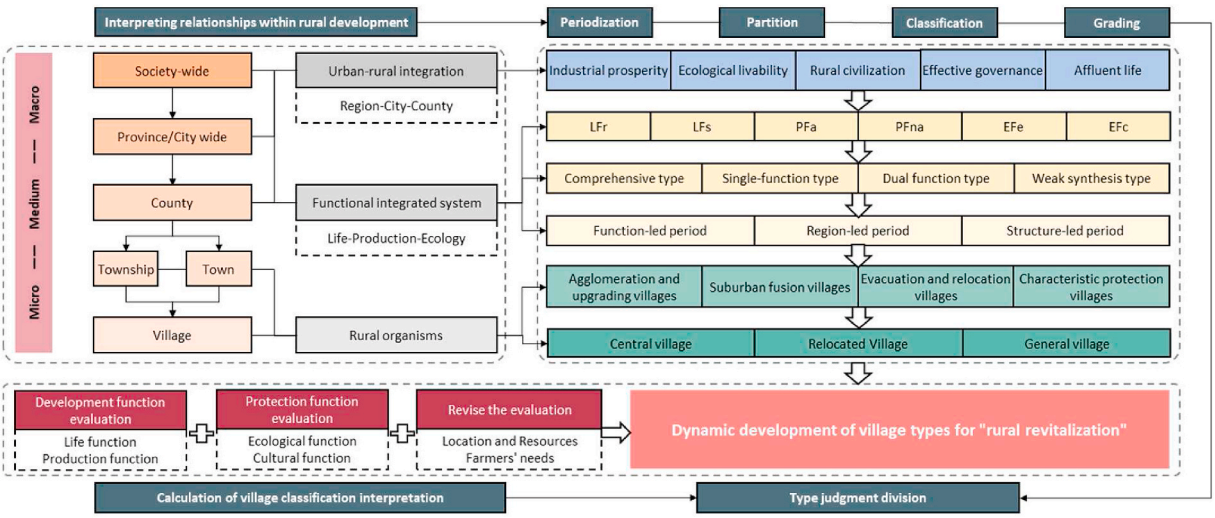

Fig. 8. The process of classifying village types for the dynamic development of "rural revitalization".

certain extent, and making rural tourism, homestays, catering services and other industries active, thus creating conditions for rural development [94].

Secondly, the development of rural regional functions is related to the needs of urban development to a certain extent, and the deepening of urban-rural interaction promotes the diversification of rural regional functions. In the process of urbanization, rural infrastructure and public services are gradually improved, creating conditions for economic development and employment security [95]. The circulation of education and medical resources in urban and rural areas cultivates objective factors such as the quality of farmers, enhances their subjective initiative to flexibly meet market demands and enriches regional function types [96]. In addition, urban demand for rural areas has gone beyond agricultural production to include the need to provide ecosystem services, amenities and aesthetics, and the preservation of cultural landscapes [97].

The results also reveal the law of the development pattern of rural regional functions, and reveal that the diversification of rural regional functions is the combined effect of internal development ability and external driving force. In spite of this, the diversification of rural regional functions does not completely bring favorable conditions to rural development, and the incoordination between multi-functions will have a negative impact on rural development [98]. Therefore, this study explored the existence of functional coupling mechanism of rural regions, and emphasized the promotion effect of multifunctional rural regions on "rural revitalization."

5.2. Demand of rural development for rural regional functions

Over the past 40 years of reform and opening, the evolution of China's rural development stage has been reflected in strategic transformation under the interaction of economic laws and policy guidance. From the reform of the rural economic system, the construction of small towns, and the construction of new rural areas to the current strategy of "rural revitalization," the government plays the role of "commander" in the process of rural development, and the implementation of relevant policies and systems constantly adjusts the direction of agricultural and rural development [99]. Rural development has become a necessary path to common prosperity in China. Agricultural policy orientation has accelerated the speed of rural transformation. Rural areas have gradually changed from agricultural production to specialized and large-scale production, and rural land use and industrial development have gradually changed to multifunctional direction [100].

This paper conducts an in-depth study regarding the relationship between rural regional functions and China's "rural revitalization" strategy. The study shows that, as a dynamic regulation strategy, THE overall planning of "rural revitalization" based on the evolution law of rural regional system has insufficient consideration of the endogenous mechanism of rural regional functions, which means that the existing classification system of "rural revitalization" can no longer meet the dynamic development of the countryside.

Through the study of multifunctional mechanisms in the rural regional system, it is found that the development of rural regional functions is crucial for the optimization of rural human-land relations and maximization of comprehensive benefits. To promote rural development, first, the villagers' concept should be improved and changed, the importance of green development in the regional function system should be recognized, and the market-oriented ecological compensation mechanism should be improved. Second, rural development will not hinder the process of urbanization and industrialization, and not only the modern agricultural system but also the modern nonagricultural system should be established in the rural production function to deepen the interaction between urban and rural industries. Thirdly, the "point-axis" system of the new urbanization development is also beneficial to rural development, which can be incorporated into the urban system and divided into central, general and merged villages. Finally, the internal relationship between the multi-functional coupling mechanism of rural areas and rural development is explored, so as to clarify the direction of rural development, optimize the allocation of resources, promote the classified development of villages, and enhance the regional comprehensive value [101].

5.3. The importance of policy

Behind these findings of this study is the central role of policy system in rural development. Like the guaranteed equity of the ultimate goal of China's rural modernization development derived by Fang and Liu (2015), in our study, the urban-rural equity distribution is constantly fine-tuned under the policy regime to promote rural development [42]. On the one hand, the guiding role of policies is reflected in the establishment of institutional mechanisms for integrated rural-urban development, promoting the two-way flow of urban and rural factors and enabling labor, land resources, financial capital, industrial technology and other factors to breakdown urban-rural barriers. On the other hand, the regulatory role of policies provides clear guidelines for rural development and governance, balances protection and development, and promotes social equity and equality.

Under the background of urban-rural integrated development, to promote "rural revitalization," multifunctional coordination of rural regions and realize the internal coupling of "population-land-economy" in rural areas is still an important method to improve the potential of rural development and ensure social equity. Due to the differences in natural and unnatural capital, economic demand, market distance, labor supply and infrastructure level, The rural regions of western China, represented by Gansu Province, are divided into different geographical types in the process of dynamic transformation. For regions with single regional function types, measures such as rural landscape remodeling and industrial transformation and upgrading can be taken according to comparative advantages to improve the multifunctional level. For comprehensive regions, based on the advantages of regional development, we will build a multifunctional rural service core integrating rural production, cultural entertainment, education, health and ecology. In addition, rural areas have many cultural and natural heritage, which is a continuation of the preservation of ecological civilization and culture. Therefore, in the process of rural development, we should pay attention to excavate the pluralistic value of the countryside and create the multifunctional landscape of the countryside. In the future, under the guidance of multifunctional theory and more comprehensive

regional and social policies, we should make full use of the advantages of China's rich traditional farming experience, thick rural history and culture, strong social cohesion, and take the development path of regional differentiation and adopt more targeted policies in combination with rural regional types.

6. Conclusions

At present, under the influence of various factors, rural regional functions are undergoing drastic transformation and reconstruction. This paper summarizes the functional dimensions of rural regions by sorting out the multifunctional evolution process of rural regions in China. It quantitatively analyses the spatio-temporal pattern of rural multifunctionality in Gansu Province, to build the rural multifunctionality coupling mechanism system. Based on the method of coupling coordination degree and decoupling index, the change process of this system is depicted, and the intimate relationship between the rural territorial function mechanism and the strategy of "rural revitalization" is sorted out in detail through the measurement and analysis of the characteristics, to deduce the process of dividing the village type of dynamic development of "rural revitalization".

From 2014 to 2020, the spatial and temporal differences of rural regional multifunction in Gansu Province were obvious, and the six regional functions were improved, among which LRF and NAPF were significantly improved, and the ECF area was negatively correlated with the production function area, and the high value of ecological function area was mainly concentrated in the south of Gansu Province. In the spatial dimension, there are obvious functional differentiation characteristics depending on natural conditions and the development pattern law of dispersion-agglomeration-diffusion. Rural regional functions develop from dispersion to agglomeration, and then from agglomeration core to outward diffusion, forming a wider range of functional areas and functional combination groups. Time dimension on rural regional multifunctional coupling coordination degree show the spiral features of decoupling disturbance to connect the coordination, from the decoupling of functions caused by the dysfunctional development dominated by a certain function, through the subsequent linkage and diffusion effects, the development rate of different functions is adjusted under the guidance of policies, and continuously develops towards a coordinated whole. In general, the development of rural multifunctional space in Gansu Province is still in the process of decoupling coordination to high-level connection coordination. It is necessary to find out the development orientation, strengthen policy regulation, and guide the development of rural multifunctional space in a more orderly and coordinated direction.

The research results will help to enrich the connotation and extension of the theory of rural multifunction, and further provide reference for the positioning and development of various villages in the strategy of "rural revitalization" in China. However, there are still some shortcomings in this paper. Limited by the representativeness and availability of data, only some representative data were selected to construct the evaluation system. Considering the regional variability, the differences in natural elements of rural regional functions need to be better reflected, and the representativeness of evaluation indicators needs to be improved, such as the evaluation of ecological conservation function using forest cover, which fails to reflect other ecosystem service functions like grassland and wetland [5]. This study only conducted quantitative analysis from six dimensions: housing, security, agriculture, non-agriculture, environment and conservation. However, as an important part of rural geographical function, the selection of quantitative indicators in rural culture, leisure, education and other aspects is insufficient. While this paper demonstrates the distinct positive effects of policy guidance on rural development, further critical thinking is needed to determine and measure the specific utility of policies in the process of rural development. In addition, this study uses Gansu Province as an example, and because of the geographical representativeness of the selected indicators, the conclusions are mainly for the less developed regions of western China, and are instructive for richer regional typologies, but have limited applicability.

The multifunctional attributes of rural areas evolve continuously under the comprehensive action of multiple factors, showing a high degree of heterogeneity worldwide [18]. Under the current social and economic operating system in China, the policy of leading functional areas is an indispensable means to realize the overall development of multifunctional areas in rural areas and the overall strategy of regional development. Therefore, it is urgent to deeply study the long-term mechanism and approach of multifunctional development in rural regions, and scientifically design a relatively systematic and functionally targeted policy system matching the leading functional areas. The future can be further establish rural regional multifunction grading evaluation and dynamic evaluation index system, improve the timeliness and accuracy of the evaluation, perfect the rural development evaluation factors, and highlight the unique socio-cultural, ecological protection, and even spiritual aesthetics functional values of rural regions in the current and future context.

Author contribution statement

Wen yang: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Wei Li: Conceived and designed the experiments; Contributed reagents, materials, analysis tools or data.

Lu-Cang Wang: Performed the experiments; Wrote the paper.

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Data availability statement

Data included in article/supp. material/referenced in article.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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