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Study on the Structure, Efficiency, and Driving Factors of an Eco-Agricultural Park Based on Emergy: A Case Study of Jinchuan Eco-Agricultural Park

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Abstract: The eco-agricultural park is a new comprehensive agricultural technology system integrating agricultural production, rural economic development, ecological environment protection, and efficient resource utilization. Therefore, an in-depth analysis of the ecosystem structure of eco-agricultural parks will help achieve the goal of coordinated symbiosis between human development and environmental protection. This study takes the research area of the Eco-agricultural Park of Jinchuan Town, Huinan County, a typical town in the Changbai Mountains of Northeast China. Based on field surveys, market research, farmer consultation, and related data collection, emergy theory and methods are used to construct an emergy model for the park. The value evaluation index system integrates the unique emergy index of the agricultural ecosystem with the traditional emergy index system to conduct a targeted evaluation of the park's functional structure and sustainable development capabilities in order to improve the efficiency of material and energy use and provide technical reference for ecological construction and comprehensive development of agricultural industry in mountainous areas in northern China. The research results show that: (1) The annual input total emergy of the eco-agricultural park is 4.04E+24 sej/a, and the emergy of labor input, electricity input, and topsoil loss is relatively high. The park is in a labor-intensive stage. The annual output total emergy is 5.09E+24 sej/a, the park is dominated by planting and forestry industries. (2) The park's emergy utilization intensity is high—production efficiency is high, economic development is advanced, and the system's self-control, adjustment, and feedback functions are vital—and plays a significant role in promoting the development of the regional economy. However, the park relies more on investment from external resources, and production in the park puts pressure on the environment. (3) The current sustainable development capability of the study area is weak, and the factors affecting the sustainable development capability are mainly energy loss and uneven distribution of industrial areas in the park. Effective measures to promote the transformation of the park to develop technology-intensive industries and improve the sustainable development performance of the park were proposed. These include: adjusting the proportion of industries in the park; reducing high-energy external input emergy, such as industrial auxiliary emergy; reducing the loss of non-renewable natural resources through ecological engineering measures, such as reducing the depth of slope runoff in the park; and combining modern resource-based production technology and environmentally sound management methods to reduce energy loss and rational use of natural resources.

Keywords: emergy analysis; composite ecosystem; sustainable development; influencing factors

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1. Introduction

The eco-agricultural park is a social–economic–natural complex ecosystem with the attributes of being "close to nature, multifunctional, high efficiency, and sustainable" based on the principles of ecology, focusing on ecological agriculture, and using a complex agricultural production system to construct a green ecology [1]. Eco-agricultural parks generally include agriculture, forestry, animal husbandry, and fishery subsystems. The ecosystem's material circulation, energy flow, and information transmission functions make the subsystems closely integrated into an organic whole [2]. Each subsystem is interconnected and develops collaboratively, so it has energy flow, material flow, information flow, and value flow. There are various interdependencies between these flows. Evaluation and research on them will help to grasp the laws of the ecological economic system and establish a virtuous cycle and sustainable development of the ecological economic system. There are various types of energy in the ecological economic system. Traditional ecological methods cannot evaluate value flows, and financial methods cannot evaluate essential functions and fundamental values. The only solution is to combine ecology and economics. Emergy is considered to be the bridge connecting ecology and economics. The emergy theory and analysis method is an environmental–economic value and system-analysis method that can measure and analyze the value and relationship between natural environmental resources and economic activities. Therefore, the emergy method helps to explore the value and interrelationship between humans and nature, environmental resources, and social economy in the ecosystem.

Rationally understanding and evaluating the contribution of environmental resources is one of the important topics in the sustainable development strategy of agriculture. From the perspective of research objects, emergy analysis research on agricultural ecosystems is a hot area of emergy research. According to the results of the literature review, it can be seen that the current research objects of domestic and foreign experts and scholars are mostly concentrated on typical agricultural products and agricultural production systems: integrated poultry farming systems [3], cereal-based systems [4], different types of pig farming systems [5], pasture systems [6], dairy production systems [7], mulberry fishpond systems [8], integrated agricultural systems [9], rice, rice–fish, and rice–duck integrated farming systems [10], coffee cultivation systems [11], banana-based systems [12], etc. From the perspective of research questions, current research content is mostly focused on the assessment and improvement of ecosystem sustainable development capabilities in the following ways:

(1) Concerning the current status of sustainable development capacity of composite ecosystems, Patrizi et al. conducted an emergy evaluation of monoculture systems and composite agroforestry systems, and the results showed that composite agroforestry systems can effectively save energy and generate more benefits on the same piece of land, thus having higher sustainability [13]. Zheng et al. conducted an emergy comparison analysis of the "wheat–corn rotation–pig farming" system, the "tea–pig farming" system, and the "citrus–lucerne intercropping–pig farming" system [14]. The results showed that agro–pastoral composite systems could promote greenhouse gas reduction and improve ecological and economic benefits. Tongliang Li et al. evaluated the emergy of traditional and new crop planting models in the hilly areas of southwest China. The new triple planting system has high production intensity and stability and a higher sustainable production capacity than the traditional crop system [6]. Rodríguez-Ortega et al. conducted an emergy analysis of three different planting systems for sheep farming in Spain [15]. Although the economic benefits of the composite system were lower than the other systems, the overall capacity (sustainability, pollution level, and economic benefits) achieved a balance among the three systems. Lin et al. used emergy analysis to analyze monoculture systems and composite systems [16]. The "grape–lingzhi" composite system had better economic vitality and environmental sustainability. Luo et al. evaluated the ecological and economic benefits of the ecological grassing model and the clean tillage model in Fujian honey pomelo orchards using emergy evaluation methods [17]. Consistent with the previous researchers, the

ecological grassing composite model achieved increased pomelo production and income for pomelo farmers, making it an important path to achieve coordinated green development and improve the sustainability of the orchard.

(2) Concerning the analysis and improvement of influencing factors, industrial auxiliary emergy is the main factor affecting the sustainable development capability of the system. Zhang et al. conducted an emergy assessment of the economic benefits, environmental pressures, and sustainability of China's crop production system from 2000 to 2010 [18]. The study showed that industrial auxiliary emergy inputs such as fertilizers and agricultural machinery contributed the most to the overall system inputs, weakening system sustainability. Yao et al. analyzed the emergy input and output dynamics of the planting industry system in Gansu Province [19]. By comparing the emergy indicators of Gansu Province with the national planting industry, it was determined that the planting industry system in Gansu Province lacks vitality, and reducing the input of non-renewable industrial auxiliary emergy is an effective way to promote the sustainable development of the planting industry in Gansu Province. Similarly, Chu et al. analyzed the emergy input and output dynamics of the planting and breeding industry in the Heilongjiang reclamation area. They concluded that the research area depends more on industrial product inputs [20]. Optimizing the input of diesel and nitrogen fertilizer is beneficial for developing a regional characteristic circular agricultural development model. Wang et al. conducted an emergy assessment of the sustainability of the agricultural system in Northwest China before and after the implementation of the Green Growth Plan [5]. The study showed that an increase in the input of non-renewable external resources reduces the system's sustainability and diminishes the effectiveness of green forest protection. According to the literature survey, research on the emergy analysis of agricultural ecosystems is mainly concentrated in South China, East China, and Central China. The research focuses mainly on single or multiple agricultural production systems. There is a lack of research on eco-agricultural parks in the Northeast region with eco-agricultural economic attributes.

Therefore, this study takes Jinchuan Eco-Agricultural Park as the research object and introduces emergy into the park to analyze its system structure with the aim of deeply understanding the current problems in the park, accurately determining its stage of development, and the construction of the research area to find the critical constraints and provide solutions to promote the sustainable development of the eco-agricultural park. The study will also provide support for park environmental management, project decision-making, and formulation of policies and regulations, thereby improving the utilization efficiency of the eco-agricultural park. It provides a practical basis for regional green and sustainable development and is conducive to replicating and promoting the eco-agricultural park model. At the same time, studying the same type of research objects in different regions is helpful for researchers, enabling them to be analyzed and compared from various perspectives.

2. Methods

2.1. Research Area

The eco-agricultural park is in Jinchuan Town, southeast of Huinan County, Tonghua City, Jilin Province (126°12′55″ E~126°32′02″ E, 42°16′20″ N~42°26′57″ N). The total area of the park is 150 acres (Figure 1), which is divided into three functional areas: support ribbon, core ribbon, and extend ribbon (Figure 2), and eight systems (planting system, breeding system, wetland purification system, waste treatment system, biogas treatment system, eco-tourism system, eco-education system, and eco-table system). The main feature of the park model is "compound symbiosis, waste recycling", which utilizes multi-path and multi-level recycling of by-products that were originally wasted to obtain high-value-added products while making contributions to the comprehensive environmental improvement of the region, thus systematically increasing the value of resources and energy in a park.

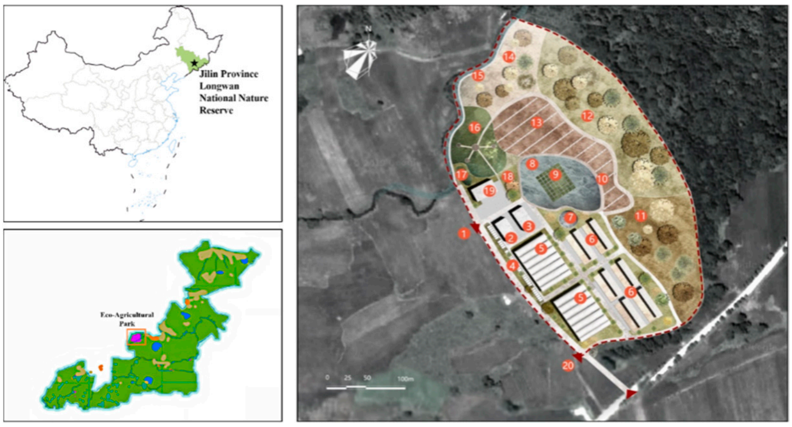

Figure 1. Study area. Note: ① Entrance to the park; ② Park Management Office; ③ Organic restaurant; ④ Eco-parking; ⑤ Eco-greenhouse; ⑥ High-quality pig breeding base; ⑦ Biogas treatment system; ⑧ Multi-function ecological pond; ⑪ Aquatic plant cultivation; ⑫ Recreational fishing; ⑬ Understory poultry farm; ⑭ Cultivation of Chinese herbal medicines under the forest; ⑮ Understory wild vegetables planting farm ⑯ Understory fungi cultivation; ⑰ Water quality and water source guarantee demonstration base; ⑱ Peatland; ⑲ Constructed wetlands; ⑳ Green Square; ① Popular science exhibition hall; ① Secondary entrance to the park.

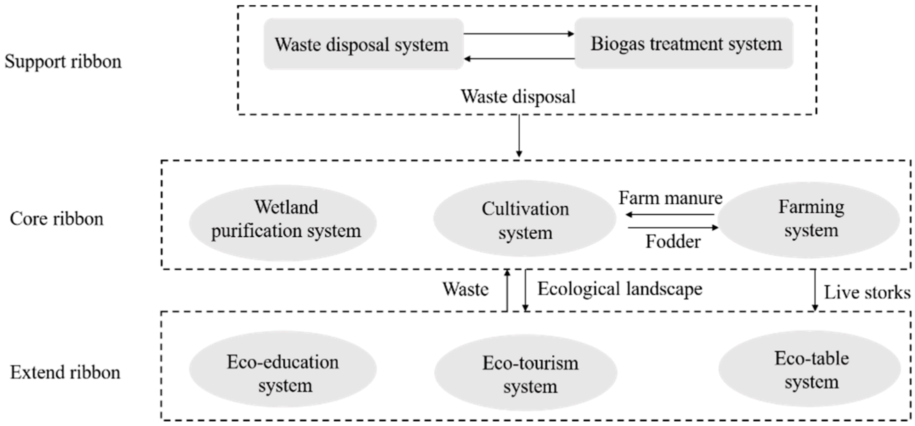

Figure 2. Functional classification of eco-agricultural park.

The research area belongs to the north temperate continental monsoon climate zone, with an annual average temperature of 4.1 °C, about 2550 h of yearly sunshine, an annual average rainfall of 704.2 mm, and a frost-free period of 110–120 days throughout the year. The park's forestland is a natural secondary forest, with seven species of tree, 12 species of shrub, and 20 species of herbaceous plant. It is classified as a deciduous broad-leaved forest. The main soil type is dark brown soil.

2.2. Emergy Analysis

In the late 1980s, American ecologist H.T. Odum established the theory of emergy analysis based on energy system analysis and integrated principles of systems ecology, energy ecology, and ecological economics [21]. He defined "emergy" as the quantity of one type of energy contained within a flowing or stored energy, which is distinguished from "energy" as a ratio-defined concept [22]. As all forms of energy originate from solar energy, emergy is measured in solar emjoules (sej) as the amount of solar energy directly or indirectly required to produce a resource, product, or service. Emergy indicates energy demand and represents the value of "energy" (matter, wealth). All products created by nature and human society contain energy and have emergy and thus value [22]. The more energy invested in forming a substance (product, energy), the greater its emergy and intrinsic value. Therefore, emergy is a scientifically quantifiable measure of true wealth value and an essential reflection of the product value.

Emergy analysis converts different kinds of non-comparable emergy into the same standard emergy in an ecosystem or ecological economic system to measure and analyze its role and position [23]. By comprehensively analyzing various ecological flows (energy flow, material flow, currency flow, population flow, and information flow) in the system, a series of emergy indices were obtained to quantitatively analyze the system's structural and functional characteristics and ecological economic benefits. Furthermore, the system can achieve maximum ecological, financial, and social benefits through the most efficient design.

2.3. Energy System Diagram

The energy system diagram is used to clarify the system's basic structure, the interrelationship between inside and outside the system, and the direction of significant ecological flows. Reasonable delineation of the boundary of the research system is a prerequisite for applying the value analysis method [7]. In this study, the boundary of the Jinchuan Eco-agriculture Park system was defined based on the "four-dimensional spatiotemporal scale". The boundary is determined by the production sites of various subsystems in the eco-agriculture park. The near-surface space is considered as the "height and depth" spatial dimension, with the upper boundary defined as the standard height of 10 m above ground level for wind measurement and the lower boundary defined as the soil depth of 1 m for grain crop roots. The "fourth dimension" is one natural year. The 2019 natural geography and socio-economic data of Jinchuan Eco-agriculture Park were collected through the collection of statistical yearbooks, on-site investigations, and academic literature.

The diagram was constructed according to the system input, output, internal material cycle and energy flow. The emergy analysis table was built according to non-renewable environmental resources, renewable resources, and product input and output. The symbols used in the diagram are all derived from the energy circuit language proposed by Odum [23]. The energy system diagram of Jinchuan Eco-agriculture Park is shown in Figure 3. The outer frame of the diagram represents the boundary of the eco-agriculture park system. The input emergy on the left side of the system exists in the form of renewable natural resources such as solar energy, wind energy, chemical energy of rainwater, and earth-cycle energy. Surface runoff, agricultural irrigation water resources, and topsoil loss are non-renewable natural inputs to the park. The feedback emergy values from the social and economic system outside the eco-agriculture park system include: electricity, seed, manure, fertilizer, pesticides, labor, service, and machines. The internal part of the eco-agricultural park is the main component of the agricultural ecological economy, including organic farming, animal husbandry, forestry, and fishing units, which are interconnected, intertwined, and develop synergistically. Eco-education, eco-table, and eco-tourism constitute the park's distinctive cultural and agricultural industry. The design of the waste treatment and biogas treatment areas is based on maximizing resource utilization and minimizing pollution discharge, integrating clean production, comprehensive resource utilization, and ecological design. It aims to rationally and sustainably utilize the materials and energy entering the park and achieve "optimal production, optimal consumption, and minimal waste". All resources within and outside the eco-agricultural park system serve as the driving force for its development. The utilization of renewable and non-renewable natural resources does not involve economic activities. At the same time, the feedback emergy from outside the eco-agricultural park system needs to act on the production process of the system through market and commodity exchange processes. The purchase and output of products are accompanied by monetary circulation.

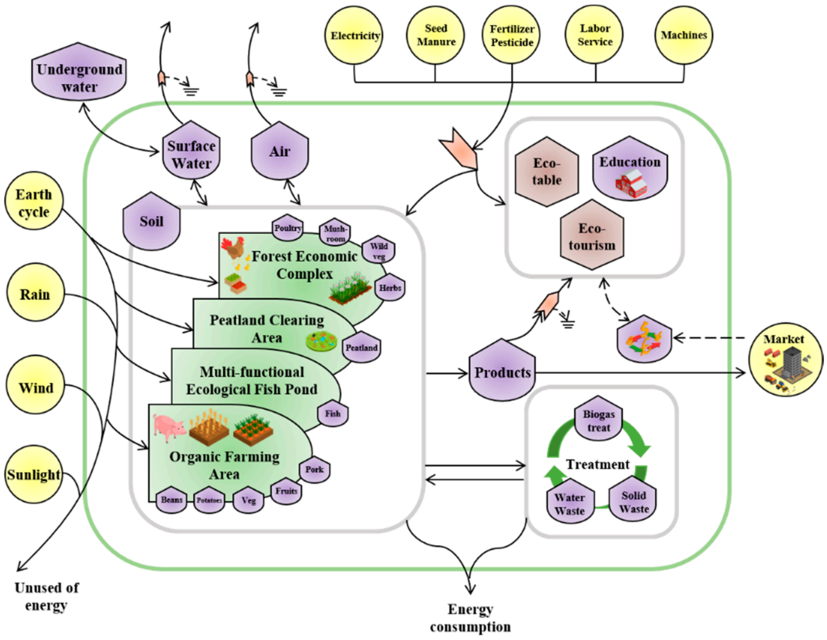

Figure 3. Energy flow diagram of Jinchuan Eco-agriculture Park.

2.4. Comprehensive Index of Emergy

The emergy comprehensive index reflects the structure, function, and efficiency of an ecosystem, as well as an indicator of the value of natural environmental resources and human socio-economic development. The emergy index system unifies various ecological flows in a complex ecosystem (energy flow, material flow, monetary flow, information flow, etc.) on the emergy scale, quantitatively analyzing the structure and function of the system to understand the relationship between the value of natural environmental production and human economy. Based on the theory of Mr. Ma Shijun, scholar Lan Shengfang has established a composite ecological system emergy index system, selected emergy indicators suitable for an eco-agricultural park and analyzed their ecological flows (Table 1). A series of emergy indicators obtained through the system can unify various ecological flows (such as energy flow, material flow, monetary flow, information flow) of a complex ecological system on an emergy scale. This also allows for quantitative analysis of the structure and function of the system.

Table 1. Emergy index system.

Emergy Value Indicator	Formula	Explanation
Social–Economic–Natural Composite Ecosystem Valuation Index		
Renewable source Emergy flow (Em_R)		
Nonrenewable resource Emergy flow (Em_N)		Existing wealth foundation of the system
Input Emergy (Em_1)		
Total Emergy (Em_U)	$Em_U = Em_R + Em_N + Em_1$	Total wealth of input resources and commodity assets.
Output Emergy (Em_O)		Output of resources and material wealth
Emergy source indicators		
Emergy Self-sufficiency rate	$(Em_R + Em_N)/Em_U$	Assessment of natural environment carrying capacity
Purchase emergy ratio	Em_1/Em_U	Degree of dependence on external resources
Renewable resource emergy ratio	Em_R/Em_U	Evaluation of potential of natural environment
Input emergy and own emergy ratio	$Em_1/Em_R + Em_N$	Assessment of industrial competitiveness
Social subsystem evaluation indicators		
Emergy per capita	Em_U/P	Standards of living and quality of life.
Emergy density	Em_U/(Land area)	Rating the intensity and efficiency of resource utilization.

Table 1. *Cont.*

Emergy Value Indicator	Formula	Explanation
Population carrying capacity	$(Em_R + Em_1)/(Em_U/P)$	The current carrying capacity of the environment in terms of population.
Economic subsystem evaluation indicators		
Emergy/currency ratio	$Em_U/(GNP)$	The level of economic modernization.
Emergy exchange rate	Em_1/Em_O	Evaluating the gains and losses of international exchanges.
The emergy of money	Emergy/(Emergy/Currency Ratio)	The equivalent amount of currency in terms of value.
Natural subsystem evaluation indicators		
Emergy investment rate	$(Em_R + Em_N)/ Em_R$	The capacity of the natural environment to accommodate economic activities.
Updatable emergy ratio	Em_R/Em_U	The potential for utilization of the natural environment.
Population affordability	$Em_R/(Em_U/P)$	The population carrying capacity of the natural environment.
Environment Sustainability Indicators	EISD = EYR × EER/ELR	The calculation results of EISD can reflect the benefits of the emergy output of the system and the satisfaction of the system's needs for economic development. The higher the calculation results, the stronger the system promotes economic development.If EISD is less than 2, the system has no development potential. If the EISD is between 2 and 18, the system is considered to be full of vitality and development potential. If the EISD is greater than 18, the system is considered to have high social and economic benefits.
	ESI = EYR/ELR	ESI < 1, the system is a resource-consuming system and is unsustainable; 1 < ESI < 10, the system is highly resilient and has room for development; ESI > 10, the system is economically underdeveloped, has strong sustainability and has room for development.
Unique Indicators of Eco-agricultural systems		
Environmental carrying capacity	$ELC = (Em_N + Em_F + Em_T)/Em_R$	In a certain period, under a certain environmental condition, the limit of the capacity of a regional environment to support human and economic activities.
Emergy–labor productivity	Em_O/H	The emergy output obtained from investing 1 h of labor.
System production advantage	$C = \sum(E_{myi}/E_{my})\hat{}^2$	i = 1, 2, 3, 4; Emyi represents the energy output of the ith subsystem, and Emy represents the total energy output of the system. The system advantage degree of the agricultural ecological economic system reflects the overall balance of production units in the structure. The system advantage degree indicator can be used for comparison of different agricultural ecological economic systems. The closer the system advantage degree is to 0, the smaller the differences in advantage degree of each production unit; the closer the system advantage degree is to 1, the more a certain industrial structure in the system is in absolute advantage, and the distribution among units is more uneven.
Stability Index of the System	$S = \sum[(E_{myi}/E_{my})\ln(E_{myi}/E_{my})]$	Among them, i = 1, 2, 3, 4; Emyi represents the energy output of the i-th subsystem, and Emy represents the total energy output of the system. The stability index of the system represents the magnitude of the production stability of the system. If the stability index of the system is high, it indicates that the material flow and energy flow network of the agricultural system are developed, and the system's self-control, regulation, and feedback effects are strong, resulting in greater self-stability.

Indicator sources: Shengfang, Lan. *Emergy analysis of the economic system*, 2002 [24].

2.4.1. Emergy Source Indicators

The emergy source index is used to describe the utilization structure of various resources in the study system, thus reflecting the competitiveness of the park system. The emergy source index of this study is composed of: emergy self-sufficiency rate, purchase emergy ratio, renewable resource emergy ratio, input emergy, and own emergy ratio. The emergy self-sufficiency rate reflects the ability of the natural environment to support the system. The purchase emergy value ratio reflects the degree of dependence of the system on the outside world. The renewable emergy ratio demonstrates the system's potential for using natural resources. The ratio of the input emergy to the own emergy reflects the system's contribution to the outside world and the competitiveness of the research region.

2.4.2. Social Subsystem Evaluation Indicators

The social subsystem takes the regional economy as the core and consists of per capita emergy, emergy density and population carrying capacity. The per capita energy value reflects the actual living standard of residents. The emergy density demonstrates the intensity of regional economic activity. The population carrying capacity reflects the number of people under the condition that the system's service function is optimal.

2.4.3. Economic Subsystem Evaluation Indicators

The economic subsystem takes resource utilization as the core, and the evaluation index consists of the emergy/currency ratio, emergy exchange rate, and emergy–monetary value. The emergy/currency ratio reflects the proportional relationship between the total applied emergy and the gross national product in the study area, that is, the park's economic development degree. The emergy exchange rate reflects the system's external exchange efficiency. Emergy–monetary value refers to converting the emergy of matter and energy in the ecosystem into a quantity of money equivalent to its currency value.

2.4.4. Natural Subsystem Evaluation Indicators

The natural subsystem takes the environmental structure as the core, and the evaluation index is composed of the emergy investment rate, the renewable energy ratio, and the population affordability. The emergy investment rate reflects the emergy investment required by the development unit's natural resources in the production process. The renewable emergy ratio reflects the proportion of renewable emergy in the total emergy input of the system, that is, the utilization of the renewable emergy value of the system. Population affordability reflects the number of people who can afford to be in the research area.

2.4.5. Environment Sustainability Indicators

To evaluate the sustainability of the system, the evaluation indicators are composed of emergy sustainability indices and the emergy index for sustainable development.

2.4.6. Unique Indicators of the Eco-Agricultural System

The agro-ecosystem emergy assessment index is used to evaluate and compare the ecological benefits and sustainability of the agro-ecosystem by evaluating the environmental carrying capacity, emergency-labor productivity, system production advantage, and stability index of the system. These indicators help to guide agro-ecosystem management and decision-making to achieve eco-friendliness, sustainable use of resources, and the ecosystem health of the agricultural ecosystem.

2.5. Data Collection

Renewable natural resource data for this calculation was sourced from field monitoring sites at the Jilin Longwan Wetland Experimental Station from the years 2019–2020. Non-renewable natural resource data was obtained through field surveys and market research. Seed, nitrogen fertilizer, phosphorus fertilizer, and potassium fertilizer data were obtained from the park's planning and design results, while ecological agriculture construction investment data were obtained from Wang Kangzhe's calculated analysis results [25]. Output data was obtained through market research and mathematical model planning and design calculations. Using Excel 2019 for statistical analysis of data.

3. Results

3.1. Emergy Characteristics

The renewable natural emergy sources in the eco-agricultural park include solar energy, wind energy, rainwater chemical energy (the potential energy of rainwater was too small to be considered), and Earth's circulation energy (The data is shown in the Table A3). These renewable emergy sources play a crucial role in the system's energy conversion and indirectly support the eco-agricultural park's production and consumption processes. The non-renewable natural resources include the emergy of topsoil loss, agricultural water use emergy, and electricity consumption emergy. The renewable organic emergy sources include labor, seeds, nitrogen, phosphorus, and potassium fertilizers. The emergy output is divided into agricultural, fishery, and plant products. Agricultural products include four categories: medicinal herbs, wild vegetables, mushrooms, and poultry. Fishery products include three grass carp, carp, and white Amur species. Planting products include beans, vegetables, potatoes, fruits. The emergy input and output calculations of Jinchuan Eco-agricultural park are shown in Table 2 (The calculation process is shown in the Table A1). The emergy/currency ratio used in the study is 9.5E+12 sej/RMB, which refers to the calculation of the emergy/currency ratio in China in 2019 by scholars such as Zhang Xiumin [26]. The research data comes from survey data in 2019 and 2020. For convenience and comparison with the latest research, the study uses the emergy conversion rate based on the latest global geosystem emergy baseline 12.0E+24 seJ/a for subsequent analysis [27]. In this study, some emergy conversion rates use the old emergy baseline, which has been multiplied by the corresponding conversion factors (The conversion coefficient of the emergy of major agricultural products is shown in the Table A2).

Table 2. Calculation of emergy value of Jinchuan Eco-agricultural Park.

No	Item	Emergy	Unit	UEVs	Ref.	Em$/$
Input						
Renewable resources						
1	Sunlight	3.08E+11	seJ/a	1		
2	Rain (chemical energy)	2.44E+15	seJ/a	7.010E+03	Brown and Ulgiati (2016) [27]	
3	Wind	2.11E+18	seJ/a	7.900E+02		
4	Earthcycle	5.80E+14	seJ/a	5.800E+04		
Total		2.12E+18	seJ/a			2.23E+05
Nonrenewable resources						
1	Soil Erosion	3.13E+19	seJ/a	6.250E+04	Brown and Ulgiati (2016) [27]	
2	Irrigating water	4.64E+12	seJ/a	5.010E+04		
3	Electricity	2.87E+23	seJ/a	7.960E+11		
Total		2.87E+23	seJ/a			3.02E+10
Updatable organic resources						
1	Human labor	3.75E+24	seJ/a	5.720E+13	Brown and Ulgiati (2016) [27]	
2	Seed	1.15E+18	seJ/a	2.400E+12		
3	Nitrogen fertilizer	2.24E+15	seJ/a	4.826E+09		
4	Phosphate fertilizer	1.16E+15	seJ/a	4.953E+09		
5	Potash fertilizer	2.51E+15	seJ/a	1.397E+09		
6	Investment in the Construction of ecological agricultural parks	5.34E+18	seJ/a	2.400E+12	Lan et al. (2002) [24]	
Total		3.75E+24	seJ/a			3.95E+11
Total Input		4.04E+24	seJ/a			4.25E+11
Output						
Forest products						
1	Herbal medicine	1.17E+24	seJ/a	1.110E+12	Lan et al. (2002) [24]	
2	Wild vegetables	2.88E+23	seJ/a	5.430E+11		
3	Fungus	2.87E+23	seJ/a	5.380E+10		
4	Poultry	2.88E+23	seJ/a	1.530E+11		
Total		2.03E+24	seJ/a			2.13E+11
Fishery products						
Fishes		2.84E+23	seJ/a	6.800E+11	Lan et al. (2002) [24]	2.99E+10
Plantation products						
1	Legume	2.87E+23	seJ/a	1.370E+12	Lan et al. (2002) [24]	
2	Potato	2.87E+23	seJ/a	5.880E+09		
3	Vegetable	2.87E+23	seJ/a	1.300E+12		
4	Fruit	1.04E+24	seJ/a	1.850E+12		
5	Pork	2.88E+23	seJ/a	1.250E+13		
Total		2.19E+24	seJ/a			2.30E+11
Total Output		4.50E+24	seJ/a			4.73E+11

The annual input emergy of the eco-agricultural park is 4.04E+24 sej/a. Wind emergy input is the most significant among the calculated renewable natural resource emergy. In 2019, the emergy input of wind emergy resources in Jinchuan eco-agricultural park was 2.11E+18 sej/a, which is the largest among all the renewable natural resources that were input. The study area has abundant rainfall. The emergy input of chemical emergy of rainwater was calculated to be 2.43E+15 sej/a, which is the second largest after wind energy input in the annual input of the eco-agricultural park. This reflects the natural climatic resource conditions in the study area. Abundant rainfall provides rich irrigation resources for agricultural production in the eco-agricultural park, while strong winds may cause soil erosion. Looking at the results of the calculation of non-renewable natural resource emergy, the emergy of topsoil loss in the Eco-agricultural park is 3.13E+19 sej/a, which is the most significant proportion in the non-renewable natural resource emergy, except for electric power emergy. Among the renewable organic emergy resources, labor is the most considerable emergy flow in the eco-agricultural park's production, followed by investment in construction and purchase of seeds. In the output system's emergy composition, forestry, fishery, and planting products of the Jinchuan Eco-agricultural Park respectively account for 45%, 6%, and 49% of the system's emergy output. The fishery system is the weak link in the entire agricultural and ecological economic system's emergy. From the perspective of emergy-currency value, the emergy-currency value of planting products in the eco-agricultural park's output is the highest, ranking first among all products.

3.2. Emergy Evaluation Indexes

A series of emergy indicators obtained through system emergy analysis can unify the various ecological flows (energy flow, logistics, currency flow, information flow, etc.) of the composite ecosystem on the emergy scale and quantitatively analyze the structure and functions of the system, understand the value of natural environment production and its relationship with the human economy, and correctly handle the relationship between humans and natural resources and the environment and the economy.

3.2.1. Emergy Source Structure Index

Emergy self-sufficiency rate describes the degree of foreign exchange and economic development of a country or region (Figure 4). The calculated result of the emergy self-sufficiency rate in the study area is 7%, which is relatively low. The purchased emergy ratio reflects the degree of dependence on external resources, and the calculated result is 92.90%, which is relatively high. The renewable resource emergy ratio reflects the sustainable development capability of the system, and the calculated result is 0.01%, which is low.

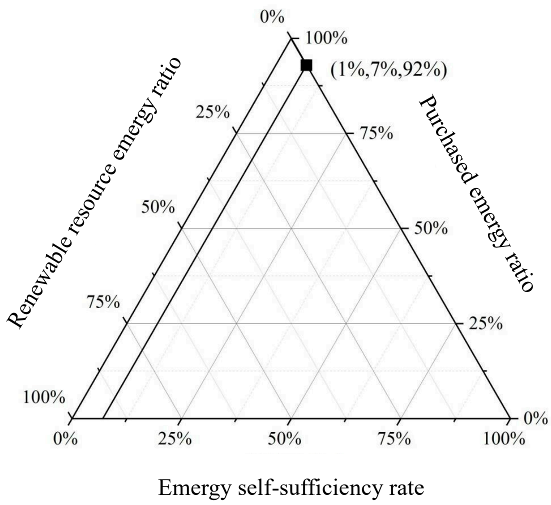

Figure 4. Emergy source structure index.

3.2.2. Emergy Analysis of Social Subsystems

The calculation gives a per capita emergy value of 3.37E+19 sej, which is higher than the national average level of 9.97E+15 sej from 2000 to 2019, and the result of the calculation of per capita emergy in 2019 is 1.42E+16 sej [28]. The amount of emergy per capita is used to measure living standards and quality standards. The larger the value, the better the living standard in the study area. The greater the amount of emergy available per capita, and the more real welfare obtained in material terms. The calculation results are much higher than the national level, indicating that the Jinchuan Eco-agriculture Park has a higher level of emergy investment and a relatively advanced economic development.

The calculation gives an emergy density of 4.04E+19 sej/a, which is higher than the national average from 2000 to 2019 of 3.99E+11 sej, and the calculation result of per capita emergy consumption in 2019 of 4.08E+11 sej. Emergy density is also called “energy utilization intensity”, and reflects the concentration of economic activities per unit area. The larger the value, the greater the intensity of emergy utilization, high production efficiency, and rapid economic development in the region. This study’s calculation results of emergy density are higher than the national level. This further shows that the emergy utilization intensity in the study area is high and the economic development is relatively advanced, consistent with the analysis of the per capita emergy consumption results. The calculated value of population carrying capacity emergy is 1.11E+05, which reflects the number of people the park can accommodate within the study time interval.

3.2.3. Economic Subsystem Emergy Indicators

The emergy/money ratio calculation result is 2.84E+11 sej/yuan, which is higher than the national average of 8.76E+11 sej/yuan from 2000 to 2019 and the 2019 emergy/money ratio emergy calculation result of 2.91E+11 sej/yuan. The higher the value, the higher the amount of emergy obtained by unit currency. The research results show that the contribution of currency to natural resources in the study area is relatively high. The emergy exchange rate (EER) reflects the gain and loss of wealth value in the region in terms of the economic and trade of each province. The greater the emergy exchange rate, the more real wealth the area has gained. The regional emergy exchange rate is 0.8343, which is less than 1. This shows that the emergy input into the system has been utilized to a greater extent, but it also indicates that the park products have lost wealth value during the transaction process. According to the park emergy input, the park’s power energy is mainly used.

3.2.4. Natural Subsystem Emergy Indicators

The calculated result of the emergy investment rate is 1.35E+05, which is higher than the average value of 78.93% from 2000 to 2019, and the calculated result of the emergy investment rate of 84.14% in 2019 [28]. The emergy investment rate is an indicator that measures the degree of economic development and environmental load. The larger the value, the higher the economic development of the system. The smaller the value, the lower the development level and the stronger the dependence on the environment. The calculation result of the emergy investment rate in this study is relatively high, indicating that the study area is in a high resource consumption economic development model. Attention should be paid to appropriately balancing low-energy renewable resources with high-energy external input energy and striving to achieve harmony between regional economic development and environmental pressure. The renewable energy ratio reflects the utilization potential of the system’s natural resources. The calculation result of the renewable energy ratio is 5.24E−07, which is low. The calculation results show that the park depends on external input resources.

The environmental load rate is used to examine the pressure on the environment during the energy transfer and transfer process. The calculated result is 0.0629, which is far lower than the national average of 3.16 from 2000 to 2019, and the 2019 environmental load rate emergy calculation result of 3.23. The rate reflects the degree of utilization of the emergy of the system. The environmental load rate in the study area is low, which shows that the ecological environment of the park is relatively fragile. Therefore, protecting the park environment is a solution to improve the ecological carrying capacity.

3.2.5. Unique Indicators of the Eco-Agricultural System

The calculation result of environmental load is 1.023E+06, which is high, indicating a certain pressure on the ecosystem from agricultural production in the park.

The emergy-labor productivity calculation result is 3.58E+19. Emergy-labor productivity relates to the traditional concept of labor productivity, it is equal to the emergy output of the system divided by the labor time of the investment system (in hours), and indicates the corresponding emergy output obtained by 1h of human labor. Emergy-labor productivity is expressed in solar emergy to labor results. Emergy is real wealth, and is a better reflection of the total value condensed in it, than traditional labor productivity. It can more fully and genuinely reflect and evaluate the labor efficiency of producers. The emergy-labor productivity of Jinchuan Eco-agricultural Park is 3.58E+19 sej/h, indicating that the production level of Jinchuan Eco-agricultural Park is relatively high.

The system dominance degree reflects the balance of the structure's overall production unit. The system dominance degree index can be used to compare different agricultural ecological economic systems. The production dominance degree of Jinchuan Ecological Agriculture System is 0.469, which is lower than 0.5, indicating the uneven industrial output distribution of Jinchuan Eco-agriculture Park.

The system stability index indicates the size of the production stability of the system, and the high system stability index suggests that the agricultural system's material flow and energy flow connection network are developed, and the system has strong self-control, regulation, and feedback effects, and greater self-stability. System stability indicators can be used to compare different agro-economic systems. The system stability index is 0.899, indicating that the stability of the ecosystem is high, the subsystems within the system are rich in networking, and the system's automatic control, regulation and feedback are strong.

4. Discussion

4.1. Analysis of Influencing Factors

The park is a consumption-driven economic system currently in the labor-intensive industrial stage. The agricultural production in the park puts pressure on the ecosystem, and the level of sustainable development could be higher.

From the perspective of park emergy input, park labor input, power input, and topsoil loss rank at the forefront. Excessive labor input indicates that the park is in a labor-intensive industry, while excessive labor emergy investment will lead to low utilization efficiency of environmental resources in the park, which will affect the sustainable development of the park. High power loss means high energy consumption, highlighting the contradiction between economic growth and the energy environment, thereby affecting the sustainable development of the economy and society. Topsoil loss is one of the most significant losses of non-renewable resources in the eco-agricultural park production process, except for electric energy value. According to previous research [29–31], excessive topsoil loss in the study area directly affects the sustainable development capability of the system. The growth of crop products in the study area consumes a lot of water, and the large water consumption of crop products will further aggravate the soil loss in the park, that is, the loss of topsoil. At the same time, wind energy accounts for the most significant proportion of renewable natural resources in the park, and wind speed is responsible for soil erosion and water and soil loss. This is the main reason for the loss, which can further explain the phenomenon of significant loss of emergy of topsoil in the study area. Although the calculation result of industrial auxiliary emergy input is smaller than other inputs, according to the calculation result of the emergy source index, it can be seen that the purchased emergy ratio is higher, indicating that the study area is highly dependent on external resources. At the same time, combined with the ratio of input emergy to self-owned emergy, which can be used to measure the ratio of external resources to internal resources of the system, and the emergy calculation results of the eco-agricultural park, further analysis shows that the park relies on the input of industrial auxiliary energy, and the significant investment in industrial auxiliary energy. It will also significantly affect the sustainability of the park.

From the perspective of the emergy output of the park, the economic output of the forest plays an important role, and fishery is a weak link. The low fishery output results in low system production advantage calculation results, and the uneven emergy output reflects the unequal distribution of resources in the park, which will affect the development of the park's sustainable capabilities. The EISD calculation result is 13.26, indicating that the system structure needs to be adjusted. Therefore, the park should optimize resource allocation and adjust the allocation and use of fishery resources to increase fishery value output. Although the park's output is uneven, the system has high stability and strong self-control, adjustment, and feedback effects. The calculation results of emergy density, emergy exchange rate and emergy investment rate in the study area are high, which shows that the regional emergy utilization intensity is high, production efficiency is high and economic development is rapid. At the same time, the calculation results of emergy-labor productivity further show that the production level of Jinchuan Eco-agricultural Park is relatively high. Although a higher economic growth model can promote regional economic development and is worthy of promotion, the park is in a state of low sustainable development capacity.

Therefore, high labor input, energy loss, soil erosion, high dependence on external resources, and uneven distribution of park output leads to high agricultural production pressure and low sustainable development levels in the park. Xie Hualian [32] and Wang Xinya [33], who have the same research conclusions as this study, proposed an increase in the input of production factors through soil testing and formula fertilization and improvements in the traditional agricultural production system method to optimize the planting structure to achieve sustainable and balanced development of the system. Yang Xiaolei [34] and Yanfeng Lyu [35] stated that reducing the input of industrial auxiliary emergy such as nitrogen fertilizers can significantly improve the system's sustainability. Therefore, in view of the problems in this study area, the following solutions are proposed based on previous research: Combined with land nutrient management strategies, clean raw materials could be used to reduce high-emergy external input. Reduce the loss of non-renewable natural resources such as soil by minimizing the depth and speed of park slope runoff and other ecological engineering measures, thereby enhancing the park's soil sustainability. Combining modern resource-based production technology and environmentally sound management methods, taking science and technology as the guide, entirely using natural resources, and promoting material transformation and energy circulation. Continuously optimize and improve the production process, adopt advanced process technology and equipment, reduce energy losses such as electricity, and achieve the goal of efficient energy utilization.

Therefore, the emergy analysis method can comprehensively evaluate the overall performance of the system from the perspective of the system view and quantify the system while paying attention to the efficiency of system resource utilization. The emergy method focuses on energy orientation (focusing on the energy efficiency and resource utilization efficiency of the system, emphasizing the optimization of energy conversion and utilization efficiency), physical constraint consideration (focusing on the physical constraints of energy in the system, focusing on the physical nature and limitations of energy, considering the relationship between energy input and output), and energy efficiency assessment (quantitative evaluation of energy flow, calculating the ratio between energy input and energy output, and evaluating the energy conversion efficiency of the system and the overall energy efficiency). The environmental cost–benefit analysis, ecosystem service assessment, natural capital accounting, and environmental value assessment in the ecological economics method pay more attention to the value of the ecosystem and ecological capital, and can evaluate and analyze the contribution of the ecosystem to human society. The ecological economics method focuses on economic orientation (focusing on the analysis of economic systems and the assessment of economic interests, focusing on the consideration of economic benefits and feasibility), market mechanisms (solving environmental problems through economic incentives and market means), social cost–benefit analysis (using social cost–benefit analysis to evaluate environmental policies and projects). The two methods have different focuses and analytical aspects when solving environmental and sustainable development problems. The appropriate method can be selected or combined according to the needs and specific issues to obtain more comprehensive and accurate evaluation results.

4.2. The Limitation of This Study

Although the emergy analysis method is a scientific measure of real wealth value and a substantial reflection of product value, different classifications of resources invested in different studies lead to varying calculations of system resource inputs and inconsistent definitions of system boundaries. Different handling methods of details will increase the uncertainty of the results. Uncertainty reduces the comparability between indicators. At the same time, during the data processing, the emergy calculation results are based on statistical data of the natural environment and social economy. Differences in data collection and processing methods will lead to data instability. These problems will be affected by the researcher's subjective understanding and thus jeopardize the emergy analysis results. Therefore, in future research, improvements can be made in the following areas: in terms of data collection, the system boundaries should be reasonably defined based on the "four-dimensional boundary", and sensitivity analysis of ecological environment accounting data should be used to improve the accuracy and scientificity of the research emergy calculation results.

5. Conclusions

Based on the emergy theory, this study defines the boundaries of the eco-agricultural park system through the "four-dimensional space–time scale"; it discusses the input and output emergy of material and energy in the park from the perspectives of ecology and economics, and analyzes the emergy of the park based on emergy indicators. Structure, efficiency, and drivers are assessed. The study area is currently in the labor-intensive industry stage, with a high intensity of emergy utilization, which promotes the regional economy but faces the problem of pressure from agricultural production on the ecosystem. The current sustainable development capability of the study area needs to be stronger, and the main influencing factors are the park's energy loss, water and soil erosion, and reliance on external industrial auxiliary emergy input. Based on this, suggestions are put forward to promote the transformation of the park into a technology-based industrial area and improve the park's sustainable development capabilities in the following ways: use clean raw materials, reduce the loss of non-renewable natural environmental resources such as soil, combine resource-based modern production technology and harmless management methods, rationally utilize natural resources, promote material transformation and energy circulation, and reduce high energy losses. This study explores a new perspective for adjusting the organizational structure and configuration of the eco-agricultural park system and improving operational efficiency. It also provides a practical basis for the implementation of regional sustainable development strategies.

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Appendix A

Table A1. Emergy accounting of Jinchuan Eco-agriculture Park.

Note	Item	Data Processing	Units
Input			
RENEWABLE RESOURCES			
1	Solar Energy		
	Emergy =	(Land Area) × (Avg. Insolation) × (1-Albedo) × UEV	
	=	(1.0E+05) × (3.42E+06) × (1–10%) × 1	
	=	3.08E+11	seJ/a
2	Rain (chemical energy)		
	Emergy =	(Land Area) × (Rain Land) × (Gibbs no.)× UEV	
	=	(1.0E+05) × (0.704) × (1.0E+06) × (4.94) × (7.01E+03)	
	=	2.44E+15	seJ/a
3	Wind Energy		
	Emergy =	(Ave.Altitude) × (Density of Air) × (Drag Coeff.) × (Grace gradient) × (Land Area) × UEV	
	=	(500 m) × (1.23 kg/m³) × (1.38 m^2/s) × (3.154E+07 s/a) × (1.0E+05 m^2) × (7.90E+02)	
	=	2.11E+18	seJ/a
4	Earth Cycle		
	Emergy =	(Land Area) × (Heat Flow) × UEV	
	=	(1.0E+05) × (1E+06 J/(m^2a)) × (5.80E+04)	
	=	5.80E+14	seJ/a
Total	2.12E+18		
NON-RENEWABLE RESOURCES			
1	Topsoil Loss		
	Emergy =	(Land Area) × (Organic matter content) × (Gibbs free energy of Topsoil) × UEV	
	=	(1.0E+05 m^2) × (52.78 ± 2.62 g/kg) × (45 × 667 × 1400) × (2.26044 J/g) × (6.25E+04)	
	=	3.13E+19	seJ/a
2	Water for Agriculture		
	Emergy =	(Water consumption) × (Emergy conversion factor) × UEV	
	=	(20 × 1000 × 54) × (8.58 J/kg) × (5.01E+04)	
	=	4.64E+12	seJ/a
3	Electricity Loss		
	Emergy =	(Electricity consumption per unit time) × (Emergy conversion factor) × UEV	
	=	(1.0E+04) × (3.60E+06 J/kWh) × (7.96E+11)	
	=	2.87E+22	seJ/a
Total	2.87E+23		
RENEWABLE ORGANIC ENERGY INPUTS			
1	Human Labor		
	Emergy =	(Labor quantity) × (Emergy conversion factor) × UEV	
	=	(40) × (1.64E+09 J/person) × (5.72E+13)	
	=	3.75E+24	seJ/a
2	Seed		
	Emergy =	(Seed purchase amount) × (Emergy conversion factor) × UEV	
	=	(6.85139+05E) × (0.7 $/¥) × (2.4E+12)	
	=	1.15E+18	seJ/a

Table A1. *Cont.*

Note	Item	Data Processing	Units
3	Nitrogen Fertilizer		
	Emergy =	(Nitrogen fertilizer usage) × UEV	
	=	(4.65E+05) × (4.826E+09)	
	=	2.24E+15	seJ/a
4	Phosphate Fertilizer		
	Emergy =	(Phosphate fertilizer usage) × UEV	
	=	(2.34E+05) × (4.953E+09)	
	=	1.16E+15	seJ/a
5	Potash fertilizer		
	Emergy =	(Potash fertilizer usage) × UEV	
	=	(1.8E+06) × (1.397E+09)	
	=	2.51E+15	seJ/a
6	Investment in the construction of Eco-agricultural park		
	Emergy =	(Fixed assets investment amount) × (Emergy conversion factor) × UEV	
	=	(3.18+06E) × (0.7 $/¥) × (2.4E+12)	
	=	5.34E+18	seJ/a
Total	3.75E+24		
Output			
Forest products			
1	Herbal medicine		
	Emergy =	(Yield)× (Emergy conversion factor) × UEV	
	=	(5.04E+04) × (2.09E+07 J/kg) × (1.11E+12)	
	=	1.17E+24	seJ/a
2	Wild vegetables		
	Emergy =	(Yield) × (Emergy conversion factor) × UEV	
	=	(2.53E+04) × (2.09E+07 J/kg) × (5.43E+11)	
	=	2.87E+23	seJ/a
3	Fungus		
	Emergy =	(Yield) × (Emergy conversion factor) × UEV	
	=	(2.55E+05) × (2.09E+07 J/kg) × (5.38E+10)	
	=	2.86E+23	seJ/a
4	Poultry		
	Emergy =	(Yield) × (Emergy conversion factor) × UEV	
	=	(9.00E+04) × (2.09E+07 J/kg) × (1.53E+11)	
	=	2.88E+23	seJ/a
Total	2.90E+24		
Fishery products			
1	Fishes		
	Emergy =	(Yield) × (Emergy conversion factor) × UEV	
	=	(2.0E+04) × (2.09E+07 J/kg) × (6.8E+11)	
	=	2.84E+23	seJ/a
Plantation products			
1	Legume		
	Emergy =	(Yield) × (Emergy conversion factor) × UEV	
	=	(1.0E+04) × (2.09E+07 J/kg) × (1.37E+12)	
	=	2.86E+23	seJ/a
2	Potato		
	Emergy =	(Yield) × (Emergy conversion factor) × UEV	
	=	(3.75E+06) × (1.30E+10 J/kg) × (5.88E+09)	
	=	2.87E+23	seJ/a
3	Vegetable		
	Emergy =	(Yield) × (Emergy conversion factor) × UEV	
	=	(8.85E+04) × (2.50E+06 J/kg) × (1.30E+12)	
	=	2.87E+23	seJ/a

Table A1. *Cont.*

Note	Item		Data Processing	Units
4	Fruit			
	Emergy	=	(Yield) × (Emergy conversion factor) × UEV	
		=	(1.7E+05) × (3.30E+06 J/kg) × (1.85E+12)	
		=	1.04E+24	seJ/a
5	Pork			
	Emergy	=	(Yield) × (Emergy conversion factor) × UEV	
		=	(5t) × (4.598E+09 J/t) × (1.25E+13)	
		=	2.88E+23	seJ/a
Total	2.19E+24			

Appendix B

Source of the Emergy Conversion Factor [36].

Table A2. Conversion coefficient of the emergy of major agricultural products.

Name	Value	Unit
Water for agriculture	8.58	J/kg
Electricity	3.60+06E	J/kwh
Labor	1.64+09E	J/Person
Seed	1.60+10E	J/t
Beans	2.09+07E	J/kg
Potato	4.00+06E	J/kg
Vegetable	2.50+06E	J/kg
Fruit	3.30+06E	J/kg
Aquatic products	5.50+06E	J/kg

Appendix C

Table A3. Natural resource data.

Project	Annual Average Data
The amount of solar radiation	3.42E+06 J/m^2/a
Wind velocity	1.38 m^2/s
Rainfall	0.704 m
Loss of soil organic matter	52.78 ± 2.62 g/kg

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