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Spatial–Temporal Evolution and Coupling and Coordination of "Production–Life–Ecological" in Energy-Rich Area: A Perspective on Structure and Function

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Abstract: The conflict between socio-economic development and ecological protection is prominent, as the practice framework for territorial spatial planning and the rational layout and function coordination of production–life–ecological (PLE) spaces are crucial for achieving regional sustainable development. However, the dynamic evolution of PLE structure and function, as well as the driving mechanisms for the sustainable development of PLE, are still understudied. Therefore, this study takes the Ji-shaped bend Energy-Rich Area (ERA) of the Yellow River basin as a case study, classifies the PLE spaces based on land use data, and develops a PLE function indicator system consistent with the regional characteristics of an ERA. This paper characterizes PLE from both structure and function perspectives and explores the coupling and coordinated degree (CCD) among PLE functions and their driving factors. The results show the following: (1) From 2000 to 2020, the area of living space increased by 35.86%, while areas of production and ecological space decreased by 2.10% and 0.08%, respectively. (2) The PLE function increased, with the production function performing better in the typical ERA and the ecological function performing well in the atypical ERA. (3) From 2000 to 2020, the CCD of the PLE function increased by 24.85%, with atypical ERA demonstrating a higher CCD than typical ERA. (4) Factors in production function had the most significant impact on the CCD of PLE function, followed by living drivers. These results provide valuable insights and guidance for regulating PLE and promoting sustainable development.

Keywords: production–living–ecological; spatio-temporal pattern; coupling coordination; energy rich area; Ji-shaped bend of Yellow River basin

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1. Introduction

The evolution of territorial space patterns is the result of the combined influence of natural and human factors [1]. Production–living–ecological (PLE) space is a complex system that is shaped by mutual interaction with individual activities in the process of providing places for human activities. It serves as the primary subject of practice in territorial spatial planning [2]. Rapid urbanization, informatization, and industrialization have led to the intensity of land resource development that has gradually exceeded its carrying capacity [3], generating atmospheric and water pollution, the depletion of natural resources such as coal, oil, and natural gas, and the aggravation of spatial contradictions in production, life, and ecology [4,5]. Therefore, the major challenge for current PLE research is how to guarantee economic and social development and living standards of

people while safeguarding a good natural ecological environment and integrating the synergistic development of PLE space [6]. On the other side, the function among PLE does not exist independently; there is a phenomenon of overlapping among the PLE functions, and any imbalance in one of the functions can affect the harmonized development of the PLE [7,8] (Figure 1). The positive development of production function (PF) can enhance the economic strength of the country and invest the money in infrastructure construction and social security, which in turn improves the living function (LF). The uncontrolled expansion of PF can coerce the ecological function (EF), while with technological progress and production techniques evolving, there has been a significant conservation impact on the ecological environment. EF is supportive of the sustainable development of PF and LF, and the coordination of PF and EF leads to a high qualitative development of LF [9,10]. Thus, to achieve the sustainable development of PLE, it is imperative to study the spatial distribution characteristics of PLE in depth to optimize land resource management and to address the imbalance problem in the PLE functions.

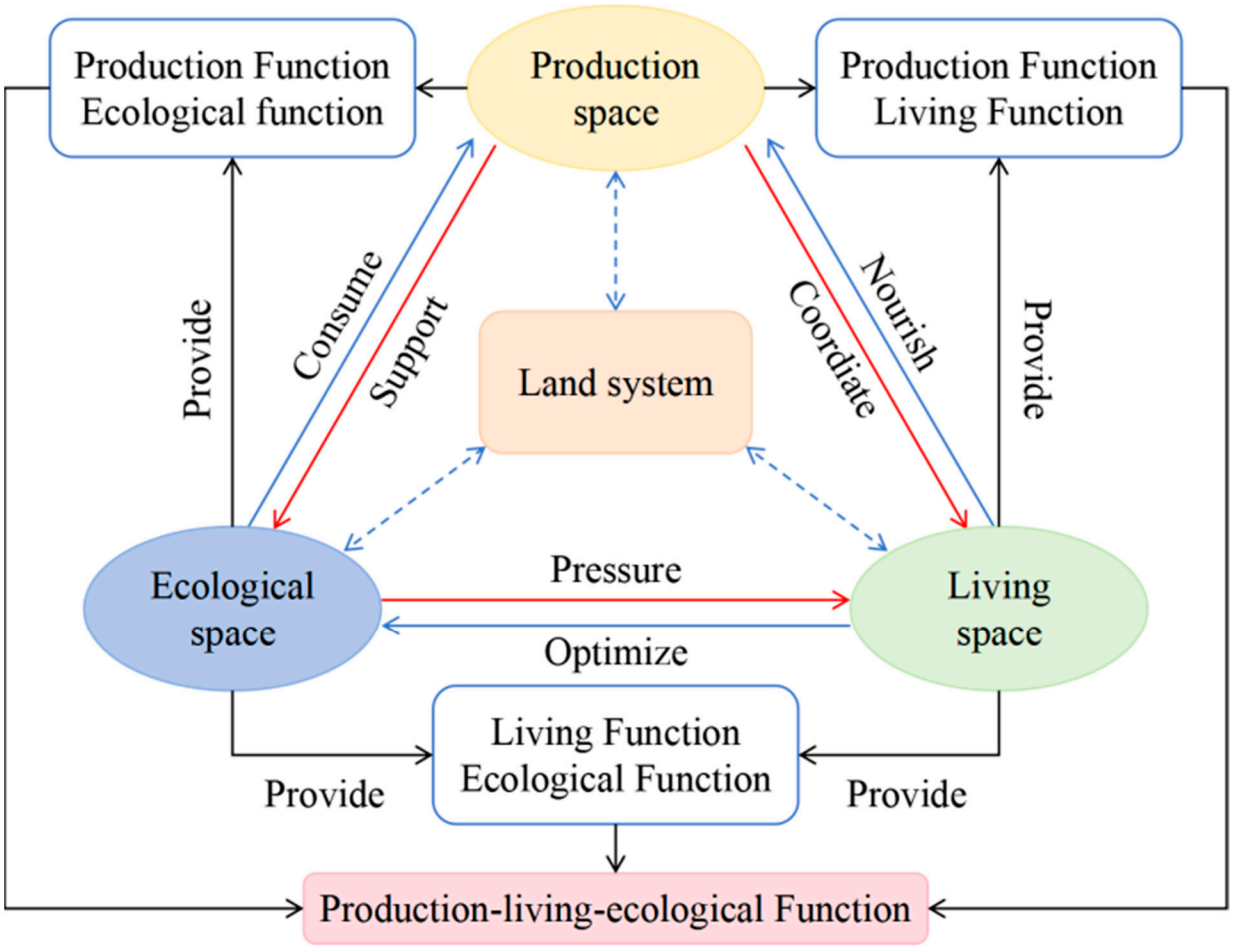

Figure 1. Spatial relationship diagram of production–living–ecological.

Researchers on PLE have made rapid development from theory to practice, including the construction of theoretical systems, spatial identification and classification, pattern evolution, and functional evaluation [11–13]. Arturo Soriay Mata put forward the "Linear City Theory" for the spatial demarcation of urban transportation arteries. Ebenezer Howard put forward the "Garden City Theory" for integrating the city and the countryside, which is an early proposal for urban–rural integration and is an inspiration for territorial spatial planning [14]. As research expands, studies on land suitability evaluation, multi-functionality analysis, and comprehensive system assessment are gaining attention [15–17], aiming

to support balanced regional development by analyzing the development trend of PLE functions and their internal relationship [18]. In terms of quantitative analysis, the wide application of remote sensing technology, GIS, and multi-source data have made the pattern analysis and functional evaluation of PLE more accurate [19,20]. In practical applications, researchers on PLE have been extensively applied in region spatial planning, ecological red line strategy, rural revitalization, etc., especially providing theoretical support for addressing the salient contradiction between socio-economic progress and the preservation of the ecological environment [21–23]. Although significant progress has been made in PLE research, there are still some gaps. Firstly, current research has mainly focused on the static characteristics of individual functions, neglecting a comprehensive revelation of the dynamic evolution patterns of PLE space and function [24]. Secondly, studies on PLE function mostly focus on the multifunctionality of land use, yet fail to fully integrate socio-economic factors, which cannot accurately reflect the complex interrelationship between land use and socio-economic activities, particularly overlooking the impact of factors such as industrial structure and income levels on land use patterns [25]. In addition, some studies focus on the coupling and coordination relationships of the PLE functions, proposing differentiated development strategies based on their distribution characteristics [26,27]. However, the lack of analysis on the driving factors often leads to imprecise policy formulation that fails to meet regional characteristics and needs, which in turn affects the sustainable assessment and effective management within the region.

The Yellow River basin is an important grain production area, energy hub, and key water resource supply region, has an important position in the economic and social development of China, and in the construction of ecological security barriers [28]. The Ji-shaped bend is situated in the midstream of the Yellow River basin and is an energy-rich region with coal, oil, and other fossil energy reserves accounting for approximately 50% of the country. It supports economic construction across the country with its robust resource supply capability, thereby further enhancing its status as a comprehensive energy base and becoming the core area for high-quality coal production capacity and the increase in oil and gas reserves and production [29]. The industrial structure in the region is dominated by heavy industry and resource-based sectors, with a high intensity of energy extraction and an irrational industrial structure. Industrial exploitation characterized by high energy consumption, high investment, and high pollution has led to the ecological carrying capacity of the watershed approaching, or even exceeding, the threshold, resulting in an imbalance between regional economy, environment, and society. This has led to serious environmental pollution and the degradation of ecological functions [30,31]. Moreover, the region is situated in the western arid and semi-arid areas, characterized by a delicate ecosystem that faces significant challenges balancing production, living, and ecological demands, which impact the ecological security in ERA [32]. Consequently, investigating the evolution of the PLE space in the Ji-shaped bend and enhancing the coordinated development of PLE functions hold significant value for safeguarding regional ecological security, maintaining ecosystem stability, and resolving the conflicts between ecological conservation and economic development.

Hence, this study took the Ji-shaped bend ERA of the YRB, where the tension between socio-economic development and ecological sustainability is particularly prominent, as the study area. Utilizing land use, natural environment, and socio-economic data, this study analyzes the spatiotemporal evolution patterns of the PLE structure and function, as well as the coupling and coordination mechanisms of the PLE functions. Our study aims to conduct a comprehensive analysis of PLE, achieve structural optimization and functional enhancement, and identify the key driving factors influencing the coupled coordination degree of PLE functions. This, in turn, will contribute to the formulation of targeted

development strategies and provide a scientific basis for regional land use optimization and ecological management.

2. Materials and Methods

2.1. Study Area

The Ji-shaped bend in the Yellow River basin (YRB) is the region where the Yellow River flows through the five provinces of Gansu, Ningxia, Shaanxi, Inner Mongolia, and Shanxi, which is a strategic base for the socio-economic development of the country and has an important strategic value [33]. The Energy-Rich Area of the Ji-shaped bend comprises 17 prefecture-level cities (Figure 2), namely, Baiyin in Gansu, Shizuishan, Zhongwei, Wuzhong, and Yinchuan in Ningxia, Hohhot, Ordos, Baotou, Wuhai, and Bayannur in Inner Mongolia, Yan'an and Yulin in Shaanxi, and Datong, Shuozhou, Xinzhou, Luliang, and Linfen in Shanxi. The study area is rich in energy resources, with the coal industry as the main economic pillar. Coal reserves account for about two-thirds of the nation's total, with Ordos alone holding about one-sixth of the nation's coal reserves [29,34]. This study categorized the study area into two types: typical ERA, where the coal production per unit area exceeds 5000 metric tons, and atypical ERA, where the coal production per unit area is less than 5000 metric tons (Figure 2c).

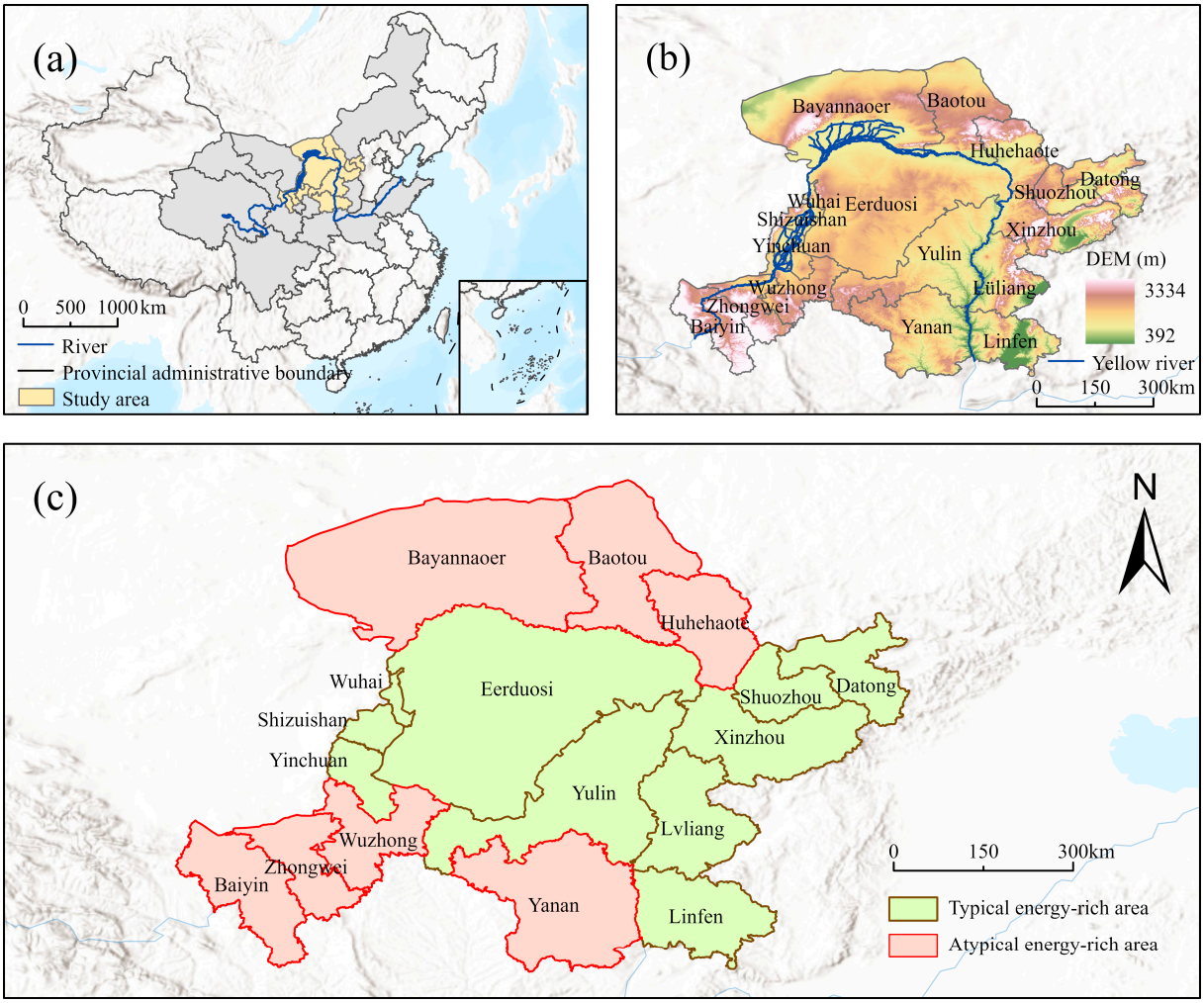

Figure 2. Study area. (**a**) Study area location. (**b**) Digital Elevation Model (DEM). (**c**) Energy-rich areas.

2.2. Methods

2.2.1. Classification of Production–Living–Ecological Space

The production–living–ecological space refers to a spatial system that encompasses production spaces mainly for industrial production and service functions, living spaces for functions such as residence, consumption, leisure, and entertainment, and ecological spaces for ensuring ecological security and enhancing the quality of life [35]. Based on the characteristics of human activities and land use functions, with reference to the land use classification method, and based on the actual situation of land space development and ecological protection in the study area, and with the principle of prioritizing ecological functions and highlighting the dominant functions [36], the classification of PLE space was constructed, as shown in Table 1.

Table 1. Classification of production–living–ecological space.

Classification	Sub-Classification	Land Use Type
Production space (PS)	Agricultural production space (PAS)	Paddy fields, drylands
	Industrial and mining production space (PIS)	Other construction land
Living space (LS)	Urban living space (LUS)	Urban land
	Rural living space (LRS)	Rural settlements
Ecological space (ES)	Forestry ecological space (EFS)	Forests, shrub land, sparse woodland, and other woodlands
	Grassland ecological space (EGS)	High-coverage grasslands, medium-coverage grasslands, and low-coverage grasslands
	Water ecological space (EWS)	Rivers and channels, lakes, reservoirs and ponds, permanent glaciers and snowfields, and beaches and sandflats
	Other ecological spaces (EOS)	Sandy lands, gobi deserts, saline–alkali land, bare rock terrain, marshland, and other land types

2.2.2. Construction of the Production–Living–Ecological Function Evaluation Index System

PLE function, as one of the important attributes of PLE space, and its evolution patterns can not only reflect the impact of land use changes but also reflect the development needs of regional multiple interest subjects, including government, enterprises, residents, and environmental organizations. This study, based on the conceptual connotations of the PLE function, with reference to the theoretical findings on the PLE function [24,37,38], has selected 34 indicators from 3 aspects of production function, living function, and ecological function to establish a PLE function evaluation index system. Specifically, the production function comprises the agricultural production function (PAF) and the non-agricultural production function (PNF). The PAF reflects the comprehensive agricultural production capacity of a region, the PNF characterizes the intensity of non-agricultural economic activities and their contribution to the regional economy. The living function includes the living security function (LSF) and the living quality function (LQF). The LSF primarily evaluates the basic livelihood security of the residents, while the LQF focuses on residents' quality of life and consumption levels. The ecological function consists of the ecological security function (ESF) and the ecological pressure function (EPF). The ESF reflects the quality of the regional ecological environment and its sustainable development capacity through indicators such as the status of ecological resource conservation. The EPF quantifies the negative impacts of regional economic activities on the ecological environment. Specific indicators are shown in Table 2.

Table 2. Index system of production–life–ecological function evaluation.

System	Sub-System	Indicator	Unit	Character	Weight
Production function (PF)	Agricultural production function (PAF)	Total crop sown area (X1)	10^3 hectares	+	0.0670
		Total power of agricultural machinery (X2)	10^4 kilowatts	+	0.1910
		Output value of agriculture, forestry, animal husbandry, and fishery (X3)	CNY 10^4	+	0.0838
		Per capita grain output (X4)	kg/person	+	0.1130
		Fertilizer usage (X5)	10^4 tons	-	0.1208
		Primary industry GDP share (X6)	%	+	0.0290
		Secondary industry GDP share (X7)	%	+	0.0327
	Non-agricultural production function (PNF)	Tertiary industry GDP share (X8)	%	+	0.1473
		Raw coal production (X9)	10^4 tons	+	0.0552
		Industrial water usage (X10)	10^8 m^3	-	0.0455
		Electricity generation (X11)	GWh	+	0.0491
		Energy consumption (X12)	10^4 tce	-	0.0812
		Industrial SO_2 emissions (X13)	tons	-	0.1197
		Industrial dust emissions (X14)	tons	-	0.0356
Living function (LF)	Living security function (LSF)	Per capita disposable income of urban residents (X15)	CNY	+	0.0148
		Per capita net income of rural residents (X16)	CNY	+	0.0322
		Number of health institution beds (X17)	beds/10^4 person	+	0.0403
		Total water supply (X18)	10^4 m^3	+	0.2089
		Per capita green park area (X19)	m^2/person	+	0.0415
	Living quality function (LQF)	Per capita GDP (X20)	CNY	+	0.1021
		Engel coefficient for urban households (X21)	%	-	0.0723
		Engel coefficient for rural households (X22)	%	-	0.0508
		Total retail sales of consumer goods (X23)	CNY 10^4	+	0.1061
		Urbanization rate (X24)	%	+	0.0590
Ecological function (EF)	Ecological security function (ESF)	Proportion of ecological land area (X25)	%	+	0.1825
		Ecological water usage (X26)	108 m^3	+	0.0600
		Average annual precipitation per area (X27)	104 m^3/km^2	+	0.0576
		NDVI (X28)	/	+	0.2237
		Forest coverage rate (X29)	%	+	0.0457
		Grassland area proportion (X30)	%	+	0.2030
		Water area proportion (X31)	%	+	0.0686
	Ecological pressure function (EPF)	Wastewater discharge volume (X32)	104 m^3	-	0.0646
		CO_2 emissions (X33)	104 tons	-	0.0353
		$PM_{2.5}$ (X34)	$\mu g/m^3$	-	0.0670

2.2.3. Comprehensive Evaluation of PLE Function

The comprehensive evaluation method was used to calculate the PLE function value. The raw data were subjected to dimensionless processing to ensure comparability among various indicators, and then, the weights of the indicators were assigned. To mitigate the impact of subjective biases on the weighting of indicators, the objective assignment method was employed. This study combines the entropy weight method with the coefficient of variation method to determine a comprehensive weight. This integrated method effectively addresses the limitations and reduces the inherent errors of single-objective weighting methods [39,40]. The formulas are as follows, and the result of weight is shown in Table 2.

(1) Data standardization:

$$\text{Positive indicator}: \ X_{ij} = \frac{x_{ij} - \min(x_{ij})}{\max(x_{ij}) - \min(x_{ij})} \quad (1)$$

$$\text{Negative indicator}: \ X_{ij} = \frac{\max(x_{ij}) - x_{ij}}{\max(x_{ij}) - \min(x_{ij})} \quad (2)$$

where X'_{ij} denotes the value of the indicator i in year j, and for the next operation to ensure the validity of the result, X'_{ij} = 0.000001 is taken when X'_{ij} = 0.

(2) The entropy weight $\omega_{i,EWM}$ is calculated as follows:

$$\omega_{i,EWM} = \frac{1 - e_i}{\sum_{i=1}^{n}(1 - e_i)} \tag{3}$$

where $e_i = -\frac{1}{\ln n}\sum_{j=1}^{n} P_{ij} \ln(P_{ij})$ is the entropy value, $P_{ij} = \frac{x_{ij}}{\sum_{j=1}^{n} x_{ij}}$ is the proportion of indicator i in year j.

(3) The coefficient of variation weight $\omega_{i,CVW}$ is calculated as follows:

$$\omega_{i,CVW} = \frac{\sigma_i \sqrt{\overline{x}_i}}{\sum_{i=1}^{n} \sigma_i \sqrt{\overline{x}_i}} \tag{4}$$

where σ_i is deviation of the i indicator, and $\overline{x}_i$ is the mean of the i indicator.

(4) The combined weight ω_i is calculated as follows:

$$\omega_i = \alpha\omega_{i,EWM} + \beta\omega_{i,CVW} \tag{5}$$

where α and β are predefined coefficients.

(5) The PLE function value A_i is calculated using a comprehensive evaluation method:

$$A_i = \sum_{i=1}^{n} X_{ij} \times \omega_{ij} \tag{6}$$

where X_{ij} is the normalized value of each indicator, and ω_i is the combined weight.

2.2.4. The Coupled Coordination Degree

The coupling degree quantifies the degree of interaction among multiple physical systems in various ways, but it does not indicate the level of coordinated development. Even with a high degree of coupling among systems, a low overall development level does not equate to an optimal state for sustainable development. Therefore, a coupling degree is insufficient to address the issue, while the coupling coordination degree (CCD) is necessary to assess the level of coordination within these interactions [41,42]. Therefore, this study employs the CCD model to evaluate the integrated development level of the PLE functions, with the formulas as follows:

$$C = \frac{n \cdot \sqrt[n]{\prod_{n=1}^{i} A_i}}{\sum_{n=1}^{i} A_i} \tag{7}$$

$$\mathrm{CCD} = \sqrt{C \times A} \tag{8}$$

where C is the coupling degree, $C \in [0, 1]$, A is the comprehensive evaluation score, CCD is the coupling coordination degree, CCD $\in [0, 1]$, and a larger value of CCD indicates a higher degree of coordination between systems, greater consistency in the development direction and speed between systems, and a higher level of comprehensive development of the research unit. The classification of CCD is shown in Table S2.

2.2.5. Analysis of Drivers of PLE Function

GeoDetector is a statistical technique designed to identify spatial disparities and quantify the impact of driving factors, which can elucidate the intrinsic mechanisms between influencing factors and target variables and determine whether there are interactions between single or multiple factors [43,44]. Factor and interaction detectors are utilized in this study to calculate the explanatory power of different diversities and their interactions on the PLE function, and the criterion basis of the interactive detector is shown in Table S3.

3. Results and Analysis

3.1. Characteristics of the Spatio-Temporal Evolution of the PLE Space

The ecological space (ES) of PLE space had the largest area in ERA (73.73%), followed by production space (PS) at 24.41%, and living space (LS) constituted only 1.87% of ERA. LS and PS are predominantly distributed along the main stream of the Yellow River and its tributaries, reflecting the characteristics of the regional, industrial, and agricultural production, which are based on water resources for production and city development. The change area of PLE space from 2000 to 2020 is shown in Figure 3. The PS space is decreased as a whole, of which the agricultural production space (PAS) is showing a general decline, while the industrial and mining production space (PIS) increases significantly. Specifically, the PAS in both typical ERA and atypical ERA decreased by 2617.93 km^2 and 3532.14 km^2, respectively. Conversely, the PIS has increased by a total of 3918.42 km^2, with a peak of the growth concentrated in the period of 2005–2015, which was primarily reflected in the typical ERA. The space of LS has gradually expanded, with the urban living space (LUS) showing a more significant increase, and was mainly concentrated in 2005–2010, and the rural living space (LRS) increased notably in 2015–2020. The change trend of ES exhibited more fluctuations, and overall, they tend to be opposite to that of PS. In the sub-system, the forestry ecological space (EFS) is on an upward trend, mainly concentrated in the atypical ERA. The grassland ecological space (EGS) changes are more volatile, with opposite trends in the typical ERA and atypical since 2005.

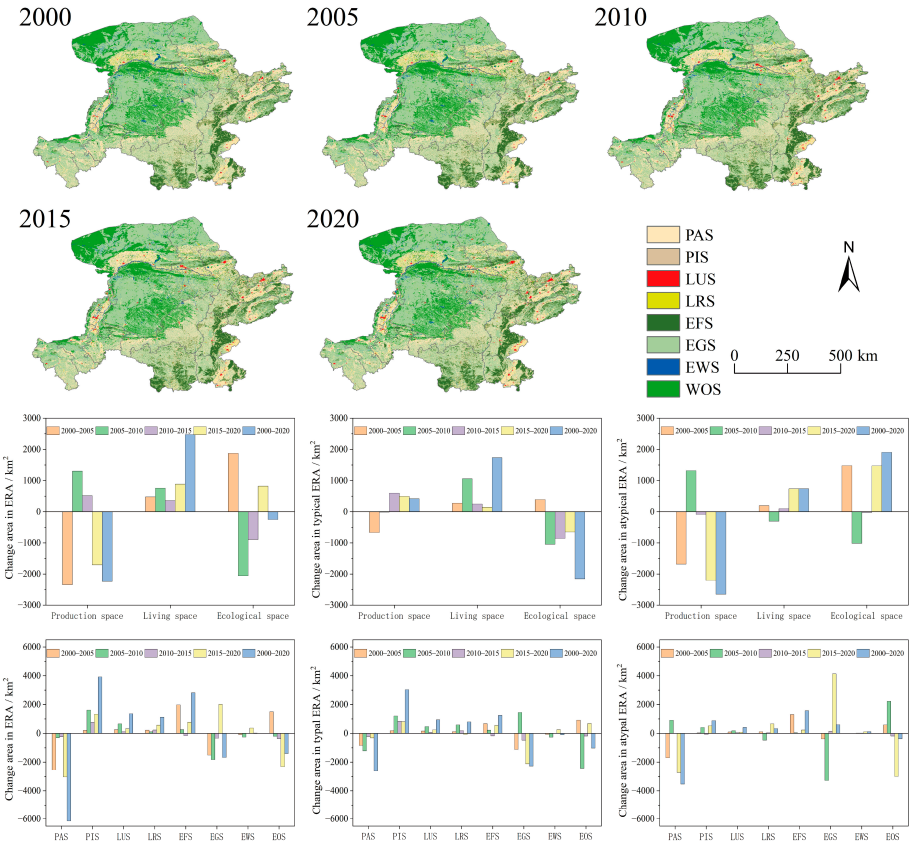

Figure 3. Spatial and temporal changes in production–living–ecological space.

Land use transfer is primarily characterized by the conversion between PAS and EGS (Figure S1). Among them, the outflow of PAS is 13,218.96 km^2 and the inflow is 11,472.05 km^2. The outflow from PIS is minimal, only 122.049 km^2, while the inflow is substantial at 4040.31 km^2, which is mainly transferred from EGS and PAS. This indicates

that the rapid industry expansion resulted in the encroachment of industrial and mining land use on EGS and PAS.

3.2. Characteristics of the Spatio-Temporal Evolution of the PLE Function

The PLE function in the ERA exhibited a positive trend from 2000 to 2020 (Figure 4). Notably, the living function (LF) has the highest growth rate, reaching 173.12%. From 2000 to 2007, the LF in the atypical ERA was slightly higher than that in the typical ERA, and after 2007, the LF value and development trends in both regions were largely similar. Spatially, the LF shows a higher concentration in the north compared to the south, and the high value areas are spreading from the center to the surrounding area. The production function (PF) exhibited a sustained increasing trend but with a modest growth rate (9.71%). From a spatial perspective, the high PF values are mainly in the east and central regions, while they are lower in the western region. The PF in the typical ERA is slightly higher than that in the atypical ERA. Ecological function (EF) demonstrated a fluctuating upward trend, with a growth rate of 17.04%, and the EF was spatially characterized by a pattern of "southeast higher than northwest", and the high values were mainly distributed in the southeastern regions of Shanxi Province and Yan'an City of Shaanxi Province. The EF in the atypical ERA was significantly higher than that in the typical ERA.

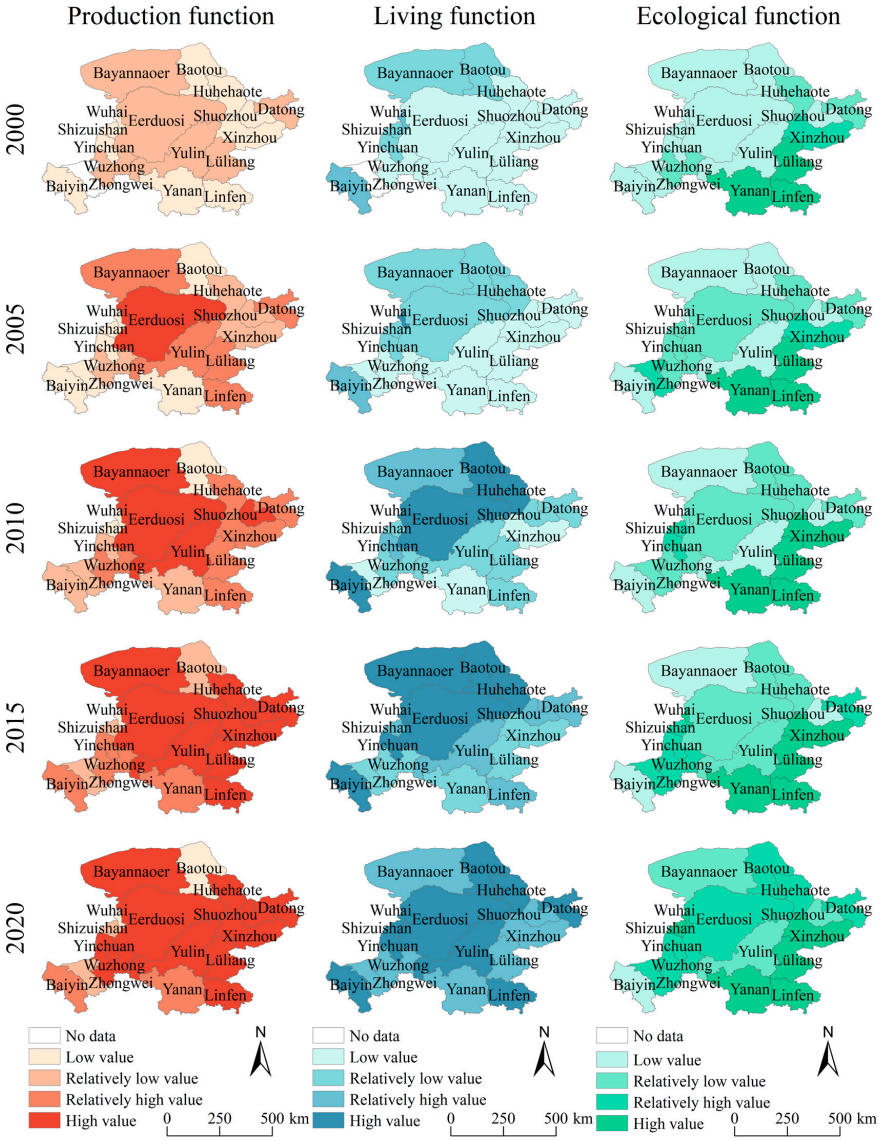

Figure 4. Spatial and temporal changes in production–living–ecological function.

3.3. Analysis of the Coupling Coordination of PLE Functions

Between 2000 and 2020, the CCD of the PLE functions showed an upward trend with a growth rate of 24.85%, experiencing the transitioned progression from the stage of moderate disequilibrium to basic coordination, and subsequently to moderate coordination (Figure 5). Yulin has the most significant growth rate in CCD, Yinchuan city has the lowest, and the typical ERA has a higher growth rate than that in the typical area, at 15.56% and 23.27%, respectively. Spatially, the difference in CCD among cities has gradually diminished, and the high value areas shows the trend of diffusion from individual cities to broader areas, expanding from the center outwards, resulting in a spatial pattern with higher values in the northwest and southeast, contrasted by diminished values in the southwest and northeast.

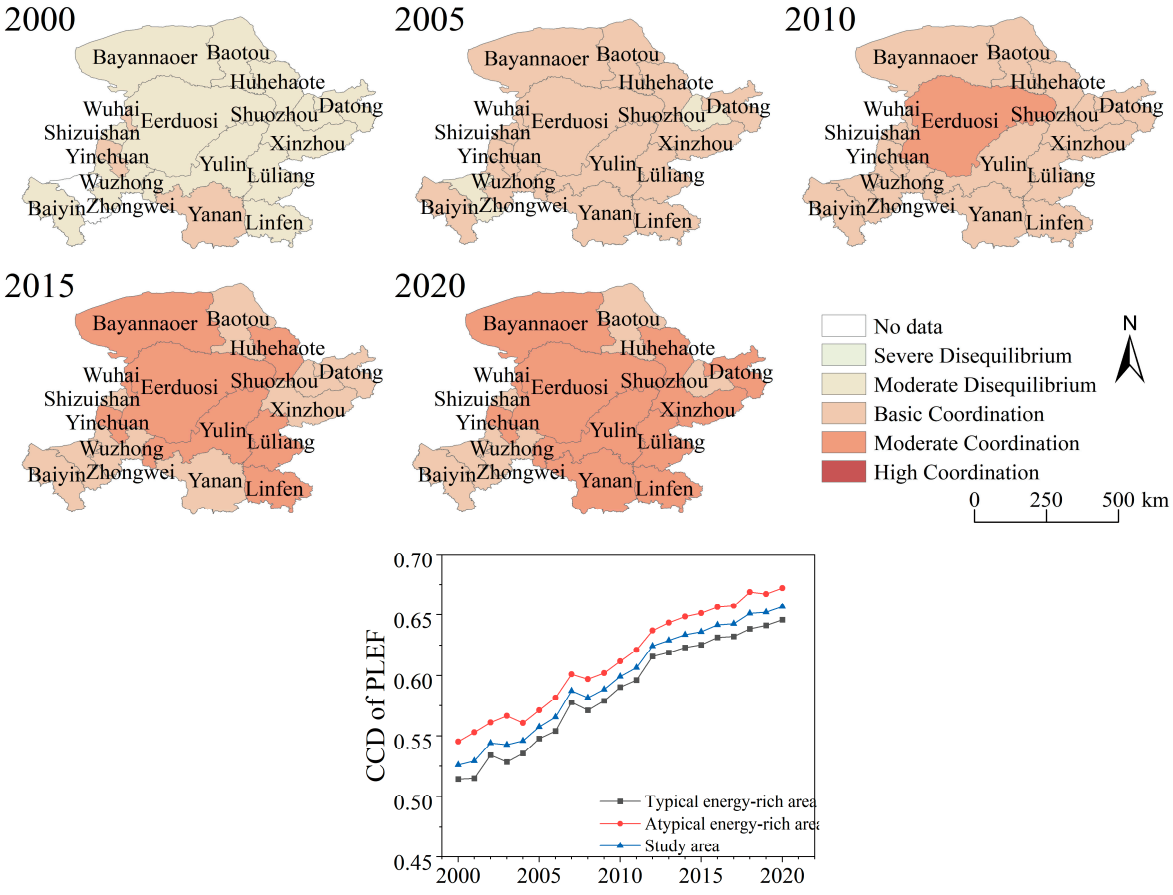

Figure 5. Characterization changes in CCD of production–living–ecological.

3.4. Analysis of Driving Factors of CCD in PLE Function

The Geodetector results show that there are considerable variations in the q-values of the drivers in different time periods, and specifically, the main drivers for 2000–2020 are shown in Table 3. In terms of long time series, X14 (0.7356) is identified as the primary driver of the PLE function CCD, followed by X23 (0.6908), X11 (0.6764), X9 (0.6696), X20 (0.6652), and X13 (0.6626). Drivers in the PF system have a greater impact on the CCD of PLE, followed by LF. Specifically, in 2000, factors X26, X25, and X27 had the most significant effect on CCD, showing that the ecological security function (ESF) exerted a significant influence on the PLE function at this stage, while the industrial pollution indicators (X14) and the socio-economic indicator (X20) also have a greater effect on CCD. In 2005, X14 and X23 were the main drivers of CCD, indicating that industry and socio-economic development play an important role in this stage. Meanwhile, the driving force of X1, X3, X16, and X15 increased, showing that the importance of the living security function (LSF)

and the agricultural production function (PAF) is gradually increasing. In 2010, factors related to industrialization and resource development (X2, X9, and X13) became the main drivers, indicating that the intensity of ERA development has strengthened and had a substantial influence on the CCD development of the PRE function. On the other hand, the significant driving effect of X13 and X32 suggests that the environmental pollution problem has gradually emerged. In 2015, energy and economic indicators such as X9, X13, X20, and X22 still had a greater driving effect on CCD, while the importance of ecological-related indicators such as X33 and X30 increased. In 2020, energy indicators like X9, X12, and X11, and agricultural production indicators like X5, X1, and X3 drove to be the main influencing factors, which means that the CCD of the PLE function was still under greater pressure from energy development and agricultural investment, while indicators such as X14 and X13 reflect the continuing impact of industrial pollution on the ecosystem.

Table 3. Driving factors of CCD among production–living–ecological functions.

2000		2005		2010		2015		2020	
Driver	**q**	**Driver**	**q**	**Driver**	**q**	**Driver**	**q**	**Driver**	**q**
X26	0.9404	X14	0.7858	X2	0.7952	X9	0.7820	X31	0.1894
X25	0.8880	X23	0.7086	X9	0.7889	X13	0.7337	X10	0.2006
X14	0.8626	X12	0.6922	X22	0.7741	X20	0.7290	X34	0.2065
X27	0.8368	X1	0.6619	X14	0.7618	X22	0.7250	X16	0.2597
X20	0.8125	X3	0.6578	X26	0.7523	X11	0.7192	X29	0.2947
X30	0.8064	X27	0.6407	X7	0.7495	X4	0.7153	X22	0.3372
X23	0.8042	X16	0.6002	X11	0.7460	X31	0.7053	X17	0.3482
X11	0.8029	X15	0.5758	X13	0.7396	X30	0.6892	X33	0.3569
X7	0.7855	X2	0.5549	X32	0.7048	X5	0.6715	X21	0.4314
X34	0.7839	X24	0.5369	X20	0.7018	X14	0.6613	X4	0.4613

The interaction factor analysis indicates (Figure S2) that there is a dual factor enhancement and nonlinear enhancement among the driving factors, indicating that the CCD of the PLE function was an outcome of the combined effects of various factors. In 2000, the interaction between factors in FP was more pronounced, while in 2005 and 2010, they were mainly characterized by interactions between the PF and LF factors, and in 2015 and 2020, the influence of the factors in the EF on the CCD of PLE functions was significantly enhanced.

4. Discussion

4.1. Discussion on Structure and Function of PLE

From the perspective of PLE space, ES is the primary component within ERA, and LS has the smallest area. However, with socio-economic development, the LS in the ERA increases, and the expansion of LUS is particularly significant. It reflects the impact of economic development and urbanization on the PLE structure. As the economy develops and the population grows, the demand for LS increases, and the urbanization process has significantly driven the expansion of LUS. PS exhibited more fluctuations from 2000 to 2020, where the typical ERA shows a steady decrease in PAS and a significant increase in PIS, and the atypical ERA shows a sharp decrease in PAS and a slight increase in PIS. The ES in the typical ERA shows an overall decreasing trend, while the atypical ERA shows an increasing trend, except for a slight decrease from 2005 to 2010.

It can be seen that the typical ERA is more focused on the development of energy and resources, especially in the early stages where the dominant economic growth model centered on energy development increased the demand for energy sources such as coal and oil. Consequently, the conversion of agricultural and ecological land to industrial use has driven economic development but also resulted in significant ecological degradation,

environmental pollution, and resource depletion [45]. In atypical ERA, the reduction in PAS has facilitated the localized recovery of ES. In addition, atypical ERAs are mostly located in marginal areas with more fragile ecologized environments and a relatively low intensity of economic activities [46], which reduces human disturbances and allows these regions to maintain a certain level of ecosystem stability and exhibit a higher potential for natural restoration. In terms of PLE functions, all three functions showed an upward trend. Typical ERA have better PF and lower EF than atypical ERA, and there is little difference in LF between the two regions. The typical ERA is abundant in coal resources, and has a large proportion of heavy industry and coal industry structures, indicating a large amount of coal mining and a strong development of industrial production, so that the PF in the region is at a relatively high level, especially in Ordos and Yulin, where the PF value exhibits a higher growth than other cities [47]. Bayan Nur is known as the "granary of Inner Mongolia" and has a high agricultural production function because of cropland expansion and per capita grain output [48], resulting in a high level of PF. The size of the LF is mainly derived from the living security function and living quality function. With the progression of societal development, the urbanization rate has been consistently increasing, which has led to a rise in disposable income and the leisure parks, which enhanced the sense of well-being, so the overall LF shows an upward trend [49]. The LF in typical ERA and atypical ERA exhibits similar values due to their geographical proximity and the influence of relevant policies [50]. The EF consists of two aspects of security and pressure. A higher level of ecological security and lower ecological pressure correspond to better EF. The typical ERA is dominated by the coal industry, and during its development, there has been a strong focus on economic growth while neglecting environmental protection. This has resulted in large amounts of industrial wastewater, exhaust gas, and waste emissions, causing serious pollution of air, water, and land. Consequently, the EF value is lower than in atypical ERAs.The typical ERA is dominated by the coal industry, and in the process of development, due to the prioritized economic development but neglected protection of the environment, this results in substantial emissions of industrial wastewater, exhaust, and waste emissions, causing serious pollution of air, water, and land resources, affecting the ecological environment [46]. As a result, the EF in the typical ERA is lower than that in atypical ERA.

4.2. Coupling Coordination Development of PLE

The CCD of the PLE function in the ERA showed a positive trend, with a more harmonious interrelationship among these three aspects. The CCD in an atypical ERA is superior to that in a typical ERA. The typical ERA is characterized by its reliance on energy extraction and the dominance of the secondary industry in its economic structure. The rough production leads to severe environmental degration, which leads to higher production and living standards and lower ecological functions [47], so the degree of PLE function CCD is weaker than that of the atypical ERA. The drivers of CCD have undergone a transfer shift from ecologically driven to economically driven and then to economically and ecologically co-driven, reflecting the adjustments in development needs and policy orientations during different stages of ERA. At the initial stage of research, the development intensity in ERA was low and the ecological environment played a fundamental role in maintaining the CCD of PLE function [51]. The region's abundant energy and ecological resources provided essential support for economic growth and environmental balance, thereby sustaining regional development. With rapid industrialization and urbanization, production and economic factors gradually become the main driving factors. Meanwhile, due to intensified resource development and industrial activities in ERA, factors indicative of pollution pressure, such as industrial SO_2 emissions and industrial water usage, have gradually emerged. This result is consistent with the region's energy abundance and rapid

industrial development, and it also reflects that the pressure from the overexploitation of resources and energy on the ecological environment is gradually become a limiting factor for region development [32,52]. After 2015, with the implementation of ecological protection and increased awareness of environmental protection and restoration, the importance of ecological function has increased significantly. However, the problems of overexploitation and pollution are still prominent [53]. Therefore, the ERA should optimize energy and agricultural production methods and improve production efficiency. While promoting economic development and resource utilization, it should also continue to strengthen ecological restoration and pollution control. Adhering to a sustainable development path that harmonizes economic growth with ecological balance is essential to better achieve sustainable regional development.

5. Conclusions

This study provides a comprehensive analysis of the PLE in the Ji-shaped bend ERA from the perspectives of structure and function. By dividing the PLE space and constructing a PLE function index system, this study investigates the dynamics and changes in PLE from 2000 to 2020, revealing the CCD characteristics of the PLE functions and its driving factors. The results indicated that ES occupies the largest proportion at 73.73%, while the LS accounts for the smallest proportion at only 7.87%. There is a downward trend in ES and PS, whereas LS showed an increase trend. PLE function has an overall upward trend. The typical ERA slightly outperforms atypical ERA, while the opposite is true for the EF. The CCD of the PLE function has shown an increasing trend, transitioning from a state of basic coordination to moderate coordination. With the increase in time, the difference in CCD among cities has gradually diminished, showing a spatial distribution with higher values in the northwest and southeast, and lower values in the southwest and northeast. The factors within PF have the greatest influence on the PLE function's CCD in the study area, followed by factors within the LF, while the EF factors exert a weaker driving effect. This study integrates the spatial analysis of land use data and functional evaluation based on an indicator system to achieve a systematic analysis of the structure and functions of the PLE. It contributes to the optimization of the PLE structure and the enhancement of its functions. By identifying the main driving factors influencing PLE functions at different periods, this study provides targeted recommendations for the sustainable development of regional PLE, thereby promoting regional sustainability.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/land14030520/s1, Table S1: Weight of production-living-ecological function indicators. Table S2: Classification of Production–Life–Ecological function coupling coordination degree. Table S3: Criterion basis of interactive detector. Figure S1: Production-living-ecological space transfer in ERA. Figure S2: Interaction detection result for the CCD of production-living-ecological functions.

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