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Obstacle Indicators Diagnosis and Advantage Functions Zoning Optimization Based on "Production-Living-Ecological" Functions of National Territory Space in Jilin Province

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Abstract: Frequent human activities have led to different types of land use conflicts which seriously restricted the multi-functional land use and the optimal allocation of resources. Optimizing the development and utilization pattern of land space, carrying out strategic layout, taking all aspects into consideration, and promoting green production and lifestyle are important measures to alleviate the contradiction between human and land and realize the harmonious coexistence between human beings and nature. Therefore, we constructed an evaluation index system of production-living-ecological (PLE) functions in Jilin Province, and analyzed the characteristics of PLE functions via evaluation models and a spatial concentration index. Obstacle degree model and normalized revealed comparative advantage index (NRCA) were used to identify regional dominant function and diagnose obstacle factors, and function zoning and optimization strategies were carried out. The results showed that the average score of ecological function was higher than production and living functions; the spatial agglomeration degree of the three functions was low and the distribution was scattered; the regional functions were affected and hindered by obstacle factors, including total book stock in public libraries, the proportion of nature reserve area, grassland coverage rate, and the proportion of industrial and mining storage land area. Jilin Province was divided into 14 types of advantage function areas and optimization strategies were put forward. The concept of functional regionalization was applied to measure regional multifunctionality at provincial scale, which enriched the theory and practice of territorial spatial pattern optimization, promoted the coordinated development of territorial space, and provided references for provincial territorial space planning and regional sustainable development.

Keywords: production-living-ecological functions; national territory space; advantage functions; obstacle degree; zoning optimization; Jilin Province

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1. Introduction

As natural resources, land resources have the characteristics of limitation and scarcity. Reasonable planning, development and utilization of land resources is a major project for mankind. The stakeholders' pursuit of efficiency first leads to different types of land use conflicts, which seriously limits the multi-functional land use and the optimal allocation of land resources, and puts great pressure on resources and environment [1]. People realized that this was not only a challenge faced by a country or region, but also a challenge faced by all countries in the world. Therefore, each country also paid more attention to territory space planning work [2]. For example, in 2008 and 2015, Japan prepared the national land formation plan twice, and land-use master plans were developed from the layering of several zoning regulations based on multiple levels of legislation [3]; in 2012, the United Kingdom formally established the spatial planning system of national-local secondary structure, and delegated the planning authority to the local government to a greater extent [4]; Germany's spatial planning system was local oriented [5]; the United

States implemented a zoning system for land management [6]. Due to the differences in system and development level, the form, content, and influence of the space planning in various countries were also different, but the essence of spatial planning was a method to correct market failure. It was a series of strategies and means for the government to ensure the rational arrangement of space and realize sustainable development through the regulation and reallocation of public resources [4].

The concept of agricultural multi-function was put forward in the "Agenda 21" document of the earth summit in Rio de Janeiro in 1992 [7,8], as well as the views of ecosystem multi-function [9,10] and landscape multi-function [11,12] successively discussed by other scholars. The PLE function was derived from these studies on land use multi-function [13–15]. Since the 18th National Congress of the Communist Party of China, optimizing the territory space development pattern had been promoted as the primary task of the construction of ecological civilization, and the ultimate purpose of carrying out the research on PLE space was to serve the optimization of the territory space development pattern [16]. Since the concept of PLE space was put forward, Chinese scholars have carried out research in many aspects, such as connotation discrimination and land use classification systems [17,18], functional classification [19], functional coupling coordination and evolution characteristics [20], driving force analysis [21] and zoning optimization [22,23], and formed interdisciplinary cross research. Although the research on PLE space had been carried out from the scales of the nation, urban agglomeration, province, city and county, village, and other spatial scales [17,18,20,23], most of them were concentrated in areas with rapid economic development or areas with historical and cultural characteristics, while the relevant research in areas with national key strategic status but slow development level such as Jilin Province need to be supplemented.

PLE space covered the spatial scope of human social life activities and was the basic carrier of human economic and social development [24]. From the connotation of PLE spaces, production space can provide agricultural products, industrial products and service products to ensure human survival and development; living space carries and maintains human daily life and provides places for human residence, consumption, leisure and entertainment; ecological space is the basis of human survival and can provide the value of ecological products and ecological services [25]. The classification of PLE functions was the refinement and extension of the connotation of PLE spaces [16]. The production function referred to the function of directly obtaining land as a working object or producing various products and services with land as a carrier, including agricultural production and industrial production; life function referred to the various space bearing, material, spiritual and cultural security functions provided by land in the process of human survival and development; ecological function referred to the natural conditions and utility formed by ecosystem and ecological process to maintain human survival, which can regulate, maintain and ensure regional ecological security [16,19]. The PLE functions were independent and synergetic, closely related and mutually restricted, and affected each other, and there was a phenomenon of multi-functional overlapping in the spatial pattern (Figure 1).

In order to achieve the goal of "PLE win-win", the overall planning and optimization of PLE space should be supported by regional sustainable development theory, human-land system coupling theory, system science theory, spatial equilibrium theory, and community theory [26]. The optimization of PLE functions was based on the spatial identification of PLE functions, seeking a scheme with better comprehensive benefits in a longer time period and a larger spatial scale, as an adjustment scheme for the combined action of natural and human factors and the comprehensive optimization of social and environmental composite system [15]. The research on the reconstruction and optimization of PLE spaces mainly covered the fields of theoretical discussion, conflict diagnosis analysis, and the application of optimization methods [22,23,27]. At present, the commonly used optimization method is the spatial zoning optimization countermeasure method. It is used to clarify the direction of optimization and regulation, formulate the implementation scheme of spatial zoning, and establish the regulation strategy of space development, utilization, and regulation [28].

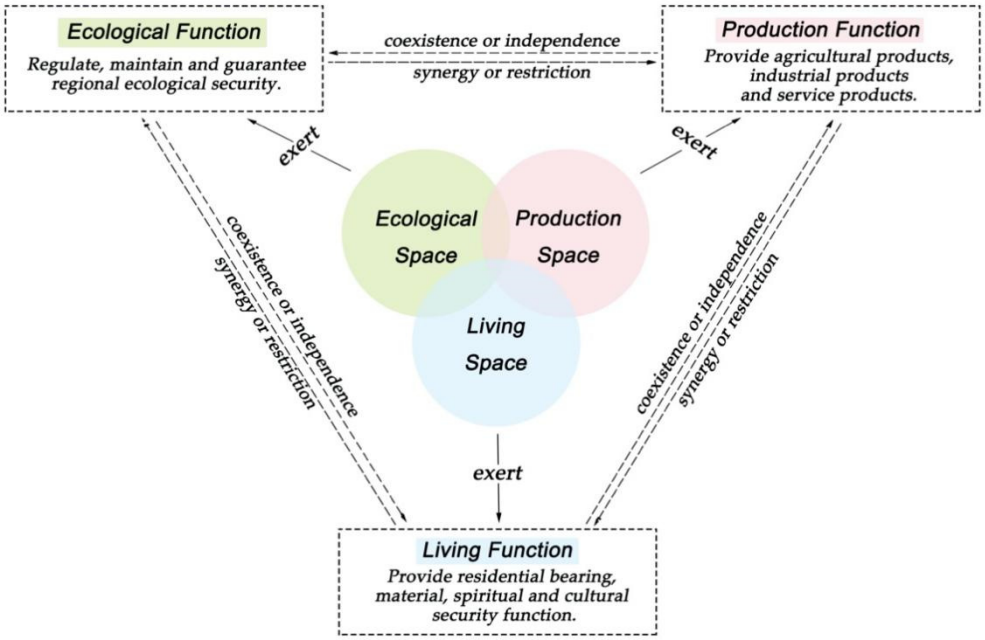

Figure 1. The connotation and interrelation of production-living-ecological spaces and production-living-ecological functions.

Many functions of territory space coexist in the same area. Some functions are the leading functions, and other functions play an auxiliary role. Comparative advantage was a theory put forward by David Ricardo to compare the comparative advantages of international trade between the two countries [29], and its application in the research of PLE functions was an interdisciplinary application. At present, the main methods for measuring comparative advantage include the revealed comparative advantage index (RCA), the subsequently derived revealed comparative advantage index (ARCA), and the normalized revealed comparative advantage index (NRCA) [22,30]. After the improvement and application of scholars, the NRCA had the advantages of not being limited by time and space, and was suitable for the research on identifying the dominant functions of PLE spaces [27,31]. In the process of space optimization, we should not only identify the advantageous functions, but also clarify the "short board" of development (that is, obstacle factors) so as to "suit the remedy to the case" and implement detailed regulation and control strategies. In recent years, the obstacle degree model had been applied maturely in the research of land ecological security [32], land use performance evaluation [33], green development evaluation [34], and other fields. It was used to diagnose the obstacle factors in the development process of things. Therefore, it can be used to explore the weakness of regional PLE functions, accurately improve weak functions, and provide a specific basis for pattern optimization.

After more than 40 years of rapid development of reforms and 'opening up', China's social productivity had significantly improved, and the territory space was facing a series of challenges such as unbalanced development pattern, tighter resource constraints, degraded ecosystem, and increased environmental pollution. Therefore, we need to implement important measures to alleviate the contradiction between human beings and land and implement a harmonious coexistence between human beings and nature. The Nineteenth National Congress of the Communist Party of China (CPC) proposed scientifically delineating three control lines (an ecological protection red line, permanent basic farmland, and an urban development boundary) to coordinate the spatial pattern of production, living and ecology, promote the regional sustainable development [35], coordinate the relationship between human beings and land, and promote the realization of the development goal of "intensive and efficient production space, livable and moderate living space and beautiful ecological space" [36]. In the 14th five year plan of the CPC Central Committee and based

on their long-term goals for 2035, it is further clarified that in the future, based on the carrying capacity of resources and environment, one should give full play to the comparative advantages of various regions, gradually form three spatial patterns of urbanized areas, main agricultural product producing areas, and ecological functional areas, and shape a new pattern of territory space development and protection with obvious main functions, complementary advantages, and high-quality development [37].

As an important commodity grain production base and main grain production area in China, Jilin Province had formed a regional multi-functional development pattern dominated by grain production function and coexisting with other auxiliary functions for a long time [38]. Under the development background of revitalizing the old industrial base in Northeast China, exploring the spatial function development level characteristics of PLE functions had a certain reference value for territory space planning and overall regional coordinated development in Jilin Province. Therefore, we analyzed the characteristics of PLE functions in Jilin Province by constructing the PLE function evaluation index system and using the methods of function evaluation model, spatial concentration index, obstacle degree model, and NRCA. We used quantitative methods to guide the exertion of regional functions, to determine the regional functional orientation and development direction and promote regional sustainable development, to provide scientific basis and optimization ideas for national top-level design, regional overall planning and layout, and land pattern optimization.

2. Materials and Methods

2.1. Study Area

Jilin Province is located in the central part of Northeast China (Figure 2), spanning 121◦ 380 ~131◦ 190, 40◦ 500 ~46◦ 190. It covers a total area of 187,400 square kilometers, and currently has jurisdiction over one sub-province-level division, seven prefecture-level cities, the Yanbian Korean Autonomous Prefecture, and the Changbai Mountain Protection and Development Zone Management Committee. In terms of the topography, Jilin Province is characterized by a high elevation in the southeast and a low elevation in the northwest. The ecological environment is characterized by diversity, and the forest coverage rate of the province reached 43.9% in 2018. There is the Songliao Plain in central Jilin where the land is flat and fertile, and rich in corn, rice and other high-quality agricultural products. There is the Changbai Mountain area in eastern Jilin where is an important ecological barrier in northeast China with a large area of forests and rare natural resources. Western Jilin is the interlacing area of agriculture and animal husbandry, and its ecological environment is fragile. Grassland vegetation has recovered obviously due to the continuous strengthening of ecological restoration and protection in recent years.

As a nationally important black soil reserve, the core area of China's golden corn belt, and the northeast commodity grain base, Jilin Province shoulders the important mission of guaranteeing nation food security. In 2018, the grain planting area of Jilin Province was 5.6 million hectares, and the total grain output reached 36.33 million tons, accounting for 5.52 percent of the national total, making a great contribution to national grain production. Although it was a veritable agricultural province, the economic and social development in recent years had been relatively slow. In 2018, GDP was 1.51 trillion yuan, ranking 22nd in China. Therefore, to study the regional functional characteristics of Jilin Province under the macro background of revitalizing northeast China has a strong reference significance for other regions (which are also major grain producing areas) to formulate territorial space development and utilization planning. The study unified the municipal districts of each city in Jilin Province into a single unit, and was sorted into a total of 47 research units, including 8 urban areas, 20 county-level cities, and 19 counties [39].

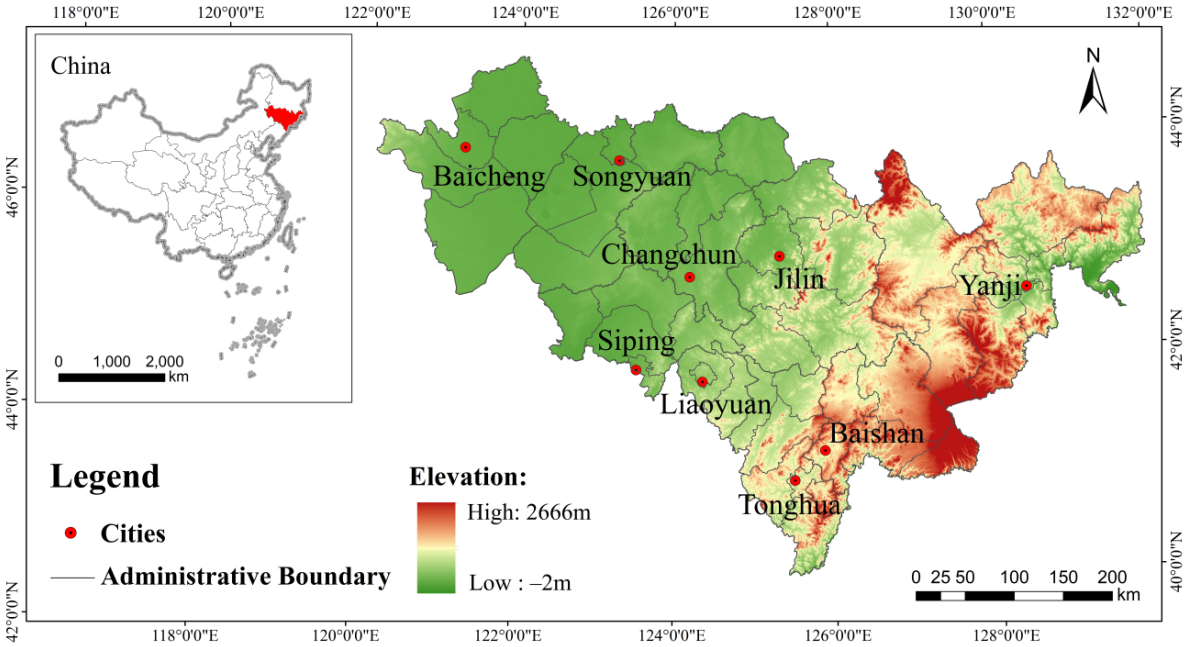

Figure 2. Schematic diagram of the study area location.

2.2. Data Sources

The land use status data in Jilin Province in 2018 came from Jilin Institute of Land and Resources Survey. The elevation data came from Geographic Science and Resources, Resources and Environment Science, and the Data Center in the Chinese Academy of Sciences Institute (https://www.resdc.cn/data.aspx?DATAID=284, accessed on 15 October 2021) [40]. The social, economic and ecological data came from the "Statistical Yearbook of Jilin Province" (https://data.cnki.net/yearbook/Single/N2021030158, accessed on 9 September 2021) [41] and Ecology and Environment Department of Jilin Province (http://was.jl.gov.cn/, accessed on 21 October 2021) [42].

2.3. Methodology

2.3.1. Construction of Evaluation Index System

The classification of PLE functions was the refinement and extension of the PLE spaces connotation. The three basic functions of PLE must be refined from various spatial scales to sub-functional levels to form the classification system of PLE functions which was suitable for all levels of spatial scale [16]. Based on the theory of PLE spaces in territorial space planning, we analyzed the connotation of PLE functions [19], and identified the function of territorial space as production function, life function, and ecological function, considering the combination relationship of the leading function and multiple functions, and exploring the strength and weakness of each function in the region, learning from each other to improve the integrity and comprehensiveness of the PLE functions in order to make regional territorial space planning more scientific and reasonable. Based on the principles of science, representativeness, comparability and data availability, and with reference to previous studies [1,2,20,30,36,38], in this paper 26 indexes of 8 criteria levels (namely agricultural production function, non-agricultural production function, economic development function, social security function, cultural and tourist leisure function, ecological supply function, ecological regulation function, and ecological conservation function) were selected to evaluate the spatial function of territorial space in three dimensions of production, life and ecology. The original data of each index were standardized [43], and then the weights of each index were given by the entropy method to construct the evaluation index system of PLE functions in Jilin Province (Table 1).

(1) Data Standardization

In order to eliminate the differences in dimensions, orders of magnitude and attributes of each index, the original data of positive and negative indexes were treated by Equations (1) and (2), respectively, to get the initial normalized values [44]. X_{ij} was the evaluation index data of the j item in the i evaluation unit, X_{max} and X_{min} represented, respectively, the maximum and minimum value of the original data of the j item, and the formulas were shown as follows:

$$Y_{ij} = \frac{X_{ij} - X_{min}}{X_{max} - X_{min}} \quad (1)$$

$$Y_{ij} = \frac{X_{max} - X_{ij}}{X_{max} - X_{min}} \quad (2)$$

Then the comprehensive standardized value P_{ij} was calculated by Equation (3), and the range of P_{ij} was (0,1). In the calculation, if $P_{ij} = 0$, in order to make $ln(P_{ij})$ meaningful, attach a minimal value to $ln(P_{ij})$ (we took 0.0000001 in this paper).

$$P_{ij} = \frac{Y_{ij}}{\sum Y_{ij}} \quad (3)$$

(2) Entropy Weight Method

As one of the objective evaluation methods, entropy method can embody the comprehensiveness of indexes and express the implicit information of index elements [26]. Therefore, in order to eliminate the influence of subjective judgment, we used the entropy method to give weight to each index. Based on the comprehensive standardized value P_{ij} of each index, the information entropy E_j of the evaluation index data of j item was calculated by Equation (4), and then the weight W_j of the index was calculated by Equation (5), m was the number of evaluation units.

$$E_j = -\frac{1}{lnm} \sum_{i=1}^{m} P_{ij} \times lnP_{ij} \quad (4)$$

$$W_j = \frac{(1 - E_j)}{\sum_{j=1}^{n} (1 - E_j)} \quad (5)$$

Table 1. Evaluation index system of the production-living-ecological functions.

Target Layer	System Layer	Index Layer		Calculation Method or Index Explanation	Direction	Weight
Production function	Agricultural production function	X1	Per capita cultivated land area (m^2/person)	=cultivated land area/total land area	+	0.0287
		X2	Per capita total grain output (kg/person)	=total grain output/total population	+	0.0344
		X3	Per capita output value of agriculture, forestry, animalhusbandry and fishery (yuan/person)	=agriculture, forestry, animal husbandry and fishery output value/total population	+	0.0245
		X4	Per capita meat production (kg/person)	=total meat production/total population	+	0.0495

Table 1. *Cont.*

Target Layer	System Layer		Index Layer	Calculation Method or Index Explanation	Direction	Weight
Production function	Non-agricultural production function	X5	The proportion of gross output value of the second and third industry (%)	=gross output value of the second and third industry/gross domestic product	+	0.0110
		X6	The proportion of industrial and mining storage land area (%)	=industrial and mining storage land area/total land area	+	0.0651
		X7	Density of traffic land (%)	=traffic land area/total land area	+	0.0297
		X8	Per capita main business income of industrial enterprises above scale (10,000 yuan/person)	The data was from Statistical Yearbook of Jilin Province.	+	0.0302
Living function	Economic development function	X9	Per capita GDP (yuan/person)	=gross domestic product/total population	+	0.0203
		X10	Urbanization rate of population (%)	=urban population/ total population	+	0.0298
		X11	Per capita total retail sales of consumer goods (yuan/person)	=total retail sales of consumer goods/ total population	+	0.0292
	Social security function	X12	Per capita local public revenue (yuan/person)	=local public revenue/ total population	+	0.0440
		X13	Number of hospital beds per 10,000 persons (beds per 10,000 persons)	=number of hospital beds/total population	+	0.0223
		X14	Number of students in primary and secondary schools (person)	Total number of students in primary, junior and senior high schools.	+	0.0614
		X15	The proportion of social security and employment spending (%)	=social security and employment spending/local public expenditure	+	0.0165
	Cultural and tourist leisure function	X16	Idyllic landscape index (no unit)	The index reflected the richness of rural landscape, and was calculated by Simpson Diversity Index with the proportion of cultivated land, garden land, facility farmland and water area [45].	+	0.0347
		X17	Total book stock in public libraries (10,000 books)	The data was from Statistical Yearbook of Jilin Province.	+	0.1138

Table 1. *Cont.*

Target Layer	System Layer		Index Layer	Calculation Method or Index Explanation	Direction	Weight
Ecological function	Ecological supply function	X18	Forest coverage rate (%)	=forest area/total land area	+	0.0370
		X19	Water coverage rate (%)	=water area/total land area	+	0.0454
		X20	Grassland coverage rate (%)	=grassland area/total land area	+	0.0816
		X21	Per hectare ecological service value (yuan/hectare)	=total ecological service value/total land area. The total ecological service value of Jilin province was calculated and modified by using the existing research of Gaodi Xie [46] and other scholars [47–49].	+	0.0334
	Ecological regulation function	X22	Habitat quality index (no unit)	Based on the calculation method of habitat quality index in "Technical Criterion for Ecosystem Status Evaluation" (HJ192-2015) [50].	+	0.0340
		X23	Fertilizer application intensity (kg/hectare)	=fertilizer application/regional cultivated land area	-	0.0205
	Ecological conservation function	X24	The proportion of nature reserve area (%)	=nature reserve area/total land area	+	0.0974
		X25	The proportion of saline-alkali land area (%)	=saline-alkali land area/total land area	-	0.0054

2.3.2. Construction of PLE Functions Evaluation Model

(1) Single Function Evaluation Model

Based on the evaluation index system of PLE functions and the results of the weight, the index values of the research unit and the corresponding weight were multiplied and then added. Then, the single function evaluation value of production, living and ecological functions of the research unit was obtained. The single function evaluation model was as follows Equation (6), where P_{ij} was the index data standardization value, W_j was the index weight and Z_i was the single function evaluation value of the i unit.

$$Z_i = \sum_{j=1}^{m} (P_{ij} \times W_j) \quad (6)$$

(2) Comprehensive Functions Evaluation Model

There was an interactive relationship among the PLE functions, which promoted or coerced each other [20], and the whole function in a region was a comprehensive reflection of the interaction of individual functions. However, it was not a simple superposition of individual functions [43]. In this paper, a multi-dimensional evaluation model was used to evaluate the comprehensive functions (Figure 3). The production, living, and ecological functions were taken as three dimensions and the score of each dimension was taken as a single function evaluation value. The area of the triangle formed by each dimension assignment was regarded as the score of comprehensive function evaluation. The larger the area of the triangle was, the stronger the overall function of the area was.

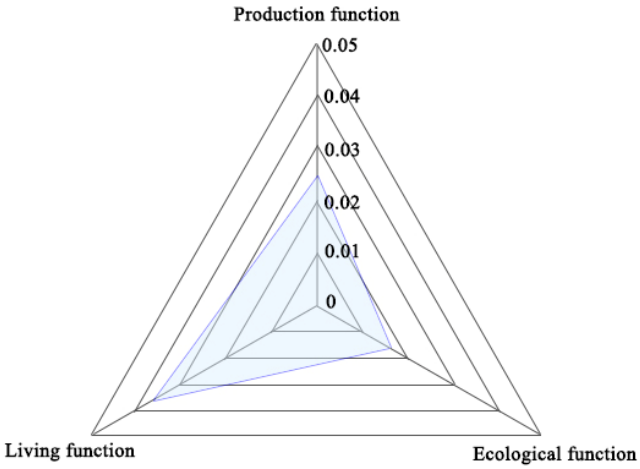

Figure 3. Schematic diagram of comprehensive functions evaluation model of production-living-ecological functions.

2.3.3. Spatial Concentration Index

The spatial concentration degree of PLE functions of territorial space was represented by the spatial Gini coefficient, which was used to measure the concentration degree of regional PLE functions in spatial distribution [51]. In this paper, production, living, and ecological functions were calculated, respectively, and the formula was as follows Equation (7), where G_j was the Gini coefficient of j function; F_{ij} was the function value of j function of i unit; F_j was the sum of the function values of j function of all research units; i was the ordinal number of research units (i = 1,2, . . . , n); n was the number of research units; and j was the type of PLE functions. The G_i value ranged from (0,1), and the larger the G_i value was, the more the function was spatially clustered [44].

$$G_j = \sum_{i=1}^{n} \left| F_{ij} - F^j/n \right| / \left[\sum_{i=1}^{n} F_{ij} + F^j(n-2)/n \right] \quad (7)$$

2.3.4. Obstacle Degree Model

The obstacle degree model identified the influence degree of the obstacle indicators to the function index by the index deviation degree, the factor contribution degree, and the obstacle degree. Through this model, we can find out the problem of territorial space utilization in the PLE function-oriented effectively [26]. In this paper, the obstacle degree model was used to calculate the obstacle degree of each index and find out the intrinsic obstacle factor [28,52–54], to provide the basis for optimizing the PLE functions and achieve the effect of scientific management. The formula was as follows Equations (8) and (9), where I_{ij} was the index deviation degree, that was the difference between the value and the ideal state; Y_{ij} was the standardized value; W_j was the factor contribution degree, which was represented by the index weight; and O_{ij} was the index barrier degree.

$$O_{ij} = \frac{I_{ij} \times W_j}{\sum_{i=1}^{m} I_{ij} \times W_j} \quad (8)$$

$$I_{ij} = 1 - Y_{ij} \quad (9)$$

2.3.5. Normalized Revealed Comparative Advantage Index

The comparative advantage function can reflect the leading direction of the development and utilization of territorial space, so the scientific determination of regional advantage function was an important premise to promote the coordinated development of territorial space. The normalized revealed comparative advantage index (NRCA) can measure the dynamic and continuous comparative advantage among different regions

without the restriction of time and space [55]. The formula of NRCA was as follows Equation (10) [45], where F_{ij} was the j function evaluation value of i unit, and F was the total value of all research units' function scores in the region; F_j was the sum of j function evaluation values of all research units; F_i was the sum of all function values of i research unit. When $NRCA_{ij} > 0$, the j function had comparative advantage in i research unit; when $NRCA_{ij} < 0$, the j function has no comparative advantage in i research study unit.

$$NRCA_{ij} = F_{ij}/F - F_iF^j/FF \quad (10)$$

3. Results

3.1. Evaluation Results of the PLE Functions Level in Jilin Province

Based on the PLE functions evaluation index system, we calculated the PLE functions evaluation value in each unit in Jilin Province in 2018 (Table 2). On the whole, the average value of ecological function (0.0068) was higher than living function (0.0062) and production function (0.0046), and the average value of comprehensive functions was 1.9310. Among the 47 counties and districts, 44.68% of the counties and districts exceeded the average value of production function, 31.91% exceeded the average value of the living function, 40.43% exceeded the average value of the ecological function, and 29.79% exceeded the average value of the comprehensive functions.

Table 2. The evaluation values of production function (P), living function (L), ecological function (E), and comprehensive functions (C).

Name	P	L	E	C	Name	P	L	E	C
Changchun urban area	0.0057	0.0471	0.0032	7.6109	Baishan urban area	0.0031	0.0072	0.0072	2.0459
Nong'an County	0.0074	0.0044	0.0033	1.2507	Fusong County	0.0017	0.0082	0.0096	2.1488
Yushu City	0.0060	0.0109	0.0011	1.4299	Jingyu County	0.0028	0.0039	0.0074	1.2508
Dehui City	0.0071	0.0134	0.0016	2.2109	Changbai County	0.0018	0.0053	0.0254	3.4685
Jilin urban area	0.0037	0.0114	0.0043	1.8621	Linjiang City	0.0018	0.0050	0.0072	1.1382
Yongji County	0.0041	0.0023	0.0034	0.5455	Songyuan urban area	0.0132	0.0081	0.0037	5.0620
Jiaohe City	0.0041	0.0047	0.0054	1.4989	Qianguo County	0.0063	0.0046	0.0096	2.8076
Huadian City	0.0038	0.0074	0.0049	1.9307	Changling County	0.0054	0.0033	0.0049	1.3788
Shulan City	0.0057	0.0024	0.0036	0.9644	Qian'an County	0.0050	0.0044	0.0061	1.7580
Panshi City	0.0049	0.0040	0.0032	1.1674	Fuyu City	0.0056	0.0058	0.0061	2.3456
Siping urban area	0.0040	0.0084	0.0034	1.8769	Baicheng urban area	0.0059	0.0067	0.0024	1.8960
Lishu County	0.0089	0.0028	0.0008	1.0322	Taonan City	0.0068	0.0029	0.0037	1.3071
Yitong County	0.0064	0.0023	0.0060	1.4131	Zhenlai County	0.0063	0.0040	0.0196	4.3779
Gongzhuling City	0.0062	0.0050	0.0010	1.2750	Tongyu County	0.0041	0.0024	0.0119	1.7025
Shuangliao City	0.0080	0.0026	0.0032	1.2942	Da'an City	0.0043	0.0040	0.0118	2.2951
Liaoyuan urban area	0.0046	0.0071	0.0022	1.5637	Yanji City	0.0030	0.0134	0.0071	3.4108
Dongfeng County	0.0052	0.0032	0.0024	0.9327	Tumen City	0.0020	0.0044	0.0117	1.6121
Dongliao County	0.0045	0.0018	0.0031	0.6216	Dunhua City	0.0025	0.0058	0.0094	1.8657
Tonghua urban area	0.0055	0.0091	0.0050	2.9831	Hunchun City	0.0025	0.0065	0.0148	2.8738
Tonghua County	0.0025	0.0042	0.0071	1.1930	Longjing City	0.0025	0.0036	0.0193	2.3795
Huinan County	0.0037	0.0032	0.0065	1.2008	Helong City	0.0025	0.0037	0.0089	1.2880
Liuhe County	0.0033	0.0034	0.0059	1.0796	Wangqing County	0.0024	0.0042	0.0108	1.5871
Meihekou City	0.0046	0.0062	0.0028	1.5212	Antu County	0.0018	0.0037	0.0096	1.1526
Ji'an City	0.0016	0.0047	0.0080	1.1444	Average value	0.0046	0.0062	0.0068	1.9310

3.2. Spatial Characteristics of the PLE Functions in Jilin Province

Through the calculation of spatial concentration, the spatial Gini coefficients of production function, living function, and ecological function of territorial space in Jilin Province were 0.0776, 0.1398, and 0.1539, respectively, which indicated the spatial agglomeration degrees of the three functions were low and the layouts were relatively scattered. In order to intuitively display the spatial characteristics of the PLE functions, we used ArcGIS to divide the evaluation scores of production function, living function, ecological function and comprehensive functions in Jilin Province into five levels by using the natural breakpoint

method, in which the first level area indicated the corresponding function was the strongest, and the level area was spatially visualized, with obvious differences in the spatial layout of each function (Figure 4).

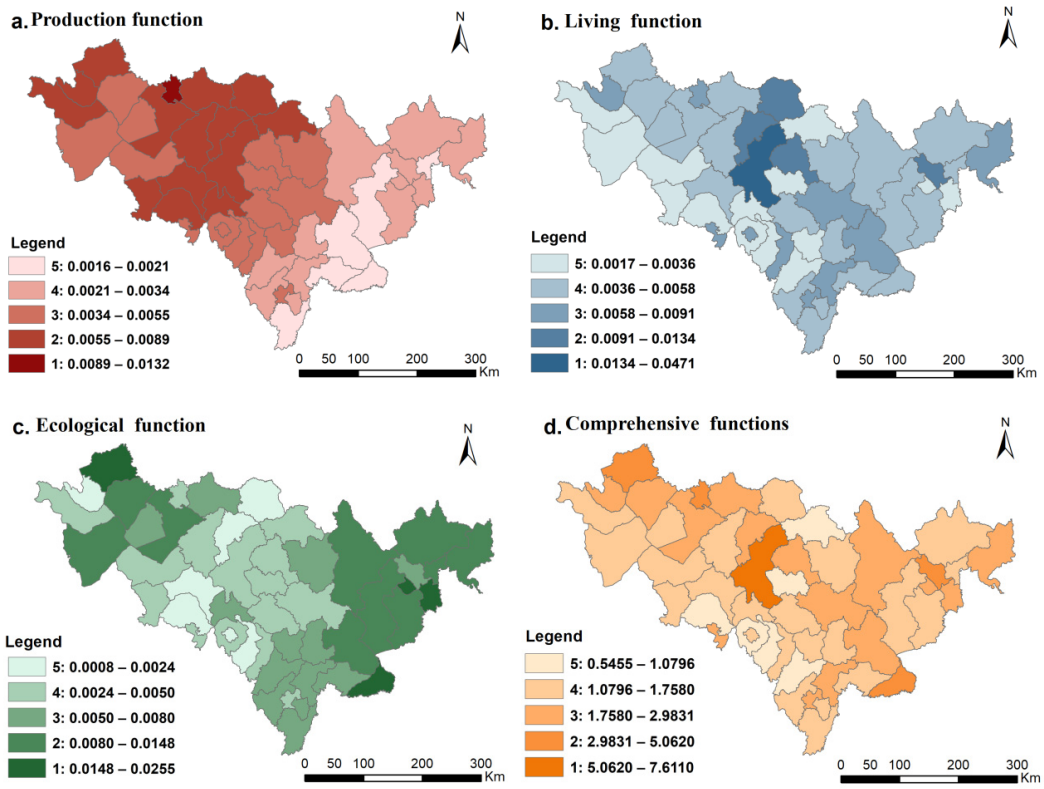

Figure 4. Functional grading diagrams of production function, living function, ecological function and comprehensive functions in Jilin Province.

From the perspective of production function, high value areas were mainly distributed in central and western Jilin, and low value areas were mainly distributed in eastern Jilin. The area with the highest level of production function was the Songyuan urban area, which was mainly non-agricultural production and rich in underground mineral resources, so secondary and tertiary industries were developed. From Songyuan urban area to the southeast, the production function level showed a decreasing trend. The Level 2 areas were mainly counties with strong agricultural production function, such as Fuyu City, Qianguo County, Yushu City, Dehui City, Nong'an County, Gongzhuling City and Lishu County. Due to being located in the black soil plain area with flat terrain and fertile soil, the scale of cultivated land was large, the output of grain crops was high, so the agricultural production function was strong. In Zhenlai County, Taonan City and Baicheng urban area in western Jilin Province, a large number of ecological space had been transformed into production space in recent years, so the production function of these areas has been improved. However, most counties and districts in Da'an City, Qian'an County, Tongyu County, and Changling County in the western Jilin Province and Jilin areas, Liaoyuan areas and Siping areas in central Jilin Province belonged to the Level 3 areas. These areas were located in plain areas, with a strong agricultural production capacity, concentrated population, and high level of industrial development. Level 4 and Level 5 areas were mainly distributed in the east. Due to the limitations of natural factors, these areas cannot carry out large-scale production activities, and the level of production function was generally low.

From the perspective of life function, only Changchun urban area was in the Level 1 area. Due to its high urbanization level and complete life infrastructure, Changchun urban area was an area with the highest level of economic and social development in Jilin Province,

so its life function evaluation score was the highest. The Level 2 areas were distributed in Yushu City, Dehui City, and Jilin urban area in the central Jilin Province and Yanji City in the east. These areas had great living environment and rapid economic and social development, so their life quality was high. The Level 3 areas were sporadically distributed in the west and east of Jilin Province. Most of them were urban areas of major cities, such as Baicheng, Songyuan, Baishan, and Tonghua. These areas had a high level of urbanization and were the gathering places for people's living. The counties and districts with living functions in Level 4 and Level 5 low value areas were mainly concentrated in the western part, central-southern part and the eastern part, such as Taonan City, Tongyu County, Changling County, Shuangliao City and Lishu County, which focused on the development of agricultural production, while the areas around Yanbian Korean Autonomous Prefecture in the east focused on the exertion of ecological functions, so the living functions of these areas were weak.

From the perspective of ecological function, the high-value areas of Level 1 and Level 2 were mainly concentrated in the eastern and western regions. The ecological function values of Changbai County, Longjing City, and Zhenlai County were relatively high. The first two were rich in forest resources and can provide great ecological service value and the last one was rich in grassland resources, water resources and a large number of unused spaces. Therefore, all of the counties and cities in Level 1 areas were rich in ecological resources. The Level 2 areas were distributed in Yanbian Korean Autonomous Prefecture with abundant forest resources and Da'an City, Tongyu County and Qianguo County in the west. Due to the continuous promotion of ecological restoration projects in recent years, the ecological environment had been well restored and the ecological function was relatively high in the west. The Level 3 areas were mainly concentrated in the Baishan and Tonghua areas in the southeast. These areas not only had good ecological resources, but also had a certain degree of production and living behavior and development and utilization activities, which had a negative impact on the ecological environment. Level 4 and Level 5 low value areas were mainly concentrated in the central plain. Due to the high level of urbanization, high intensity of land development, intense human activities, large discharge of industrial production, and domestic wastewater (among other reasons), the ecosystem was certainly damaged, so the ecological function values of the central areas were at a relatively low level.

From the perspective of comprehensive functions, the highest-level area was Changchun urban area. As the first city in Jilin Province and the radiation center driving regional development, it had many advantages such as location, resources, transportation and policies. The Level 2 areas included Songyuan urban area, Yanji City, Zhenlai County and Changbai County, which were scattered, with high agricultural production level, strong industrial agglomeration capacity, perfect infrastructure services and strong social security capacity. Therefore, the comprehensive functions of these regions were more significant. The Level 3 areas included 15 counties and districts such as Jilin City, Baicheng City, Dehui City and Dunhua City, which were all around high-value areas with significant comprehensive functions. Driven and radiated by core cities, these areas had a high level of functional development. Level 4 and Level 5 areas did not have prominent PLE functions, poor industrial agglomeration capacity and basic service level. Compared with the areas in high level, the comprehensive development gap was large, the regional functions were not coordinated to promote the regional development, and the core competitiveness and development power were lacking.

3.3. Obstacle Factors Diagnosis of the PLE Functions in Jilin Province

In this paper, the obstacle degree model Equations (8) and (9) was used to accurately identify the main obstacle indicators affecting PLE functions in various regions, and the top four were taken as the main obstacle factors of PLE functions according to the obstacle degree value of the indicators from large to small (Table 3). The results showed that the main obstacles to PLE functions in counties and districts of Jilin Province were the

following five indicators: the total book stock in public libraries (X17), the proportion of nature reserve area (X24), the grassland coverage rate (X20), the proportion of industrial and mining storage land area (X6), and the number of students in primary and secondary schools (X14). From the frequency of obstacle factors, 97.87% of counties and districts affected the improvement of cultural, tourism and leisure function in living function due to the total book stock in public libraries (X17); 89.36% of counties and districts affected the improvement of ecological conservation function due to the proportion of nature reserve area (X24); 87.23% of counties and districts were affected by the grassland coverage rate (X20) and the proportion of industrial and mining storage land area (X6), which affected the exertion of ecological and production functions; and 34.04% of counties and districts are affected by the number of students in primary and secondary schools (X14), and the social security function in life function was limited.

Table 3. Main obstacle factors of production-living-ecological functions in Jilin Province.

Name	No. 1	No. 2	No. 3	No. 4	Name	No. 1	No. 2	No. 3	No. 4
Changchun urban area	X24	X20	X6	X4	Baishan urban area	X17	X24	X20	X14
Nong'an County	X17	X24	X20	X6	Fusong County	X17	X24	X6	X14
Yushu City	X24	X17	X20	X6	Jingyu County	X17	X24	X20	X6
Dehui City	X24	X20	X17	X6	Changbai County	X17	X6	X14	X4
Jilin urban area	X17	X24	X20	X6	Linjiang City	X17	X24	X20	X6
Yongji County	X17	X24	X20	X6	Songyuan urban area	X17	X24	X20	X14
Jiaohe City	X17	X24	X20	X6	Qianguo County	X17	X24	X6	X14
Huadian City	X17	X24	X20	X6	Changling County	X17	X24	X6	X20
Shulan City	X17	X24	X20	X6	Qian'an County	X17	X24	X14	X6
Panshi City	X17	X24	X20	X6	Fuyu City	X17	X24	X20	X6
Siping urban area	X17	X24	X20	X14	Baicheng urban area	X17	X24	X20	X14
Lishu County	X17	X24	X20	X6	Taonan City	X17	X24	X20	X6
Yitong County	X17	X20	X24	X6	Zhenlai County	X17	X6	X14	X20
Gongzhuling City	X17	X24	X20	X6	Tongyu County	X17	X6	X14	X20
Shuangliao City	X17	X24	X20	X6	Da'an City	X17	X24	X6	X14
Liaoyuan urban area	X17	X24	X20	X14	Yanji City	X24	X17	X6	X20
Dongfeng County	X17	X24	X20	X6	Tumen City	X17	X24	X14	X6
Dongliao County	X17	X24	X20	X6	Dunhua City	X17	X24	X6	X20
Tonghua urban area	X17	X24	X20	X14	Hunchun City	X17	X6	X20	X14
Tonghua County	X17	X24	X20	X6	Longjing City	X17	X6	X14	X20
Huinan County	X17	X20	X24	X6	Helong City	X17	X24	X20	X6
Liuhe County	X17	X20	X24	X6	Wangqing County	X17	X20	X24	X6
Meihekou City	X17	X24	X20	X6	Antu County	X17	X24	X20	X6
Ji'an City	X17	X24	X20	X6					

Since most of the large libraries were located in Changchun urban area, the number of books was huge and the types were rich, which can provide high-quality reading conditions for local residents, while other areas couldn't ensure that residents enjoy the same level of cultural services, which hindered the exertion of life functions. For most regions, the area of nature reserves was small, which restricted the exertion of ecological environment conservation function to a certain extent. All regions need to actively integrate and optimize nature reserves and build a nature reserve system network. Grassland was concentrated in western Jilin Province, while the grassland coverage rate in other regions was low, so the ecological supplied function provided by grassland ecosystem was hindered. Industrial and mining land was concentrated in areas with high industrialization level, mainly distributed in municipal districts or suburbs. Other areas were limited by natural, social, economic, and other conditions and cannot develop large areas of land for industrial production. It was difficult to attract enterprises to invest in construction, so the function of industrial production was limited. The level of education in various regions of Jilin Province was uneven, and the distribution of educational resources was uneven. Excellent teacher allocation and hardware facilities were mostly distributed in areas with high urbanization level, while the social security function of other areas was limited. Different regions had different degrees of obstruction due to different indicators.

Based on this, targeted optimization ideas can be put forward, which will help to accurately coordinate the development of regional PLE functions.

3.4. Comparative Advantage Measurement of the PLE Functions in Jilin Province

In order to realize the coordinated development of national territory space in Jilin Province, based on the analysis of the spatial characteristics of the PLE functions, we determined the comparative advantage function of each county to provide a basis for national territory space planning and optimizing the spatial pattern. According to the single function evaluation score of the PLE functions, substitute it into the NRCA model Equation (10), and calculate the comparative advantage index of PLE functions in Jilin Province (Table 4). If NRCA > 0, it indicated that this function had a comparative advantage in the region, which can be determined as the advantageous function of the region; If the NRCAs of two or more functions in the region were > 0, the one with larger NRCA value was the main dominant function, and the one with smaller NRCA value was the secondary dominant function. Thus, the dominant functional types of counties and districts in Jilin Province were determined as the basis for the preliminary optimization zoning of territorial space.

Table 4. Comparative advantage index value and advantage function types of PLE functions in Jilin Province.

Name	NRCA (P)	NRCA (L)	NRCA (E)	Types	Name	NRCA (P)	NRCA (L)	NRCA (E)	Types
Changchun urban area	−0.0051	0.0404	−0.0140	L	Baishan urban area	−0.0001	0.0036	0.0031	L–E
Nong'an County	0.0057	0.0009	−0.0009	P–L	Fusong County	−0.0021	0.0042	0.0053	E–L
Yushu City	0.0033	0.0079	−0.0045	L–P	Jingyu County	0.0004	0.0006	0.0044	E–L–P
Dehui City	0.0038	0.0097	−0.0052	L–P	Changbai County	−0.0048	−0.0032	0.0203	E
Jilin urban area	0.0003	0.0081	−0.0010	L–P	Linjiang City	−0.0009	0.0019	0.0042	E–L
Yongji County	0.0028	−0.0001	0.0010	P–E	Songyuan urban area	0.0106	0.0024	−0.0035	P–L
Jiaohe City	0.0019	0.0015	0.0020	E–P–L	Qianguo County	0.0032	−0.0005	0.0050	E–L
Huadian City	0.0011	0.0042	0.0008	L–P–E	Changling County	0.0036	0.0000	0.0016	P–E–L
Shulan City	0.0043	−0.0006	0.0006	P–E	Qian'an County	0.0028	0.0007	0.0024	P–E–L
Panshi City	0.0033	0.0012	0.0001	P–L–E	Fuyu City	0.0030	0.0019	0.0017	P-L–E
Siping urban area	0.0014	0.0055	−0.0010	L–P	Baicheng urban area	0.0039	0.0037	−0.0019	P–L
Lishu County	0.0081	−0.0003	−0.0030	P	Taonan City	0.0053	−0.0004	0.0002	P–E
Yitong County	0.0046	−0.0015	0.0025	P–E	Zhenlai County	0.0012	−0.0040	0.0141	E–P
Gongzhuling City	0.0048	0.0025	−0.0027	P–L	Tongyu County	0.0010	−0.0025	0.0085	E–P
Shuangliao City	0.0067	−0.0009	−0.0006	P	Da'an City	0.0008	−0.0010	0.0078	E–P
Liaoyuan urban area	0.0026	0.0045	−0.0018	L–P	Yanji City	−0.0014	0.0093	0.0011	L–E
Dongfeng County	0.0040	0.0007	−0.0006	P–L	Tumen City	−0.0014	0.0001	0.0083	E
Dongliao County	0.0034	−0.0006	0.0007	P–E	Dunhua City	−0.0008	0.0018	0.0057	E-L
Tonghua urban area	0.0024	0.0052	−0.0002	L–P	Hunchun City	−0.0021	0.0009	0.0103	E-L
Tonghua County	0.0001	0.0010	0.0042	E–L–P	Longjing City	−0.0024	−0.0031	0.0152	E
Huinan County	0.0016	0.0001	0.0035	E–P	Helong City	−0.0002	0.0001	0.0059	E–L
Liuhe County	0.0013	0.0004	0.0031	E–P–L	Wangqing County	−0.0009	−0.0001	0.0075	E
Meihekou City	0.0027	0.0035	−0.0010	L–P	Antu County	−0.0011	0.0001	0.0068	E–L
Ji'an City	−0.0011	0.0015	0.0050	E-L					

3.5. Advantageous Function Zoning and Optimization of PLE Functions in Jilin Province

3.5.1. Advantageous Function Zoning of PLE Functions

The purpose of regional multi-functional evaluation and zoning was to scientifically identify the strategic layout of national sustainable development and the functional positioning of each county, so as to provide a scientific basis for giving full play to comparative advantages and maximizing regional functions [56]. In some areas, the level of single function was prominent, and the single function was the dominant function to guide regional development. Some regions had two or more advantageous functions, and the dominant advantageous function was supplemented by the auxiliary advantageous function to guide the regional development direction. Adhering to the principles of giving full play to advantages, coordinated development, and ecological priority, and according to the comparative advantage measurement and type division results of PLE functions (Table 3), we named

each region according to the principle of "high-intensity functions first and low-intensity functions last", and divided the territorial space advantageous functional areas in Jilin Province into the following 14 types: production function advantage area (P), production-ecological functions advantage area (P-E), production-ecological-living functions advantage area (P-E-L), production-living functions advantage area (P-L), production-living-ecological functions advantage area (P-L-E), living function advantage area (L), living-ecological functions advantage area (L-E), living-production functions advantage area (L-P), living-production-ecological functions advantage area (L-P-E), ecological function advantage area (E), ecological-living functions advantage area (E-L), ecological-living-production functions advantage area (E-L-P), ecological-production functions advantage area (E-P), and ecological-production-living functions advantage area (E-P-L).

In order to give full play to the local advantageous functions, enhance the local weak functions, maximize the rational allocation and benefits of natural resources, promote the coordinated development of regional production, living and ecological functions, and realize the optimization of land spatial pattern and regional sustainable development, based on the determination of the advantageous functions of counties and districts in Jilin Province we divided the national territory space of Jilin Province into 14 advantageous functional areas and visualized (Figure 5), which intuitively showed the zoning types of each county. In terms of spatial distribution characteristics, the areas with ecological function as the dominant advantage function were mainly distributed in the east and west of Jilin Province, and the areas with production function or living function as the dominant advantage function were mainly concentrated in central Jilin Province. In terms of quantity, the type with the largest number was the ecological-living functions advantage area, and a total of eight counties belonged to this type; the second was the living-production functions advantage area, and a total of seven counties belonged to this type; five counties and districts belonged to production-living and production-ecological functions advantage areas; four counties and districts belonged to ecological function and ecological-production functions advantage areas; the number of counties belonging to other types was small.

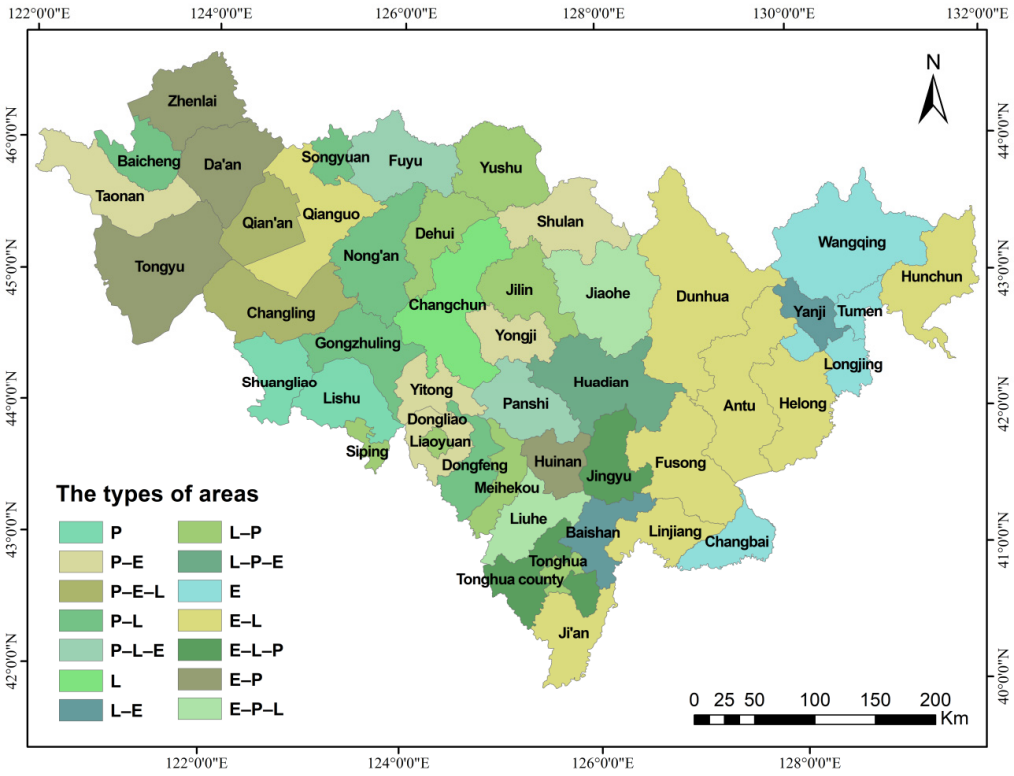

Figure 5. Diagram of advantage function zoning type of the PLE functions in Jilin Province.

3.5.2. Zoning Optimization Strategy of PLE Functions

National territory space planning was a process of arranging the structure and layout of future land use in a certain region and formulating corresponding measures according to the needs of social and economic development and land endowment conditions in order to realize the optimal allocation of resources and sustainable development [57]. With the goal of "PLE win-win ", following the principle of "giving priority to ecological protection", combined with the actual situation and development characteristics of each region, referring to the relevant regional development planning and guiding policies [58,59], we pointed out the main characteristics and functional positioning of each region, and put forward suggestions on the optimal regulation of territorial space according to local conditions in combination with the regional main obstacle factors, to provide detailed, specific and operable reference suggestions for local and provincial territory space planning (Table 5).

Table 5. The advantage function and zoning optimization strategy of PLE functions in Jilin Province.

Zoning Types	Areas	Main Features	Optimization Suggestions
P	Lishu County, Shuangliao City	The production function of the area is outstanding.	Relying on its geographical and resource advantages, the area should vigorously develop agricultural production, moderately promote agricultural large-scale, scientific and technological and intelligent production, innovate technology to improve output, strengthen the improvement and protection of black soil, and promote green production mode.
P–L	Nong'an County, Gongzhuling City, Dongfeng County, Songyuan urban area, Baicheng urban area	The area is dominated by production function, supplemented by living function.	The area should give full play to the regional agricultural production capacity, reasonably plan the living space, facilitate people's life and production, and improve the intensive utilization rate of land; industrial production areas should appropriately exploit mineral resources, prevent and control the deterioration of ecological environment, pay attention to land restoration and improve the quality of human settlements.
P–E	Yongji County, Shulan City, Yitong County, Dongliao County, Taonan City	The area is dominated by production function, supplemented by ecological function.	The region should give full play to the advantages of agricultural production, improve the output of agricultural products and speed up the green transformation of production mode; vigorously protect local ecological resources and establish nature reserves or national parks relying on a large number of forestry resources.
P–L–E	Panshi City, Fuyu City	The area has the advantage of all three functions but production function is the strongest, living function is the second, and ecological function is relatively weak.	The ecological function of this area should be moderately enhanced to realize the integration and coordinated development of PLE functions; strengthen the improvement of ecological environment quality and promote green production and lifestyle; rationally develop industrial production and reduce industrial pollution; increase investment in social undertakings such as medical treatment, education and health, and improve the level of public services; rationally plan and renovate unused land and optimize spatial structure.

Table 5. *Cont.*

Zoning Types	Areas	Main Features	Optimization Suggestions
P–E–L	Changling County, Qian'an County	The area has the advantage of all three functions but production function is the strongest, ecological function is the second, and living function is relatively weak.	The living function of this area should be moderately enhanced to realize the integration and coordinated development of PLE functions; optimize the layout of residential areas to facilitate production and life; strengthen the construction of public service facilities and improve the level of social security; protect forestry resources and build natural scenic spots; popularize and apply new agricultural technologies to increase grain output; develop new energy industry and make effective use of green natural resources.
L	Changchun urban area	The living function of the area is outstanding.	The area should strengthen greening projects, enhance the treatment of waste gas, waste water and pollutants, and improve the living environment; further optimize the spatial structure and strengthen the intensive use of land; renovate the idle land in and around the city and improve the land utilization rate; strengthen ecological protection, build urban parks and beautify the urban environment.
L–P	Yushu City, Dehui City, Jilin urban area, Siping urban area, Liaoyuan urban area, Tonghua urban area, Meihekou City	The area is dominated by living function, supplemented by production function.	The area should actively create a better living environment, improve the level of public service facilities and enhance the ability of social security; improve the exertion of production functions, be radiated by Changchun, accelerate the development of industry and service industry, and improve the level of economic and social development.
L–E	Baishan urban area, Yanji City	The area is dominated by living function, supplemented by ecological function.	The area should rely on a good ecological environment to create a high-quality environment suitable for people's living and improve the population agglomeration degree; improve traffic convenience and strengthen the construction of urban public service facilities; to promote the production function, actively build industrial development zones and speed up the development of secondary and tertiary industries.
L–P–E	Huadian City	The area has the advantage of all three functions but living function is the strongest, production function is the second, and ecological function is relatively weak.	The ecological function of this area should be moderately enhanced to realize the integration and coordinated development of PLE functions; build ecological scenic spots and national forest parks; enhance the ability of agriculture to resist natural disasters and improve the agricultural and rural ecological environment; strengthen the infrastructure construction of agricultural industry and promote the formation of advantageous and characteristic industries.

Table 5. *Cont.*

Zoning Types	Areas	Main Features	Optimization Suggestions
E	Changbai County, Tumen City, Longjing City, Wangqing County	The ecological function of the area is outstanding.	Priority should be given to the protection of ecological environment and ecological resources in this area; strengthen water and soil conservation and water conservation; relying on forest resources to create forest oxygen bar leisure services and increase tourism value; plant local specialties and improve the processing, sales and service industry.
E–P	Huinan County, Zhenlai County, Tongyu County, Da'an City	The area is dominated by ecological function, supplemented by production function.	Ecological restoration should be strengthened, important ecological resources such as grassland and wetland should be restored, ecological business cards should be created and habitat quality should be improved; give full play to the production function, appropriately carry out large-scale agricultural production, pay attention to soil treatment and protection, and improve soil fertility.
E–L	Ji'an City, Fusong County, Linjiang City, Qianguo County, Dunhua City, Hunchun City, Helong City, Antu County	The area is dominated by ecological function, supplemented by living function.	The area should give priority to protecting the ecological environment and protecting the water source; relying on advantageous ecological resources, moderately develop tourism, create ice and snow sports brands, and establish Changbai Mountain International Tourism Resort; border port areas should actively attract foreign investment and expand employment income; create an industrial chain of local characteristic agricultural products and specialties to increase the living income of local people; optimize the structural layout of residential areas and improve the convenience of life.
E–L–P	Tonghua County, Jingyu County	The area has the advantage of all three functions but ecological function is the strongest, living function is the second, and production function is relatively weak.	The production function of this area should be moderately enhanced to realize the integration and coordinated development of PLE functions; create characteristic agricultural development in mountainous areas, reasonably reclaim paddy fields and increase production; protect water and forest resources and make rational use of hydropower; vigorously develop characteristic industries to increase residents' income and improve the quality of life.
E–P–L	Jiaohe City, Liuhe County	The area has the advantage of all three functions but ecological function is the strongest, production function is the second, and living function is relatively weak.	The living function of this area should be moderately enhanced to realize the integration and coordinated development of PLE functions; optimize the layout of residential areas, improve public service facilities, and increase the number of schools and hospitals; build key ecological demonstration counties and characteristic towns, optimize the living environment and improve the quality of life; maintain great ecological resources, rationally develop mineral resources and moderately develop industrial production.

4. Discussion

To optimize the pattern of territory space development, we need to reveal the differentiation law of space function types from the perspective of regional and even national

development and overall interests, horizontally optimize the allocation of various elements such as economy, society, population and environment, and vertically optimize the allocation of current and future elements, as the basic basis for the optimization and adjustment of territory space function structure, finally the coordination of population, resources, environment and development and the unity of economic, social and ecological benefits will be realized [16]. At present, in a large number of exploratory studies on territory space spatial functions and their zoning, the main research approaches in functional evaluation included the function value expression according to the expression of various functions or biophysical processes, or the merging and classification of territory space spatial functions according to the development suitability of different land types; in terms of function zoning, spatial superposition or spatial clustering algorithms were mostly used, and spatial zoning of different levels or topics was carried out according to the size or type of functional values, but most of the existing zoning practices were difficult to theoretically ensure the connectivity between regions and the integrity within regions, which affected the practicability of zoning results [60]. Therefore, on the premise of maintaining connectivity and integrity, it was of great practical significance to put forward a clear, understandable and widely applicable idea of functional zoning of provincial territory space, which will help to build a high-quality land space with coordinated production, living and ecology.

At present, the 14th Five Years Plan of Jilin Province proposed to "optimize the pattern of national territory space development and protection, promote the differentiated positioning and integrated development of the 'three plates' of the central, eastern and western parts, accelerate the construction of new urbanization, promote the rational flow and efficient agglomeration of various factors, and promote the realization of regional coordinated development" [59]. Based on the research results of this paper, it was known that the functions of the central, eastern and western regions in Jilin Province had their own emphases. Different regions should distinguish the strong and weak functions, overcome the obstacles, strengthen the regional advantageous functions according to local conditions and innovate the mechanisms and policies to optimize the allocation of resources. The central and western regions took the production function as the leading advantage function. We should earnestly strengthen the ability of food security, strengthen the protection and utilization of black land, appropriately promote the large-scale and scientific and technological development of agriculture, implement the new development concept, accelerate the green transformation and development, promote the green production mode, actively adjust the industrial structure and realize technological innovation, create emerging industries. The regions with living function as the dominant advantage function were scattered, mainly the municipal districts of various cities. These had remarkable urbanization characteristics, livable environment, population agglomeration and complete urban infrastructure. We should vigorously promote the green lifestyle, build a new layout of residential areas, strengthen the construction of social undertakings, promote the equalization of public services and improve the level of public cultural services, improve people's sense of well-being. Taking ecological function as the dominant function, the eastern regions and a few western regions should vigorously protect the ecological environment, adhere to the path of ecological priority and green development, implement ecological conservation projects, strengthen ecological restoration, build a system network of nature reserves, actively explore new ways of ecological protection and development of ecotourism, and build an ecological brand.

The evaluation of PLE functions was the direct feedback of territory space utilization quality, and balancing the relationship between various spatial functions can maximize the overall efficiency of territory space [30], which helped to promote regional sustainable development and make land space utilization more efficient. The optimal zoning of territory space was a phased policy orientation for the development, protection and renovation of land space. Therefore, regional land space planning must focus on all-round coordination, adhere to departmental cooperation and up-down linkage, promote the integrated development of urban and rural areas and regional coordinated development,

meet the people's yearning for a better life, and improve the level of infrastructure and public services, improve the living environment and quality of life, improve the livable level, and build a spatial pattern of resource conservation, environmental protection, and the coordinated coexistence of human and nature.

In this paper, the concept of functional zoning was applied to the regional multi-function measurement at the provincial scale, and scientific quantitative calculation was used to determine the regional advantageous functions and diagnose the obstacle factors in Jilin Province, which enriched the theory and practice of land spatial pattern optimization and helped to promote the coordinated development and utilization of land space. The NRCA index can applicable widely to the research of other regions and other regional scales. It can also refine and compare the sub-functions in the indicators of PLE functions and identify more accurate advantageous functions. However, the index can only identify the static situation at a certain point in time, so for areas with rapid development, urbanization, and industrialization, it cannot reflect the dynamic and continuous change of a function in time. The index can only compare and judge the existing index data results, cannot measure the impact of other sub-functions on the study area, and it is limited to the construction of the index system, so more in-depth exploration and research can be carried out on the index. The case study can provide reference for provincial territory space planning, and can be applied to other regions at home and abroad. However, further research was needed to realize the fine zoning of land space, such as quantitatively depicting the mapping relationship between land space and functions, and whether the promotion of functions was collaborative, restrictive or independent; the research scale also needs to be enriched, and we can conduct in-depth research from the micro scale of towns or villages to refine the regional functional zoning. In addition, due to the lack of data, there were limitations in the assessment of ecological function, and the comprehensiveness of ecosystem assessment need to be enhanced. Future research in this field should also be combined with the planning of main functional areas, the delimitation of "three zones and three lines" and "double evaluation" (i.e., resource and environment carrying capacity evaluation and territory space suitability evaluation) to guide national territory space planning, deepen the consideration of evaluation mechanism, improve the practicability and reliability of results, and do a good job of foundation, pre-emption and guidance for regional space development activities.

5. Conclusions

In this paper, we analyzed the characteristics of PLE functions in Jilin Province by constructing the PLE function evaluation index system, using the research methods of PLE function evaluation model, spatial concentration index, obstacle degree model and normalized revealed comparative advantage index (NRCA), and divided the advantageous functions based on the calculation results of comparative advantage index, and optimization strategies were proposed for different partition types. The main conclusions of this paper were as follows:

1. Jilin Province had stronger ecological function as a whole. The average value of ecological function (0.0068) in each county was higher than that of living function (0.0062) and production function (0.0046), and the average value of comprehensive function was 1.9310. Among the 47 counties and districts, 44.68% of the counties and districts had production function scores exceeding the average value, 31.91% had life function scores exceeding the average value, 40.43% had ecological function scores exceeding the average value, and 29.79% had comprehensive function scores exceeding the average value.
2. The spatial Gini coefficients of production function, living function and ecological function in Jilin Province were 0.0776, 0.1398, and 0.1539, respectively, indicating that the spatial agglomeration degrees of the three functions were low and the layout was relatively scattered. The spatial visualization showed that the high value areas of production function were mainly distributed in the central part and western part; the

high value areas of life function were mainly distributed in the central region; the high value area of ecological function were distributed in the eastern part; and the high value areas of comprehensive functions were small and scattered.

3. In 2018, the main obstacle factors affecting the PLE functions in counties and districts in Jilin Province were five indicators: the total book stock in public libraries (X17), the proportion of nature reserve area (X24), the grassland coverage rate (X20), the proportion of industrial and mining storage land area (X6), and the number of students in primary and secondary schools (X14). The most frequent obstacle index in all units was X17, up to 97.87%, followed by X24, up to 89.36%.
4. According to the comparative advantage measurement and type division results of the PLE functions, we divided the advantage function areas of the territory space into 14 types, and put forward optimization strategies for each zoning type, so as to give full play to the regional advantage function, overcome obstacles, enhance the weak function, comprehensively coordinate the development of the regional PLE functions, and enhance the regional core competitiveness, to provide detailed, specific, and operable reference suggestions for local provincial territory space planning.

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