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Emergy-Based Evaluation on the Systemic Sustainability of Rural Ecosystem under China Poverty Alleviation and Rural Revitalization: A Case of the Village in North China

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Abstract: A number of new rural management models have emerged to solve the problems of economic backwardness, insufficient resource utilization, and technical shortages in rural areas in the context of poverty alleviation to the rural revitalization strategy in China. However, the influence of new rural management model under all countermeasures for rural sustainable development with a comprehensive perspective is lacking. Therefore, exploring whether the new rural management model meets the requirements of sustainable development is an urgent issue. From the theory of system metabolism and emergy accounting method, this study classified the government funds for poverty alleviation measures as import resources, and analyzed the metabolic structure, efficiency, and the rural development factors of Chehe Village before and after poverty alleviation measures are carried out (the year of 2012 and 2019) to verify whether the new model was sustainable. According to the results of this study, the new management model of Chehe Village declined the rural system sustainability with the emergy sustainability index decreasing from 1.96 in 2012 to 0.32 in 2019. With the development of economy, the system metabolic efficiency of Chehe Village promoted and the metabolic structure became more reasonable manifesting in the decline of emergy use per unit GDP and the increase of emergy exchange rate. Moreover, production and livelihood had been highly valued in Chehe Village. In conclusion, it is feasible to add countermeasures of poverty alleviation and rural revitalization into the village system metabolism. The new management model of Chehe Village needs to change exogenous force into endogenous force to meet the requirements of rural sustainable development.

Keywords: system sustainability; poverty alleviation; rural revitalization; emergy; system metabolism; Chehe Village

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1. Introduction

Sustainability can be defined as a development process that minimizes consumption of natural resources and the resulting environmental impacts while simultaneously providing economic and quality of life benefits [1]. Sustainable rural development is a noteworthy issue to enhance the economic, social, and ecological sustainability of developing countries in which poverty is a dominant phenomenon that adversely affects livelihood [2]. Moreover, there are many goals in SDGs related to rural sustainable development, covering nature, society, economy, and human well-being, such as life on land, no poverty, zero hunger, quality education, clean water and sanitation, decent work and economic growth, good health and wellbeing, etc., [3]. Rural development is a comprehensive issue involving rural management, industrial economic development, natural resource utilization, technological progress, and trade exchanges [4,5]. China has more than 500 million rural population, accounting for 39.4% [6]. However, compared with urban residents, the status of rural is relatively low, with the low agricultural production income due to low land productivity [7]. In addition, many farmers suffer from exposure to ecological risks such as drought, soil erosion, environmental pollution, and land degradation, especially in the ecologically fragile areas [8–11]. Therefore, rural development is an essential issue although it is complex.

Escaping poverty and realizing rural sustainable development are the global challenges. Some polices related to natural resources, people livelihoods, and social equity influence rural sustainable development. Strict environmental protection in poverty-stricken areas hinders farmers' effective use of resources to some extent, thereby exacerbating poverty [12]. Insufficient quantity and poor quality of land are important reasons for rural poverty, and land system reform plays an important role in poverty reduction [13,14]. Access to and use of clean energy is essential for poverty alleviation and sustainable development. China's photovoltaic poverty alleviation projects have effectively enhanced the economic conditions and social capital of poor families yet increases in human and natural capital performed poorly [15,16]. Furthermore, social factors, such as prioritizing gender inclusion, concerning childbearing, positively affect many social and well-being outcomes, including poverty alleviation, hunger reduction and health improvement [17,18]. On the whole, although each policy has played a role in promoting farmers' income, they may not necessarily benefit for sustainable rural development.

In recent years, the Chinese government has given great importance of the issues concerning agriculture, rural areas, and peasants. Strategies aimed at improving livelihoods are always limited by unsustainable rural resources, high population growth rate, vulnerable agricultural ecological conditions, and significant social inequity, such as in the uneven distribution of wealth and allocation of limited resources [19,20]. Since China's reform and opening up in 1978, the countryside has undergone earth-shaking changes, such as economic growth, land use change, rural governance, social and cultural transition [21]. A series of polices and strategies on rural construction has been introduced one after another in China, for example, new countryside construction (2006), urban and rural coordination development (2010), a new agricultural management system construction (2013), structural reforms on the agricultural supply side (2015). Since 2012, China has eradicated poverty as a basic requirement for building a moderately prosperous society in all respects. By 2021, China has secured a "complete victory" in its fight against poverty, with the final 98.99 million impoverished rural residents living under the current poverty line having all been lifted out of poverty, and all 832 impoverished counties and 128,000 villages having been removed from the poverty list [22]. Currently, the main contradiction in Chinese society has been transformed into a contradiction between the people's growing need for a better life and unbalanced and inadequate development. The Chinese government has proposed a new rural revitalization strategy, focusing on the five major aspects of agricultural and rural issues such as industrial prosperity, ecological livability, rural civilization, effective governance, and rich life in 2017 [23]. The emergence of new business entities, investment of external funds, and the transformation of village entities make the villages a new operating model. However, whether measures of poverty alleviation and rural revitalization promote rural sustainable development is even unclear.

The theory of ecological emergy analysis combining ecosystem and economic system together for emergy analysis was found by American ecologist H.T. Odum in the 1980s [24,25]. It provides a new way for the analysis of eco-economic system and has increasingly become an important theoretical method to evaluate the sustainable development of human socioeconomic systems. The emergy method breaks the narrow, human-centered definition of environmental and ecological economics to estimate the value of ecosystem inputs and attempts to capture the ecological center value. It attempts to assign correct values to ecological and economic products and services based on the theory of energy flow in system ecology and its relationship with system survival [26]. Emergy accounting converts different kinds of materials and energy into a unified unit of measurement for comparison and calculation. It was used in many different systems, for example, agriculture system [27,28], industrial production system [29,30], tourism system [31,32] because of its universality of providing a standard for the unification of material flow, energy flow, currency flow, information flow, and population flow in the system [33]. In addition, emergy method can be used for regional macro evaluation at different scales, such as global scales [34], national scales [35], urban scales [36], and village scales [37] to evaluate regional sustainability.

The aim of this study is to explore whether the new rural management model under the measures of poverty alleviation and rural revitalization promote rural sustainable development. In this study, the emergy accounting is mainly used to express the indicators related to rural development and calculate the sustainability index of the village. Villages are analogous to the cities that have complex structure and are affected by external environmental conditions and internal element organization [38] in Chinese. We attempted to combine the factors of rural development and emergy accounting together, especially the related funds invested by the government or company in the poverty alleviation measures of the village. The related funds were calculated from the system as the external resources from outside the system. Resources flows from multiple aspects, such as nature, economy, society, culture, trade services, and pollution were analyzed to show the metabolic process of the village composed of the entire complex system. Then we explored the village metabolic structure, metabolic efficiency, system sustainability, and rural development based on emergy indexes. Finally, we analyzed Chehe Village as a classic case to compare the rural sustainable development level before (2012) and after (2019) the organic agriculture construction in the year of 2013 and put forward sustainable development countermeasures.

2. Materials and Methods

2.1. Analysis Method

Emergy concept was first introduced by Howard T. Odum [24,34,39,40] which was defined as "the available energy of one kind previously used directly or indirectly to generate a service or a product" [41]. Emergy accounting calculated the energy, materials, and services inputs with a same unit (solar equivalent joule (sej)) used in natural resources, economic resources, and social resources together. The different energy inputs was converted into emergy by multiplying a suitable unit emery value (UEV), it could be obtained by formular (1), and the global emergy baseline used in this paper was 1.20 $\times$ 10^{25} sej/yr [42].

$$Em_i = Q_i \times UEV_i \quad (1)$$

where, Em_i is the emergy of ith type flow of material or energy; Q_i is the quantity of item i; UEV_i is the unit emergy value of item i, which was referenced to previous literatures.

The system boundary of the village was typically defined using its administrative boundary. The resources including raw materials, energy sources, currency flows, and services that flowed through the village were classified into five categories (Figure 1), which are renewable resources (R), non-renewable resources (N), import resources (IMP), export resources (EXP), and waste (W) respectively. The renewable resources contained natural resources including solar energy, wind energy, rain energy. Non-renewable resources involved local non-renewable natural resources and products (topsoil loss, groundwater, electricity, etc.). The import resources (IMP) included some items originating from the government which was carried out in the context of poverty alleviation and rural revitalization, such as spiritual civilization publicity column fund, cultural activity room construction fund, harmless toilet construction fund, and other basic living security investment expenses (medical treatment, pension, etc.,). Non-renewable natural resources and products like coal, diesel, fertilizer, etc., that support people's live and agricultural production were contained in the imported resources. In addition, tourism income of the village was contained in the import resources. Products and services were included in the export resources (EXP). Moreover, this study classified all items originating from the government which was carried out in the context of poverty alleviation and rural revitalization into five categories (U_1, U_2, U_3, U_4, U_5), corresponding to industrial economy, ecologically livable, rural governance, social civilization, and rich life of rural ecosystem respectively. All items of U_1, U_2, U_3, U_4, U_5 are listed in Appendix A.

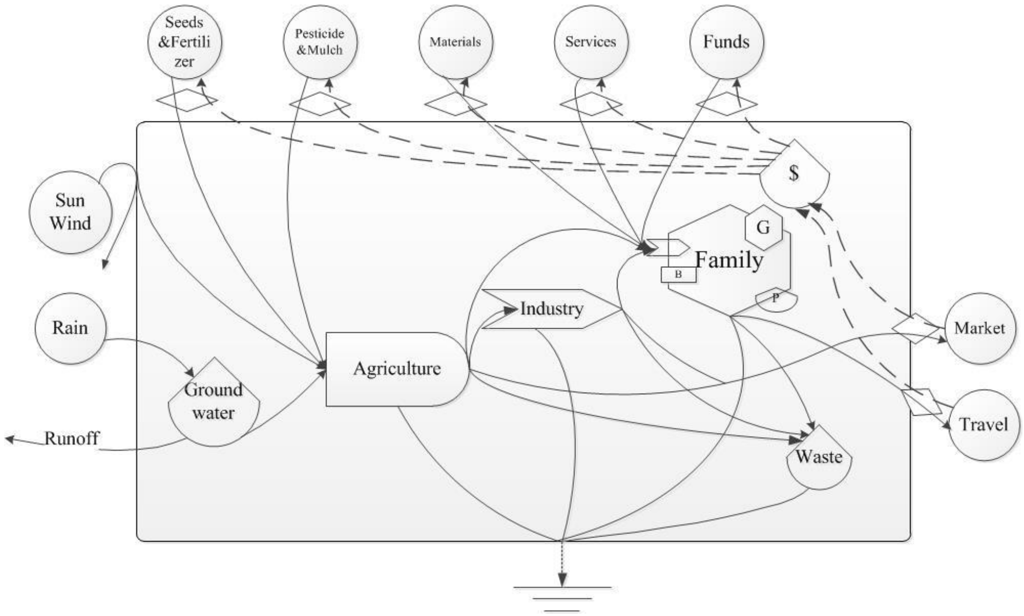

Figure 1. Emergy flows of a rural ecosystem. Note: B, business; P, people; G, government; $, dollar.

Emergy indices of rural ecosystem are shown in Table 1. System emergy flows represented the basic metabolic process in the rural system. Social subsystem indicators (ED, Ucap, $Ucap_1$, $Ucap_2$, $Ucap_3$) indicated per unit area emergy consumption and per capita emergy usage of life living. Emergy yield rate (EYR) measured an ability to promote economy by increasing imports and could be used to signify the regional economic competitive strength [33,43]. Emergy to currency rate (EMR) was emergy used per unit of GDP. Emergy exchange rate (EER) made a comparison between import resources and export resources. Emergy load rate (ELR) indicated the pressure of human activities on local natural system. Emergy sustainability index (ESI) evaluated sustainability of the system. Rural development indicators were the new indicators in this paper that contained the key tasks in poverty alleviation and rural vitalization strategy of China, including industrial economy, ecologically livable, rural governance, social civilization, and rich life. These factors are the proportion of the whole emergy flows in rural ecosystem, which express the structure of rural development.

2.2. Case Study

Chehe Village, located in the central of Lingqiu County (Shanxi province) which is a national poverty-stricken county, covered an area of 27 km^2 with 182 people living. It had a good foundation for developing organic agriculture such as advantages of traditional agriculture, less polluted land, suitable climate, and beautiful view. Under the poverty alleviation strategy, Chehe Village was developed as a pilot project for the comprehensive development of organic agriculture from the year of 2013, with the project of construction of organic agricultural parks throughout the village. The industrial combination of Chehe Village adopted the model of "organic agriculture + beautiful rural construction + ecologically happy tourism + decent work to support aspirations". Through the development of characteristic industries, eco-tourism, and other ditch economies, it will help farmers to alleviate poverty, increase agricultural efficiency, and promote rural development, so as to break the new path of poverty alleviation and in situ urbanization. Figure 2 is the view of Chehe Village in 2020.

Table 1. Emergy indices of rural ecosystem.

Emergy Indices		Unit	Abbreviation	Expression
System emergy flows	Natural resources	sej	R	-
	Natural products	sej	R_1	-
	Non-renewable resources	sej	N	-
	Import resources	sej	IMP	-
	Export resources	sej	EXP	-
	Total emergy	sej	U	R + N + IMP
	Emergy of industrial economy	sej	U_1	-
	Emergy of ecologically livable	sej	U_2	-
	Emergy of rural governance	sej	U_3	-
	Emergy of social civilization	sej	U_4	-
	Emergy of rich life	sej	U_5	-
Emergy structure index	Renewable emergy rate	%	RER	R/U
Social subsystem indicators	Emergy density	sej/m^2	ED	U/Area
	Per capita emergy usage	sej/person	Ucap	U/P
	Per capita fuel energy consumption	sej/person	$Ucap_1$	Fuel/P
	Per capita electricity energy consumption	sej/person	$Ucap_2$	Elec/P
Economic subsystem indicators	Emergy yield rate	-	EYR	U/IMP
	Emergy to currency rate	-	EMR	U/GDP
	Emergy exchange rate	-	EER	IMP/EXP
Natural subsystems and sustainability indicators	Environmental Loading Ratio	-	ELR	(IMP + N)/R
	Emergy sustainability index	-	ESI	EYR/ELR
	Pressure of waste on environment	-	PWE	W/R
Rural development indicators	Emergy rate of industrial economy	-	EIP	$U_1/(U + R_1)$
	Emergy rate of ecologically livable	-	EEL	$U_2/(U + R_1)$
	Emergy rate of rural governance	-	EEG	$U_3/(U + R_1)$
	Emergy rate of social civilization	-	ERC	$U_4/(U + R_1)$
	Emergy rate of rich life	-	ERL	$U_5/(U + R_1)$

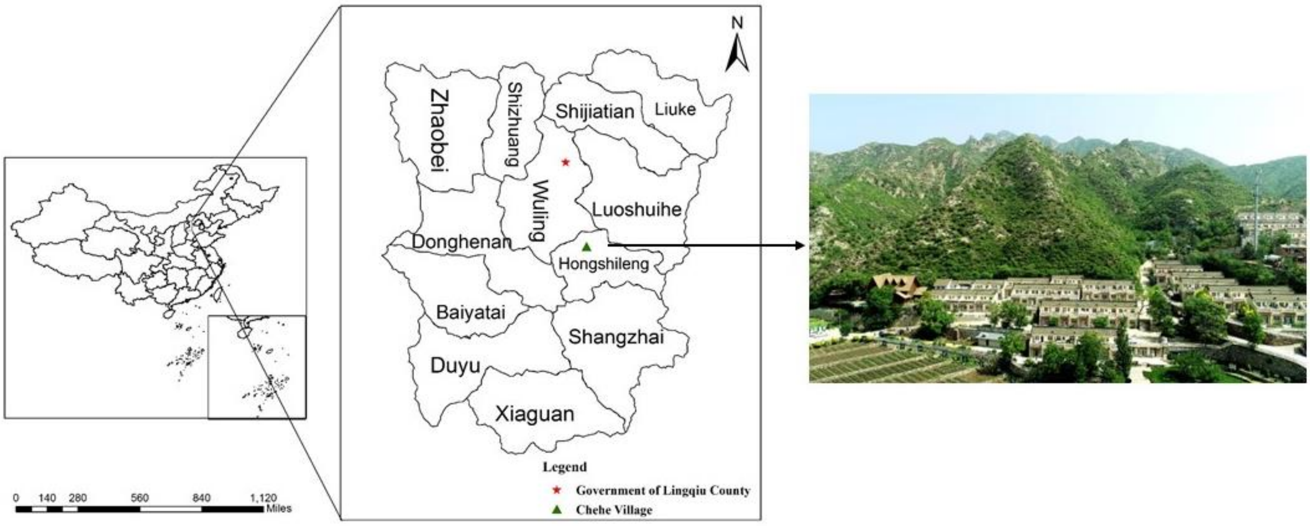

Figure 2. Location of Chehe Village. Note: the first picture in the left is the map of China, the second picture is the map of Lingqiu County, and the third picture is the view of Chehe Village. The location picture of Chehe Village was drawn with Arcgis by the author and the right view picture of Chehe Village is from the website. Website address is http://k.sina.com.cn/article_6433760072_17f7b634800100ot6r.html?wm=3049_0032 (accessed on 18 May 2020).

Chehe Organic Farming Community, with 1213 acres of arable land, including organic corn, organic rice and organic potatoes, were managed by the company. In addition, 30,000 chickens and 5000 sheep were raised. Leisure and tourism facilities, such as Mengyou valley, open-air cinema, sky bike and rock climbing, attracted people from the city to take leisure vacations and carry out outdoor sports. At the same time, the catering industry, sales industry, homestay industry, and the leisure tourism industry complement each other, and bring huge benefits to local villagers. In general, Chehe Organic Agriculture Community is a demonstration village integrating agriculture, agricultural product processing industry, catering industry, retail industry, and leisure tourism industry. Under the supervision of the government and the unified management of the company and cooperatives, Chehe Village employed village labors, subsidies for land transfer, and distributes company dividends to increase farmers' income (RMB 18,500 per capita in 2019, and RMB 5096 per capita in 2012), attracting migrant workers back to the village. The operation mode (Figure 3) has been widely publicized and reported and has become a typical case of poverty alleviation in China.

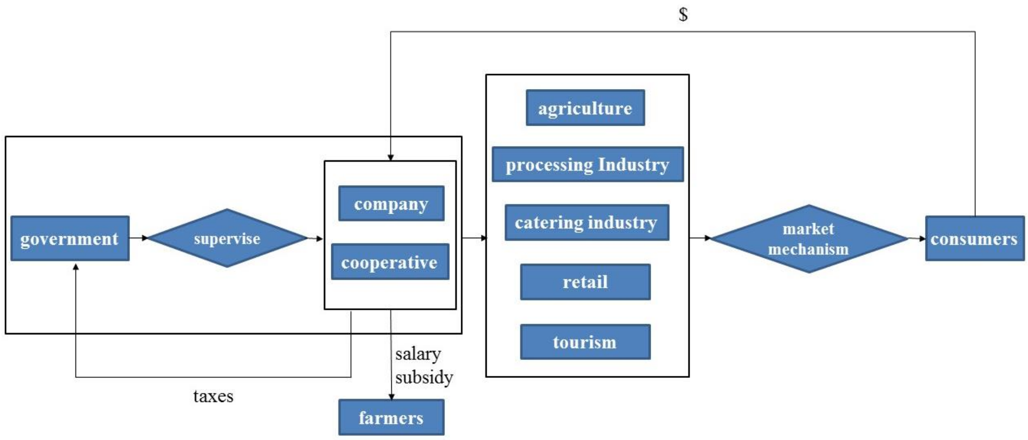

Figure 3. Flowchart of Chehe Village operation mode. Note: the flowchart was drew by author according to survey and interview.

2.3. Data Collection

The climate information involving sunlight, precipitation, wind speed, and average altitude were obtained from Bureau Meteorology and Lingqiu County statistical yearbook. Raw data of diesel and waste were referred to China statistical yearbook, Ministry of Industry and Information Technology of the People's Republic of China, Wang et al. (2004) [44]. Furthermore, we extracted some information from the local government report, related documents and website, and relevant personal interviews.

Moreover, most raw data of different flows including renewable resources, nonrenewable resources, import products and services, export products and services were acquired through questionnaire survey of village head or farmers in a field investigation activity for one week in August 2020 to insure the specificity and validity of the data. Finally, we revised the questionnaire according to the local conditions and get the validity data to analyze the results. There were three people who contributed to this paper participating in the field investigation for 30 farmers randomly and collected 30 valid questionnaires. The village head had worked since 1997 and was awarded as "National Advanced Individual in Poverty Alleviation" by the Party Central Committee and the State Council in 2021.

3. Results

3.1. Emergy Analysis of Chehe Village

Five categories resources in the Figure 1 of Chehe Village representing the system metabolism are listed in Table 1: renewable resources (R), nonrenewable resources (N), imported resources (IMP), exported resources (EXP), and waste (W). The detailed data and the source of UEV are shown in Table 2 [45–50].

Table 2. Emergy accounting of Chehe Village in the year of 2012 and 2019.

Items	Raw Data		Unit	UEV (Sej/Unit)	Emergy (Sej)		Reference
	2012	2019			2012	2019	
R							
Sun	5.80×10^{14}	5.83×10^{14}	J	1.00×10^{0}	5.80×10^{14}	5.83×10^{14}	Ulgiati, 2016
Wind	4.16×10^{12}	5.04×10^{12}	J	7.90×10^{2}	3.29×10^{15}	3.98×10^{15}	Ulgiati, 2016
Rain	5.02×10^{13}	5.43×10^{13}	J	1.28×10^{4}	6.42×10^{17}	6.95×10^{17}	Ulgiati, 2016
R_1							
Maize	8.00×10^{7}	3.50×10^{7}	g	1.84×10^{11}	1.47×10^{19}	6.45×10^{18}	Odum, 1996
Potato	0	1.00×10^{8}	g	1.84×10^{11}	0	1.84×10^{19}	Odum, 1996
Rice	0	1.80×10^{6}	g	1.84×10^{11}	0	3.32×10^{17}	Odum, 1996
Lucid ganoderma	0	3.20×10^{5}	g	3.09×10^{11}	0	9.88×10^{16}	Lan, et al., 2002
Morels	0	2.25×10^{7}	g	3.09×10^{11}	0	6.95×10^{18}	Lan, et al., 2002
Egg	0	5.11×10^{4}	kg	8.84×10^{12}	0	4.52×10^{17}	Ulgiati, 2016
Meat	0	1.25×10^{5}	kg	1.93×10^{13}	0	2.41×10^{18}	Ulgiati, 2016
N							
Topsoil loss	4.51×10^{11}	4.51×10^{11}	J	9.40×10^{4}	4.24×10^{16}	4.24×10^{16}	Brandt-Williams, 2002
Groundwater	3.44×10^{7}	3.58×10^{7}	kg	4.96×10^{11}	1.71×10^{19}	1.77×10^{19}	Ulgiati, 2016
Electricity	4.19×10^{11}	4.36×10^{11}	J	2.21×10^{5}	9.26×10^{16}	9.63×10^{16}	Ulgiati, 2016
IMP							
Natural gas	0	4.50×10^{4}	m^3	5.36×10^{12}	0	2.41×10^{17}	Ulgiati, 2016
Fertilizer	2.18×10^{7}	2.00×10^{8}	g	6.28×10^{9}	1.37×10^{17}	1.26×10^{18}	Han, 2019
Pesticide	1.20×10^{4}	0	$	2.58×10^{12}	3.09×10^{16}	0	Brandt-Williams, 2002
Mulch	2.81×10^{3}	0	$	2.58×10^{12}	7.24×10^{15}	0	Brandt-Williams, 2002
Seeds	1.37×10^{10}	4.89×10^{9}	J	8.41×10^{4}	1.16×10^{15}	4.11×10^{14}	Odum et al., 2000
Coal	1.75×10^{8}	0	g	5.81×10^{4}	1.02×10^{13}	0	Brown et al., 2011
Diesel	2.08×10^{4}	2.20×10^{4}	kg	6.12×10^{12}	1.27×10^{17}	1.35×10^{17}	Ulgiati, 2016
Invested funds by government or company	1.42×10^{4}	7.11×10^{4}	$	2.58×10^{12}	3.67×10^{16}	1.83×10^{17}	Ulgiati, 2016
Labor	0	6.55×10^{10}	J	5.73×10^{6}	0	3.75×10^{17}	Brandt-Williams, 2002
Tourism income	0	1.45×10^{4}	$	2.58×10^{12}	0	3.74×10^{16}	Ulgiati, 2016
EXP							
Maize	6.40×10^{7}	2.80×10^{7}	g	1.84×10^{11}	1.18×10^{19}	5.16×10^{18}	Odum, 1996
Rice	0	1.80×10^{6}	g	1.84×10^{11}	0	3.32×10^{17}	Odum, 1996
Lucid ganoderma	0	3.20×10^{5}	g	3.09×10^{11}	0	9.88×10^{16}	Lan, et al., 2002
Morels	0	2.25×10^{7}	g	3.09×10^{11}	0	6.95×10^{18}	Lan, et al., 2002
Egg	0	5.11×10^{4}	kg	8.84×10^{12}	0	4.52×10^{17}	Ulgiati, 2016
Meat	0	1.25×10^{5}	kg	1.93×10^{13}	0	2.41×10^{18}	Ulgiati, 2016
Labor	1.32×10^{11}	9.07×10^{10}	J	5.73×10^{6}	7.58×10^{17}	5.20×10^{17}	Brandt-Williams, 2002
W							
Domestic wastewater	3.67×10^{5}	3.82×10^{5}	Gallon	6.65×10^{11}	2.44×10^{17}	2.54×10^{17}	Lan, et al., 2002
Domestic garbage	3.21×10^{11}	3.34×10^{11}	t	1.36×10^{6}	4.38×10^{17}	4.55×10^{17}	Lan, et al., 2002

The emergy of the renewable resources achieved 6.95×10^{17} sej (2019) of Chehe Village, which was 8.22% higher than 2012 (Figure 4). Moreover, we only calculated the largest renewable flow between the sun, wind, and rain to avoid double accounting [39]. There were no large-scale industries in the Chehe Village due to the ban of coal mining since 2011, and thus, the amount of non-renewable resources was relatively low. Non-renewable resources in 2019 (1.79×10^{19} sej) increased by 3.99% compared to 2012 (1.72×10^{19} sej), mainly because the electricity usage had increased with population increase. Imported resources increased exponentially (from 3.40×10^{17} sej in 2012 to 2.23×10^{18} sej in 2019) mainly because the government and enterprises had unified management of Chehe Village in 2019. They invested a lot of money in poverty alleviation and rural revitalization measures such as built bulletin board, party building funding, harmless toilet, education input, and others (Appendix A). In addition, tourism was also a new type of industry in the construction and development of agricultural parks, and there was no such income in 2012. Natural gas, as a clean energy replaced coal, was much more environmentally friendly [51]. However, there were no pesticide and mulch in 2019, which protected the condition of agroecosystem and the village environment [52,53]. Export resources increased 26.90% from 1.25×10^{19} sej in 2012 to 1.59×10^{19} sej in 2019, which was mainly due to the amount of exporting products increasing. After the establishment of organic farming in 2013, Chehe produced organic eggs, grew morels, and lucid Ganoderma in the greenhouse, which were important resources for Chehe Village to export to other places. Finally, the waste flow remained basically unchanged, with 6.82×10^{17} sej in 2012 and 7.09×10^{17} sej in 2019.

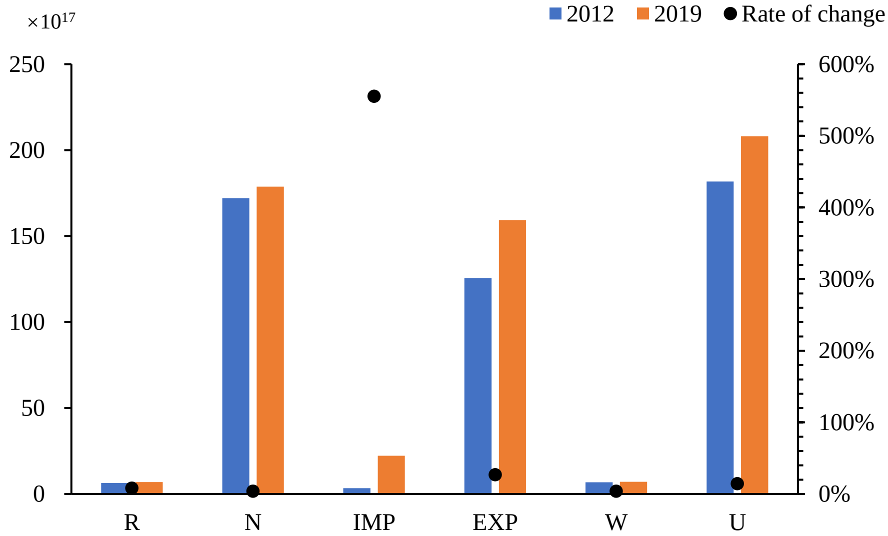

Figure 4. Resources and rate of change of Chehe Village in the year of 2012 and 2019.

3.2. Emergy Indices of Chehe Village

Renewable emergy ratio decreased from 0.04 in 2012 to 0.03 in 2019, which could be a result of the increase of nonreneable resources or purchased inputs. The emergy indices results were listed in Table 3.

Table 3. Emergy indices of Chehe Village.

Emergy Indices		Unit	Abbreviation	Values	
				2012	**2019**
Social subsystem indicators	Emergy density	sej/m^2	ED	6.73×10^{11}	2.61×10^{12}
	Per capita emergy usage	sej/person	Ucap	1.04×10^{17}	1.14×10^{17}
	Per capita fuel energy consumption	sej/person	$Ucap_1$	7.27×10^{14}	2.06×10^{15}
	Per capita electricity energy consumption	sej/person	$Ucap_2$	5.29×10^{14}	5.29×10^{14}
Emergy structure index	Renewable emergy rate	%	RER	3.53×10^{-2}	3.34×10^{-2}
Economic subsystem indicators	Emergy yield rate	%	EYR	53.46	9.34
	Emergy to currency ratio	-	EMR	1.30×10^{14}	3.99×10^{13}
	Emergy exchange rate	%	EER	36.90	7.15
Natural subsystems and sustainability indicators	Emergy load rate	%	ELR	27.31	28.94
	Emergy sustainability index	%	ESI	1.96	0.32
	Pressure of waste on environment	%	PWE	1.06	1.02
Rural development indicators	Emergy rate of industrial economy	%	EIP	0.00	0.69
	Emergy rate of ecologically livable	%	EEL	0.00	0.03
	Emergy rate of rural governance	%	EEG	0.00	0.01
	Emergy rate of social civilization	%	ERC	0.00	0.02
	Emergy rate of rich life	%	ERL	0.00	0.41

3.2.1. Social Emergy Indices

Emergy density (ED) reflects not only the emergy-intensive degree and intensity, but also reflects the economic development intensity and level of economic development of the evaluated object. ED increased from 6.73×10^{11} sej/m^2 in 2012 to 2.61×10^{12} sej/m^2 in 2019, showing that the village economy had developed and its hierarchical status had become higher. Per capita emergy usage (Ucap) is an index to evaluate people's living standard and quality. The value of Ucap was 1.04×10^{17} sej/person in 2012 and was 1.14×10^{17} sej/person in 2019, indicating that the people's living standard improved after organic agriculture construction of Chehe Village in 2013. Moreover, the per capita fuel energy consumption ($Ucap_1$), with slight degree of growth, demonstrated people's lives getting better and better. Per capita electricity energy consumption ($Ucap_2$) were unchanged. In general, farmers' lives have been significantly improved with the construction of organic agriculture in the whole village.

3.2.2. Economic Emergy Indices

EYR is the ratio of total emergy to imported emergy, which is used to measure an ability to extract the resources through the use of the imports. The value of EYR was 53.46 in 2012 and was 9.34 in 2019, representing the economic development of Chehe Village was less dependent on local resources. EMR was much lower (1.30×10^{14}) in 2019 than that in 2012 (3.99×10^{13}). The results showed that the level of economic modernization in Chehe Village had improved, and the amount of energy required to create unit GDP had decreased. EER still increased (0.03 in 2012 and 0.14 in 2019) based on the exponential increase of import resources although increase of exports resources. Besides, export resources included agricultural products and secondary products after processing of agricultural products, and import resources mainly were services, nonrenewable resources, and currency, which promote trade balance. On the whole, since the establishment of the organic farming community, the economy of Chehe Village had developed.

3.2.3. Natural Emergy Indices and Sustainability Indices

ELR indicates the sustainable use of resources in Chehe Village. The higher the ELR, the higher the utilization of the local non-renewable resources in Chehe, which will cause serious pressure on the local resource usage in the future. Therefore, although the economic development level of Chehe Village has improved, it is also facing high environmental pressure (27.31 in 2012 and 28.94 in 2019). ESI is the ratio of the production efficiency in the system to the environmental pressure load of the system. The results in this paper showed that ESI declined from 1.96 in 2012 to 0.32 in 2019. PWE reduced from 1.06 in 2012 to 1.02 in 2019 showing the increasing pressure of waste on the environment. In short, the sustainability of Chehe Village had decreased after the organic agriculture construction.

3.2.4. Rural Development Indices

The rural development indicators evaluates the situation of rural development from the aspects of industry, ecology, social civilization, and people's well-being. The indicator is the proportion of the emergy input or output value of each part to the all emergy of the system (Table 1). From the results, we could see the industrial economy (0.69) was much important in Chehe Village. The emergy rate of rich life, ecologically livable, social civilization and rural governance was 0.41, 0.03, 0.02, and 0.01 respectively.

3.3. Structural Analysis of Rural Development Indices

All kinds of resources included in the system metabolism process were classified into the five categories of rural development (industrial economy, ecologically livable, rural governance, social civilization, and rich life) according to National Rural Revitalization Plan. The internal composition of the five categories is shown in Figure 5.

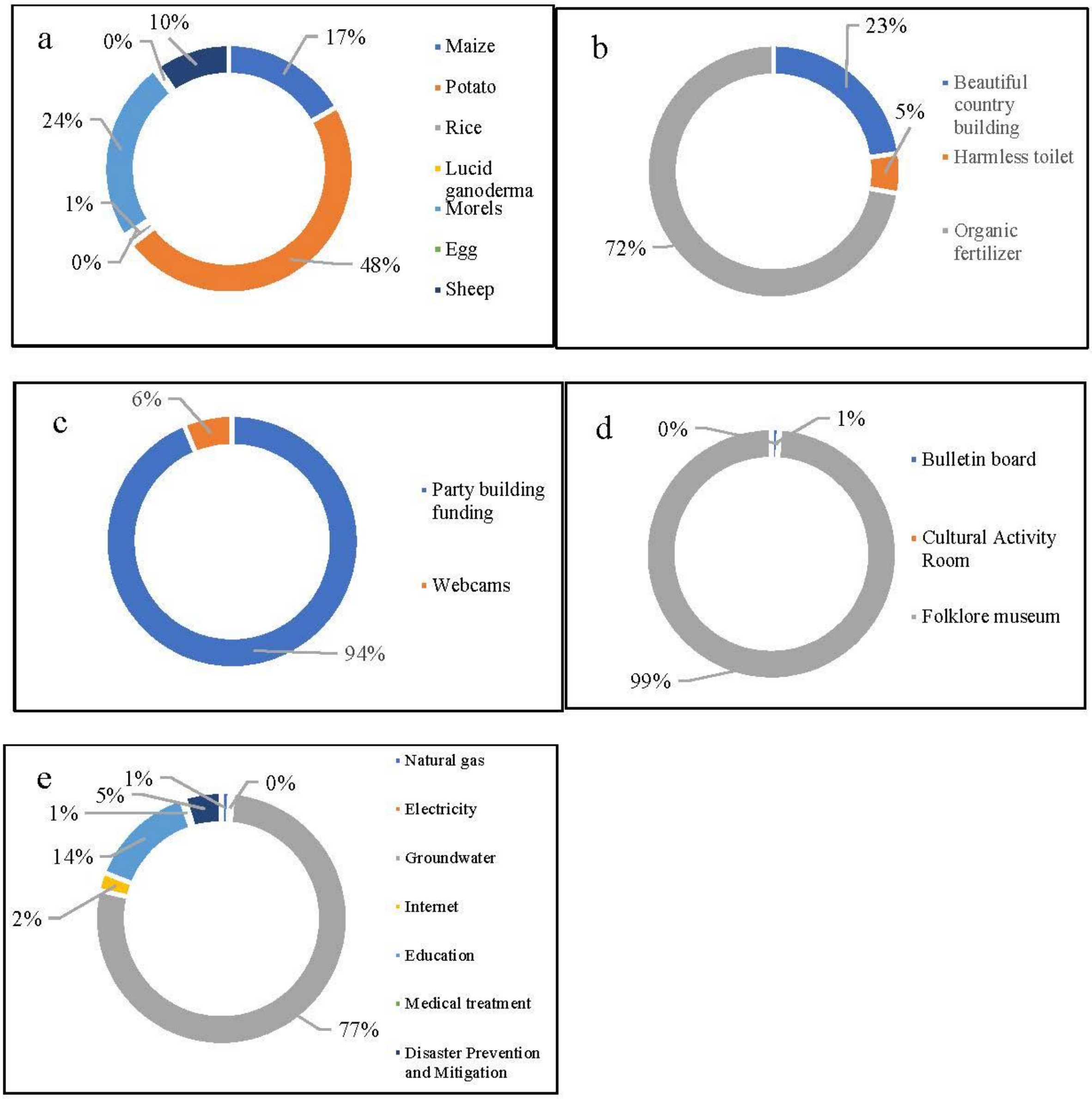

Figure 5. Structural analysis of rural revitalization of Chehe Village. Note: the subfigures is the proportion of items included in each part, (**a**) is the industrial economy; (**b**) is the ecologically livable; (**c**) is the rural governance; (**d**) is the social civilization; (**e**) is the rich life.

Industrial economy mainly included agricultural products in renewable resources, such as maize, potato, rice, lucid Ganoderma, morels, egg, and sheep (Figure 5a). Potatoes accounted for the highest proportion as 48% due to its high production. However, medicinal agricultural products (lucid Ganoderma and morels) created more economic values which were specially sold in organic supermarket. Beautiful county building, rural planning, harmless toilet, road hardening, domestic waste disposal, centralized water supply, organic fertilizer, pesticide and mulch were involved in the ecologically livable (Appendix A). All items were converted from invest funds into emergy. Organic fertilizer input had the highest proportion for 72% in 2019 and there were no pesticide and mulch input because of organic agricultural construction. The construction of beautiful villages continued for 50 years, so this study averaged the construction funds to 50 years. Therefore, the construction of beautiful villages accounted for 23%, which included rural planning, road hardening, domestic waste disposal, and centralized water supply (Figure 5b). The beautiful county building project was invested by the government. Harmless toilet made up

5% of the whole items, which was invested by Lingqiu County Chehe Organic Agriculture Comprehensive Development Co., Ltd. (Datong, China). Rural governance contained party building funding and webcams, which used to carry out rural governance work (Figure 5c). In rural China, excellent traditional culture needs to be inherited and developed, and thus, bulletin board, cultural activity room, and folklore museum were built to promote social civilization and harmony (Figure 5d). Folklore museum costs much more money than others, which could attract a lot of visitors every year. Rich life included natural gas, electricity, groundwater, coal, Internet, education, medical treatment, pension, and disaster prevention and mitigation, which are closely related to people's lives. Natural gas took place of coal in the Chehe Village, and the village had no pension agency. Groundwater occupied 77% in all items. In addition, Chehe Village had completed the task of poverty alleviation, and realized that there was no need to worry about food and clothing, and guarantee the conditions of housing, medical care, and education. Therefore, the villagers had a high degree of security for basic materials of life, which was shown in the Figure 5e.

4. Discussion

4.1. Sustainability and Poverty Alleviation Measures of Chehe Village

China's poverty alleviation measures included developing local industry, education programs, health programs, ecological protection programs, relocation, and government subsidies for low-income households, etc. Chehe Village was a typical demonstration village in Lingqiu County (a national poverty-stricken county) [54,55]. Under the poverty alleviation measures and the rural revitalization strategy, Chehe Village carried out the construction of full-scale organic agriculture, building the entire village into an organic agricultural community, including agricultural production, small-scale agricultural products processing, catering, retail (organic product supermarket), and eco-tourism. These measures not only increased farmers' income, but also increased imports. EYR declined and ELR increased, mainly due to the imports increasing, which were in accordance with urban metabolic of Xining city [33]. The decrease of ESI indicates that the sustainable development level of Chehe Village declined from the year of 2012 to 2019, indicating external resources input also temporarily improved farmer's income, but were unsustainable and affect the development adversely.

The government purchases publicity boards for the construction of traditional culture and spiritual civilization, and builds activity rooms for villagers' leisure and entertainment, which improved the civilization and harmony of the village. The construction of beautiful villages and the construction of toilets had greatly improved the cleanliness of the village. The allocation of party building funds and the increase in the number of village cameras ensured the effective government affairs of the village and the safety of the villagers. Moreover, the government's investment in medical care and the Internet has guaranteed the basic lives of the people.

4.2. Advantages of Chehe Operation Mode

A variety of rural industry development models had emerged in China to alleviate poverty and increased income. For example, the Diqing Tibetan Autonomous Prefecture in Yunnan Province has developed eco-tourism routes based on its unique "natural protection forest," which instead of the traditional single way asked for the product to provide value [56]; Poyang Lake area combines ecological agriculture, ecological industry, and ecological tourism to carry out diversified operations [57]. The poverty-stricken areas of Enzhou City, Hubei Province summarized three poverty alleviation mechanisms: agricultural ecological resource development-based poverty alleviation, agricultural ecological environment compensation-based poverty alleviation, and agricultural system function integration poverty alleviation mechanisms [58]. However, the poverty alleviation development model pays more attention to economic growth and lacks investment in rural environmental governance and spiritual civilization construction.

Chehe Village not only implemented industrial integration in the construction of full-scale organic agriculture, but also reduced pollution during the construction of beautiful villages, optimized the environment, made the neighborhood harmonious, and attracted foreign workers to return to work (Figure 4). Apart from this, Chehe model integrated the whole village together including land and farmers to extend industry and promote spiritual civilization, which was the biggest difference from other villages. The changes mostly were conductive to ecotourism, and the results were consistent with previous research [59]. Moreover, residents in Chehe Village have confidence with its dwelling environment which was consciously protected by each person and emphasized by government. Some residents working in the village were full of happiness for women who not only increased income but also took care children and the old. Men could live in the village with a decent income. Therefore, the Chehe model achieved sustainable development in economic, ecological, and social aspects, and was a new rural development model under the rural revitalization strategy.

4.3. Policy Suggestions

Based on the results of this study and reality factors of Chehe Village, we put forward a series of policy recommendations to achieve a higher degree of sustainable development in the economic, ecological, and social aspects.

First, protecting natural resources. Renewable resources are the basic elements that affect sustainability in system metabolism, showing that the higher the renewable resources, the higher the sustainability. However, renewable emergy ratio declined from 0.04 in 2012 to 0.03 in 2019 of Chehe Village and renewable resources invested could be ignored. Located in an ecologically fragile area, Chehe Village should pay more attention to the exploitation and utilization of renewable resources, as well as the protection and rational use.

Second, increasing trade and eco-tourism. While relying on local resources for development and construction, the presence of government and corporate funds provides advantageous conditions for the sustainable development of Chehe Village. Emergy exchange ratio increased indicating the import was much more than export. At the same time, trade between the local and the outside should be increased, focusing on the development of eco-tourism projects to attract tourists, and increasing income by means of tickets and organic agricultural products. Improving tourism innovation raises the demand expectations of tourists and indirectly promotes tourism revenue [60]. Moreover, the economic growth achieved by relying on external capital investment is not sustainable (ESI has decreased), and the endogenous development of the village needs to be dependent on industrial development.

Third, strengthening publicity and reporting. Enhance communication between Chehe Village and the media and promote the publicity of brand culture in the village through activities. Use the activities of the National Agricultural Science Sub-practice Alliance to establish cooperative relations with universities and increase the publicity of the Chehe model in the form of scientific research papers. Apart from this, increasing publicity can also enhance farmers' awareness of being masters, starting from themselves, and promoting the sustainable development of the village.

5. Conclusions

Poverty alleviation and rural revitalization strategies in China are conducive to address the problems of escaping poverty and realizing sustainable development, which are the biggest challenges in the global scale, especially rural ecosystem. The new model in China rural formed under the strategies can promote farmers' income, but whether they will affect the ecological environment of the rural ecosystem and whether farmers' well-being will be effectively improved remain to be determined. Additionally, most previous research focused on the effectiveness of single measure for rural sustainable development, while the influence of new rural management model under all countermeasures with a comprehensive perspective is lacking. Therefore, evaluating the level of rural sustainable development is particularly important after the poverty alleviation and rural revitalization strategy are put forward. This paper took Chehe Village, a new model village in poverty stricken county, to analyze the rural ecosystem sustainability and rural development structure before and after the organic agriculture construction (poverty alleviation measures) using traditional emergy indicators and indexes constructed in this paper. In addition, we put "government funds" of poverty alleviation measures into "imported resources" during rural development and constructed new factors to analyze the rural ecosystem metabolic process, metabolic efficiency, and structure of rural development.

It was found that system sustainability and system metabolic efficiency had been improved. The emergy consumption per unit of GDP has decreased from 1.30×10^{14} sej/$ to 3.99×10^{13} sej/$. Both of the per capita emergy value and the emergy value per unit area increased, indicating that the standard of living had greatly improved. These changes benefited from the great achievement of the new model and government policies carried out in poverty alleviation and rural revitalization. In addition, industrial economy were especially highly valued in Chehe Village. Increasing ecological resource protection, enhancing trade, improving publicity are the focus of the next step to improve. In conclusion, it is feasible to add countermeasures of poverty alleviation and rural revitalization into the rural ecosystem metabolism. Although "Chehe Model" can produce greater economic benefits and improve farmers' living standards, it cannot meet the requirements of rural sustainable development in longtime. Therefore, rural development needs to rely on exogenous power to promote endogenous development to promote sustainable development.

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Appendix A

Table A1. Items of emergy accounting of Chehe Village in the year of 2012 and 2019.

Items	Raw Data		Unit	UEV (Sej/Unit)	Emergy (Sej)		Reference
	2012	2019			2012	2019	
R							
Sun	5.80×10^{14}	5.83×10^{14}	J	1.00×10^{0}	5.80×10^{14}	5.83×10^{14}	Ulgiati, 2016
Wind	4.16×10^{12}	5.04×10^{12}	J	7.90×10^{2}	3.29×10^{15}	3.98×10^{15}	Ulgiati, 2016
Rain	5.02×10^{13}	5.43×10^{13}	J	1.28×10^{4}	6.42×10^{17}	6.95×10^{17}	Ulgiati, 2016
R_1							
Maize	8.00×10^{7}	3.50×10^{7}	g	1.84×10^{11}	1.47×10^{19}	6.45×10^{18}	Odum, 1996
Potato	0	1.00×10^{8}	g	1.84×10^{11}	0	1.84×10^{19}	Odum, 1996
Rice	0	1.80×10^{6}	g	1.84×10^{11}	0	3.32×10^{17}	Odum, 1996
Lucid ganoderma	0	3.20×10^{5}	g	3.09×10^{11}	0	9.88×10^{16}	Lan, et al., 2002
Morels	0	2.25×10^{7}	g	3.09×10^{11}	0	6.95×10^{18}	Lan, et al., 2002
Egg	0	5.11×10^{4}	kg	8.84×10^{12}	0	4.52×10^{17}	Ulgiati, 2016
Meat	0	1.25×10^{5}	kg	1.93×10^{13}	0	2.41×10^{18}	Ulgiati, 2016
N							
Topsoil loss	4.51×10^{11}	4.51×10^{11}	J	9.40×10^{4}	4.24×10^{16}	4.24×10^{16}	Brandt-Williams, 2002
Groundwater	3.44×10^{7}	3.58×10^{7}	kg	4.96×10^{11}	1.71×10^{19}	1.77×10^{19}	Ulgiati, 2016

Table A1. *Cont.*

Items	Raw Data		Unit	UEV (Sej/Unit)	Emergy (Sej)		Reference
	2012	2019			2012	2019	
Electricity	4.19×10^{11}	4.36×10^{11}	J	2.21×10^{5}	9.26×10^{16}	9.63×10^{16}	Ulgiati, 2016
IMP							
Natural gas	0	4.50×10^{4}	m^3	5.36×10^{12}	0	2.41×10^{17}	Ulgiati, 2016
Fertilizer	2.18×10^{7}	2.00×10^{8}	g	6.28×10^{9}	1.37×10^{17}	1.26×10^{18}	Han, 2019
Pesticide	1.20×10^{4}	0	$	2.58×10^{12}	3.09×10^{16}	0	Brandt-Williams, 2002
Mulch	2.81×10^{3}	0	$	2.58×10^{12}	7.24×10^{15}	0	Brandt-Williams, 2002
Seeds	1.37×10^{10}	4.89×10^{9}	J	8.41×10^{4}	1.16×10^{15}	4.11×10^{14}	Odum et al., 2000
Coal	1.75×10^{8}	0	g	5.81×10^{4}	1.02×10^{13}	0	Brown et al., 2011
Diesel	2.08×10^{4}	2.20×10^{4}	kg	6.12×10^{12}	1.27×10^{17}	1.35×10^{17}	Ulgiati, 2016
Bulletin board	0	1.55×10^{2}	$	2.58×10^{12}	0	3.99×10^{14}	Ulgiati, 2016
Cultural Activity Room	0	1.55×10^{1}	$	2.58×10^{12}	0	3.99×10^{13}	Ulgiati, 2016
Other input	0	1.55×10^{4}	$	2.58×10^{12}	0	3.99×10^{16}	Ulgiati, 2016
Party building funding	0	6.96×10^{3}	$	2.58×10^{12}	0	1.79×10^{16}	Ulgiati, 2016
Webcams	0	4.64×10^{2}	$	2.58×10^{12}	0	1.20×10^{15}	Ulgiati, 2016
Beautiful country building	0	6.19×10^{3}	$	2.58×10^{12}	0	1.59×10^{16}	Ulgiati, 2016
Rural planning	0	0	$	2.58×10^{12}	0	0	Ulgiati, 2016
Harmless toilet	0	1.39×10^{3}	$	2.58×10^{12}	0	3.59×10^{15}	Ulgiati, 2016
Road hardening	0	0	$	2.58×10^{12}	0	0	Ulgiati, 2016
Domestic waste disposal	0	0	$	2.58×10^{12}	0	0	Ulgiati, 2016
Centralized water supply	0	0	$	2.58×10^{12}	0	0	Ulgiati, 2016
Medical treatment	1.67×10^{3}	1.67×10^{3}	$	2.58×10^{12}	4.31×10^{15}	4.31×10^{15}	Ulgiati, 2016
Internet	0	8.36×10^{3}	$	2.58×10^{12}	0	2.15×10^{16}	Ulgiati, 2016
Education	0	0	$	2.58×10^{12}	0	0	Ulgiati, 2016
Pension	0	0	$	2.58×10^{12}	0	0	Ulgiati, 2016
Disaster Prevention and Mitigation	0	1.70×10^{4}	$	2.58×10^{12}	0	4.38×10^{16}	Ulgiati, 2016
Investment in poverty alleviation	0	3.87×10^{2}	$	2.58×10^{12}	0	9.97×10^{14}	Ulgiati, 2016
Agricultural subsidies	1.26×10^{4}	1.26×10^{4}	$	2.58×10^{12}	3.24×10^{16}	3.24×10^{16}	Ulgiati, 2016
Science and technology contribution	0	4.64×10^{2}	$	2.58×10^{12}	0	1.20×10^{15}	Ulgiati, 2016
Invested funds by government or company	1.42×10^{4}	7.11×10^{4}	$	2.58×10^{12}	3.67×10^{16}	1.83×10^{17}	Ulgiati, 2016
Labor	0	6.55×10^{10}	J	5.73×10^{6}	0	3.75×10^{17}	Brandt-Williams, 2002
Tourism income	0	1.45×10^{4}	$	2.58×10^{12}	0	3.74×10^{16}	Ulgiati, 2016
EXP							
Maize	6.40×10^{7}	2.80×10^{7}	g	1.84×10^{11}	1.18×10^{19}	5.16×10^{18}	Odum, 1996
Rice	0	1.80×10^{6}	g	1.84×10^{11}	0	3.32×10^{17}	Odum, 1996
Lucid ganoderma	0	3.20×10^{5}	g	3.09×10^{11}	0	9.88×10^{16}	Lan, et al., 2002
Morels	0	2.25×10^{7}	g	3.09×10^{11}	0	6.95×10^{18}	Lan, et al., 2002
Egg	0	5.11×10^{4}	kg	8.84×10^{12}	0	4.52×10^{17}	Ulgiati, 2016
Meat	0	1.25×10^{5}	kg	1.93×10^{13}	0	2.41×10^{18}	Ulgiati, 2016
Labor	1.32×10^{11}	9.07×10^{10}	J	5.73×10^{6}	7.58×10^{17}	5.20×10^{17}	Brandt-Williams, 2002
W							
Domestic wastewater	3.67×10^{5}	3.82×10^{5}	Gallon	6.65×10^{11}	2.44×10^{17}	2.54×10^{17}	Lan, et al., 2002
Domestic garbage	3.21×10^{11}	3.34×10^{11}	t	1.36×10^{6}	4.38×10^{17}	4.55×10^{17}	Lan, et al., 2002

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