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Sustainability of Regional Agroecological Economic System Based on Emergy Theory: A Case Study of Anhui Province, China

Xue Wu ¹, Yaliu Yang ^{1,*}, Conghu Liu ^{1,2} , Guowei Xu ³, Yuxia Guo ¹, Fan Liu ¹ and Yuan Wang ¹

¹ Business School, Suzhou University, Suzhou 234000, China; gw Xu@ahszu.edu.cn (X.W.); lch339@126.com (C.L.); gyx@ahszu.edu.cn (Y.G.); fl@ahszu.edu.cn (F.L.); wangyuan151617@163.com (Y.W.)

² School of Economics and Management, Tsinghua University, Beijing 100084, China

³ School of Environmental and Surveying Engineering, Suzhou University, Suzhou 234000, China; jgxywx@163.com

* Correspondence: yangyaliu123@126.com

Abstract: The agroecological economic system is the basic system on which human beings depend for survival. In order to better evaluate the operation status of a regional agroecological economic system and deepen the cognition of the input and output of the regional agroecological economic system from the angle of emergy, the evaluation method of sustainable development of the regional agroecological economic system with comprehensive consideration of resources, economy, and environment was proposed by constructing a unified dimensional measurement model. This paper analyzed and evaluated the data of the agroecological economic system in Anhui Province from 2010 to 2019. The results showed that the agroecological economic system in Anhui Province bore less environmental pressure and gradually decreased, and had a good system efficiency and economic benefits. The average emergy sustainability index (ESI) was 3.12, indicating that the agroecological economic system in Anhui Province had certain vitality of sustainable development. Based on this, the paper puts forward some suggestions on sustainable and high-quality agricultural development in Anhui Province, which provides theoretical and methodical support for sustainable development of a regional agricultural economy.

Keywords: emergy analysis; sustainable development; regional agroecological economic system; assessment; Anhui Province



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1. Introduction

Agricultural production is considered the basis of a nation's economy. With the continuous increase of the global population and the increasingly severe constraints on environmental resources, the conflict between agricultural production and the natural environment has become critical. The sustainable development of agriculture faces significant problems, such as increasing energy use, agricultural surface pollution, carbon peaking, and carbon neutrality [1–3]. For example, China is already the world's largest carbon emitter, of which agricultural carbon emissions account for 17%. In 2017, the utilization rates of chemical fertilizers and pesticides of rice, corn, and wheat in China were only 37.8% and 38.8%, respectively, and the annual pollutant emissions of livestock and poultry in China reached 3.8 billion tons [4,5]. According to statistics, the average annual growth rate of energy consumption after 1996 in 26 developed countries is 0.62%, while that in developing countries is 4.36% [6]. Therefore, most countries promote the coordinated development of agricultural production and ecology, which focuses on accelerating the modernization of agriculture and improving its quality, efficiency, and competitiveness for its sustainable development [4]. Meanwhile, ending hunger, achieving food security and improved nutrition, and promoting sustainable agriculture are among the 17 Sustainable Development Goals (SDGs) of the United Nations. The sustainability of agriculture is subject to the agroecological economic system. The sustainable development of this system

is an effective way to address hunger and a critical, organic element of global sustainable development [7].

The method for properly evaluating the sustainability of agroecological economic systems and the use of appropriate methods to maintain their sustainability based on different evaluation results are important topics. In order to effectively assess the sustainability of an agroecological economic system, scholars have conducted research using many different methods and tools. They have constructed agroecological economic system sustainability evaluation methods, such as *Indicateurs de Durabilité des Exploitations Agricoles* (IDEA) or farm sustainability indicators [8], Sustainability Assessment of Food and Agriculture (SAFA) [9], the driving force pressure state impact response (DPSIR) framework [10], the technique for order of preference by similarity to ideal solution (TOPSIS) method [11], grey relational analysis [12], and spatial data analysis [13]. However, these methods have an obvious shortcoming: there is still a lack of uniform standards for measuring inputs and outputs, natural and artificial resource consumption, and ecological losses of agroecological economic systems. The fundamental reason for this shortcoming is that agroecological economic systems are complex systems with social, economic, and ecological interconnections. Moreover, the energy flowing and materials circulating in the system are diverse and heterogeneous, and cannot therefore be compared with each other. The emergence of the emergy analysis method has changed this. Emergy was introduced by the famous American ecologist Odum [14]. He believed that as all the energy on the earth is ultimately derived from solar energy, it is possible to convert the input and output materials or energy of any agroecological economic system into solar emergy in specific ratios, the unit being solar emjoules (sej). Thus, it is possible to convert different types of non-comparable energy into the same standard—emergy—for quantitative measurement and analysis.

In recent years, emergy theory and emergy analysis have been widely used for eco-efficiency and sustainability evaluation of urban, industrial, agricultural, and regional systems. In evaluating the sustainability of urban development, Falahi et al. [15] used emergy analysis to analyze the waste management system in Tehran, Iran, to suggest the best way to achieve maximum environmental benefits and the most cost-effective sustainability technologies. Wei et al. used emergy analysis to analyze the sustainability of Wuhan, Qingdao, and Xi'an in China [16–18]. In terms of industrial system evaluation analysis, Yazdani et al. [19] compared three energy storage systems for a typical wind farm to assess their sustainability. Pan et al. [20] proposed an emergy-based metal production evaluation framework to evaluate a lead–zinc production system in Yunnan Province, China, for the entire life cycle of the metal production from the formation of the deposit to the final metal production. Liu et al. [21] constructed an emergy-based eco-efficiency evaluation model for industrial production systems. They analyzed the correlation between various production factors and eco-efficiency through quantitative evaluation to improve eco-efficiency and production effectiveness in industrial production. In the evaluation of agricultural production systems, international scholars now mainly focus on the sustainability evaluation of individual crop production systems, such as cucumber production, rapeseed production, and mushroom production [22–24]. Domestic scholars have focused more on regional ecological economic system emergy analysis. Xie et al. [25] used emergy analysis methods to analyze the input–output flow of arable land use in Ruijin, China, evaluate its sustainability, and propose policy recommendations. Asgharipour et al. [26] used emergy to evaluate the sustainability of greenhouse systems. They showed that greenhouse systems are much more sustainable than open farm systems due to the associated significant reduction in soil erosion and greater sustainability. There is an abundance of research using emergy value analysis methods to evaluate system sustainability. However, there are shortcomings when it comes to the evaluation of the sustainability of agricultural production systems: (1) in terms of the subjects of evaluation, emergy analysis methods mainly focus on the evaluation of crop production systems and less on that of regional agroecological economic systems. There are significant regional differences in agricultural natural resource endowments, as regional economic and agricultural development is uneven. The evaluation of

the sustainability of agricultural production in one region is unlikely to reflect the sustainability of other regions; (2) in selecting evaluation indicators, it is difficult for the indicators designed in previous studies to comprehensively reflect agricultural production resources, environment, economy, and development in a particular region because the agroecological economic system is a comprehensive system involving many factors; and (3) in terms of time period, most studies have evaluated the development status of the agroecological economic systems in a specific year—this indicates the lack of a dynamic grasp of the situation in previous years and of a continuous focus on the high-quality development of agriculture in terms of time evolution.

Therefore, in order to coordinate agricultural economic development and ecological and environmental protection, balance the proportion of environmental resources and industrial product inputs in the agroecological economic system, improve the utilization efficiency of resources, optimize the mode of agricultural production, and promote the sustainable development of agriculture, we conducted a quantitative study on the input–output of the agroecological economic system of Anhui Province in China from 2010 to 2019 using emergy analysis. The aim of this paper was to deepen our understanding of the inputs and outputs of the regional agroecological economic system by scientifically evaluating emergy indicators such as resource input, operational efficiency, environmental load, economic development, and sustainability. This paper proposes a sustainable development evaluation method of the regional agroecological economic system with comprehensive consideration of resources, economy, and the environment by constructing a standardized scale measurement model. The structure of this paper is as follows. Section 1 deals with the literature review. Section 2 focuses on the methodology, where we describe the emergy flow of the regional agroecological economic system and construct sustainability evaluation indicators. In Section 3, we use Anhui Province as an example to evaluate the sustainability of the regional agroecological economic system and verify the validity and feasibility of the evaluation method. Section 4 presents policy recommendations and research summary. The methodology is illustrated in Figure 1.

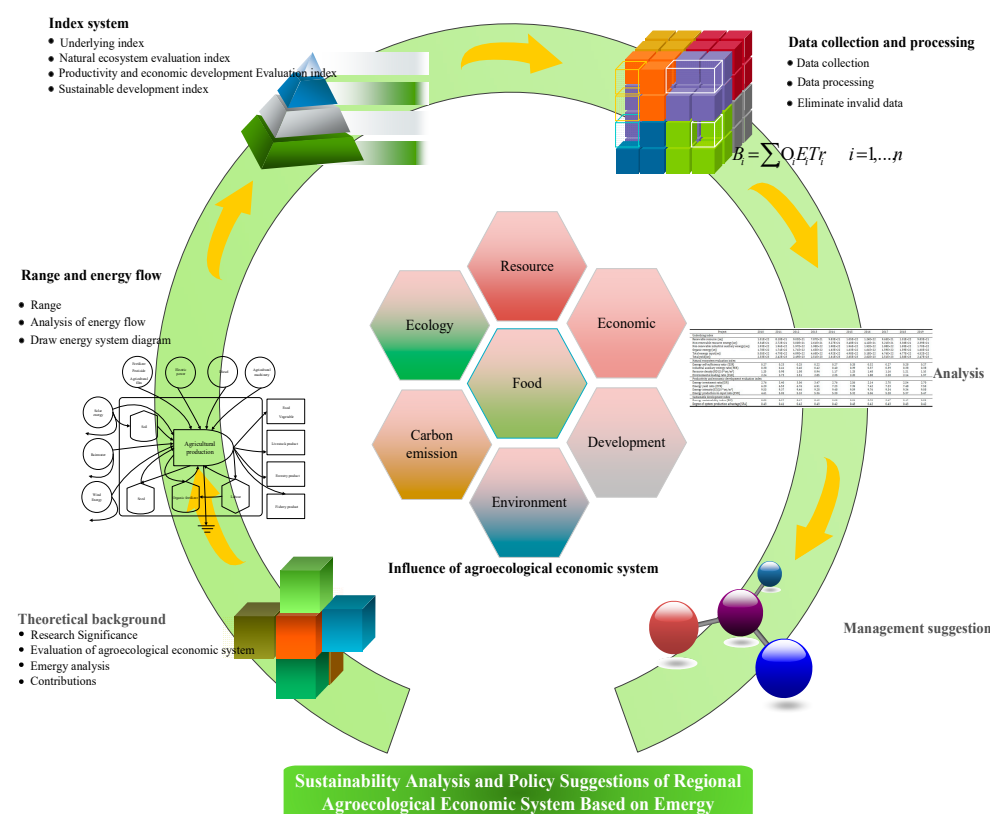


Figure 1. Research Framework.

2. Methodology

2.1. Research Methodology

The agroecological economic system is an organic whole. In order to evaluate the operation and development characteristics scientifically and comprehensively, the evaluation indicators selected should have relative independence. In this study, the energy of the regional agroecological economic system is divided into total input energy and total output energy. According to the energy source, the input energy can be divided into renewable environmental resource input, non-renewable environmental resource input, renewable organic energy input, and non-renewable industrial auxiliary energy input. The output energy can be divided into crop farming, animal husbandry, forestry, and fishery based on the structure of the agricultural industry. The boundary is determined according to the characteristics of the agroecological economic system (see Figure 2 for a flow chart of the regional ecological economic system energy).

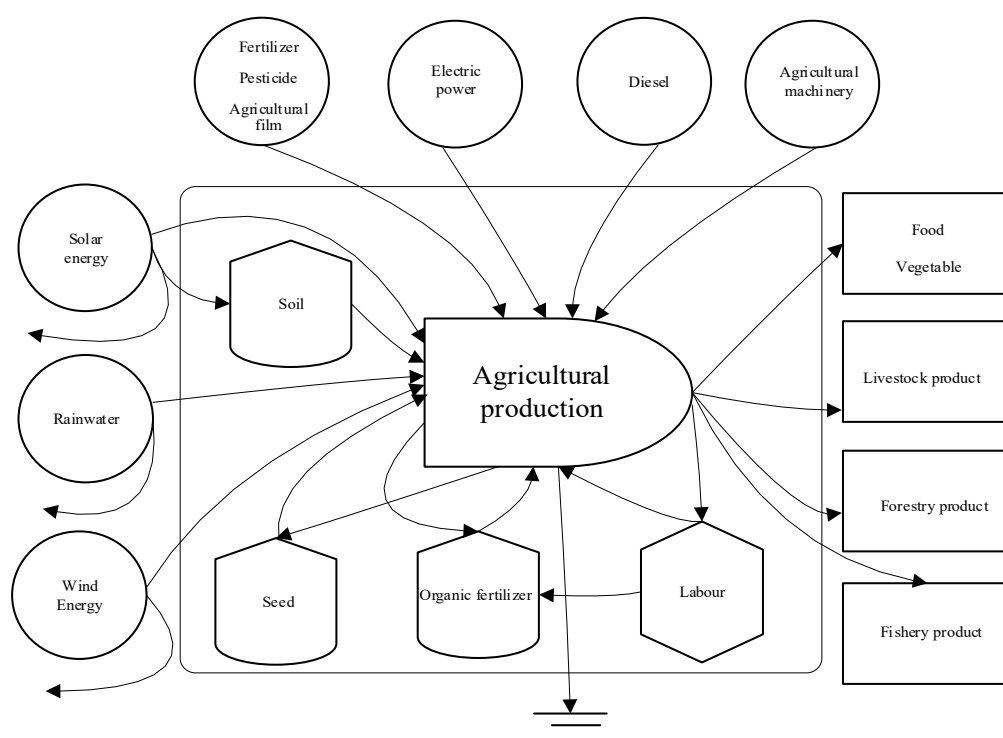


Figure 2. Energy flow chart of the regional agroecological economic system.

According to the energy calculation method, each of the above input and output energies is listed separately for calculation. The equations are as follows.

$$B_i = \sum_i O_i E_i Tr_i \quad i = 1, \dots, n \quad (1)$$

where B_i is the solar energy of the i -th input or output of the system, O_i is the actual collected data of the i -th item, E_i is the energy conversion factor of the i -th item, and Tr_i is the conversion rate of the i -th solar energy. After applying Equation (1), each input or output unit of energy is standardized in solar emjoules (sej).

2.2. Indicators

Resources, the environment, and the economy are the three main elements that constitute the regional agroecological economic system. Their operational characteristics determine the sustainable development capacity of the system and the people's living standards. To understand the system's operation, we established a sustainability evaluation indicator system for the regional agroecological economic system with regard to

resources, environment, economy, and sustainable development by referencing the relevant literature [27,28]. The system inputs and outputs are the base indicators, while the agricultural natural ecosystem, agricultural production efficiency, economic development, and sustainable development of the agricultural ecosystem are the sustainability evaluation indicators (see Table 1).

Table 1. Emery evaluation index system of regional agroecological economic system.

Emery Index	Expression	Remark
Underlying index		
Renewable resource	R	Renewable energy from nature, such as solar, wind, and rain energy
Non-renewable resource energy	N	All kinds of non-renewable energy from nature, such as coal, oil, and natural gas
Non-renewable industrial auxiliary energy	F	The fraction of the energy of imported resources that is considered to be of non-renewable origin
Organic energy	T	Organic energy input into the system, including labor, seeds, organic fertilizers, etc.
Total energy input	$E = R + N + F + T$	The total energy flows needed to support a production system
Total yield	Y	The total energy produced by the agroecological economic system
Natural ecosystem evaluation index		
Emery self-sufficiency ratio (ESR)	$ESR = (R + N)/E$	The supporting capacity of the natural environment
Industrial auxiliary energy ratio (FER)	$FER = F/E$	Measures economic and environmental stress of agroecological economic system
Resource density (RD)	$RD = (R + N)/A$	Reflects the abundance of natural resources
Environmental loading ratio (ELR)	$ELR = (F + N)/R$	Evaluates the impact of activities on the environment
Productivity and economic development evaluation index		
Emery investment ratio (EIR)	$EIR = (F + T)/(R + N)$	Measures the degree of economic development and environmental load
Emery yield ratio (EYR)	$EYR = Y/(F + T)$	Measures the contribution of system output to the economy
Emery intensity (EI)	$EI = E/A$	Reflects the land-use efficiency
Emery production-to-input ratio (EVR)	$EVR = Y/E$	Reflects the economic benefits of the system
Sustainable development index		
Emery sustainability index (ESI)	$ESI = EYR/ELR$	Measures the status and level of sustainable development
Degree of system production advantage (SPA)	$SPA = \sum (E_{Yi}/E_Y)^2$	The production unit equilibrium that reflects the overall system structure

The emery self-sufficiency ratio (ESR) is the ratio of the sum of renewable resources (R) and non-renewable natural resources (N) contributed by the agroecological economic system to the total input energy. It corresponds to the share of natural resource inputs in agricultural inputs (see Equation (2)) and is an indicator used to assess the capacity of the system to develop independently, that is, to be self-sufficient. In general, a larger value reflects a larger share of natural resources in the system inputs and greater self-sufficiency of the system. Among these, renewable resources include solar energy, wind energy, rainwater potential energy, and rainwater chemical energy. According to previous studies, wind energy, rainwater potential energy, and rainwater chemical energy are ultimately

derived from solar energy. Therefore, in the calculation of renewable resources, the system's renewable resources input energy is taken as the maximum value [29,30].

$$ESR = (R + N)/E \quad (2)$$

The industrial auxiliary energy ratio (FER) is the ratio of non-renewable industrial auxiliary energy (F) to total input energy. It measures the share of non-renewable industrial inputs in a regional agroecological economic system (see Equation (3)). The larger the indicator, the higher the non-renewable industrial auxiliary energy input in the regional agroecological economic system, the higher the degree of agricultural development, and also, the greater the pressure on the environmental and agricultural income.

$$FER = F/E \quad (3)$$

Resource density (RD) is the amount of natural resource energy per unit area in sej/m^2 (see Equation (4)). This indicator reflects the abundance of natural resources in the regional agroecological economic system. A large value indicates that a high abundance of natural resources in a regional agroecological economic system will benefit agricultural production.

$$RD = (R + N)/A \quad (4)$$

The environmental loading ratio (ELR) is an indicator of the magnitude of environmental pressure on the agroecological economic system (see Equation (5)). A larger ELR value indicates that there are more non-renewable resource inputs in the agroecological economic system, such as the use of more chemical fertilizers and pesticides, suggesting an excessive dependence on artificial resources, contrary to the essence of agricultural development. This is also likely to create greater pressure on the environmental system, which is not conducive to the sustainable development of the economic system. An ELR greater than 10 indicates excessive environmental pressure; an ELR greater than 3 but less than 10 indicates medium-level environmental pressure; an ELR less than 3 indicates that low environmental pressure. If the ELR remains too high for an extended period, the ecological system function will be in a state of irreversible degradation or loss.

$$ELR = (F + N)/R \quad (5)$$

The energy investment ratio (EIR) is the ratio of the sum of non-renewable industrial auxiliary energy (F) and organic energy (T) to the value of natural environmental inputs ($R + N$), which is used to measure the degree of agroecological system development and resource and environmental pressures. Larger EIR values indicate a higher degree of economic development of the agroecological economic system in the region and higher pressure on the environment (see Equation (6)).

$$EIR = (F + T)/(R + N) \quad (6)$$

The net energy yield ratio (EYR) is the ratio of the value of output energy from agricultural production activities to the sum of the non-renewable industrial auxiliary energy (F) and organic energy (T) from human inputs (see Equation (7)). This indicator reflects, to some extent, the sustainability of the system. A larger value indicates a more efficient and sustainable agroecological economic system and more competitively priced agricultural products.

$$EYR = Y/(F + T) \quad (7)$$

Emergy intensity (EI) is the total emergy input per unit area in sej/m^2 (see Equation (8)). This indicator reflects the degree of regional agricultural development. A larger value reflects greater emergy from regional agricultural inputs and more developed agricultural production.

$$EI = E/A \quad (8)$$

The emergy production-to-input ratio (EVA) is the ratio of the total output emergy to the total input emergy of a regional agroecological economic system. This indicator reflects the production efficiency of the regional agroecological economic system. The higher the ratio, the higher the production efficiency.

$$EVR = Y/E \quad (9)$$

In 1997, Italian scientist Ulgiati and American ecologist Brown [31] proposed the emergy sustainability index (ESI), which is the emergy yield ratio (EYR) to the ELR (see Equation (10)). If a region has a high net emergy output ratio and a low ELR, it has a high ESI and is sustainable and vice versa. An ESI value between 1 and 10 indicates a dynamic system with potential for development, while an ESI less than 10 indicates a poorly sustainable ecosystem. An ESI less than 1 indicates a consumption-based economic system.

$$ESI = EYR/ELR \quad (10)$$

The degree of system production advantage (SPA) is a measure of the balance of subsystems in an agricultural production system. A large value indicates a more uneven distribution of the production subsystems (see Equation (11)). Here, EY_i represents the emergy value of the output of each subsystem of the agroecological economic system, and EY is the total output emergy. In this paper, $i = 1, 2, 3$, and 4 denote crop farming, animal husbandry, forestry, and fishery, respectively.

$$SPA = \sum (EY_i/EY)^2 \quad (11)$$

3. Evaluation of the Sustainability of the Agroecological Economic System in Anhui Province

3.1. Background

Anhui Province (total area of 140,100,000 km²) is located in eastern China, between 114°54'–119°37' E and 29°41'–34°38' N. It is connected to Jiangsu to the east, Henan and Hubei to the west, Zhejiang to the southeast, Jiangxi to the south, and Shandong to the north. The terrain consists of plains, hills, and mountains. Three major water systems run through the province: the Huai River, the Yangtze River, and the Xin'an River (see Figure 3). Anhui Province has a transitional climate, between the warm temperate zone and the subtropics. The area north of the Huai River has a warm temperate semi-humid monsoon climate, and the area south of the Huai River has a subtropical humid monsoon climate. The province experiences four distinct seasons and has mild climate and moderate rainfall. The average multi-year temperature is 15.26 °C, the average annual precipitation is 910.14 mm, the average annual sunshine hours is 2079.95 h, and the total annual radiation is 5.25×10^5 J/cm².

Anhui Province is an integral part of the Yangtze River Delta. It is located at the strategic point of the country's economic development and the major economic sectors. The province has historical and natural connections to the economy, culture, and other areas of the Yangtze River Delta. In 2018, there were 11,128.88 thousand hectares of agricultural land in Anhui Province, which accounted for 1.72% of agricultural land in the country; of that, 5866.8 thousand hectares was cultivated land. In 2019, Anhui Province had a population of 63.659 million, and the population engaged in agriculture, forestry, animal husbandry, and fishery accounted for 29.18% of the province's total population. In 2019, the province produced 40.54 million tons of grain, accounting for 6.11% of the national grain production, making it a major grain-producing region. The same year, the provincial GDP was RMB 3711.398 billion, of which the primary sector contributed RMB 291.57 billion, or 7.86% of the provincial GDP.

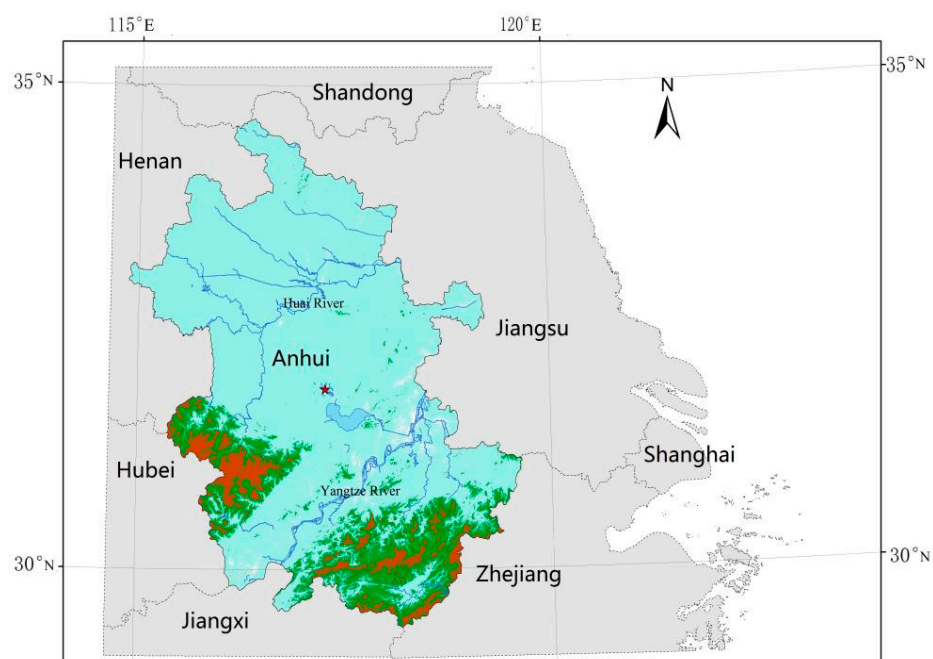


Figure 3. Map of Anhui Province.

3.2. Results

The primary agricultural data used in this paper were taken mainly from the Anhui Province Countryside Statistical Yearbook (2011–2020) prepared by the Anhui Provincial Bureau of Statistics, China Statistical Yearbook (2011–2020) prepared by the National Bureau of Statistics, as well as the author's field research, which mainly covers organic fertilizer application, seed usage, and labor. The climatic data on temperature, precipitation, and sunshine in Anhui Province were obtained from the National Meteorological Information Center. We referred to the research results [32–39] in determining the energy conversion coefficients, emergy value conversion ratios (see Table 2), and the calculation method and processes. After performing calculations based on the energy flow data of Anhui's agroecological economic system (see Figure 1) and Equation (1), items with small values were excluded. Only 34 inputs and outputs that could have an impact on the calculation results were retained. The calculation results are shown in Tables 3 and 4, respectively.

According to the emergy data and calculation methods in Tables 3 and 4 and based on the evaluation indicator system constructed in Section 2, the values of each evaluation indicator of the agroecological economic system in Anhui Province from 2010 to 2019 were calculated (Table 5).

Table 2. Unit emergy values cited in this study.

	Input	Unit	Transformity (Sej/Unit)	References		Output	Unit	Transformity (Sej/Unit)	References
1	Solar energy	J	1	Odum (1996)	1	Wheat	J	1.14×10^5	Lan et al. (1998)
2	Wind energy	J	6.63×10^2	Odum (1996)	2	Rice	J	6.03×10^4	Lan et al. (1998)
3	Chemical energy of rainwater	J	1.54×10^4	Odum (1996)	3	Maize	J	2.70×10^4	Chao et al. (2009)
4	Potential energy of rainwater	J	8.89×10^3	Odum (1996)	4	Beans	J	8.30×10^4	Ulgiati et al. (1993)
5	Soil Loss	J	1.24×10^5	Wang et al. (2017)	5	Peanut	J	8.60×10^4	Ulgiati et al. (1993)
6	N fertilizer	g	4.83×10^9	Odum (1996)	6	Rapeseed	J	8.60×10^4	Ulgiati et al. (1993)
7	P fertilizer	g	4.95×10^9	Odum (1996)	7	Cotton	J	1.36×10^4	Brandt-Williams (2002)
8	K fertilizer	g	1.40×10^9	Odum (1996)	8	Vegetable	J	4.54×10^4	Lan et al. (1998)
9	Compound fertilizer	g	3.56×10^{10}	Odum (1996)	9	Amphisarca	g	6.87×10^9	González-Mejía (2017)
10	Pesticide	g	4.81×10^9	Cheng et al. (2017)	10	Pork	J	1.70×10^6	Chao et al. (2009)
11	Agricultural film	g	3.80×10^8	Chao et al. (2009)	11	Beef	J	4.00×10^6	Chao et al. (2009)
12	Agricultural machinery	J	7.50×10^7	Chao et al. (2009)	12	Mutton	J	2.00×10^6	Chao et al. (2009)
13	Electric power	J	2.00×10^4	Cheng et al. (2017)	13	Egg	J	1.71×10^6	Chao et al. (2009)
14	Diesel	J	2.00×10^4	Cheng et al. (2017)	14	Milk	J	1.71×10^6	Chao et al. (2009)
15	Organic fertilizer	g	1.35×10^{10}	Odum (1996)	15	Other meat	J	2.00×10^6	Chao et al. (2009)
16	Labor	J	1.26×10^8	Cheng et al. (2017)	16	Forestry product	J	1.54×10^{10}	Pulselli et al. (2007)
17	Seed	g	3.36×10^5	Lan et al. (1998)	17	Fishery product	J	3.30×10^{10}	Cheng et al. (2017)

Table 3. Emergy input of agroecological economic system of Anhui Province, 2010–2019 (sej).

	Project	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
1	Renewable Resources (R)	1.01×10^{22}	8.18×10^{21}	9.03×10^{21}	7.87×10^{21}	9.83×10^{21}	1.05×10^{22}	1.24×10^{22}	9.65×10^{21}	1.01×10^{22}	9.83×10^{21}
	Solar energy	3.78×10^{19}	3.71×10^{19}	3.74×10^{19}	3.88×10^{19}	3.79×10^{19}	3.76×10^{19}	3.86×10^{19}	3.90×10^{19}	3.88×10^{19}	5.31×10^{19}
	Wind energy	5.65×10^{20}	5.65×10^{20}	5.65×10^{20}	5.65×10^{20}	5.65×10^{20}	5.65×10^{20}	5.65×10^{20}	5.65×10^{20}	5.65×10^{20}	7.72×10^{20}
	Chemical energy of rainwater	1.01×10^{22}	8.18×10^{21}	9.03×10^{21}	7.87×10^{21}	9.83×10^{21}	1.05×10^{22}	1.24×10^{22}	9.65×10^{21}	1.01×10^{22}	9.83×10^{21}
4	Potential energy of rainwater	1.52×10^{21}	1.23×10^{21}	1.36×10^{21}	1.19×10^{21}	1.48×10^{21}	1.58×10^{21}	1.87×10^{21}	1.46×10^{21}	1.52×10^{21}	1.48×10^{21}
5	Non-Renewable Resources (N)	3.34×10^{21}	2.72×10^{21}	3.00×10^{21}	2.61×10^{21}	3.27×10^{21}	3.48×10^{21}	4.12×10^{21}	3.21×10^{21}	3.36×10^{21}	2.39×10^{21}
	Soil Loss	3.34×10^{21}	2.72×10^{21}	3.00×10^{21}	2.61×10^{21}	3.27×10^{21}	3.48×10^{21}	4.12×10^{21}	3.21×10^{21}	3.36×10^{21}	2.39×10^{21}
6	Non-renewable industrial auxiliary emergy (F)	1.93×10^{22}	1.96×10^{22}	1.97×10^{22}	1.98×10^{22}	1.98×10^{22}	1.96×10^{22}	1.92×10^{22}	1.88×10^{22}	1.83×10^{22}	1.70×10^{22}
	N fertilizer	4.92×10^{21}	5.02×10^{21}	5.01×10^{21}	4.98×10^{21}	4.90×10^{21}	4.72×10^{21}	4.60×10^{21}	4.42×10^{21}	4.20×10^{21}	3.86×10^{21}
	P fertilizer	3.65×10^{21}	3.67×10^{21}	3.71×10^{21}	3.61×10^{21}	3.63×10^{21}	3.46×10^{21}	3.26×10^{21}	3.29×10^{21}	2.87×10^{21}	2.66×10^{21}
	K fertilizer	8.24×10^{20}	8.50×10^{20}	8.42×10^{20}	8.13×10^{20}	8.43×10^{20}	8.31×10^{20}	7.96×10^{20}	7.70×10^{20}	7.22×10^{20}	6.96×10^{20}
	Compound fertilizer	2.22×10^{21}	2.33×10^{21}	2.39×10^{21}	2.51×10^{21}	2.57×10^{21}	2.62×10^{21}	2.53×10^{21}	2.48×10^{21}	2.54×10^{21}	2.49×10^{21}
	Pesticide	1.89×10^{20}	1.90×10^{20}	1.89×10^{20}	1.91×10^{20}	1.84×10^{20}	1.80×10^{20}	1.71×10^{20}	1.61×10^{20}	1.52×10^{20}	1.43×10^{20}
	Agricultural film	2.35×10^{15}	2.50×10^{15}	2.65×10^{15}	2.76×10^{15}	2.80×10^{15}	2.85×10^{15}	2.82×10^{15}	2.84×10^{15}	2.85×10^{15}	3.02×10^{15}
	Agricultural machinery	7.46×10^{21}	7.52×10^{21}	7.59×10^{21}	7.65×10^{21}	7.71×10^{21}	7.77×10^{21}	7.85×10^{21}	7.70×10^{21}	7.76×10^{21}	7.13×10^{21}
	Electric power	6.15×10^{18}	6.71×10^{18}	7.37×10^{18}	7.92×10^{18}	8.44×10^{18}	8.97×10^{18}	9.25×10^{18}	9.80×10^{18}	1.03×10^{19}	1.08×10^{19}
	Diesel	4.49×10^{16}	4.64×10^{16}	4.75×10^{16}	4.84×10^{16}	4.84×10^{16}	4.99×10^{16}	4.99×10^{16}	4.98×10^{16}	4.98×10^{16}	4.92×10^{16}
	Organic energy (T)	1.78×10^{22}	1.74×10^{22}	1.71×10^{22}	1.65×10^{22}	1.63×10^{22}	1.63×10^{22}	1.61×10^{22}	1.59×10^{22}	1.59×10^{22}	1.60×10^{22}
	Organic fertilizer	2.67×10^{20}	2.68×10^{20}	2.68×10^{20}	2.67×10^{20}	2.66×10^{20}	2.69×10^{20}	2.67×10^{20}	2.68×10^{20}	2.68×10^{20}	2.68×10^{20}
	Labor	1.75×10^{22}	1.72×10^{22}	1.69×10^{22}	1.63×10^{22}	1.60×10^{22}	1.60×10^{22}	1.58×10^{22}	1.56×10^{22}	1.57×10^{22}	1.57×10^{22}
	Seed	6.44×10^{17}	6.55×10^{17}	6.87×10^{17}	6.85×10^{17}	7.14×10^{17}	7.39×10^{17}	7.14×10^{17}	7.26×10^{17}	8.37×10^{17}	8.47×10^{17}
Total emergy input (E)		5.05×10^{22}	4.79×10^{22}	4.89×10^{22}	4.68×10^{22}	4.92×10^{22}	4.98×10^{22}	5.18×10^{22}	4.76×10^{22}	4.77×10^{22}	4.52×10^{22}

Table 4. Emergy yield of agroecological economic system of Anhui Province, 2010–2019 (sej).

	Project	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
	Crop farming	6.15×10^{22}	6.78×10^{22}	6.50×10^{22}	6.28×10^{22}	6.55×10^{22}	6.51×10^{22}	6.21×10^{22}	6.05×10^{22}	6.00×10^{22}	5.92×10^{22}
1	Wheat	1.38×10^{22}	1.35×10^{22}	1.43×10^{22}	1.48×10^{22}	1.54×10^{22}	1.84×10^{22}	1.54×10^{22}	1.54×10^{22}	1.78×10^{22}	1.84×10^{22}
2	Rice	1.81×10^{22}	1.74×10^{22}	1.75×10^{22}	1.71×10^{22}	1.75×10^{22}	2.03×10^{22}	1.76×10^{22}	1.84×10^{22}	2.11×10^{22}	2.04×10^{22}
3	Maize	1.56×10^{21}	1.60×10^{21}	1.88×10^{21}	1.87×10^{21}	2.05×10^{21}	2.99×10^{21}	2.05×10^{21}	1.96×10^{21}	2.62×10^{21}	2.83×10^{21}
4	Beans	1.49×10^{21}	1.59×10^{21}	1.67×10^{21}	1.58×10^{21}	1.70×10^{21}	1.33×10^{21}	1.82×10^{21}	1.89×10^{21}	1.43×10^{21}	1.40×10^{21}
5	Peanut	9.77×10^{20}	1.21×10^{21}	1.25×10^{21}	1.27×10^{21}	1.36×10^{21}	1.01×10^{21}	1.30×10^{21}	1.30×10^{21}	1.02×10^{21}	1.01×10^{21}
6	Rapeseed	1.45×10^{21}	1.76×10^{21}	1.93×10^{21}	1.87×10^{21}	1.83×10^{21}	1.39×10^{21}	1.68×10^{21}	1.59×10^{21}	1.21×10^{21}	1.25×10^{21}
7	Cotton	1.47×10^{22}	2.14×10^{22}	1.68×10^{22}	1.43×10^{22}	1.50×10^{22}	8.41×10^{21}	1.05×10^{22}	8.13×10^{21}	5.04×10^{21}	3.16×10^{21}
8	Vegetable	1.37×10^{21}	1.49×10^{21}	1.57×10^{21}	1.63×10^{21}	1.72×10^{21}	1.83×10^{21}	1.95×10^{21}	1.95×10^{21}	1.43×10^{21}	1.49×10^{21}
9	Amphisarca	8.15×10^{21}	7.89×10^{21}	8.14×10^{21}	8.46×10^{21}	8.88×10^{21}	9.52×10^{21}	9.84×10^{21}	9.84×10^{21}	8.39×10^{21}	9.21×10^{21}
	Animal husbandry	1.35×10^{23}	1.35×10^{23}	1.43×10^{23}	1.46×10^{23}	1.51×10^{23}	1.55×10^{23}	1.53×10^{23}	1.47×10^{23}	1.52×10^{23}	1.43×10^{23}
10	Pork	8.12×10^{22}	7.92×10^{22}	8.49×10^{22}	8.62×10^{22}	9.00×10^{22}	8.81×10^{22}	8.33×10^{22}	8.25×10^{22}	8.29×10^{22}	6.73×10^{22}
11	Beef	6.95×10^{21}	6.42×10^{21}	6.53×10^{21}	6.53×10^{21}	6.44×10^{21}	5.83×10^{21}	5.94×10^{21}	2.91×10^{21}	3.13×10^{21}	3.42×10^{21}
12	Mutton	3.64×10^{21}	3.63×10^{21}	3.74×10^{21}	3.84×10^{21}	3.97×10^{21}	4.24×10^{21}	4.44×10^{21}	4.23×10^{21}	4.39×10^{21}	4.82×10^{21}
13	Egg	1.81×10^{22}	1.85×10^{22}	1.92×10^{22}	1.98×10^{22}	1.98×10^{22}	2.21×10^{22}	2.33×10^{22}	2.21×10^{22}	2.26×10^{22}	2.41×10^{22}
14	Milk	1.51×10^{22}	1.65×10^{22}	1.77×10^{22}	1.86×10^{22}	2.05×10^{22}	2.25×10^{22}	2.40×10^{22}	2.35×10^{22}	2.42×10^{22}	2.66×10^{22}
15	Other meat	1.01×10^{22}	1.02×10^{22}	1.06×10^{22}	1.08×10^{22}	1.06×10^{22}	1.19×10^{22}	1.25×10^{22}	1.17×10^{22}	1.43×10^{22}	1.66×10^{22}
	Forestry	3.37×10^{21}	3.64×10^{21}	3.65×10^{21}	3.51×10^{21}	4.25×10^{21}	4.17×10^{21}	4.11×10^{21}	4.09×10^{21}	4.04×10^{21}	3.75×10^{21}
16	Forestry product	3.37×10^{21}	3.64×10^{21}	3.65×10^{21}	3.51×10^{21}	4.25×10^{21}	4.17×10^{21}	4.11×10^{21}	4.09×10^{21}	4.04×10^{21}	3.75×10^{21}
	Fishery	3.30×10^{22}	3.59×10^{22}	3.73×10^{22}	3.88×10^{22}	4.03×10^{22}	4.15×10^{22}	4.24×10^{22}	3.92×10^{22}	4.05×10^{22}	4.17×10^{22}
17	Fishery product	3.30×10^{22}	3.59×10^{22}	3.73×10^{22}	3.88×10^{22}	4.03×10^{22}	4.15×10^{22}	4.24×10^{22}	3.92×10^{22}	4.05×10^{22}	4.17×10^{22}
	Total yield	2.33×10^{23}	2.42×10^{23}	2.49×10^{23}	2.51×10^{23}	2.61×10^{23}	2.65×10^{23}	2.62×10^{23}	2.51×10^{23}	2.56×10^{23}	2.47×10^{23}

Table 5. Agroecological economic system evaluation index data of Anhui Province,2010–2019.

Project	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Underlying index										
Renewable resource (sej)	1.01×10^{22}	8.18×10^{21}	9.03×10^{21}	7.87×10^{21}	9.83×10^{21}	1.05×10^{21}	1.24×10^{22}	9.65×10^{21}	1.01×10^{22}	9.83×10^{21}
Non-renewable resource emergy (sej)	3.34×10^{21}	2.72×10^{21}	3.00×10^{21}	2.61×10^{21}	3.27×10^{21}	3.48×10^{21}	4.12×10^{21}	3.21×10^{21}	3.36×10^{21}	2.39×10^{21}
Non-renewable industrial auxiliary emergy (sej)	1.93×10^{22}	1.96×10^{22}	1.97×10^{22}	1.98×10^{22}	1.98×10^{22}	1.96×10^{22}	1.92×10^{22}	1.88×10^{22}	1.83×10^{22}	1.70×10^{22}
Organic emergy (sej)	1.78×10^{22}	1.74×10^{22}	1.71×10^{22}	1.65×10^{22}	1.63×10^{22}	1.63×10^{22}	1.61×10^{22}	1.59×10^{22}	1.59×10^{22}	1.60×10^{22}
Total emergy input (sej)	5.05×10^{22}	4.79×10^{22}	4.89×10^{22}	4.68×10^{22}	4.92×10^{22}	4.98×10^{22}	5.18×10^{22}	4.76×10^{22}	4.77×10^{22}	4.52×10^{22}
Total yield (sej)	2.33×10^{23}	2.42×10^{23}	2.49×10^{23}	2.51×10^{23}	2.61×10^{23}	2.65×10^{23}	2.62×10^{23}	2.51×10^{23}	2.56×10^{23}	2.47×10^{23}
Natural ecosystem evaluation index										
Emergy self-sufficiency ratio (ESR)	0.27	0.23	0.25	0.22	0.27	0.28	0.32	0.27	0.28	0.27
Industrial auxiliary emergy ratio (FER)	0.38	0.41	0.40	0.42	0.40	0.39	0.37	0.39	0.38	0.38
Resource density (RD) (10^{11} sej/m ²)	1.20	0.98	1.08	0.94	1.17	1.25	1.48	1.16	1.21	1.10
Environmental loading ratio (ELR)	2.24	2.73	2.51	2.85	2.35	2.20	1.88	2.28	2.14	1.97
Productivity and economic development evaluation index										
Emergy investment ratio (EIR)	2.76	3.40	3.06	3.47	2.76	2.56	2.14	2.70	2.54	2.70
Emergy yield ratio (EYR)	6.29	6.53	6.76	6.91	7.23	7.39	7.42	7.23	7.48	7.50
Emergy intensity (EI) (10^{11} sej/m ²)	9.55	9.37	9.46	9.28	9.48	9.59	9.76	9.34	9.34	9.08
Emergy production-to-input ratio (EVR)	4.61	5.05	5.10	5.36	5.30	5.32	5.06	5.28	5.37	5.47
Sustainable development index										
Emergy sustainability index (ESI)	2.80	2.39	2.69	2.43	3.08	3.36	3.95	3.17	3.49	3.80
Degree of system production advantage (SPA)	0.43	0.41	0.42	0.43	0.42	0.43	0.42	0.43	0.43	0.42

3.2.1. Analysis of Underlying Index

Emergy Analysis of System Input

From 2010 to 2019, the emergy of renewable resource inputs of the agroecological economic system in Anhui Province averaged 9.75×10^{21} sej, which is relatively stable; the value was mainly determined by the change in rainwater chemical energy caused by the amount of precipitation in each year. Since topsoil erosion and precipitation are closely linked, the emergy of non-renewable resource inputs had a significant positive correlation with those of renewable resources (see Table 3). Since 2010, the non-renewable industrial auxiliary emergy invested in the agroecological economic system of Anhui Province has increased, rising from 1.93×10^{22} sej in 2010 to 1.98×10^{22} sej in 2014 (see Table 5, Figure 4). After 2014, the non-renewable industrial auxiliary emergy input in Anhui Province steadily decreased and gradually fell to 1.70×10^{22} sej in 2019. The reduction of industrial auxiliary emergy input helps reduce chemical fertilizer and pesticide residues and improves the environment of the agroecological economic system and farmers' quality of life. Since 2010, the organic emergy input of the province's agroecological economic system has shown a significant downward trend, decreasing from 1.78×10^{22} sej in 2010 to 1.60×10^{22} sej in 2019 (see Figure 4), mainly due to the decrease in the number of people working in agriculture, forestry, animal husbandry, and fishery and the shift of agricultural population in recent years. This shift is expected to bring about results such as the adjustment of the farming structure and the transformation of production methods. In addition, there has been a decrease in rural cattle reared, with the population falling from 1.509 million heads in 2010 to 878,000 heads in 2019. The organic emergy inputs of the agroecological economic system in Anhui Province have gradually decreased.

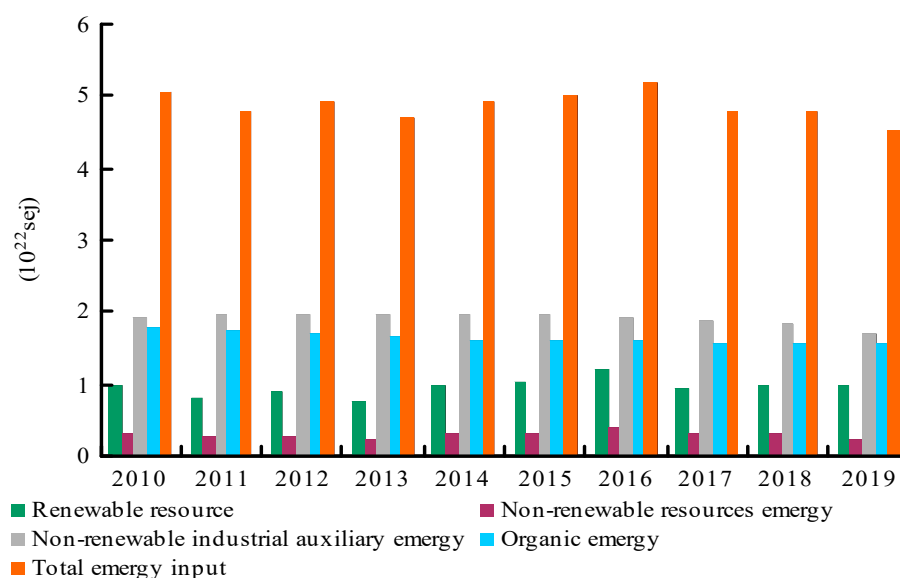


Figure 4. Emergy inputs of the agroecological economic system in Anhui Province, 2010–2019.

The total emergy input in Anhui Province's agroecological system from 2010 to 2019 averaged 4.85×10^{22} sej, of which renewable resources, non-renewable resources, non-renewable industrial auxiliary emergy, and organic emergy inputs averaged 9.75×10^{21} sej, 3.15×10^{21} sej, 1.91×10^{22} sej, and 1.65×10^{22} sej, respectively. These account for 20.08%, 6.49%, 39.37%, and 34.06% of the emergy input, respectively (see Table 5). In the past 10 years, the total emergy of fertilizer and pesticide inputs was 1.15×10^{23} sej, accounting for 60.10% of non-renewable industrial auxiliary emergy inputs and 23.66% of total emergy inputs; this indicates that fertilizers and pesticides still occupy the relative bulk of industrial emergy inputs in Anhui Province. Among the fertilizer inputs, N fertilizer accounted for the highest proportion, and showed a decreasing trend from 2011 to 2019, dropping from 5.02×10^{23} sej in 2011 to 3.86×10^{23} sej in 2019. The analysis also shows that the value

of non-renewable industrial auxiliary energy was much larger than those of renewable natural resources, non-renewable natural resources, and organic energy inputs from 2010 to 2019. Among these, the inputs of chemical fertilizers and pesticides are still important drivers of industrial energy inputs, indicating that the agricultural production methods in Anhui Province will cause some pressure on the soil and water environments (see Table 3, Figure 4).

Emergy Analysis of System Output

The total emergy yield in Anhui's agroecological economic system from 2010 to 2019 averaged 2.52×10^{23} sej, with a low of 2.33×10^{23} sej in 2010 and a high of 2.65×10^{23} sej in 2015. The increase from 2010 to 2015 was most prominent. After 2015, there was a fluctuating downward trend going from 2.65×10^{23} sej in 2015 to 2.47×10^{23} sej in 2019 (see Table 5, Figure 5). Among the emergy output values in the last 10 years, animal husbandry (average of 1.46×10^{23} sej) has the highest emergy, followed by crop farming (average of 6.30×10^{22} sej); animal husbandry and crop farming accounted for 58.01% and 25.01% of the total emergy output, respectively (see Table 4). These results show that the agricultural output of Anhui Province is still dominated by animal husbandry and crop farming, indicating evident regional characteristics. Anhui Province is an important grain producer in China. Since forest land in Anhui Province is mainly used as ecological forests and the amount of freshwater is small, the emergy output of forestry products and fishery products are small, which together only accounted for 17.05% of total emergy.

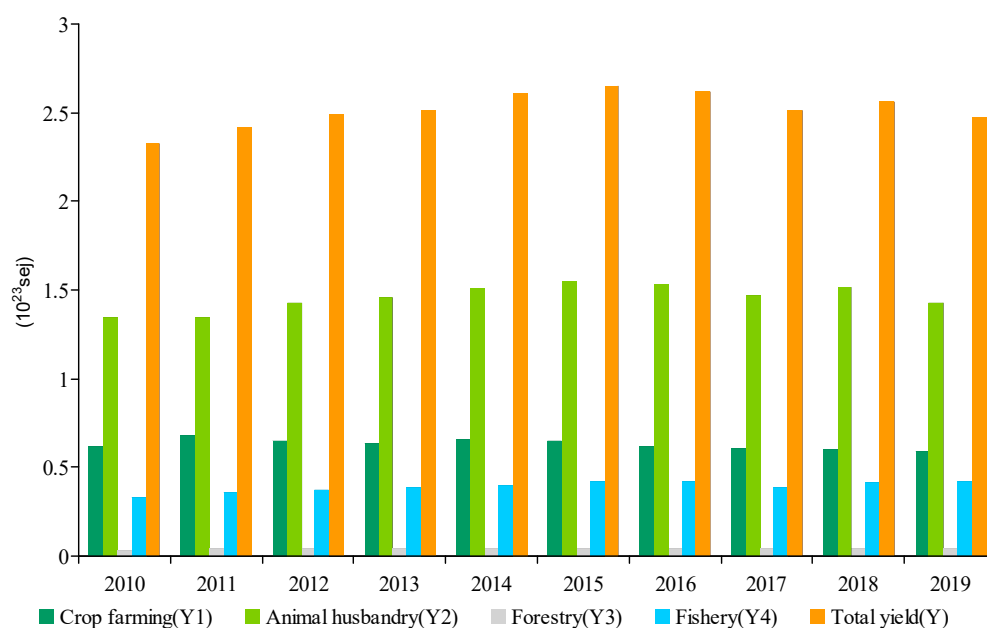


Figure 5. Key emergy yield of the agroecological economic system in Anhui Province, 2010–2019.

3.2.2. Analysis of Sustainability Index

Based on the above emergy data analysis results, this study analyzed and evaluated the sustainable development of the agroecological economic system in Anhui Province from three dimensions: resources, environment, and economy.

Agricultural Natural Ecosystem Evaluation Index

The emergy self-sufficiency ratio (ESR) of the agroecological economic system in Anhui Province has not changed much in the last 10 years. It was highest in 2016 with a value of 0.17 and lowest in 2014 with a value of 0.10; the average was 0.13 (see Table 5). On the one hand, these values indicate that the amount of renewable natural resources (R), non-renewable natural resources (N), and total input emergy (E) invested in the agroecological economic system in Anhui Province are relatively stable (see Figure 6). Renewable and

non-renewable natural resources are natural environmental conditions of agroecologies and are stable. In terms of total input energy, although the inter-annual variation of each input is not consistent and fluctuates, there is no significant increase or decrease in the total energy input between years. On the other hand, the values indicate that the share of natural resource inputs in the agroecological economic system is relatively small. The contribution of natural environmental resources in the agroecological system is minimal, which suggests that the dependence of the agroecological economic system in Anhui Province on natural resources is relatively low. The dependence on industrial inputs is relatively high. The average industrial auxiliary energy ratio of the system in the past 10 years was 0.20, which is small and varies little from year to year, suggesting that the industrial auxiliary energy input to agriculture in Anhui Province is small and stable, and that the economic pressure and environmental pressure on the system are slight.

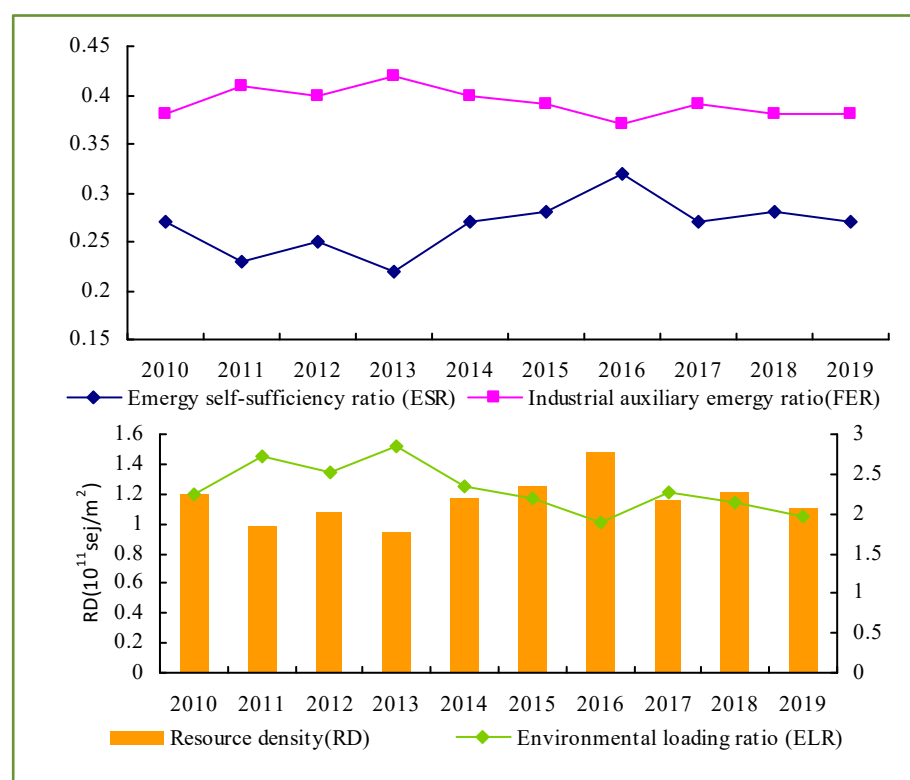


Figure 6. Analysis of natural system energy indicators, 2010–2019.

The ELR of the agroecological economic system in Anhui Province has been low and decreasing between 2010 and 2019, with an average of 2.32, a maximum of 2.85 in 2013, and a minimum of 1.88 in 2016 (see Table 5, Figure 6). These values show that the environmental pressure on the development of the agroecological economic system is low, which will benefit its sustainable development. Anhui Province enjoys a monsoon climate of medium latitude and good water and heat conditions. The resource density (RD) has been maintained at above 0.94×10^{11} sej/m², with a maximum of 1.48×10^{11} sej/m² in 2016 and slight changes between years. This resource will produce good economic and ecological benefits for Anhui's agroecological economic system.

Agricultural Productivity and Economic Development Evaluation Indicators

Since 2010, the average EIR of the agroecological economic system in Anhui Province was 2.81; the highest was 3.47 in 2013 and the lowest was 2.14 in 2016, with a decrease from 2013 onwards (see Table 5, Figure 7). These values show that the non-renewable industrial auxiliary energy (F) and organic energy (T) inputs, as well as the proportion of purchased energy inputs, are high. This introduces a certain degree of resource and environmental

pressure on the sustainable development of the agroecological economic system. Since 2010, the emergy yield ratio (EYR) of the system averaged 7.07, with the lowest being 6.29 in 2010 and the highest being 7.50 in 2019; there was a steady increase from 2010 to 2019 (see Table 5, Figure 7). This indicates that the emergy conversion efficiency of the inputs of the province's agroecological economic system is high and continues to rise. The overall function of the agroecological system is relatively good and sustainable.

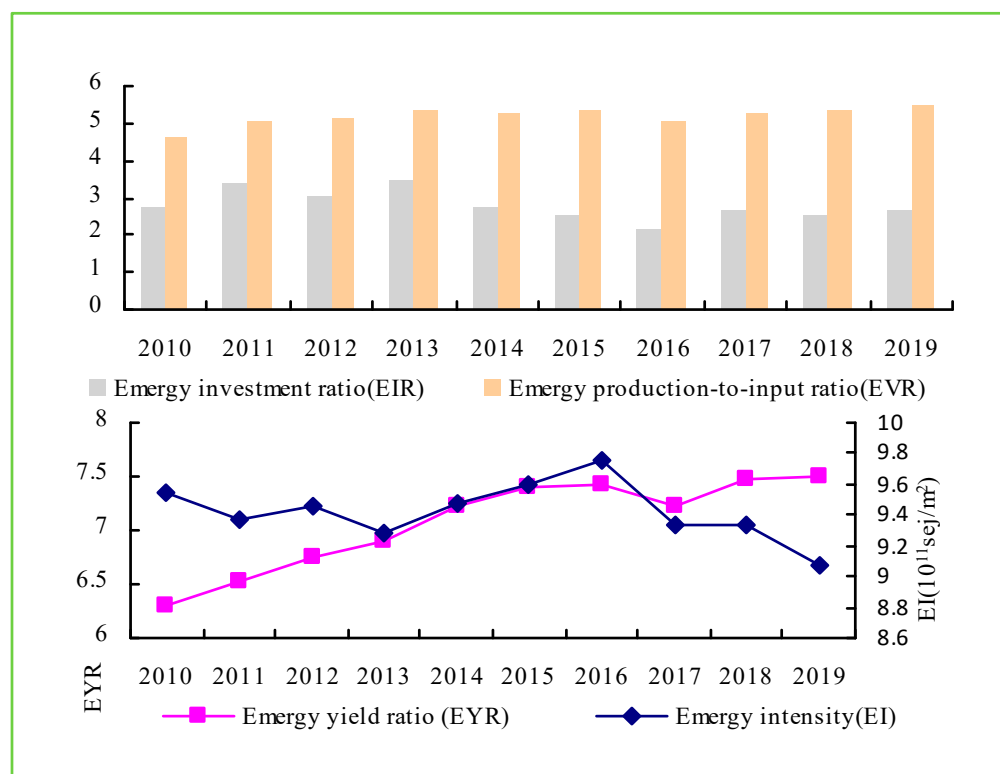


Figure 7. Analysis of productivity and economic development performance indicators.

Since 2010, the average emnergy intensity of the agroecological economic system in Anhui Province has been 9.42×10^{11} sej/m², which is relatively high; this indicates a high level of agricultural development in Anhui Province. The system's average emnergy production-to-input ratio (EVR) since 2010 has been 5.19, with the lowest in 2010 and the highest in 2019, which indicates that the production efficiency of the agroecological economic system is high and yields high economic and social benefits.

Comprehensive Index of Sustainable Development

From 2010 to 2019, the ESI of the agroecological economic system in Anhui Province averaged 3.12, with the highest being 3.95 in 2016 and the lowest being 2.38 in 2011 (see Table 5, Figure 8). The sustainability index showed a fluctuating increase from 2010 to 2019, which indicated that the agroecological system has a strong potential for sustainable development that is increasing.

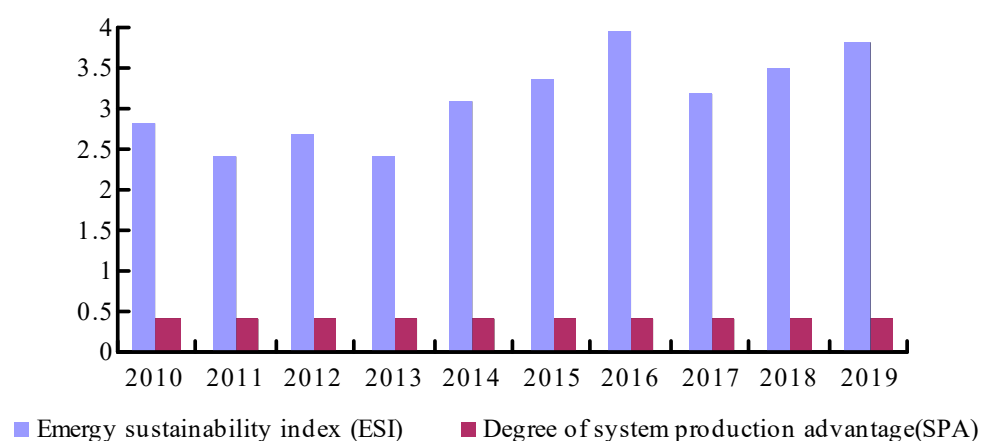


Figure 8. Analysis of the comprehensive sustainable development index.

The degree of production advantage in an agroecological economic system is used to describe the equilibrium of the overall production units of the system structure. A larger value indicates a more uneven distribution of the production subsystems. Within Anhui's agroecological economic system, the degree of production advantage was 0.42 on average, which is higher than the national average of 0.46; this value is relatively low. Changes in the production advantage in the past 10 years have been relatively small, which indicates that the subsystems of the agroecological economic system in Anhui Province are relatively balanced, that between-year changes are small, and that it has good production stability and sustainability.

3.3. Policy Recommendations

In addition to sustainability evaluation and comparisons with previous studies, this study more comprehensively considered the impact of system processes on the ecological environment and evaluated the sustainable development of regional agroecological systems through the horizontal and vertical analysis of emergy indicators. The quantitative analysis and assessment of natural resources, ecological and environmental stress, agricultural production efficiency, and sustainability of the regional agroecological system help determine the economic contributions of the primary sources of emergy and uncover resource-allocation problems. Based on the existing problems, corresponding countermeasures were proposed, which are essential for coordinating regional agricultural economic development with ecological and environmental protection, balancing the ratio of environmental resources and industrial product inputs in the agroecological economic system, improving the efficiency of resource utilization, optimizing agricultural production patterns, and promoting the sustainable development of agriculture.

According to the evaluation and research results of the system of indicators for Anhui's agroecological economic system, problems must be solved from multiple angles to promote the sustainable development of the province's agroecological economic system, boost the green transformation and upgrading of agriculture, and revitalize the countryside as soon as possible. Thus, we propose the following recommendations.

3.3.1. Reduce Non-Renewable Resource Inputs

In terms of emergy inputs in the agroecological economic system in Anhui, the renewable resource inputs are relatively stable, staying around 9.75×10^{21} sej in a long time. Non-renewable resource inputs are considered expendable in the agroecological economic system as they damage the ecological environment. Therefore, these inputs should be reduced to improve the sustainable development of the province's agroecological economic system. Among the non-renewable resource inputs, topsoil erosion has significant effects, so soil erosion should be prevented by afforestation and conservation tillage [40].

3.3.2. Improve the Utilization Efficiency of Non-Renewable Industrial Auxiliary Energy Resources

The research shows that non-renewable industrial auxiliary energy accounts for 39.37% of the total energy input in the agroecological economic system of Anhui. Thus, FER, ELR, EIR, and EYR of the agroecological economic system are affected. However, non-renewable industrial auxiliary energy plays a special role in the energy input in the agroecological economic system of Anhui. On the one hand, industrial auxiliary energy is an artificial input, and excess of it will affect the economic efficiency of agriculture, farmers' incomes, the competitiveness of agricultural products, and the environment. On the other hand, industrial auxiliary energy input is an important safeguard for stable agricultural production. Therefore, decision makers should rely on scientific and technological inputs to improve the utilization efficiency of industrial auxiliary energy to reduce its input. For example, soil testing and the use of formula fertilization while increasing the input of organic fertilizers, promoting straw return, and strengthening the resource utilization of livestock and poultry waste can help reduce the use of chemical fertilizers [41–43]. Decision makers should support and promote new agricultural businesses and socialized service providers to carry out unified pest and disease control, promote green pest prevention and control, and reduce the amount of pesticides used [44].

3.3.3. Develop Ecological Agriculture

The government should formulate relevant policies to promote organic agriculture and ecological agriculture. On the one hand, we should encourage the development of ecological planting and ecological breeding, and strengthen the certification and management of green food and organic agricultural products. On the other hand, we should guide farmers to change the traditional mode of production, give certain subsidies to environment-friendly mode of production, and ensure the sustainable development of agriculture by setting environmental protection regulations. These policy measures and economic means have certain positive effects.

3.3.4. Formulate a Reasonable Circular Economy Model according to Local Conditions

On the one hand, planting and animal husbandry are the main industries in Anhui, and their output energy accounts for 83.02% of Anhui. For the former, field intercropping, combined with aquaculture, can be adopted to realize efficient utilization and recycling of resources; for the latter, a circular economic model mainly based on animal husbandry, the combination of agriculture and animal husbandry should be adopted, for example, in the mountainous and hilly areas of central and southern Anhui, and the integrated development of breeding and processing should be considered as the development focus to realize waste utilization and resource recycling. On the other hand, in the areas where planting is the main industry in northern Anhui Plain, the comprehensive utilization of crop straw should be promoted, and returning straw fields to crop fields or using straw to grow mushrooms should be encouraged. At the same time, we should strengthen the pollution control of agricultural film and improve the recycling rate of agricultural film.

3.4. Management Suggestions

The ultimate goal of the development of agroecological economic systems is to generate ecological, environmental, economic, and social benefits. The agricultural production economic system takes various resource inputs then outputs products. To achieve sustainable development, the system must be ecologically, environmentally, and economically sustainable. Therefore, for those in the agricultural industry, the output value of agricultural production must be greater than the input value, and the greater this value, the better. Only then is the efficiency of the agricultural production system sustainable. Regarding agroecological management, the non-renewable industrial auxiliary energy of the system inputs brings about resource depletion, agricultural surface pollution, and carbon emissions, and reduces economic and social benefits. Moreover, the output value of agricultural

production systems is affected by the external environment, and the existence of various elements in agricultural production systems is a process of diminishing returns. Thus, agricultural production systems need to continuously optimize internal management and technology to realize and exploit its value and achieve sustainable development.

Combining the above analysis and conclusions, we can draw two suggestions.

First, improving the ecological and economic efficiency of agricultural production systems is important for promoting sustainable development. Although many scholars have studied how to improve ecological and economic efficiency, it would be helpful to improve the sustainable development of agroecological economic systems by making full use of the comprehensive data-driven emergy analysis, combined with indicator evaluation and input-output analysis.

Second, the agroecological economic system is a complex system with many components, various resources, biological and environmental factors, and economic and technological factors that coexist and interact, and are therefore volatile. Any factor will affect the sustainable development of agroecological and economic systems to some extent. It is necessary to identify, analyze, and optimize these influencing factors for the sustainable, stable, and coordinated development of agriculture.

4. Conclusions

The sustainable development of agroecological economic systems is an important component of global sustainable development, involving resources, ecology, environment, economy, food, and development. This study examined the measurement and evaluation of agroecological economic system sustainability and proposed policy recommendations.

Taking 2010–2019 as the time series, this paper analyzes the agroecological economic system of Anhui by using emergy method, and draws the following conclusions: (1) From 2010 to 2019, the contribution of natural system to emergy input of the system varies from year to year, which reflects that the agroecological economic system of Anhui is still affected by the natural environment, especially precipitation; (2) The artificial emergy input shows a downward trend from 3.71×10^{22} sej in 2010 to 3.30×10^{22} sej in 2019, which is conducive to reducing the pressure on the environment; and (3) The agroecological economic system of Anhui has good energy conversion efficiency and high economic benefits, and the system's sustainability is good, showing an upward trend despite some fluctuations.

The innovations of this study are as follows: (1) we constructed a standardized scale to process regional agroecological economic system input-output data using the emergy analysis method which directly reflects the energy flow relationship between system elements; (2) we established an emergy evaluation indicator system for the regional agroecological economic system to evaluate its ecological benefits and sustainability; and (3) we proposed targeted policy recommendations and management insights based on our evaluation.

This study has promising implications for the sustainable development of regional agroecological economic systems, providing theoretical and methodological support for high-quality agricultural development and effective solutions for policymakers. In future research, comparative analysis with other regions can be added. Through comparative study, more problems can be found, and more targeted and effective suggestions can be put forward for the development of high-quality agriculture.

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