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Evaluation of the sustainability of Hakka villages in the Lui–Tui area of Taiwan via emergy analysis

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Abstract The traditional Hakka spirit of Taiwan gives the impression of a frugal people who believe in the virtue of hard work, in their relationship with the land and in environmental stewardship. This study contrasts the ecological economic systems of Hakka and non-Hakka villages in the Lui–Tui area in southern Taiwan, and the features of and changes in the development of diverse Hakka villages in the area from the view of ecological economics through emergy analysis methods. The study found that from the 1920s to the 2010s, there were significant differences in environmental sustainability between Hakka and non-Hakka villages in the Lui–Tui area. Hakkas knew how to make good use of environmental resources and properly allocate external economic resources. There were few differences among the Hakka villages, in particular the right militia, former militia and rear militia. Over half a century, Hakkas in the Lui–Tui area used their resources more efficiently. In terms of energy usage density, there was no significant difference between Hakka and non-Hakka villages in the 1920s; however, in the 1970s non-Hakka villages had greater density than Hakka villages.

Keywords Emergy analysis · Lui–Tui Hakka village · Ecological economics · Emergy index

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1 Introduction

Faced with climate change and the escalating threat of greenhouse effect, sustainable development has become a global campaign. Ecosystem planning is being applied to urban and rural planning, and sustainable community and eco-settlement is becoming the goal of local business development.

Hakka is a derivative of Han ethnicity. The Hakka people were Han people who migrated south to the border area of Fujian, Guangdong and Jiangxi Provinces during the late Tang and early Song dynasties. Under the Qing Dynasty, in the southeast coastal provinces of Mainland China, there were too many people with limited fertile land; there was also a rice shortage. A group of Hakka ancestors from the Guangdong Province moved to the Gaoping River Plain, forming a community of 13 large and 64 small villages. The word "Lui–Tui" was introduced when organizations recruited more than 8000 young men and divided them into center, left, right, former, rear and forward militias (in the Hakka dialect, "Tui" and "Militia" are homophones), to assist the government in fighting civil disorder and to defend Lui–Tui Hakka territory.

Over a thousand years of migration and development, Hakka people experienced conflict, adjustment and integration with their environment. They learned to live in harmony with the land, to make good use of natural resources and to choose a hospitable living environment. Hakka understood symbiosis with the environment and how to make the best use of geographical conditions. A Hakka village is not only site for traditional food, language, folklore, songs, but also a place to inherit and pass on Hakka culture. Again, Hakka emphasize mutualism between the village and water, symbiosis of the Hakka group and the environment, and thus the formation of a Hakka human–geographic landscape.

International environmental resource utilization strategies have focused on the promotion of sustainable communities (Gouzee and Eeckhout 1999; Shmelev 1999), improvement in the relationship between human activities and the natural environment (i.e., thinking globally and acting locally). However, there will be a problem if this concept is used to evaluate the development of Hakka settlements. In the past, economic research methodologies were used in studies of settlements and communities (i.e., to evaluate the environmental cost on humans by currency value); however, the value of environmental systems often cannot be measured in monetary terms. More recently, the prices of raw materials, agricultural products and fossil fuels have been rising due to growing demand from developing countries. Was the true value of resources underestimated in the past? Can money reflect the actual value of fossil fuels and water resources? On the one hand, an ecological method cannot provide a way to fully understand the significance of the ecosystem in human activities. On the other hand, ecological research methodologies stress the environmental assessments of ecosystems, ignoring the impact and feedback of human and settlement development on the ecosystem, thus making it difficult to explore the real impact on the environment.

In summary, to evaluate whether a region uses its resources in a sustainable way, and whether a settlement makes good use of resource symbiosis, a different method of evaluation is required. The field of ecological economics seems to offer a comprehensive evaluation of urban and rural ecosystems. In view of this, this study, through emergy analysis, and from the perspective of ecological economics, evaluates the evolution of the ecosystem of Hakka villages, as the way in which the Hakka are environmental stewards, and how they wisely allocate external economic resources.

Although very little direct evidence on this issue is currently forthcoming, it is possible to contribute further insights into the comprehensive understanding of the Hakka ancestors' use of their environmental resources and the ecological characteristics of Hakka villages and agriculture. Thus, contributing to the problem is the lack of understanding of environmental resources and ecological economics by different cultures.

In order to understand the Hakka ancestors' use of their environmental resources and the ecological characteristics of Hakka villages and agriculture, this study focuses on the Japanese colonial period in the 1920s, 1970s and 2010s, when Taiwan's settlements had yet to become highly urbanized and industrialized. We study the evolution and characteristics of economic systems between Hakka and non-Hakka villages in the Lui–Tui area and among different militias. Does the Hakka village emphasize agricultural development? Is the way that the Hakka use environmental resources more sustainable? Is the frugality of the Hakka reflected in their pattern of settlement development?

2 Ecological economics and emergy analysis

2.1 Ecological economics

The terms "ecology" and "economics" are both derived from the Greek word *Oikos*. Ecology focuses on problems and the management of nature, and economics on those of human society. Both disciplines require discussions of a complex system, but environmental and economic policies have tended to be mutually exclusive in the long term (Huang 1991). Unlike traditional economics and ecology, ecological economics explores the interactions between the environment and the economy by taking a broad, long-term view. Given that the monetary system does not include the value of nature, energy is recommended for use as a common unit of evaluating the relations between the human economic system and the ecological system.

Based on Lotka's theory (1925), the ecologist Howard T. Odum posited the maximum power principle to explain the structure and function of an ecosystem: A system that can maximize the flow of its useful energy will outperform other systems. Odum's energy-building methods include the self-design principle, meaning building the feedback mechanism and autocatalytic reaction on the energy illustration that he designed (see Fig. 1). In this way, we can explore the role of a biological system in energy utilization and the development of an ecosystem, through its self-design function, and can improve the efficiency of energy utilization, gather more information and establish the symbiosis of different components of the system (Huang 2002, pp. 192–193).

In order to compare the contribution and impact of forms of energy contained by the molecular components of a system, Odum argued that the quantity of a type of energy is contained by another type of energy-flow storage (Huang and Odum 1991; Odum 1988a). In the 1960s, ecological planning and design entered a stage of expansion and interdisciplinary integration. Odum's *Fundamentals of Ecology* (date) laid the cornerstone of ecosystem theory. The theory contends that every ecosystem has its own energy-flow mode, which corresponds to its system structure. All flows originate from solar energy and successively distribute energy to the organisms throughout the system via photosynthesis. In 1989, Odum updated the textbook *Ecology and Our Endangered Life Support System*, stating that the analysis of energy has become part of the core structure of the ecosystem.

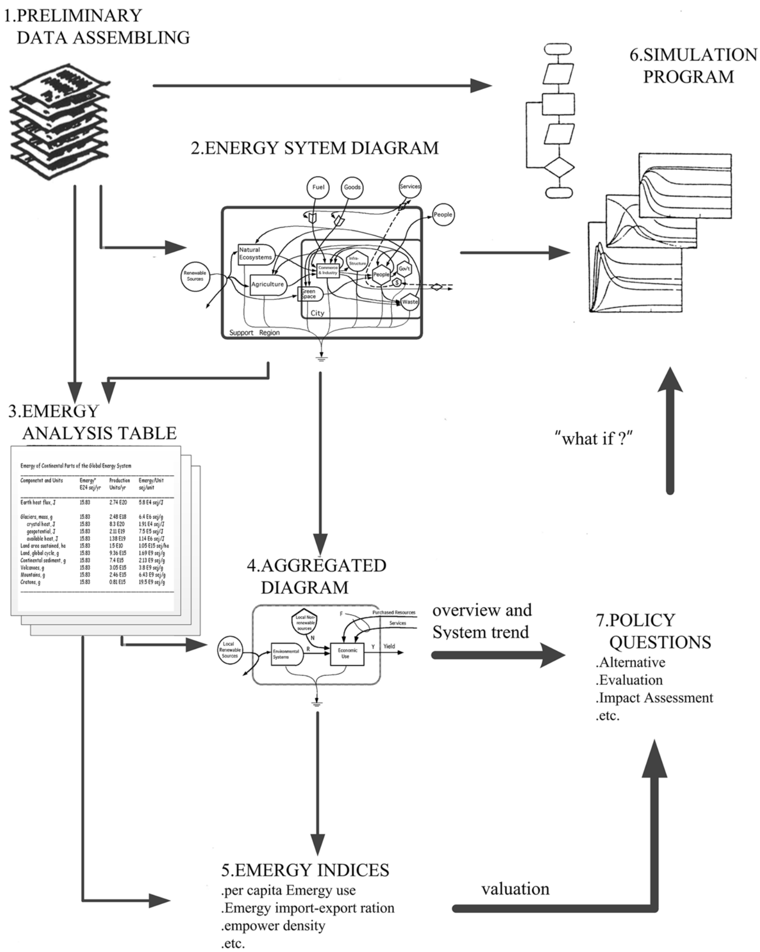

Fig. 1 Emergy analysis step. *Source*: Huang and Odum (1991, p. 193)

In this core structure, based on ecological economics, using general system theory and the laws of thermodynamics, a set of energy illustrations was designed (Wu et al. 2015). Through energy analysis, urban economic wealth was estimated on the basis of energy complex systems and emergy (Campbell and Garmestani 2012; Dang and Liu 2012; Wu et al. 2014; Zhao et al. 2014). Energy language is used to study the interactions between creatures and non-creatures and even between human beings and the natural environment (Hossaini and Hewage 2013; Sharmaa et al. 2016; Wijitkosum 2016). It establishes a conceptual ecosystem through illustrations, assisting researchers in understanding the operative process of system components and sub-elements, and then proposing appropriate policies.

2.2 Emergy analysis

"Emergy" converts various types of energy in a system to the same unit for comparison (Pulselli 2009; Zhang et al. 2011). The energy quality of components in an ecosystem can be compared and measured through conversion into a standard quantization unit (Günther 2001; Gasparatos 2010). According to the theory of emergy, transformity can be used to represent the quality of different types of energy in a hierarchical system, defined as the amount a type of energy required to generate an energy unit of another type. The higher the level of component or function in the ecosystem, the higher the transformity, and vice versa. This is because, within system operation, energy is not only a quantity; energy contains comparisons of energy quality, meaning that the functions and the quality of energy in a system are different on each level.

Emergy is the virtual monetary value of resources, including the virtual value of solar energy. The most basic solar energy is used as the quantity representing the circulation of money, to illustrate the relationship between human and nature and between the environment and the economy, with the unit being solar emjoules (sej). Emergy is defined as "the quantity of a type of energy, contained by another type of energy-flow storage" (Odum 1988b). Its purpose is to make various types of energy flow or to store energy, to reflect their contribution to the system (Huang 1991).

According to the concept of emergy, transformity can be used to represent the energy quality of different energy types in a hierarchical system, defined as the quantity of a type of energy required to generate an energy unit of another type. The energy of various storage or functions multiplied by the solar transformity equals the solar emergy contained by the storage or function. The conversion method is as follows:

$$\text{Solar Emergy} = \text{Energy} \times \text{Transformity}$$

The higher the level of components or functions in the ecosystem, the higher the level of transformity. That is because in the process of system operation, energy is not only a quantity, but, more importantly, contains a comparison of energy quality. This means that the functions and the quality of the energy in a system are different on each level (Huang 1993). Solar transformity is defined as the solar energy required to form 1 Joule of a certain type of energy, the unit of which is solar emjoule/joule (sej/j). The calculation formula is:

$$\text{Solar Transformity of Energy A} = \text{Solar Emjoule used/1 Sej of Energy A}$$

For example, in the process of system energy flow, 159,000 joules of solar energy must be consumed to generate 10.3 joules of rain energy. We calculated the solar transformity of rain energy to be 1.54 E4 sej/j; in other words, each joule of rain energy contains 15,400 units of solar emergy. As shown in Fig. 1, there are six steps when applying emergy analysis in the discussion of the ecological economic characteristics in an area (Cheng 2011; Huang and Odum 1991). Emergy can convert various types of energy in a system to the same unit for purposes of comparison.

In the early 1980s, academics started to use emergy analysis to discuss sustainable urban development and environmental quality evaluation. Since 1986, the emergy analysis method created based on ecological economics has matured into a theory. Relevant papers have been published by Ferreyra and Brown (2007), case studies on sustainable development by Cheng (2011), research on spatial organization and urban development by Huang (2004), Huang et al. (2011) and Cheng (2011). Because dynamic interactions among components of the ecosystem can be understood through computer simulations, and with the assistance of geographic information systems, the distribution of emergy analysis in a geographical space reflects the relations with the urban economic system (Wu et al. 2015). It is more widely used in urban development and regional governance, such as the relationship between a river and changes in urban development (Huang et al. 2011), space simulation of land resources (Huang et al. 2012; Wang et al. 2012), studies of the impact on urban ecological economic system by changes in the global environment and land use around urban areas (Huang et al. 2010; Wang et al. 2012; Table 1).

2.3 Ecological economic system modeling

Using Odum's energy illustration, this study will organize the flow data of types of energy, socioeconomic conditions and characteristics of the natural environment to construct a conceptual ecological economic system in the Lui–Tui Hakka area. The following characteristics are considered in the construction process: (1) the main components of the ecological economic system; (2) the functions and roles of the components; and (3) the relationship with the external world of the components. Different types of energy are ranked according to their hierarchal level, and clockwise from bottom to top, and from left to right.

2.3.1 *Standardized land-use numerical image data*

This study collected numerical image data of land use in the 1920s, 1970s and 2010s. The original unit of each type of energy is regarded as the calculation basis of spatial energy flow. This study performs standardization when estimating various types of land-use emergy and then follows the research steps to achieve the research objectives of this study.

2.3.2 *Simplified land-use ecological economic system model*

This study divides the ecological economic system model in Fig. 2 into three types of lands—natural, agricultural and architectural—and then estimates based on the inputs and outputs of the energy type. For example, in the natural environment, only renewable resources inputs such as solar, wind and rain energy (e.g., potential energy, chemical energy) are calculated. Agricultural land, in addition to the renewable resources of natural environment, includes groundwater or surface water, fertilizer, fossil fuel, electricity and other goods and services required in the production process. Outputs are based on the agricultural products produced in agricultural sub-systems.

Table 1 Emergy analysis table. *Sources*: Odum et al. (1987) and Huang and Odum (1991)

Item	Flows of materials labor and energy (units/year)	Solar transformities—solar emjoules per joule (sej/unit)	Solar emergy (sej)	em$ value* (1970 US$)

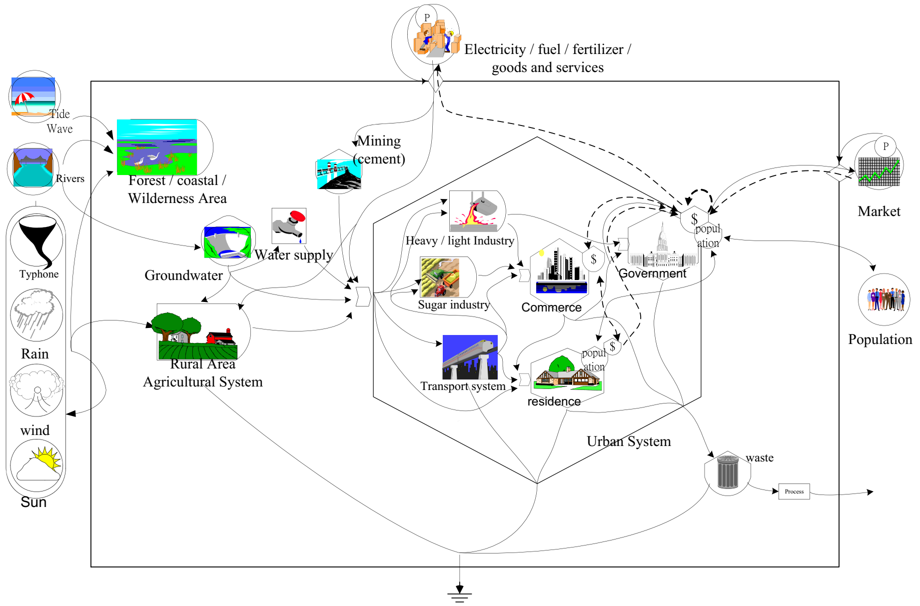

Fig. 2 Ecological economic system of a Hakka village

2.4 Emergy index evaluation

Taiwan had experienced Japanese occupation for 50 years, and modern science and civilization was introduced for researching Taiwanese local resources and finishing 1/25,000 ordnance survey map of Taiwan as well. Thus, these set up accurate observational data, detailed statistics and township governance of socioeconomic status each year. The present study has used of the aforementioned data and numerical estimation of land-use map by Kriging method in geographic information system and spatial analysis to carry out research into the natural environment of number systems and then convert the Japanese official statistics districts (villages) input and output analysis of urban and rural socioeconomic situation (Cheng 2015). Thus, all inputs were converted into emergy values either via original emergy calculations or by using previously calculated unit emergy values which relate input flows in the inventory to emergy values (Odum 1996).

The emergy index is a series of emergy indicators established by Odum and colleagues through the study of the earth effect viewpoint. The emergy index is used as the measurement of interactions between the natural environment and human economic systems, and through the result shown by the emergy index, we can understand the living standard and the real value of the natural environment in the system. Therefore, the emergy index is used as a basis for public policy. The establishment and estimation of the emergy index is used to examine and test the system characteristics in emergy analysis. The symbolic importance of a different emergy index is reflected in the study of different calculations and interpretations. The emergy index selected for this study will assist in explaining resource utilization in the agricultural land-use changes in Lui–Tui Hakka villages, in addition to the relationship between energy characteristics of the settlements and their interactions with the system. In general, the analysis of ecosystem emergy mostly converts numerical data calculated from various types of energy flow in the system components into the following types of energy indices. The emergy index is divided into five types: structure of emergy source (01 renewable emergy ratio, 02 non-renewable emergy ratio, 03 self-sufficient emergy ratio), energy intensive and density (04 emergy intensity, 05 emergy concentrated ratio, 06 electricity of total emergy ratio), the exchange relations of resources (07 emergy exchange ratio, 08 emergy self-sufficiency ratio), emergy efficiency of production inputs (09 environmental loading ratio, net emergy yield ratio, 11 emergy investment ratio) and sustainable development (12 ecological footprint, 13 emergy sustainable index, 14 emergy index for sustainable development); see Table 2 for their meaning and calculation methods.

3 Data analysis and research findings

The difference of Hakka and non-Hakka villages is that Hakka villages have been largely shaped by the new environment which they had to alter many aspects their culture to adapt, which helped influence their architecture and cuisine. When the Hakka expanded into areas with preexisting populations in the south, there was often little agricultural land left for them to farm. Thus, the self-defense against attack from outside is their cultural virtue that they cherish generation after generation. Hakkas villages are on the whole more independent, daring and prone to act than native non-Hakka villages (Cheng 2015; Kiang 1991).

Below is a brief analysis on the emergy index meaning of the sustainable development of different Hakka villages in the Lui–Tui area in the 1920s, 1970s and since 2010, the difference between Hakka and non-Hakka villages, among Hakka villages and the difference in the emergy index of Hakka village over the past 90 years.

3.1 Emergy index evaluation

Tables 3, 4 and 5 show differences in the emergy index of ecological economic systems of Hakka villages in the Lui–Tui area in the 1920s, 1970s and since 2010. The characteristics of the ecological economic systems of Lui–Tui Hakka villages are analyzed according to the meaning and characteristics of the five types of emergy indices.

3.1.1 Structure of energy source

Table 3 shows that in the 1920s Hakka and non-Hakka villages in the Lui–Tui area did not differ much in terms of renewable and non-renewable emergy ratio and self-sufficient emergy ratio. Table 4 shows that these three indices of non-Hakka villages decreased significantly, and resource utilization also moved toward being less sustainable. However, compared to 1970s, Table 5 shows that under sustainable development and global change in the common market, both Hakka and non-Hakka villages increased their use of local resources and helped the land revert to its natural environment.

Table 2 Evaluation methods and the meaning of emergy indices for Hakka ecological economic system. *Source*: Upgraded and revised from Huang (2004: 80) and (Lu et al. 2002)

No	Emergy indices	Calculation	Indices significance	Sustainable trends
Structure of energy source				
01	Renewable emergy ratio	Renewable resources/total emergy	Judge the contribution of renewable resources in the region	Positive
02	Non-renewable emergy ratio	Non-renewable emergy ratio	Judge the contribution of non-renewable resources in the region	–
03	Self-sufficient emergy ratio	Self-sufficient resources/total emergy	Judge the contribution of self-sufficient resources in the region	Positive
Energy intensive and density				
04	Emergy intensity	Total emergy/area	Reflect the intensity of development	Negative
05	Emergy concentrated ratio	Emergy intensive/emergy extensive	Judge the concentrated emergy in the region	Negative
06	Electricity of total emergy ratio	Total electricity/total emergy	Reflect the relative intensity of development	Negative
The exchange relations of resources				
07	Emergy exchange ratio (EER)	Buyer purchased energy/paid money to obtain equivalent energy value ratio	Emergy exchange ratio by different markets or cultures	–
08	Emergy self-sufficiency ratio (ESR)	Self-sufficient resources/industrial output	To evaluate the local input in the system	Positive
Emergy efficiency of production inputs				
09	Environmental loading ratio (ELR)	Input (purchase) emergy/renewable resources	Determine environmental loading capacity	Negative
10	Net emergy yield ratio (EYR)	Input (purchase) emergy/self-sufficient resources	Determine natural environment usage in economic system is economic or not	–
11	Emergy investment ratio (EIR)	Yield emergy/input (purchase) emergy	Determine resources usage is economic or not	Positive
Sustainable development				
12	Ecological footprint	Total emergy/subsistence emergy	Determine how to maintain the standard of living in the urban region	Negative
13	Emergy sustainability index	EYR/ELR	To assessment a region is sustainable or not	Positive
14	Emergy index for sustainable development (EISD)	EYR*EER/ELR	Judge the contribution of system in the human society and economy is sustainable or not	Positive

Table 3 Emergy indices of Hakka village non-village ecological economic system during the 1920s

Item	Emergy indices	Hsien Feng Tui (forward militia)	You Tui (right militia)	Chien Tui (former militia)	Chung Tui (center militia)	Hou Tui (rear militia)	Tso Tui (left militia)	Non-Hakka village
A	Structure of energy source							
1	Renewable emergy ratio	0.0740	0.1088	0.0994	0.0840	0.0632	0.1020	0.0900
2	Non-renewable emergy ratio	0.1819	0.3520	0.2028	0.2044	0.1681	0.2881	0.1898
3	Self-sufficient emergy ratio	0.2559	0.4608	0.3022	0.2884	0.2313	0.3901	0.2798
B	Energy intensive and density							
4	Emergy intensity	4.39E+18	3.06E+18	2.51E+18	3.47E+18	4.75E+18	4.49E+18	4.39E+18
5	Emergy concentrated ratio	0.2139	0.1143	0.1307	0.1708	0.2481	0.1038	0.2185
6	Electricity of total emergy ration	0.0069	0.0002	0.0005	0.0013	0.0077	0.0002	0.0160
C	The exchange relations of resources							
7	Emergy exchange ratio, EER	4.8641	1.4898	5.1907	4.9839	7.9237	4.5755	0.1484
8	Emergy self-sufficiency ratio, ESR	0.7330	1.8853	1.1827	0.7432	0.9426	1.4428	1.4554
D	Emergy efficiency of production inputs							
9	Environmental loading ratio (ELR)	0.4549	0.2057	0.3239	0.3872	0.5521	0.1797	0.3890
10	Net emergy yield ratio (EYR)	10.3660	10.9218	7.9359	11.9254	7.0363	14.7492	5.4912
11	Emergy investment ratio (EIR)	0.1316	0.0486	0.1065	0.1128	0.1508	0.0470	0.1251
E	Sustainable development							
12	Ecological footprint	0.64155	0.34219	0.47420	0.67441	0.51921	0.44309	0.45634
13	Emergy sustainability index	22.7850	53.1044	24.4975	30.7976	12.7441	82.0837	14.1154
14	Emergy index for sustainable development, EISD	110.8281	79.1128	127.1591	153.4929	100.9797	375.5739	2.0948

Table 4 Emergy indices of Hakka village non-village ecological economic system during the 1970s

Item	Emergy indices	Hsien Feng Tui (forward militia)	You Tui (right militia)	Chien Tui (former militia)	Chung Tui (center militia)	Hou Tui (rear militia)	Tso Tui (left militia)	Non-Hakka village
A	Structure of energy source							
1	Renewable emergy ratio	0.0498	0.0486	0.0194	0.0266	0.0212	0.0414	0.0067
2	Non-renewable emergy ratio	0.2167	0.3158	0.0472	0.0921	0.0631	0.1753	0.0131
3	Self-sufficient emergy ratio	0.2664	0.3644	0.0666	0.1187	0.0844	0.2167	0.0198
B	Energy intensive and density							
4	Emergy intensity	7.03E+18	7.60E+18	1.45E+19	1.13E+19	1.49E+19	9.52E+18	6.26E+19
5	Emergy concentrated ratio	1.0496	1.0679	1.9205	1.9078	2.1025	1.8476	7.8141
6	Electricity of total emergy ration	0.0101	0.0112	0.0157	0.0131	0.0147	0.0111	0.0273
C	The exchange relations of resources							
7	Emergy exchange ratio (EER)	23.8044	5.2960	10.1305	15.4636	22.9621	21.3071	0.3269
8	Emergy self-sufficiency ratio (ESR)	1.7017	3.7621	0.8423	0.8828	0.8924	2.2563	0.9222
D	Emergy efficiency of production inputs							
9	Environmental loading ratio (ELR)	2.0923	1.8127	4.2898	4.1255	4.3802	3.4393	12.8399
10	Net emergy yield ratio (EYR)	1.5033	1.1000	0.9497	1.2267	1.0162	0.6741	0.2487
11	Emergy investment ratio (EIR)	0.3909	0.2416	1.2501	0.9235	1.1027	0.6575	4.3608
E	Sustainable development							
12	Ecological footprint	0.3674	0.1985	0.3875	0.5657	0.5666	0.2226	0.4889
13	Emergy sustainability index	0.7185	0.6068	0.2214	0.2973	0.2320	0.1960	0.0194
14	Emergy index for sustainable development, EISD	17.1032	3.2138	2.2426	4.5979	5.3273	4.1762	0.0063

Table 5 Emergy indices of Hakka village non-village ecological economic system during the 2010s

Item	Emergy indices	Hsien Feng Tui (forward militia)	You Tui (right militia)	Chien Tui (former militia)	Chung Tui (center militia)	Hou Tui (rear militia)	Tso Tui (left militia)	Non-Hakka village
A	Structure of energy source							
1	Renewable emergy ratio	0.0361	0.0581	0.0156	0.0199	0.0178	0.0355	0.0200
2	Non-renewable emergy ratio	0.5676	0.5483	0.0247	0.0483	0.0840	0.2510	0.1140
3	Self-sufficient emergy ratio	0.6037	0.6064	0.0404	0.0682	0.1017	0.2865	0.1340
B	Energy intensity and density							
4	Emergy intensity	1.12E+19	6.65E+18	2.01E+19	1.77E+19	2.08E+19	1.23E+19	2.42E+19
5	Emergy concentrated ratio	13.1027	10.8429	38.3404	25.9000	40.6257	15.0612	42.6373
6	Electricity of total emergy ration	0.0637	0.0776	0.1182	0.1580	0.1210	0.0933	0.3390
C	The exchange relations of resources							
7	Emergy exchange ratio (EER)	91.4673	21.4970	18.8583	71.9335	39.4801	51.0354	0.7168
8	Emergy self-sufficiency ratio (ESR)	0.9446	0.8920	0.0528	0.1480	0.1035	0.3690	0.2127
D	Emergy efficiency of production inputs							
9	Environmental loading ratio (ELR)	23.8243	17.3025	72.8087	47.7606	74.8110	26.0885	60.9058
10	Net emergy yield ratio (EYR)	0.7432	0.6764	0.6708	0.4852	0.7394	0.8390	0.5172
11	Emergy investment ratio (EIR)	1.4245	1.6573	28.2218	13.9263	13.0649	3.2301	9.0920
E	Sustainable development							
12	Ecological footprint	0.34925	0.49589	0.80935	0.64861	1.43385	0.54224	1.26873
13	Emergy sustainability index	0.0312	0.0391	0.0092	0.0102	0.0099	0.0322	0.0085
14	Emergy index for sustainable development, EISD	2.8533	0.8404	0.1737	0.7307	0.3902	1.6414	0.0061

3.1.2 Energy intensity and density

In terms of energy intensity and density, forward and rear militias were similar to non-Hakka villages, with relatively high density. In terms of electricity of total emergy ration, all six militias were lower than non-Hakka villages, showing that their living standards (quality) were more rural.

3.1.3 The exchange relations of resources

Emergy exchange ratio indicates the opening of settlement system and its impact on the external world. Data in the two tables show that in the 1920s or 1970s, all Hakka villages had higher emergy exchange ratios than non-Hakka villages in the Lui–Tui area, showing better efficiency in resource output and utilization. There were few differences between Hakka and non-Hakka villages in the emergy self-sufficiency ratio. After 2010, in both the Hakka and non-Hakka villages in the Lui–Tui area, local input in the system decreased greatly and depended more on outside resources.

3.1.4 Emergy efficiency of production inputs

From the perspective of system economic inputs efficiency, in the 1920s less economic activity was affecting the natural environment of Hakka villages. In the 1970s, rear militia, forward militia and non-Hakka villages faced increasing environmental loads. In terms of net emergy yield ratio, the energy inputs and internal non-renewable resources of Lui–Tui Hakka village areas were far higher than internal renewable resources, showing that the economic development benefits of all militias in the Hakka village area were higher than those in non-Hakka villages. Since 2010, the environmental loading capacity of all villages was under great pressure.

3.1.5 Sustainable development of Hakka villages

It is not feasible to assess the differences between Hakka and non-Hakka villages in the Lui–Tui area by ecological footprint in the 1920s and 1970s, and it is still inaccurate to assess the sustainability of a place based on its ecological footprint. Using Emergy Index for Sustainable Development (EISD) to reflect the sustainable development emergy index of the contribution the system has made to human society; it is obvious that the Lui–Tui Hakka villages are more sustainable than non-Hakka villages.

3.2 Difference analysis of Lui–Tui Hakka village emergy indices

3.2.1 Difference analysis of Hakka and non-Hakka villages in the 1920s

The analysis of results in Table 6 shows that in the 1920s, Hakka and non-Hakka villages had significant differences in 9 out of 14 indices—non-renewable emergy ratio, self-sufficient emergy ratio, emergy intensity, emergy concentrated ratio, emergy exchange ratio, environmental loading ratio (ELR), emergy investment ratio (EIR), ecological footprint, and emergy index for sustainable development.

Among these indices, Hakka villages were higher than non-Hakka villages in non-renewable emergy ratio and self-sufficient emergy ratio, indicating that Hakka village areas

Table 6 Difference analysis of Hakka and non-Hakka villages in the 1920s

Item	Emergy indices	Average		Standard deviation		T value	p value
		Non-Hakka village	Hakka village	Non-Hakka village	Hakka village		
Structure of energy source	Renewable emergy ratio	0.114	0.110	0.139	0.101	0.315	0.753
	Non-renewable emergy ratio	0.186	0.243	0.160	0.146	−3.757	0.000**
	Self-sufficient emergy ratio	0.300	0.353	0.249	0.212	−2.407	0.017*
Energy intensive and density	Emergy intensity	1168.708	1090.632	917.953	372.827	1.708	0.089
	Emergy concentrated ratio	1.702	0.985	6.523	1.114	3.191	0.001*
	The exchange relations of resources	0.006	0.002	0.015	0.006	5.663	0.000**
The exchange relations of resources	Emergy exchange ratio (EER)	47,099.799	596.909	291,987.520	1367.824	5.279	0.000**
	Emergy self-sufficiency ratio, ESR	6.655	2.154	89.748	4.150	0.514	0.608
Emergy efficiency of Production inputs	Environmental loading ratio (ELR)	1.585	0.424	6.927	0.390	5.468	0.000**
	Net emergy yield ratio(EYR)	32.205	30.997	195.357	144.957	0.062	0.951
	Emergy investment ratio (EIR)	0.449	0.119	1.577	0.126	6.706	0.000**
Sustainable development	Ecological footprint	14.068	0.837	34.480	0.534	12.705	0.000**
	Emergy sustainability index	10,445.302	10,752.331	180,956.869	78,281.597	−0.017	0.986
	Emergy index for sustainable development, EISD	280,750.881	53,867.082	888,234.017	312,483.100	5.528	0.000**

* $p < 0.05$, ** $p < 0.01$

relied more on renewable resources, and less on external resources, and were more self-sufficient than non-Hakka villages.

In emergy intensity, emergy concentrated ratio, emergy exchange ratio, environmental loading ratio, emergy investment ratio, ecological footprint and emergy index for sustainable development, non-Hakka villages were higher than Hakka villages, indicating that the capacity of Hakka villages' natural environment for economic activities, and the investment process of Hakka villages was more economical. Moreover, the ecological economic system of Hakka villages made a better contribution to society by having characteristics of sustainable development.

3.2.2 Analysis of different militias in Lui–Tui area in the 1920s

By adopting Scheffe's method, we know that in the 1920s, the militias in Lui–Tui had significant differences in 3 out of 14 indices (see Table 7)—emergy concentrated ratio, environmental loading ratio and emergy investment ratio. In emergy concentrated ratio, rear militia was higher than the right, left and former militias. In environmental loading ratio, rear militia was higher than left militia. In emergy investment ratio, the rear militia was higher than the right and left militias. Among the six militias, the rear militia was under greater environmental pressure, and its resource utilization was less economical.

3.2.3 Analysis of Hakka and non-Hakka villages in the 1970s

A comparison of Hakka and non-Hakka villages in the 1970s reveals significant differences in 9 out of 14 emergy indices (Table 8)—non-renewable emergy ratio, self-sufficient emergy ratio, emergy intensity, emergy concentrated ratio, the exchange relations of resources, emergy exchange ratio, environmental loading ratio, emergy investment ratio and ecological footprint.

Among these indices, Hakka village areas were higher than the non-Hakka in non-renewable emergy ratio and self-sufficient emergy ratio, indicating that the ecological economic system of Hakka villages relied more on local resources and was more self-sufficient. In emergy intensity, emergy concentrated ratio, the exchange relations of resources, emergy exchange ratio, environmental loading ratio, emergy investment ratio and ecological footprint, non-Hakka areas were higher than Hakka areas, indicating that non-Hakka areas had higher emergy utilization density, higher development intensity and greater environmental ecological pressure and that resource utilization was less economical.

3.2.4 Analysis of different militias in the Lui–Tui area in the 1970s

In the 1970s, the militias in Lui–Tui (Table 9) had significant differences in 6 out of 14 emergy indices—renewable emergy ratio, non-renewable emergy ratio, self-sufficient emergy ratio, emergy self-sufficiency ratio, environmental loading ratio and emergy investment ratio.

In renewable emergy ratio, non-renewable emergy ratio and self-sufficient emergy ratio, right militia was higher than former militia, showing that right militia used more local resources, and there were more local resources in its ecological economic system. In the emergy self-sufficiency ratio, center and former militias were higher than the right militia, indicating that the resource inputs in their ecological economic systems were more local. In

Table 7 Difference analysis of different militias in the 1920s

Emergy indices	Average						F value	p value	Post hoc tests (Scheffe's method)
	1. Chung Tui (center militia)	2. You Tui (right militia)	3. Tso Tui (left militia)	4. Hsien Feng Tui (forward militia)	5. Chien Tui (former militia)	6. Hou Tui (rear militia)			
Renewable emergy ratio	0.086	0.157	0.104	0.087	0.097	0.067	2.196	0.061	
Non-renewable emergy ratio	0.222	0.320	0.241	0.216	0.206	0.170	3.085	0.013*	–
Self-sufficient emergy ratio	0.308	0.477	0.345	0.304	0.304	0.237	3.782	0.004*	–
Emergy intensity	1210.362	1025.301	1289.882	1311.135	921.415	1204.187	3.330	0.008*	–
Emergy concentrated ratio	0.802	1.443	1.132	0.875	0.506	0.916	2.412	0.042*	–
The exchange relations of resources	0.001	0.000	0.000	0.001	0.001	0.007	3.948	0.003*	6 > 2 = 3 = 5
Emergy exchange ratio (EER)	353.051	289.304	256.510	169.970	1406.964	412.373	2.931	0.017*	–
Emergy self-sufficiency ratio (ESR)	0.805	3.946	1.386	1.205	1.788	1.227	1.871	0.106	
Environmental loading ratio (ELR)	0.422	0.364	0.225	0.376	0.411	0.627	3.123	0.012*	6 > 3
Net emergy yield ratio (EYR)	13.881	75.423	17.372	16.193	8.188	7.973	0.854	0.515	
Emergy investment ratio (EIR)	0.117	0.088	0.077	0.104	0.118	0.180	4.234	0.002*	6 > 2 = 3
Ecological footprint	0.613	0.763	0.892	0.666	0.970	0.849	1.431	0.220	
Emergy sustainability index	42.204	3,5147.084	213.667	44.850	21.199	18.282	0.876	0.500	
Emergy index for sustainable development, EISD	10,265.348	142,506.407	42,258.410	5414.966	18,373.393	5946.601	0.680	0.640	

* $p < 0.05$

Table 8 Difference analysis of Hakka and non-Hakka villages in the 1970s

Item	Emergy indices	Average		Standard deviation		*T* value	*p* value
		Non-Hakka village	Hakka village	Non-Hakka village	Hakka village		
Structure of energy source	Renewable emergy ratio	0.03	0.04	0.06	0.03	−1.850	0.065
	Non-renewable emergy ratio	0.06	0.16	0.11	0.17	−5.574	0.000**
	Self-sufficient emergy ratio	0.09	0.20	0.15	0.19	−5.660	0.000**
Energy intensive and density	Emergy intensity	39,151.44	1740.91	77,825.19	2519.27	15.849	0.000**
	Emergy concentrated ratio	53.64	4.22	119.93	4.49	13.561	0.000**
	The exchange relations of resources	0.02	0.01	0.02	0.01	8.848	0.000**
The exchange relations of resources	Emergy exchange ratio (EER)	3057.75	389.07	16,817.92	550.70	5.231	0.000**
	Emergy self-sufficiency ratio (ESR)	16.74	2.49	452.61	3.77	0.323	0.747
Emergy efficiency of production inputs	Environmental loading ratio (ELR)	54.23	4.65	101.34	4.89	16.025	0.000**
	Net emergy yield ratio (EYR)	0.92	1.27	2.14	0.85	−1.669	0.095
	Emergy investment ratio, EIR	23.27	1.42	51.76	2.50	13.824	0.000**
Sustainable development	Ecological footprint	372.33	12.28	797.81	42.75	14.741	0.000**
	Emergy sustainability index	7.13	0.63	173.73	0.88	0.383	0.702
	Emergy index for sustainable development, EISD	2771.58	149.71	42,218.11	200.28	0.636	0.525

* $p < 0.05$, ** $p < 0.01$

environmental loading ratio, right militia was higher than former militia, meaning that the right militia had greater capacity of environmental loads, with its input emergy indices obviously higher than the environmental bearing capacity. In emergy investment ratio, former militia was higher than right militia, indicating that former militia used resources more economically.

3.2.5 Analysis of Hakka and non-Hakka villages in since 2010

Table 10 shows that in the 2010s, comparisons between Hakka and non-Hakka villages, 9 of 14 indexes have a significant difference, particularly in emergy intensity. On the one

Table 9 Difference analysis of different militias in Lui–Tui area in the 1970s

Emergy indices	Average						*F* value	*p* value	Post hoc tests (Scheffe's method)
	1. Chung Tui (center militia)	1. Chung Tui (center militia)	1. Chung Tui (center militia)	1. Chung Tui (center militia)	1. Chung Tui (center militia)	1. Chung Tui (center militia)			
Renewable emergy ratio	0.035	0.054	0.045	0.053	0.022	0.029	4.285	0.001*	2 > 5
Non-renewable emergy ratio	0.135	0.263	0.156	0.202	0.055	0.089	6.146	0.000**	2 > 5
Self-sufficient emergy ratio	0.170	0.318	0.201	0.255	0.077	0.118	7.125	0.000**	2 > 5
Emergy intensity	1091.63	1188.79	1040.17	892.97	3196.20	1926.04	3.021	0.014*	–
Emergy concentrated ratio	3.209	4.401	3.352	2.516	5.690	3.432	1.150	0.339	
The exchange relations of resources	0.011	0.011	0.012	0.010	0.015	0.013	1.821	0.116	
Emergy exchange ratio (EER)	319.278	224.415	350.838	297.541	688.796	300.519	2.566	0.032*	–
Emergy self-sufficiency ratio (ESR)	0.890	4.624	3.602	2.342	1.043	0.879	4.692	0.001*	1 = 5 > 2
Environmental loading ratio (ELR)	4.330	2.817	3.582	2.252	7.919	5.040	4.605	0.001*	2 > 5
Net emergy yield ratio (EYR)	1.619	1.338	0.844	1.752	1.087	1.193	2.010	0.084	
Emergy investment ratio (EIR)	1.008	0.595	0.997	0.510	3.036	1.378	3.857	0.003*	5 > 2
Ecological footprint	4.071	3.883	3.241	3.529	33.862	8.888	2.074	0.075	
Emergy sustainability index	0.752	0.892	0.257	0.853	0.413	0.498	1.569	0.176	

Table 9 continued

Emergy indices	Average						F value	p value	Post hoc tests (Scheffe's method)
	1. Chung Tui (center militia)	1. Chung Tui (center militia)	1. Chung Tui (center militia)	1. Chung Tui (center militia)	1. Chung Tui (center militia)	1. Chung Tui (center militia)			
Emergy index for sustainable development, EISD	177.626	177.736	75.208	183.822	145.840	91.132	0.726	0.606	

* $p < 0.05$; ** $p < 0.01$

Table 10 Difference analysis of Hakka and non-Hakka villages in the 2010s

Item	Emergy indices	Average		Standard deviation		*T* value	*p* value
		Non-Hakka village	Hakka village	Non-Hakka village	Hakka village		
Structure of energy source	Renewable emergy ratio	1.294	2.195	6.944	1.788	3.306	0.001**
	Non-renewable emergy ratio	0.038	0.127	0.113	0.188	7.222	0.000**
	Self-sufficient emergy ratio	1.332	2.335	6.954	1.850	−1.606	0.109
Energy intensity and density	Emergy intensity	82,324.621	15,691.735	86,745.501	9872.193	−7.863	0.000**
	Emergy concentrated ratio	1548.977	87.862	1907.704	199.760	−7.841	0.000**
	The exchange relations of resources	7.737	6.628	9.099	3.292	−1.241	0.215
The exchange relations of resources	Emergy exchange ratio (EER)	347,990.142	6883.569	8,064,182.092	8611.337	−1.001	0.317
	Emergy self-sufficiency ratio (ESR)	0.469	0.224	8.969	0.237	−0.645	0.519
Emergy efficiency of production inputs	Environmental loading ratio (ELR)	1601.439	110.059	1899.355	217.919	−8.038	0.000**
	Net emergy yield ratio (EYR)	1.080	1.568	0.892	2.658	4.126	0.000**
	Emergy investment ratio, EIR	208.389	29.847	359.772	62.293	−5.076	0.000**
Sustainable development	Ecological footprint	537.429	26.943	696.250	92.050	−7.504	0.000**
	Emergy sustainability index	0.030	0.135	0.242	0.473	3.807	0.000**
	Emergy index for sustainable development, EISD	148.764	186.709	621.264	336.226	0.844	0.400

* $p < 0.05$, ** $p < 0.01$

hand, the emergy concentrated ratio shows the difference between Hakka and non-Hakka villages. On the other hand, in the emergy efficiency of production inputs ELR, EYR and EIR have significant differences. Hakka villages were shown to show more sustainable development.

3.2.6 Analysis of different militias in the Lui–Tui area in since 2010

Table 11 shows a significant difference among villages, especially former and right militia, since 2010. Former militia is near urbanized non-Hakka villages, so in terms of development, former militia had developed unsustainably and relied more on outside resources. However, right militia had used local resources. Thus, in terms of the intensity of resource use, former militia is higher than others.

3.2.7 Analysis of the 1920s and 1970s

Tables 6, 8 and 10 show that from the 1920s to since 2010, Hakka and non-Hakka villages differed greatly in emergy intensity and emergy index for sustainable development. In the 1920s, there was no significant difference between Hakka and non-Hakka villages in emergy intensity, but in the 1970s non-Hakka areas had a higher emergy intensity than Hakka areas. Emergy density is used to assess the intensity of an area's energy utilization—the higher the emergy density, the more economic activity, and in the 1970s, non-Hakka areas were rapidly developing. In the emergy index for sustainable development, there was a significant difference between Hakka and non-Hakka villages in the 1920s with non-Hakka groups higher than Hakka groups. However, in the 1970s there was no obvious difference, reflecting the contribution the ecological economic system of Hakka villages made to human society. Thus, Hakka villages were more sustainable in their development.

From the 1920s to the 1970s, there were obvious differences among Lui–Tui Hakka villages in terms of renewable emergy ratio, non-renewable emergy ratio, self-sufficient emergy ratio, emergy self-sufficiency ratio, environmental loading ratio and emergy investment ratio.

In renewable emergy ratio, non-renewable emergy ratio and self-sufficient emergy ratio, the militias had no significant differences in the 1920s, but in the 1970s right militia was higher than former militia. In emergy self-sufficiency ratio, there was no significant difference among the militias, but in the 1970s center and former militias were higher than right militia. Self-sufficient emergy refers to non-renewable resource emergy and renewable emergy, which are intensively and extensively used in the system, meaning that the emergy provided to the area's development depends less on external energy inputs. The development of center and former militias depended more on external energy inputs than right militia.

In emergy concentrated ratio, there was a significant difference among the militias in the 1920s—rear militia was higher than the right, left and former militias. However, in the 1970s there was no obvious difference among all militias. The emergy concentrated ratio is used to reflect the development degree of an area and people's living standards—the higher the value, the higher the development degree and people's living standards in an area. Therefore, in the 1970s, development and living standards were similar among militia. In environmental loading ratio, there was a significant difference among the militia in the 1920s—rear militia was higher than left militia. However, in the 1970s right militia was higher than former militia. The bearing capacity of environmental loads changed, and the environmental development of right militia was greater than former militia. In emergy

Table 11 Difference analysis of different militias in Lui–Tui area in the 2010s

Emergy indices	Average						*F* value	*p* value	Post hoc tests (Scheffe's method)
	1. Chung Tui (center militia)	2. You Tui (right militia)	3. Tso Tui (left militia)	4. Hsien Feng Tui (forward militia)	5. Chien Tui (former militia)	6. Hou Tui (rear militia)			
Renewable emergy ratio	2.12	2.55	3.43	2.62	1.46	1.39	3.127	0.012	2 > 5
Non-renewable emergy ratio	0.06	0.24	0.13	0.27	0.02	0.06			
Self-sufficient emergy ratio	2.758	2.791	3.823	1.697	1.403	1.578	4.819	0.001	3 > 5
Emergy intensity	12,395.89	12,180.57	15,666.30	14,074.89	20,995.99	18,343.33			
Emergy concentrated ratio	58.14	38.88	20.57	25.23	211.27	74.52	3.052	0.013	5 > 1, 2, 3, 4
The exchange relations of resources	7.84	4.48	9.27	5.11	7.54	7.17	3.269	0.009	5 > 1, 2
Emergy exchange ratio (EER)	17,059.98	4402.40	6971.18	5926.55	5090.04	2946.52	3.372	0.007	5 > 2
Emergy self-sufficiency ratio (ESR)	0.19	0.41	0.26	0.35	0.06	0.11	7.128	0.000	1, 3, 5 > 2
Environmental loading ratio (ELR)	103.60	35.20	30.59	35.69	250.78	120.15	5.851	0.000	1 > 2, 5, 6
Net emergy yield ratio (EYR)	0.74	3.22	0.79	1.22	0.78	0.94	8.280	0.000	2 > 5, 6
Emergy investment ratio (EIR)	17.55	6.06	11.77	11.37	70.36	47.45	4.148	0.002	5 > 2
Ecological footprint	11.66	3.00	3.54	3.73	83.10	15.91	4.140	0.002	2 > 5
Emergy sustainability index	0.01	0.39	0.04	0.06	0.01	0.01	4.599	0.001	5 > 2
Emergy index for sustainable development, EISD	337.20	251.52	196.66	234.28	72.64	57.67	3.189	0.010	5 > 2

* $p < 0.05$; ** $p < 0.01$

investment ratio, there was a significant difference among the militias in the 1920s—rear militia was higher than right and left militias; however, in the 1970s former militia was higher than right militia. The emergy investment ratio is the ratio of emergy inputs of the economic system to the renewable emergy of the natural environment. The higher emergy investment ratio of former militia indicates that imported energy and internal non-renewable resource emergy are much higher than the internal renewable resource emergy in this area, so the natural environment tolerates a large amount of economic activity.

Hakka villages since 2010 unlike those are the 1920s or 1970s are becoming sustainable villages. Because of their geographic location, traffic network and environmental differences, former and center militias near cities were becoming unsustainable, like non-Hakka villages. Right and forward militias had maintained the village characteristics of resource use; however, they were no longer like resources and economy of use in the 1920s.

4 Discussion and conclusion

This study, through emergy analysis and from the perspective of ecological economics, evaluates the evolution and differences of the ecosystems of Hakka villages in the Lui–Tui area. The results show that in the 1920s, the Japanese colonial period, and in the 1970s the early stage of economic development, and since 2010, Lui–Tui Hakka settlements were indeed more sustainable in development than non-Hakka areas. Hakka people in the Lui–Tui area knew how to make the best use of natural resources and to properly allocate external economic resources. Thus, Hakka people were more efficient in resource utilization. The present study is consistent with some studies (Agostinho et al. 2008; Bakshi 2002; Hau and Bakshi 2004a). It can be argued that emergy analysis can provide insight into the environmental performance and sustainability of the industrial process or product. However, in an analysis of Chinese agriculture between 1980 and 2000 using emergy offers background on the emergy concept (Chen et al. 2006). Their findings show the decreasing sustainability of Chinese agriculture as it moves from traditional methods toward methods that are based on consumption of non-renewable resources.

The results of the present study have demonstrated that the spatial model can offer insights into the spatial patterns of emergy in relation to human settlement. Moreover, the types of analyses presented demonstrate that new advances in computer and GIS technology have greatly increased the potential for researching new aspects of these complex spatial patterns (Cheng 2015). Ecological footprint is a means of assessing sustainable development. If we use the ecological footprint in the 1920s, 1970s and 2010s to assess sustainability of militias in the Lui–Tui Hakka and the non-Hakka areas, it is not feasible to assess the differences. Therefore, when using the ecological footprint to evaluate the sustainability of a place, because the settlement area is used as the reference but there is great ambiguity on the territory of each militia, its estimated results are still biased (Lehtonen et al. 2016; Mooney 2016). If assessed by the contributions made by sustainability indices and response system outputs to human society, as well as the emergy indices of sustainability development, it is apparent that Lui–Tui Hakka villages were more sustainable in their development than non-Hakka villages.

There are, of course, some limitations in the approach presented in the current study. For instance, to realize the full potential of comparable results, subsequent studies should be preceded by consensus on the values for transformities that should be used to convert various forms of values into emergy values (Voora and Thrift 2010). However, the scope of the present study was necessarily limited by time and resources available. It was limited to processes and ecosystems that were operational and had some historical data. By its very nature then, the present study had to be more or less successful. Thus, conclusions that might be drawn concerning indices regarding systems that might be unsuccessful were limited.

While literature data were cross-referenced, sometimes the lack of published data resulted in educated estimates in order to carry out the evaluations. This problem was especially true for the current study. As a result of relying on data specific to only a few sites within Hakka villages, the evaluations reflect conditions found at villages, and average values for Hakka villages should be derived with caution. Moreover, computer simulation of simplified models and evaluation of empirical data might lend insight into the question of when to double the size or when to duplicate.

Although the emergy approach has a ubiquitous appeal, it has weaknesses, like many other environmental accounting methods (Hau and Bakshi 2004b). Emergy approach critics generally complain that the method: Lacks formal links with related concepts in other disciplines; lacks adequate details on the underlying methods; is computationally and data intensive; and is based on sweeping generalizations that remain unproven. Thus, using emergy to value goods and services has been criticized for ignoring one of the fundamental tenets of economics, which centers on human preference and demand (Cleveland et al. 2000).

However, the use of emergy as an indicator of resources has significant benefits since it reduces the various inputs and environmental issues (Hau and Bakshi 2004a). Yet the indices are unfamiliar to many, and wide range acceptance of the methodology is still to come. Still, since it includes not only economic inputs, but environmental inputs as well, it is more inclusive than financial analysis. However, to apply this model to particular applications, the amount of each alternative index for the application is required. To understand a benefit of sustainability to the society, the next research should focus on ecosystems and processes. Future studies should simulate and discuss other land policies. Using scenario analysis, they should investigate agricultural land issues and man-land relationships in Hakka villages.

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References

Agostinho, F., Diniz, G., Siche, R., & Ortega, E. (2008). The use of emergy assessment and the Geographical Information System in the diagnosis of small family farms in Brazil. *Ecological Modelling, 210*(1–2), 37–57.

Bakshi, B. R. (2002). A thermodynamic framework for ecologically conscious process systems engineering. *Computers & Chemical Engineering, 26*(2), 269–282.

Campbell, D. E., & Garmestani, A. S. (2012). An energy systems view of sustainability: Emergy evaluation of the San Luis Basin, Colorado. *Journal of Environmental Management, 95*(1), 72–97. doi:10.1016/j.jenvman.2011.07.028.

Chen, G. Q., Jiang, M. M., Chen, B., Yang, Z. F., & Lin, C. (2006). Emergy analysis of Chinese agriculture. *Agriculture, Ecosystems & Environment, 115*(1–4), 161–173.

Cheng, C. F. (2011). *Rescaling city-region in the age of globalization ~ Spatial and temporal transformation of Kaohsiung-Pingtung as a region* via *the emergy analysis*. Kaohsiung: Doctoral Dissertation, Department of Geography, National Kaohsiung Normal University.

Cheng, C. F. (2015). Investigating the Liudui Hakka area through National Census and Historical Maps from the Japanese Occupation via different Scales. *Journal of National Taichung University of Education, 29*(1), 1–22.

Cleveland, C. J., Kaufmann, R. K., & Stern, D. I. (2000). Aggregation and the role of energy in the economy. *Ecological Economics, 32*(2), 301–317.

Dang, X., & Liu, G. (2012). Emergy measures of carrying capacity and sustainability of a target region for an ecological restoration programme: A case study in Loess Hilly Region, China. *Journal of Environmental Management, 102*(15), 55–64. doi:10.1016/j.jenvman.2012.02.023.

Ferreyra, C., & Brown, M. T. (2007). Emergy perspectives on the Argentine economy during the twentieth century: A tale of natural resources, exports and external debt. *International Journal of Environment and Sustainable Development, 6*(1), 17–35.

Gasparatos, A. (2010). Embedded value systems in sustainability assessment tools and their implications. *Journal of Environmental Management, 91*(8), 1613–1622. doi:10.1016/j.jenvman.2010.03.014.

Gouzee, N., & Eeckhout, D. V. (1999). Sustainable cities: Problems of integrated interdisciplinary research. *International Journal of Sustainable Development, 2*(3), 358–362.

Günther, F. (2001). Fossil energy and food security. *Energy & Environment, 12*(4), 253–273.

Hau, J. L., & Bakshi, B. R. (2004a). Expanding exergy analysis to account for ecosystem products and services. *Environmental Science and Technology, 38,* 3768–3777.

Hau, J. L., & Bakshi, B. R. (2004b). Promise and problems of emergy analysis. *Ecological Modelling, 178*(1–2), 215–225.

Hossaini, N., & Hewage, K. (2013). Emergy accounting for regional studies: Case study of Canada and its provinces. *Journal of Environmental Management, 118*(30), 177–185. doi:10.1016/j.jenvman.2012.12.034.

Huang, S. L. (1991). *Ecological energetic evolution of urban system*. Taipei: Institute Graduate of Urban Planning, National Chung Hsing University.

Huang, S. L. (1993). *Comparative analysis on Taiwan's urban ecosystem and strategy development of sustainable city. Report on the results of the special research projects of the National Science State Council, Department of Executive (NSC 81-042-F-005S-501-Z)*. Taipei: Institute Graduate of Urban Planning, National Chung Hsing University.

Huang, S. L. (2002). Ecosystem theory for regional studies. *Urban and Planning, 29*(2), 187–215.

Huang, S. L. (2004). *Urban ecological economy and emergy*. Taipei: Jane's Bookstore.

Huang, S. L., Chen, Y. H., Kuo, F., & Wang, S. H. (2011). Emergy-based evaluation of peri-urban ecosystem services. *Ecological Complexity, 8,* 38–50.

Huang, S. L., Lee, Y. C., Budd, W. W., & Yang, M. C. (2012). Analysis of changes in farm pond network connectivity in the peri-urban landscape of the Taoyuan area, Taiwan. *Environmental Management, 49,* 915–928.

Huang, S. L., & Odum, H. T. (1991). Ecology and economy: Emergy synthesis and public policy in Taiwan. *Journal of Environmental Management, 32*(4), 313–333.

Huang, S. L., Yeh, C. T., & Chang, L. F. (2010). The transition to an urbanizing world and the demand for natural resources. *Current Opinion in Environmental Sustainability, 2,* 136–143.

Kiang, C. (1991). *Hakka search for a homeland*. Corry, PA: Allegheny Press.

Lehtonen, M., Sebastien, L., & Bauler, T. (2016). The multiple roles of sustainability indicators in informational governance: Between intended use and unanticipated influence. *Current Opinion in Environmental Sustainability, 18,* 1–9. doi:10.1016/j.cosust.2015.05.009.

Lotka. (1925). *Elements of physical biology*. Baltimore: Williams and Wilkins.

Lu, H.-F., Lan, S.-F., Li, L., & Peng, S.-L. (2002). Studies on emergy indices for evaluating system sustainable development property. *China Environmental Science*, *22*(4), 380–384.

Mooney, H. (2016). Editorial overview: Sustainability science: social–environmental systems (SES) research: How the field has developed and what we have learned for future efforts. *Current Opinion in Environmental Sustainability, 19,* v–xii.

Odum, H. T. (1988a). Energy, environment and public policy: A guide to the analysis of systems, UNEP Regional Seas Reports and Studies No.95. Nairobi, Kenya: UNEP.

Odum, H. T. (1988b). Self-organization, transformity, and information. *Science, 242,* 1132–1139.

Odum, H. T. (1996). *Environmental accounting*. New York: Wiley.

Odum, H. T., Odum, E. C., & Blissett, M. (1987). *Ecology and Economy: Emergy analysis and public policy in Texas*. Policy research project report #78, L. B. Johnson School of Public Affairs, University of Texas and The Office of Natural Resources, Texas Department of Agriculture, Austin.

Pulselli, R. M. (2009). Integrating emergy evaluation and geographic information systems for monitoring resource use in the Abruzzo region (Italy). *Journal of Environmental Management, 91*(11), 2349–2357.

Sharmaa, S., Sharmac, P., Khareb, M., & Kwatrad, S. (2016). Statistical behavior of ozone in urban environment. *Sustainable Environment Research, 26*(3), 142–148.

Shmelev, S. E. (1999). Sustainable cities: Problems of integrated interdisciplinary research. *International Journal of Sustainable Development, 12*(1), 4–23.

Voora, V., & Thrift, C. (2010). *Using emergy to value ecosystem goods and services*. Canada: International Institute for Sustainable Development.

Wang, S.-H., Huang, S. L., & Budd, W. W. (2012). Resilience analysis of the interaction between typhoons and land use change. *Landscape and Urban Planning, 106,* 303–315.

Wijitkosum, S. (2016). The impact of land use and spatial changes on desertification risk in degraded areas in Thailand. *Sustainable Environment Research, 26*(2), 84–92.

Wu, X. F., Chen, G. Q., Wu, X. D., Yang, Q., Alsaedi, A., Hayat, T., et al. (2015a). Renewability and sustainability of biogas system: Cosmic exergy based assessment for a case in China. *Renewable and Sustainable Energy Reviews, 51,* 1509–1524. doi:10.1016/j.rser.2015.07.051.

Wu, X. F., Wu, X. D., Li, J. S., Xia, X. H., Mi, T., Yang, Q., et al. (2014). Ecological accounting for an integrated "pig-biogas-fish" system based on emergetic indicators. *Ecological Indicators, 47,* 189–197. doi:10.1016/j.ecolind.2014.04.033.

Wu, X. F., Yang, Q., Xia, X. H., Wu, T. H., Wu, X. D., Shao, L., et al. (2015b). Sustainability of a typical biogas system in China: Emergy-based ecological footprint assessment. *Ecological Informatics, 26,* 78–84. doi:10.1016/j.ecoinf.2014.06.006.

Zhang, L. X., Ulgiati, S., Yang, Z. F., & Chen, B. (2011). Emergy evaluation and economic analysis of three wetland fish farming systems in Nansi Lake area, China. *Journal of Environmental Management, 92*(3), 683–694. doi:10.1016/j.jenvman.2010.10.005.

Zhao, G. H., Zhao, Y. S., Liu, H. H., & Lin, T. (2014). Systems optimization for the technology route to the comprehensive utilization of coal resources in China. *Energy & Environment, 25*(1), 1–11.