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Article

Study on the Sustainability Evaluation Method of Logistics Parks Based on Emergy

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Abstract: To improve the sustainable development ability of logistics parks, this study constructs a sustainability evaluation method of logistics parks based on emergy; analyzes the input (energy, land, investment, equipment, information technology, and human resources) and output (income and waste) of logistics parks from the perspective of emergy; studies the characteristics of the emergy flow of logistics parks; and constructs the function, structure, ecological efficiency, and sustainable development indexes of logistics parks. The basic situation, resource efficiency, and environmental friendliness of the logistics parks are comprehensively evaluated from the emergy point of view. On this basis, targeted decision suggestions are provided for the sustainable development of logistics parks. Finally, the feasibility and effectiveness of the method are verified by an example. This study reveals the internal relationship among economic, environmental, and social benefits of logistics parks through emergy and provides theoretical and methodological support for the sustainable development of logistics parks.

Keywords: emergy; logistics parks; sustainability

1. Introduction

With the continuous development of the global economy and e-commerce, the demand for the logistics industry shows a steady growth trend. As an important form of the logistics industry, logistics parks have an agglomeration effect, which can improve logistics efficiency, reduce logistics cost, and promote the linkage development of the logistics industry, the manufacturing industry, and modern commerce. However, various problems emerge in the development process of logistics parks. In the early stage, the market demand was not scientifically analyzed, and the function orientation was not clear, which made the construction of logistics parks inconsistent with the actual needs of enterprises. This inconsistency led to the vacancy of parks, the low utilization rate of land and equipment in parks, the low efficiency of parks, the lack of relevant facilities, the low level of informatization, the lack of added value of logistics services provided for enterprises, the operation mode remaining in the primary stage, which results in the low-profit margin of logistics parks, and the lack of reuse of waste generated in the process of logistics in parks. Therefore, how to evaluate the basic situation, resource efficiency, and environmental friendliness of logistics parks; improve the economic and social benefits of logistics parks; and realize sustainable development have become urgent research topics.

Sustainable logistics is a trendy research theme that addresses societal, environmental, and industrial challenges. It has attracted the interest of many experts and scholars. The entropy method and the coupling coordination degree model are used to study how to coordinate economic, logistics, and ecological environment [1]. The coordinated development between the metropolitan economy and logistics for sustainability is analyzed by Lan [2]. The association between green logistics performance

and sustainability reporting is investigated drawing on signaling theory [3]. The sustainability of national logistics performance is evaluated by using data envelopment analysis [4]. Logistics themes and challenges that are environmentally sustainable are explored from a logistics service provider's view [5]. Trends in sustainable logistics in major cities in China are studied by Lan [6]. The multi-method approach, including literature review, text analysis, text mining, and statistical analysis is implemented to study environmental sustainability in city logistics measures [7–9]. The best–worst method is adopted to evaluate and rank the challenges of implementing eco-innovation practices for freight logistics sustainability [10]. The network design and planning of sustainable multi-period reverse logistics under uncertainty utilizing conditional value at risk for recycling construction and demolition waste is studied by Rahimi [11]. Operational and environmental sustainability tradeoffs in the planning of multimodal freight transportation are evaluated by Kelle [12]. A fuzzy multi-criteria model is structured by Bandeira for evaluating sustainable urban freight transportation operations [13]. Melkonyan assesses the sustainability of last-mile logistics and distribution strategies using the case of local food networks [14]. Pourhejazy integrates sustainability into the optimization of fuel logistics networks [15]. Sustainability challenges in the maritime transport and logistics industry and its way ahead are studied by Lee [16]. Some scholars directed their studies toward the methods of logistics sustainable development. The development of innovative green infrastructure solutions is mentioned to improve the sustainability of ports logistics [17]. Customer satisfaction, sufficient security and privacy, affordability, and competitive pressure are indicated as the highest-ranked critical success factors to achieve supply chain social sustainability using social media [18]. The sharing economy is used as a pathway to sustainable development in organic food supply chains [19]. A novel taxonomy of green initiatives and to investigate their diffusion among logistics service providers is provided [20]. The main challenges and opportunities for the development of river logistics as a sustainable alternative are studied by Ademar [21].

Environmental and social issues are an important part of sustainable development. The research on the sustainable development of logistics makes logistics pay attention to the impact on society and the natural environment while improving economic benefits. However, the current research on the quantitative evaluation of logistics sustainability is limited, and no unified standard exists between logistics economic and ecological systems. Starting from the ecological environment, the emergy analysis method integrates energy flow, material flow, and currency flow, and calculates a series of comprehensive index systems reflecting ecological and economic efficiency. This method also studies the interaction between human society and nature. It is a bridge connecting economic and ecological systems [22]. Emergy theory was initially used in the analysis of eco-economic systems or industrial park evaluation analysis [23–25]; now, its application scope is increasingly extensive. Emergy based sustainability evaluation of remanufacturing machining systems is studied by Liu [26], and proposes an integrated optimization control method for remanufacturing assembly system [27]. Two calculation methods of emergy indices are used to compare 10 power generation systems [28]. The comprehensive evaluation of the environmental sustainability of the case study hydropower projects on the Tibetan Plateau in 2016 using an emergy analysis approach is done by Chen [29]. An introduction and background are provided on how emergy accounting analysis can be adjusted and applied at the supply chain level [30]. Emergy analysis and combined emergy and life cycle assessment (EM-LCA) were used to evaluate the sustainability of an open-pit gold mine and an alluvial gold mine in Colombia [31]. Mohammad uses emergy to evaluate the sustainability of greenhouse systems, leading to management recommendations to increase the sustainability of production in these systems [32]. Cai proposes an emergy-based sustainability evaluation method for the outsourcing machining resources for improving resource utilization efficiency [33]. Logistics parks have a similar organization and operation mode with industrial parks. Therefore, the application of emergy theory to the eco-economic system analysis of logistics parks and the quantitative analysis and evaluation of the sustainability of logistics parks can further enrich the application scope of emergy theory.

Based on the theory and method of emergy analysis, this study first defines the boundary and scope of logistics park activities and puts forward the emergy measurement model and the evaluation index system of logistics parks. This study then selects a Logistics Park in Chuzhou City, Anhui Province, as an example to verify the feasibility of the index system in practice and finally forms a conclusion.

This study uses the theory and method of emergy analysis to transform the input of land, equipment, human resource, energy, and other resources and the output of incomes and waste into a unified emergy unit. The economic and social benefits of logistics parks are quantitatively analyzed and comprehensively evaluated. This study reveals the internal mechanism of the sustainability of logistics parks and provides a new perspective for the benefit evaluation of logistics parks.

In practice, the use of emergy theory to evaluate the benefits of logistics parks can help park managers to identify the problems in operation and the causes of low efficiency and provide directions for logistics parks to improve efficiency. The related suggestions on sustainable development provide a theoretical reference for other logistics parks. It can also help decision-makers understand the operation status of logistics parks and provide the decision-making basis for the overall planning and resource allocation of logistics parks.

2. Model

2.1. Boundary and Scope

A lot of resources need to be invested in the construction of logistics parks. They include natural resources, such as land, sunshine, and rain; other renewable resources, such as coal and oil; other non-renewable resources; and non-natural resources, such as logistics infrastructure equipment, human resources, and information technology, which all need a lot of funds. However, due to various reasons, the resource efficiency of logistics parks is low and needs to be improved. Therefore, logistics parks should analyze the various resource elements closely related to their operation to make full use of existing resources, make it play a role as much as possible, and ensure the long-term and sustainable service of logistics parks.

According to the activity flow and characteristics of logistics parks, the boundary is determined, and the emergy flow diagram of logistics parks is drawn.

From the above figure, we can see that the emergy elements are closely related to the activities of a logistics park (Figure 1). The energy input of the logistics park is mainly renewable energy, including solar, wind, geothermal, rainwater potential, and rainwater chemical energies. The emergy input outside the park includes renewable resource input and non-renewable resource input. It includes the water, electricity, coal and fuel, land resources, facilities and equipment costs, capital investment, labor, and information costs required by the operation. The emergy output of the logistics park is the business income and net profit brought by logistics and related services, as well as various wastes generated in the operation process.

In view of the availability and accuracy of production data, the model mainly considers the input and output of the logistics park. For the convenience and feasibility of the model calculation, the extension problem is not considered, such as the social benefits and risks brought by the logistics park. From another level, this is actually included in the logistics park management and service, but their impact on the emergy flow is implicit.

2.2. Emergy Measurement Model

The operation of logistics parks needs to import a variety of resources, including renewable resources, such as solar energy, rainwater, and wind from nature, and non-renewable resources, such as water, electricity, fuel oil, and coal, as well as land, facilities and equipment, human resources, and information technology. The output is mainly waste (waste water, waste gas, and waste residue) and services through the provision of logistics-related services to achieve business income and make

profits. Energy input and output have many kinds, the quantity is large, and the dimension is not unified. Based on related literature, this study uses emergy to unify measuring energy [34]. Whose basic expression is as follows:

$$EM = UEV \times N \quad (1)$$

where EM is emergy, UEV is the emergy conversion rate of different substances, and N is the different units of input flow (mass g or energy J).

Based on the above formula, we construct the input and output emergy measurement model of logistics parks as follows.

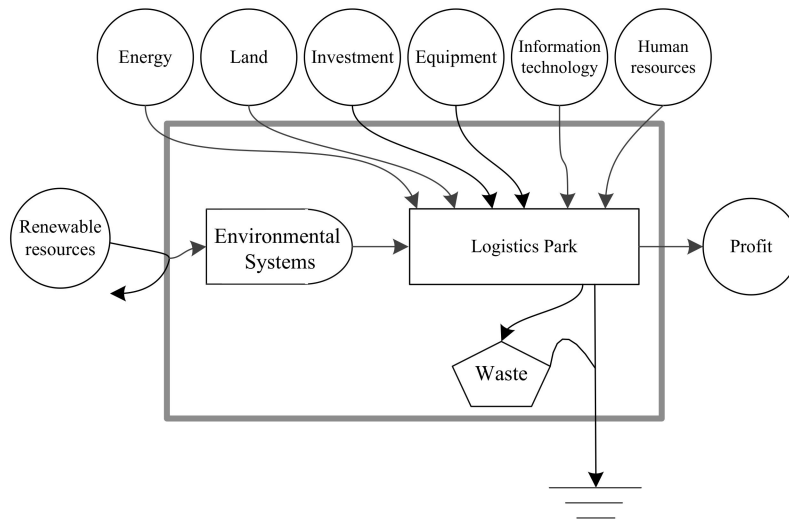


Figure 1. Emergy system diagram of a logistics park.

2.2.1. Input Emergy Value

- (1) Emergy of energy. When logistics parks provide logistics services, they are less dependent on the resources provided by the natural environment and involve relatively less energy. The input energy mainly includes solar, rainwater, and wind energy provided by nature, as well as water, electricity, coal, fuel oil, and other resources used in logistics and other value-added services [35].

$$M_e = \sum_{i=1}^I e^i \times UEV_e^i \quad (2)$$

where M_e is the emergy provided by the nature of the logistics system, e^i is the i -th energy provided by nature, and I is the total number of types of natural energy used in the logistics system.

- (2) Emergy of management. It mainly refers to all kinds of management expenses for organizing and managing business activities in the operation process of logistics parks, including the rent of warehouse and logistics sites, maintenance and depreciation costs of logistics infrastructure and equipment, business entertainment expenses generated by foreign economic exchanges, material consumption, and expenses incurred by various departments due to office needs.

$$M_m = \sum_{i=1}^I m^i \times UEV_m^i \quad (3)$$

where M_m is the emergy of various management costs in the logistics system, m^i is the i -th management cost in the logistics system, and I is the total number of types.

- (3) Energy of capital costs. Logistics parks occupy much land and need corresponding logistics facilities and equipment. Thus, the demand for funds is large. Capital costs refer to the cost paid by logistics parks for raising and using various funds, including fund-raising expenses and capital occupation expenses, such as printing, notarization, and guarantee fees generated from issuing stocks and bonds, shareholders' dividends, and bank loan interest paid for occupying others' funds.

$$M_c = \sum_{i=1}^I c^i \times UEV_c^i \quad (4)$$

where M_c is the energy of various capital costs in the logistics system, c^i is the i -th capital cost in the logistics system, and I is the total number of types of capital costs used in the logistics system.

- (4) Energy of human resource. It refers to the salary, bonus, performance, welfare, allowance, and other expenses of all kinds of managers and employees in logistics parks, as well as the training and recruitment expenses of employees.

$$M_h = \sum_{i=1}^I h^i \times UEV_h^i \quad (5)$$

where M_h is the energy of human resource in the logistics system, h^i is the i -th human resource cost in the logistics system, and I is the total number of types of human resource costs used in the logistics system.

- (5) Energy of information. Information is an important part of logistics parks. As an indispensable part of logistics parks, a logistics information platform is the bond and support of logistics park operation and an important means to provide logistics services for other enterprises. Information costs include the cost of building an information platform and the cost of management and maintenance during the operation of the platform.

$$M_f = \sum_{i=1}^I f^i \times UEV_f^i \quad (6)$$

where M_f is the energy of information cost in the logistics system, f^i is the i -th information cost in the logistics system, and I is the total number of types of information costs used in the logistics system.

2.2.2. Output Energy Value

- (1) Energy of waste. It mainly refers to waste gas, wastewater, and solid waste generated in the operation of logistics parks.

$$M_w = \sum_{i=1}^I w^i \times UEV_w^i \quad (7)$$

where M_w is the energy of waste in the logistics system, w^i is the i -th waste in the logistics system, and I is the total number of types of waste produced by the logistics system.

- (2) Energy of income. Logistics parks provide warehousing, transportation, circulation processing, and other logistics services and various value-added services. By providing these services, it can obtain various incomes, such as storage fees, equipment rentals, processing costs, and value-added services, and form the operating income of the park.

$$M_b = \sum_{i=1}^I b^i \times UEV_b^i \quad (8)$$

where M_b is the energy of incomes in the logistics system, b^i is the i -th income in the logistics system, and I is the total number of types of incomes of the logistics system.

2.3. Sustainability Evaluation Index System of Logistics Parks

Based on the analysis of the energy elements and the energy measurement model of logistics parks, combined with their characteristics, the corresponding indicators were constructed to evaluate the ecological efficiency and sustainable development of logistics parks.

2.3.1. Structural Indexes

- (1) Energy self-sufficiency ratio (ESR). It is the ratio of the energy input of local resources and total energy. For the logistics park, the energy input of local resources is mainly renewable resources in the system. Its formula is as follows:

$$ESR = EMR/EMU \quad (9)$$

- (2) Purchasing energy ratio. It is the ratio of input energy from the outside of logistics parks and the total energy the system:

$$\text{Purchasing energy ratio} = EMI/EMU \quad (10)$$

Logistics parks focus on providing a variety of logistics services and value-added services. These two indexes reflect the dependence of logistics parks on external resources. The lower the ESR and the higher the purchasing energy ratio, the stronger dependence of the system is on the outside.

- (3) Energy ratio of equipment and labor. It is the ratio between the energy of equipment, facilities, labor, and information purchased by logistics parks and the total energy. The calculation formula is as follows:

$$\text{Energy of equipment and labor ratio} = EMel/EMU \quad (11)$$

This index reflects the energy ratio of the facilities and equipment, labor, and information resources purchased by logistics parks. The higher the index is, the more developed the system is, and the less dependent the system is on the environment.

2.3.2. Functional Indexes

- (1) Energy exchange ratio (EER). It refers to the ratio of the commodity energy (the energy obtained by the buyer) to the energy equivalent to the buyer's payment currency. Its expression can be described as follows:

$$EER = EMI/EMO \quad (12)$$

For logistics parks, the buyer can obtain warehousing, transportation, circulation processing, and information services by paying currency. The index is used to study the exchange proportion of energy in the process of inflow and outflow. The larger the index is, the more energy exchange the system has, and the more advantageous it is in foreign exchange.

- (2) Energy yield ratio (EYR). It is the ratio of the output energy to input energy of parks [36]. The calculation formula is as follows:

$$EYR = EMJ/EMU \quad (13)$$

Through this index, the production efficiency and development degree of the system can be comprehensively evaluated. For logistics parks, the emergy of its output is the net profit and waste, whereas the emergy input is mainly the emergy of various materials consumed in the process of logistics activities, including energy, human resources, and information. The higher the EYR is, the higher the emergy output of logistics park under a certain emergy input, which means that the utilization rate of various resources in parks is higher and can bring greater economic benefits to the park, and the competitiveness of the logistics park is stronger.

- (3) Emergy density of land. It is the ratio of emergy output to land area.

$$\text{Emergy land density} = EMO/A \quad (14)$$

where A refers to the land area of the logistics park. This index reflects the land-use efficiency of logistics parks. The higher the index, the greater the degree of land use is, and the higher the output is.

2.3.3. Ecological Efficiency Indexes

- (1) Emergy investment ratio (EIR). It refers to the ratio of feedback emergy from the economy to free input emergy from the environment. The former includes all kinds of emergy purchased by logistics parks, such as water, electricity, labor, and information, whereas the latter is the emergy of renewable and non-renewable resources provided by the system free of charge.

$$EIR = EMI/EMR \quad (15)$$

The index is an important indicator to measure the degree of economic development and environmental load of the system. It reflects the corresponding emergy input required by the developing unit of natural resources. The larger the ratio is, the higher the degree of economic development is, and the less dependence on the environment is.

- (2) Environmental loading ratio (ELR). It is the ratio of non-renewable emergy to renewable emergy [37]. Its calculation formula is as follows:

$$ELR = (EMn + EMel)/(EMr + EMR) \quad (16)$$

This index mainly evaluates the impact of system activities on the environment and is a warning to the economic system. The larger the index is, the higher the degree of science and technology of the system, high-intensity emergy utilization is observed, and the pressure of the environmental loading is greater in parks. If the system's environmental load ratio is high for a long time, its self-organizing ability will decline, which may cause irreparable structural changes or loss of function.

- (3) Emergy ratio of waste (EWR). It is the ratio of waste emergy to the total emergy of the system. Its formula is as follows:

$$EWR = EMW/EMU \quad (17)$$

It reflects the resource utilization degree and the recycling level of the system. The lower the index is, the higher the resource recycling degree of logistics parks is.

2.3.4. Sustainable Development Index

Considering the dual attributes of logistics parks, which realizes its economic benefits and considers some government public welfare, the emergy index for sustainable development (EISD) is

adopted to evaluate the sustainable development of logistics parks. The calculation method of this index is as follows:

$$ELSD = EYR \times EER / ELR \quad (18)$$

EER reflects the gain and loss of the system in the external exchange, and *EYR* reflects the output efficiency of the system. The product of the two is the emergy output benefit of the system. *ELR* reflects the impact of various activities of the system on the environment. Therefore, *EISD* considers the environmental and socio-economic benefits of the system [38]. The higher the ratio is, the better the comprehensive benefits of the system are under unit environmental pressure, and the more competitive advantages the system has in sustainable development.

Based on the above emergy indexes, the emergy evaluation index system of logistics parks is constructed, as shown (Table 1).

Table 1. Emergy evaluation index system of logistics parks.

Emergy Index	Expression	Remark
Renewable energy in the system (EMR)		System owned resource
Input emergy outside the system (EMI)	$EMI = EMr + EMn + EMel$	
Emergy of renewable resources (EMr)		Input of renewable resources
Emergy of non-renewable resources (EMn)		Input of non-renewable resources from outside of the system, such as electricity, gas
Emergy of equipment and labor (EMel)		input of capital, information, labor resources from outside of the system
Total emergy (EMU)	$EMU = EMR + EMI$	
Output emergy (EMO)	$EMO = EMW + EMJ$	
Emergy of waste (EMW)		Output of wastes
Emergy of profits (EMJ)		Output of net profits
Structural index		
Emergy self-sufficiency ratio (ESR)	EMR/EMU	Evaluating the natural environment support capacity
Purchasing emergy ratio	EMI/EMU	Reflecting the dependence of logistics park on external resources
Emergy ratio of equipment and labor	EMr/EMU	Reflecting the degree of system development and technology dependence
Functional indexes		
Emergy exchange ratio (EER)	$EMI/EM0$	Evaluating the gains and losses in the external exchange
Emergy yield ratio (EYR)	EMJ/EMU	Measuring the contribution of system output to the economy
Emergy density of land	EMO/A	Reflecting the land use efficiency
Ecological efficiency indexes		
Emergy investment ratio (EIR)	EMI/EMR	Measuring the degree of economic development and environmental load
Environmental loading ratio (ELR)	$(EMn + EMel)/(EMr + EMR)$	Evaluating the impact of activities on the environment
Emergy ratio of waste (EWR)	EMW/EMU	Reflecting the resource utilization degree and recycling level
Sustainable development index		
Emergy index for sustainable development (EISD)	$EYR \times EER/ELR$	Measuring the status and level of sustainable development

3. Case Study

3.1. Background

A Logistics Park is located in Chuzhou City, Anhui Province. It was established in 2011, covering an area of 35 hectares, with a registered capital of 1,300,000,000 CNY (Unit of Chinese currency). Based on the surrounding industrial parks, the logistics park serves the surrounding economic areas and provides an integrated platform for logistics operation for the modern manufacturing industry, third-party logistics enterprises, and the business circulation industry. It integrates basic logistics services, such as multimodal transport, warehousing and distribution, transit distribution, container transportation, and other extended logistics services, such as raw material procurement, warehouse receipt pledge, supply chain management, and information services. It is a modern logistics park that is multi-functional, regional, and service-oriented.

3.2. Results

Through consulting the company's public annual report, combined with the investigation of the logistics park, relevant data from 2014 to 2018 were collected with the help of relevant personnel of the park. The specific data and energy flow are shown in Tables 2 and 3.

According to the energy flow table, the energy evaluation index of the logistics park is calculated, as shown (Table 4).

Table 2. The energy data of the logistics park in 2014–2018.

Collection Object	Original Data					Energy Conversion Rate (Sej/Unit)
	2014	2015	2016	2017	2018	
Renewable Resources in the System						
Solar energy (J)	7.05×10^{15}	7.11×10^{15}	6.99×10^{15}	7.26×10^{15}	7.17×10^{15}	1.00
Wind energy (J)	2.47×10^{11}	2.98×10^{11}	2.65×10^{11}	2.72×10^{11}	3.06×10^{11}	6.63×10^2
Rainwater potential energy (J)	3.42×10^8	3.79×10^8	2.93×10^8	4.55×10^8	4.21×10^8	8.89×10^3
Rainwater chemical energy (J)	8.92×10^7	9.34×10^7	8.17×10^7	9.86×10^7	9.53×10^7	1.54×10^4
Geothermal energy (J)	4.58×10^{12}	5.13×10^{12}	5.66×10^{12}	4.91×10^{12}	5.27×10^{12}	2.90×10^4
Input Resources						
Water (G)	2.23×10^9	2.89×10^9	3.32×10^9	3.72×10^9	3.37×10^9	4.10×10^4
Electric (J)	1.44×10^{12}	1.51×10^{12}	1.80×10^{12}	1.98×10^{12}	2.16×10^{12}	1.60×10^5
Fuel (J)	1.01×10^{12}	1.15×10^{12}	1.38×10^{12}	1.47×10^{12}	1.61×10^{13}	6.60×10^4
Management cost (CNY)	3.90×10^6	4.85×10^6	5.40×10^6	6.15×10^6	7.00×10^6	8.61×10^{11}
Capital cost (CNY)	5.85×10^6	6.84×10^6	6.84×10^6	7.38×10^6	7.38×10^6	8.61×10^{11}
Information (CNY)	7.50×10^5	8.80×10^5	8.00×10^5	1.20×10^6	5.50×10^5	8.61×10^{11}
Human resource (CNY)	4.60×10^6	4.80×10^6	5.40×10^6	6.80×10^6	7.50×10^6	8.61×10^{11}
Output Resources						
Incomes (CNY)	3.42×10^9	3.68×10^9	5.34×10^9	4.82×10^9	4.10×10^9	8.61×10^{11}
Net profit (CNY)	6.90×10^6	6.15×10^6	6.02×10^6	7.78×10^6	1.26×10^7	8.61×10^{11}
Waste water (G)	1.78×10^8	2.31×10^8	2.66×10^8	2.98×10^8	2.70×10^8	1.24×10^9
Waste gas (G)	1.66×10^5	1.77×10^5	2.35×10^5	2.31×10^5	6.3×10^5	1.84×10^8
Solid waste (G)	4.88×10^6	5.12×10^6	5.57×10^6	6.01×10^6	5.69×10^6	2.52×10^8

Table 3. The energy data of the logistics park in 2014–2018.

Collection Object	Energy Data				
	2014	2015	2016	2017	2018
Renewable resources in the system					
Solar energy (J)	7.05×10^{15}	7.11×10^{15}	6.99×10^{15}	7.26×10^{15}	7.17×10^{15}
Wind energy (J)	1.64×10^{14}	1.98×10^{14}	1.76×10^{14}	1.80×10^{14}	2.03×10^{14}
Rainwater potential energy (J)	3.04×10^{12}	3.37×10^{12}	2.60×10^{12}	4.04×10^{12}	3.74×10^{12}
Rainwater chemical energy (J)	1.37×10^{12}	1.44×10^{12}	1.26×10^{12}	1.52×10^{12}	1.47×10^{12}
Geothermal energy (J)	1.33×10^{17}	1.49×10^{17}	1.64×10^{17}	1.42×10^{17}	1.53×10^{17}
Input Resources					
Water (G)	9.14×10^{13}	1.18×10^{14}	1.35×10^{14}	1.53×10^{14}	1.38×10^{14}
Electric (J)	2.31×10^{17}	2.42×10^{17}	2.88×10^{17}	3.17×10^{17}	3.46×10^{17}
Fuel (J)	6.67×10^{16}	7.59×10^{16}	9.11×10^{16}	9.70×10^{16}	1.06×10^{18}
Management cost (CNY)	3.36×10^{18}	4.18×10^{18}	4.65×10^{18}	5.30×10^{18}	6.03×10^{18}
Capital cost (CNY)	5.04×10^{18}	5.89×10^{18}	5.89×10^{18}	6.35×10^{18}	6.35×10^{18}
Information (CNY)	6.46×10^{17}	7.58×10^{17}	6.89×10^{17}	1.03×10^{18}	4.74×10^{17}
Human resource (CNY)	3.96×10^{18}	4.13×10^{18}	4.65×10^{18}	5.85×10^{18}	6.46×10^{18}
Output Resources					
Incomes (CNY)	2.94×10^{21}	3.16×10^{21}	4.60×10^{21}	4.15×10^{21}	3.53×10^{21}
Net profit (CNY)	5.94×10^{18}	5.30×10^{18}	5.18×10^{18}	6.70×10^{18}	1.08×10^{19}
Waste water (G)	2.21×10^{17}	2.86×10^{17}	3.30×10^{17}	3.70×10^{17}	3.35×10^{17}
Waste gas (g)	3.05×10^{13}	1.77×10^{13}	3.26×10^{13}	4.25×10^{13}	1.16×10^{14}
Solid waste (g)	1.23×10^{15}	1.29×10^{15}	1.40×10^{15}	1.51×10^{15}	1.43×10^{15}

Table 4. The sustainable development evaluation index data of the logistics park.

Energy Indexes	Data				
	2014	2015	2016	2017	2018
Renewable energy in the system (EMR)	1.40×10^{17}	1.56×10^{17}	1.71×10^{17}	1.49×10^{17}	1.60×10^{17}
Input energy outside the system (EMI)	1.33×10^{19}	1.53×10^{19}	1.63×10^{19}	1.89×10^{19}	2.07×10^{19}
Energy of equipment, labor, information, and other resources (Emr)	9.14×10^{13}	1.18×10^{14}	1.35×10^{14}	1.53×10^{14}	1.38×10^{14}
Energy of non-renewable resources (Emn)	1.33×10^{19}	1.53×10^{19}	1.63×10^{19}	1.89×10^{19}	1.98×10^{19}
Total energy (EMU)	1.47×10^{19}	1.68×10^{19}	1.80×10^{19}	2.04×10^{19}	2.14×10^{19}
Output energy (EMO)	5.72×10^{18}	5.01×10^{18}	4.85×10^{18}	6.33×10^{18}	1.05×10^{19}
Energy of waste (EMW)	2.22×10^{17}	2.87×10^{17}	3.90×10^{17}	3.72×10^{17}	3.37×10^{17}
Energy of profits (EMJ)	5.94×10^{18}	5.30×10^{18}	5.18×10^{18}	6.70×10^{18}	1.08×10^{19}
Structural indexes					
Energy self-sufficiency ratio (ESR)	1.04×10^{-2}	1.01×10^{-2}	1.04×10^{-2}	7.80×10^{-3}	8.03×10^{-3}
Purchasing energy ratio	9.90×10^{-1}	9.90×10^{-1}	9.90×10^{-1}	9.92×10^{-1}	9.92×10^{-1}
Energy ratio of equipment and labor	9.67×10^{-1}	9.69×10^{-1}	9.66×10^{-1}	9.70×10^{-1}	9.25×10^{-1}
Functional indexes					
Energy exchange ratio (EER)	2.33	3.05	3.35	2.99	1.98
Energy yield ratio (EYR)	4.25×10^{-1}	3.25×10^{-1}	2.95×10^{-1}	3.31×10^{-1}	5.01×10^{-1}
Energy density of land	1.64×10^{13}	1.43×10^{13}	1.39×10^{13}	1.81×10^{13}	3.00×10^{13}
Ecological efficiency indexes					
Energy investment ratio (EIR)	9.49×10	9.77×10	9.50×10	1.27×10^2	1.29×10^2
Environmental loading ratio (ELR)	9.69×10	9.97×10	9.71×10	1.29×10^2	1.38×10^2
Energy ratio of waste (EWR)	1.65×10^{-2}	1.86×10^{-2}	2.02×10^{-2}	1.95×10^{-2}	1.61×10^{-2}
Sustainable development index					
Energy index for sustainable development (EISD)	1.02×10^{-2}	9.93×10^{-3}	1.02×10^{-2}	7.67×10^{-3}	7.20×10^{-3}

3.3. Index Evaluation and Analysis of the Logistics Park

According to the above emergy data, the emergy structure, system function, ecological efficiency, and sustainable development of the logistics park are analyzed as follows.

3.3.1. Analysis of Emergy Structure Indexes

The three structural indexes show that the logistics park is less dependent on the natural environment, and has a low degree of local resource development. ESR reflects the dependence of the system on natural resources. The higher the index is, the greater the contribution of local emergy resources is to the logistics system, and the higher the degree of resource development is. The ESR of the logistics park is low, ranging from 0.7% to 1%, and has a significant decline in 2017 and 2018, while the purchasing emergy ratio, which is related to the ESR, is stable and maintained at approximately 99% (Figure 2). The low ESR and high purchasing emergy ratio of the logistics park are determined by the characteristics of the logistics park itself. Different from the agricultural ecosystem or industrial products, the logistics park is a production and service-oriented logistics park, which mainly provides comprehensive services, such as raw material procurement, transportation, warehousing, circulation processing, and supply chain management for the surrounding industrial parks. Its production process is limited to the simple circulation and processing of products, and mainly rely on labor and mechanized operation, the direct use of natural environmental resources, such as sunlight, and rain, geothermal is less. The dependence on external energy is particularly large. Most of the emergy resources in logistics park need to be purchased from outside. The emergy ratio of equipment and labor is also high, ranging from 92.5% to 97.05%, which conforms to the emergy structure of the logistics park; logistics parks mainly depend on the inputs of equipment, technology, human resources, and so on.

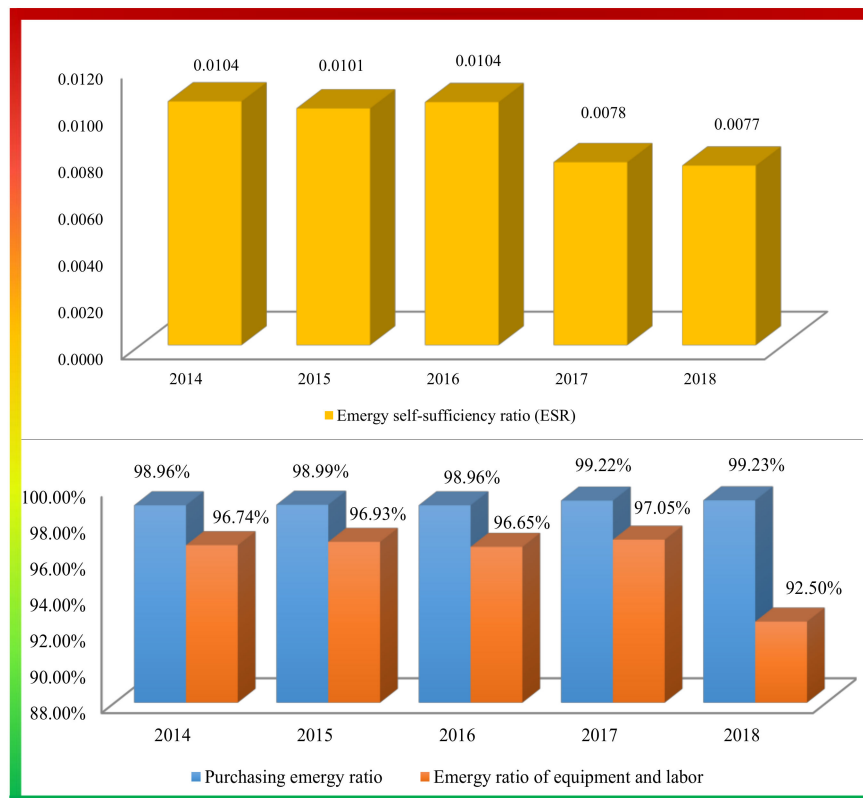


Figure 2. Analysis of emergy structure indexes.

3.3.2. Analysis of System Function Indexes

EER can be used to evaluate the gain and loss benefits of the system, whereas EYR reflects the resource utilization efficiency of the system. The higher the two ratios are, the higher the environment sustainable development is. If $EER = 1$, it means that the system is in a break-even state, $EER > 1$ indicates that the system is in a profit state, otherwise, it is in a loss. When $EYR < 2$, the emergy of the product is not increased due to production activities, but is only a process of consumption or transformation. The system operation is not a sustainable production and development process [39]. It shows that the EER of the logistics park is between 1.9 and 3.5 (Figure 3), which is always greater than 1. It indicates that, in the process of foreign economic activities, the logistics park has been in a steady state of profit and is in a favorable position. The highest EYR of the park is 0.5, which is far lower than 2 (Figure 3). EYR shows an upward trend after the previous decline. On the one hand, the logistics park mainly uses the corresponding facilities and equipment to provide logistics services for other enterprises, and the products involved are often only a transformation process from upstream suppliers to downstream customers. Production is limited to a simple process of circulation processing. Its product emergy is only consumption or transformation, and production efficiency is low. On the other hand, the logistics park is in the initial development stage, the resource system is not effectively configured, the resource structure is not reasonable, the utilization of machinery and equipment is not sufficient, and the workers have more idle time, which leads to low efficiency. Moreover, the emergy density of land in the logistics park is average because the park is still under development. Although it has been fully planned, part of the land is idle in the early stage, and the land resources are not fully utilized. With the development of the park, the ratio is gradually increasing.

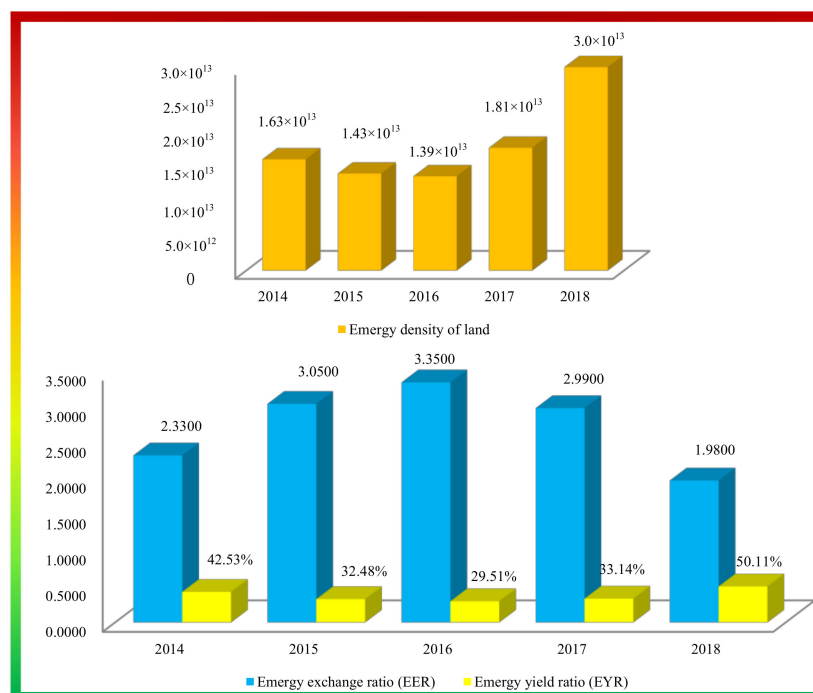


Figure 3. Analysis of system function indexes.

3.3.3. Analysis of Ecological Efficiency Evaluation Indexes

EIR is used to measure the degree of economic development and environmental load. ELR reflects the environmental pressure brought by the system [40]. EWR reflects the utilization degree and circulation of the system resources. The higher the ELR and EWR are, the lower the sustainable development level is. The above table shows that the EIR of the logistics park is distributed between 90 and 140, indicating that the logistics park has a high level of economic development and less

dependence on the environment. The ELR of the park is also between 90 and 140, which is a medium load state (Figure 4). Therefore, the park absorbs more non-renewable resources, product energy, and financial resources outside with a small range of land and a small amount of natural resources. The two indexes showed an upward trend, indicating that the pressure on the environment is increasing and needs to be controlled. In the process of logistics activities, part of the waste is formed, and EWR fluctuates around 1.8%. Therefore, more waste is produced in the logistics process of the park, and the recycling degree is poor, which bring certain pressure to the environment. The waste in the park mainly includes domestic garbage and garbage generated in the process of loading, unloading, and warehousing. The source of garbage is little. Thus, the relevant personnel in the park do not pay enough attention to waste management and lack the corresponding management of waste recycling. Therefore, EWR is high.

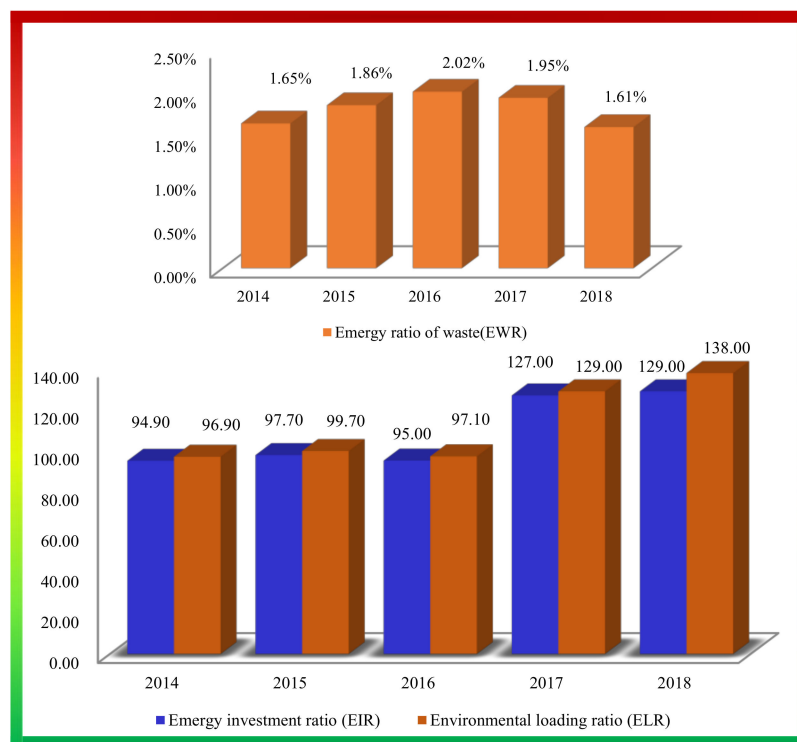


Figure 4. Analysis of ecological efficiency evaluation indexes.

3.3.4. Analysis of Sustainable Development Index

The final data shows that the improved EISD is used to measure the sustainable development of the logistics park. The sustainable development level is low. It shows a downward trend from 1.02×10^{-2} to 7.20×10^{-3} , which shows that the logistics park activities are inefficient and have great pressure on the environment and that it is in an unsustainable stage (Figure 5). The main reasons are the low EYR of the park, the decreased dependence on the natural environment in the process of logistics activities, and the increased use of non-renewable resources, resulting in high environmental load ratio and poor sustainable development level. This ratio decreased significantly in 2017 and 2018 mainly because the logistics park began to carry out container business in 2017. To load and unload containers, some fuel oil frontal cranes were introduced, which increased the investment and the use of non-renewable resources of the park. Moreover, the extensive management, the lack of enough attention from leadership, and the blind pursuit of profits ignored the input–output ratio and the recycling of waste, leading to the poor resource utilization ratio of the logistics park, which further reduced the sustainable development level of the park.

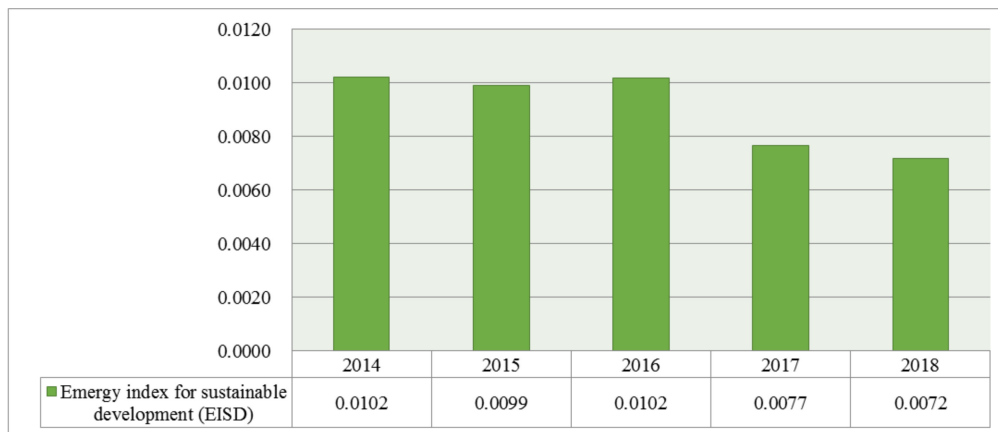


Figure 5. Analysis of the sustainable development index.

3.4. Discussion

Compared with similar research results [4,8–10], our research has the following advantages: The methods, such as data envelopment analysis, text mining, statistical analysis and best–worst method, evaluate the sustainability of logistics park, which are pay more attention to economy, technology and pollution emissions, but ignore the contribution of ecosystem to the activity process of logistics park. Emergy analysis method makes up for this defect. Moreover, it is better than other methods on measuring, evaluating, and optimizing the sustainability of logistics parks for quantitative measurement.

Combined with the above research and conclusions, we can get the following three management implications:

- First, the research on the sustainable development of logistics parks can promote the logistics park to strengthen the effective use of resources, and reduce the discharge of waste, so as to reduce the negative impact on the environment.
- Second, the sustainable development of the logistics park is the embodiment of the social responsibility of the logistics park. Improving the sustainable development ability of the logistics park can help the logistics park reduce the cost, improve the efficiency, establish a good image, and avoid the administrative punishment of the government.
- Third, the improvement of sustainable development ability of logistics parks involves a wide range, including EYR, EER, and ELR of the park. These indicators are determined by the input resources, total emergy, output resources, and waste of the system. The identification and analysis of these influencing factors and the evaluation of indicators related to sustainable development. It can improve the sustainable development ability of logistics parks.

4. Suggestions for Sustainable Development of the Logistics Park

4.1. Improving the ESR and Emergy Structure

The above analysis shows that the direct use of various resources from the natural environment of the logistics park is less, ESR is less than 1%, and its emergy mainly comes from the purchasing emergy outside the system, the purchasing emergy ratio is always maintained at approximately 99%. To improve the emergy structure, the logistics park should focus on reducing the emergy ratio of the external purchase of the system.

First, resource sharing should be strengthened, and the duplication of investment should be reduced. At present, the logistics park is developing rapidly. Before its construction, a comprehensive investigation must be conducted on the regional logistics demand and logistics development, and the radiation scope and location of the logistics park must be determined based on the local industrial

planning, economic development planning, and transportation planning to reduce the repeated investment in warehouses, facilities, and equipment and improve the utilization rate of resources.

Second, the construction of logistics standardization should be promoted further. Standardization can improve the efficiency of logistics, reduce the cost of logistics operation, speed up the turnover of logistics equipment, and reduce the investment of logistics enterprises on some equipment. At present, the energy of capital costs for the park accounts for about 35% of the total energy, and the energy related to equipment accounts for about 20%. Through these two methods, the logistics park can reduce the investment in logistics facilities and equipment. However, the implementation of these two methods is a long-term process, and its benefits cannot be seen temporarily.

Third, the utilization of natural resources should be improved by, for example, making full use of sunlight and rainwater to provide lighting power and domestic water for the park. Through these aspects, the ESR can be increased, and the energy structure can be optimized. The ESR of the logistics park is less than 1% now. By strengthening the utilization of natural resources, the ESR can reach 1.5–2%.

4.2. Improving the Operation Efficiency of the Logistics Park and the Energy Yield Ratio

The evaluation index system shows that although the EER of the logistics park is good, but the EYR is only approximately 0.5, which has a certain gap with the average level, and it directly leads to the low level of sustainable development of the park. Improving EYR is one of the important methods to improve the sustainable development level of the park, which requires the park to improve its operation efficiency. First, the integration of existing resources should be strengthened, and the optimal allocation of resources should be realized. Logistics resources include capital, land, technology, equipment, human resources, and other factors. The Energy density of land of the park is between 1.39×10^{13} and 3.00×10^{13} , which is in the middle level. It is necessary to plan the park reasonably, improve the utilization efficiency of land and capital, and avoid idle land. Advanced logistics technology and information technology can improve work efficiency, reduce energy loss in the logistics process, and improve the effective use of energy. However, the energy of information only accounts for about 4% of the total energy, the investment in information technology can be appropriately increased. In addition, the logistics park should also improve the ability of the logistics park to integrate resources such as capital and equipment, strengthen infrastructure construction, reduce the repeated construction of a single enterprise, and realize the scale benefit of logistics facilities utilization.

Second, on the basis of the existing business, the basic service functions must be improved, and more value-added services should be provided. Through diversified and perfect logistics services, more profits can be obtained, and the EYR of the logistics park can be improved.

4.3. Implementing Green Logistics to Reduce Waste Discharge

In the park logistics system, the more waste generated by various activities, the less net output, which will reduce the EYR index of the system, thus, affecting the sustainable development level of the system.

Compared with industrial parks, logistics parks' discharge has less waste. Thus, many parks pay little attention to waste emissions. However, from the energy view, the data shows that the energy of waste in the logistics park accounts for approximately 5% of the output, which has a great impact on the EYR of the park, and reduces the sustainable development index of the park. The logistics park has a lot of waste, such as waste from loading and unloading, warehousing, circulation processing, and supporting catering accommodation.

On the one hand, the park should reasonably plan the logistics park and logistics activities, reduce the discharge of waste in the process of operation, form a waste recycling system, and strengthen the supervision and management of waste. For example, we can find that waste water discharge accounts for the largest proportion of waste discharge. The park can strengthen the management of waste water discharge, realize the recycling of waste water and reduce the discharge.

On the other hand, the use of clean energy should be increased, and the environmental pollution caused by harmful gas emissions should be reduced [41–43]. For example, in the selection of handling equipment, the logistics park may tend to choose new energy equipment. When cooperating with transportation companies, the park can adopt certain ways to encourage transportation companies to use new energy vehicles.

5. Conclusions

Based on emergy theory, this study establishes the sustainable development indexes of logistics parks, including EER, ELR, EYR, and EISD. Taking a Logistics Park as an example, this study analyzes and evaluates the data of the logistics park and proposes that the park should reduce a proportion of external purchasing emergy, improve the emergy structure, enhance the operational efficiency of the park, improve EYR, implement green logistics, and reduce the environmental load ratio and other sustainable development suggestions. The study provides decision-making suggestions for park managers.

Emergy theory can be applied to the comprehensive evaluation of sustainable development of logistics parks, which can better meet the requirements of evaluation and analysis, and has operability. By establishing the emergy evaluation index system of logistics parks, the system composition and functional structure of logistics parks can be analyzed, the relationship between logistics parks and external environment can be reflected, and the comprehensive evaluation of logistics parks from economic and ecological perspectives can be realized.

Our model evaluates the sustainability of the logistics park based on the input and output resources of the system. Social problems, threats, and risks faced by investors, and so on, are difficult to quantify, which is the next direction we are trying to explore. In the future, we will conduct further research on the correlation between various elements of the system and the economic and ecological benefits of the logistics park, so as to improve the sustainability of logistics parks. Emergy theory can be further applied to all aspects of the logistics system, which is of great significance to the sustainable development of the logistics industry.

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References

1. Zhang, W.; Zhang, X.; Zhang, M.; Li, W. How to Coordinate Economic, Logistics and Ecological Environment? Evidences from 30 Provinces and Cities in China. *Sustainability* **2020**, *12*, 1058. [[CrossRef](#)]
2. Lan, S.L.; Zhong, R.Y. Coordinated development between metropolitan economy and logistics for sustainability. *Resources. Conserv. Recycl.* **2018**, *128*, 345–354. [[CrossRef](#)]
3. Karaman, A.S.; Kilic, M.; Uyar, A.G. Logistics performance and sustainability reporting practices of the logistics sector: The moderating effect of corporate governance. *J. Clean. Prod.* **2020**, *258*, 120718. [[CrossRef](#)]
4. Rashidi, K.; Cullinane, K. Evaluating the sustainability of national logistics performance using Data Envelopment Analysis. *Transp. Policy* **2019**, *74*, 35–46. [[CrossRef](#)]

5. Abbasi, M.; Nilsson, F. Developing environmentally sustainable logistics. Exploring themes and challenges from a logistics service providers' perspective Transportation Research Part D. *Transp. Environ.* **2016**, *46*, 273–283.
6. Lan, S.; Tseng, M.-L.; Yang, C.; Huisingh, D. Trends in sustainable logistics in major cities in China. *Sci. Total Environ.* **2020**, *712*, 136381. [[CrossRef](#)] [[PubMed](#)]
7. Jagienka, R.-C.; Agnieszka, S.-J. Environmental sustainability in city logistics measures. *Energies* **2020**, *13*, 1303.
8. Nathanail, E.; Adamos, G.; Gogas, M.C. A novel approach for assessing sustainable city logistics Transportation Research. *Procedia* **2017**, *25*, 1036–1045.
9. Zhan, C.; Zhao, R.; Hu, S. Emergy-based sustainability assessment of forest ecosystem with the aid of mountain eco-hydrological model in Huanjiang County, China. *J. Clean. Prod.* **2020**, *2511*, 119638. [[CrossRef](#)]
10. Orji, I.J.; Simonov, K.S.; Himanshu, G.; Modestus, O. Evaluating challenges to implementing eco-innovation for freight logistics sustainability in Nigeria Transportation Research Part A. *Policy Pract.* **2019**, *129*, 288–305.
11. Rahimi, M.; Ghezavati, V. Sustainable multi-period reverse logistics network design and planning under uncertainty utilizing conditional value at risk (CVaR) for recycling construction and demolition waste. *J. Clean. Prod.* **2018**, *172*, 1567–1581. [[CrossRef](#)]
12. Kelle, P.; Song, J.; Jin, M.; Schneider, H.; Claypool, C. Evaluation of operational and environmental sustainability tradeoffs in multimodal freight transportation planning. *Int. J. Prod. Econ.* **2019**, *209*, 411–420. [[CrossRef](#)]
13. Bandeira, R.A.M.; D'Agosto, M.A.; Ribeiro, S.K.; Bandeira, A.P.F.; Goes, G.V.A. Fuzzy multi-criteria model for evaluating sustainable urban freight transportation operations. *J. Clean. Prod.* **2018**, *184*, 727–739. [[CrossRef](#)]
14. Melkonyan, A.; Gruchmann, T.; Lohmar, F.; Kamath, V.; Spinler, S. Sustainability assessment of last-mile logistics and distribution strategies: The case of local food networks. *Int. J. Prod. Econ.* **2020**, *228*, 107746. [[CrossRef](#)]
15. Pourhejazy, P.; Kwon, O.K.; Lim, H. Integrating Sustainability into the Optimization of Fuel Logistics Networks. *KSCE J. Civ. Eng.* **2019**, *23*, 1369–1383. [[CrossRef](#)]
16. Lee, P.T.-W.; Kwon, O.K.; Ruan, X. Sustainability challenges in maritime transport and logistics industry and its way ahead. *Sustainability* **2019**, *11*, 1331. [[CrossRef](#)]
17. Twrdy, E.; Zanne, M. Improvement of the sustainability of ports logistics by the development of innovative green infrastructure solutions. *Transp. Res. Procedia* **2020**, *45*, 539–546. [[CrossRef](#)]
18. Orji, I.J.; Simonov, K.-S.; Himanshu, G. The critical success factors of using social media for supply chain social sustainability in the freight logistics industry. *Int. J. Prod. Res.* **2020**, *58*, 1522–1539. [[CrossRef](#)]
19. Sobhan, A.; Ashkan, H.; Jacob, J.J. Sharing economy in organic food supply chains: A pathway to sustainable development. *Int. J. Prod. Econ.* **2019**, *218*, 322–338.
20. Piera, C.; Roberto, C.; Emilio, E. Developing the WH2 framework for environmental sustainability in logistics service providers: A taxonomy of green initiatives. *J. Clean. Prod.* **2017**, *165*, 1063–1077. [[CrossRef](#)]
21. Vilarinho, A.; Liboni, L.B.; Siegler, J. Challenges and opportunities for the development of river logistics as a sustainable alternative: A systematic review. *Transp. Res. Procedia* **2019**, *39*, 576–586. [[CrossRef](#)]
22. Odum, T. *Environmental Accounting: Emergy and Environ-Mental Decisionmaking*; Wiley: Hoboken, NJ, USA, 1996; pp. 15–163.
23. He, Z.; Jiang, L.; Wang, Z.; Zeng, R.; Liu, J. The emergy analysis of southern China agro-ecosystem and its relation with its regional sustainable development. *Glob. Ecol. Conserv.* **2019**, *20*, e00721. [[CrossRef](#)]
24. Liu, X.; Guo, P.; Nie, L. Applying emergy and decoupling analysis to assess the sustainability of China's coal mining area. *J. Clean. Prod.* **2020**, *243*, 118577. [[CrossRef](#)]
25. Yang, Q.; Liu, G.; Biagio, F.; Agostinho, G.F.; Casazza, M. Emergy-based ecosystem services valuation and classification management applied to China's grasslands Ecosystem. *Services* **2020**, *42*, 101073. [[CrossRef](#)]
26. Liu, C.; Cai, W.; Dinolov, O. Emergy based sustainability evaluation of remanufacturing machining systems. *Emergy* **2018**, *150*, 670–680. [[CrossRef](#)]
27. Liu, C.; Zhu, Q.; Wei, F.; Rao, W.; Liu, J.; Hu, J.; Cai, W. An integrated optimization control method for remanufacturing assembly system. *J. Clean. Prod.* **2019**, *248*, 119261. [[CrossRef](#)]
28. Ren, S.; Feng, X.; Yang, M. Emergy evaluation of power generation systems. *Emergy Convers. Manag.* **2020**, *2111*, 112749. [[CrossRef](#)]

29. Chen, J.; Mei, Y.; Ben, Y.; Hu, T. Emergy-based sustainability evaluation of two hydropower projects on the Tibetan Plateau. *Ecol. Eng.* **2020**, *1501*, 105838. [[CrossRef](#)]
30. Tian, X.; Sarkis, J. Expanding green supply chain performance measurement through emergy accounting and analysis. *Int. J. Prod. Econ.* **2020**, *225*, 107576. [[CrossRef](#)]
31. Natalia, A.; Londoño, C.; Velásquez, H.I.; McIntyre, N. Comparing the environmental sustainability of two gold production methods using integrated Emergy and Life Cycle Assessment. *Ecol. Indic.* **2019**, *107*, 105600.
32. Asgharipour, M.R.; Amiri, Z.; Daniel, E. Campbell Evaluation of the sustainability of four greenhouse vegetable production ecosystems based on an analysis of emergy and social characteristics. *Ecol. Model.* **2020**, *42415*, 109021. [[CrossRef](#)]
33. Cai, W.; Liu, C.; Jia, S.; Felix, T.; Chan, S.; Ma, X. An emergy-based sustainability evaluation method for outsourcing machining resources. *J. Clean. Prod.* **2020**, *2451*, 118849. [[CrossRef](#)]
34. Odum, H.T.; Arding, J.E. *Emergy Analysis of Shrimp Mariculture in Ecuador. Narragansett*; CRC Press: Boca Raton, FL, USA, 1991; Volume 61–64, pp. 17–21.
35. Sun, H.; Liu, C.; Chen, J.; Gao, M.; Shen, X. A Novel Method of Sustainability Evaluation in Machining Processes. *Processes* **2019**, *7*, 275. [[CrossRef](#)]
36. Pan, H.; Zhang, X.; Wu, J.; Zhang, Y.; Lin, L.; Yang, G.; Deng, S.; Li, L.; Yu, X.; Qi, H.; et al. Sustainability evaluation of a steel production system in China based on emergy. *J. Clean. Prod.* **2016**, *112*, 1498–1509. [[CrossRef](#)]
37. Brown, M.T.; Ulgiati, S. Assessing the global environmental sources driving the geobiosphere: A revised emergy baseline. *Ecol. Model.* **2016**, *339*, 126–132. [[CrossRef](#)]
38. Cuadra, M.; Rydberg, T. Emergy evaluation on the production, processing and export of coffee in Nicaragua. *Ecol. Modeling* **2006**, *196*, 421–433. [[CrossRef](#)]
39. Geng, Y.; Zhang, R.; Ulgiati, S. Emergy analysis of an industrial park: The case of Dalian, China. *Sci. Total Environ.* **2010**, *408*, 5273–5283. [[CrossRef](#)]
40. Zhang, X.; Zhang, R.; Wu, J.; Zhang, Y.-Z.; Lin, L.-L.; Deng, S.-H.; Li, L.; Yang, G.; Yu, X.-Y.; Qi, H.; et al. An emergy evaluation of the sustainability of Chinese crop production system during 2000–2010. *Ecolindic* **2016**, *60*, 622–633. [[CrossRef](#)]
41. Liu, C.; Zhu, Q.; Wei, F.; Rao, W.; Liu, J.; Hu, J.; Cai, W. A review on remanufacturing assembly management and technology. *Int. J. Adv. Manuf. Technol.* **2019**, *105*, 4797–4808. [[CrossRef](#)]
42. Liu, J.; Feng, Y.; Zhu, Q.; Sarkis, J. Green supply chain management and the circular economy: Reviewing theory for advancement of both fields. *Int. J. Phys. Distrib. Logist. Manag.* **2018**, *48*, 794–817. [[CrossRef](#)]
43. Tang, J.; Li, B.Y.; Li, K.W.; Liu, Z.; Huang, J. Pricing and warranty decisions in a two-period closed-loop supply chain. *Int. J. Prod. Res.* **2020**, *58*, 1688–1704. [[CrossRef](#)]



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