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The Study on Landscape Sustainability Based on Emergy Theory - A Case Study of Nanjing Green Expo Garden

Junxue Zhang[1*]

[1] School of Architecture, Southeast University, Nanjing, China Key Laboratory of Urban and Architectural Heritage Conservation, Ministry of Education, China

Email Address
zhangjunxue2017@foxmail.com (Junxue Zhang)
*Correspondence: zhangjunxue2017@foxmail.com

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Abstract:
The assessment of the green sustainability of landscapes is currently the focus of research. This article uses a new ecological assessment -emergy method to evaluate quantitatively the ecological sustainability of Nanjing Green Expo Park. The results show that the non-renewable energy value of the main plant occupies a major position, which is much higher than the amount of renewable energy. Among 18 species of plants, tulips and citrons have absolutely more energy. The values of sustainability are: ELR=289; NEYR=2.01; ESI=0.007. The results indicate that the overall environmental loading capacity of the Green Expo Park is large, the net energy production is low, and the degree of sustainable development is extremely unreasonable. Based on emergy theory, this paper discusses the sustainability assessment of the Green Expo landscape and provides a new idea for the sustainability assessment of landscapes.

Keywords:
Emergy Method, Landscape Design, Nanjing Green Expo Park, Sustainable Assessment

1. Introduction

The green assessment of the landscape is a hot and difficult point of research. From the perspective of megatrends, green and ecological sustainability are inevitable, but it is difficult to assess the ecological sustainability of landscape quantitatively.

Some scholars have done the research of landscape sustainability. Combined various disciplines including natural and human systems and landscapes, Swedish and Russian scholars tried to find the law of sustainable development based on interdisciplinary research [1,2].Terraced paddy fields have a long history in Asia and the landscape sustainability of the Terraced paddy fields have been studied by the researchers of Kyoto University. The article focuses on the relation between the single terraced landscape and the entire landscape. The result shows that the satoyama landscape can provide unique viewing experience so as to keep the traditional landscape [3,4,5]. Several research institutions in Australia and the Netherlands have compared the ecological diversity and sustainable values of Europe, especially the Austrian cultural landscape with the European landscape based on landscape pattern method [6]. As a concept, socio-ecological production landscape has been discussed by Shanghai Academy of Social Sciences and United Nations University Institute for the Advanced Study of Sustainability. They analyzes concepts based on political perspectives, involving legal, economic, and socio-cultural perspectives through understanding the underlying factors by comparing various cases in Asia and the rest of the world [7].

Research institutions such as China, the Netherlands, and Sweden have studied the fragile relationship of floods in agricultural systems based on emergy methods and landscape fragmentation methods. Floods have a close relationship with agro-ecosystems, so the establishment of a three-tiered indicator system China's region is necessary to evaluate the vulnerability of county-level agricultural fragility [8,9]. Some literatures are related with flood and landscape [10-18]. Using emergy to assess the relation between typhoon and landscape, can pose the quantitative connection [19]. The study that the relation between impervious surface and landscape metabolism based on emergy and GIS method, had been executed by Parthenope University of Naples of Italy [20,21]. Some scholars of National Taipei University have apply the method of emergy to study the fragmentation of agricultural landscape [22,23].

This paper selects the famous scenic spot-Green Expo Park in Nanjing as the research object, and uses the ecological evaluation method-emergy theory to quantitatively evaluate the ecological evaluation of Green Expo Park.

The innovation of this paper is different from the qualitative sustainable method and the quantitative method is used to evaluate it, which provides a new idea and supplement for such green sustainability research.

1.1. Basic Situation and Main Plant Species of Nanjing Green Expo Park

Nanjing Green Expo Park was established in 2005. It is a unique green theme park along the Yangtze River in Nanjing. The landscape covers an area of 77 hectares, including dozens of various types of park attractions, domestic theme parks and foreign theme parks. There are hundreds of plant species in the park and many plant species are national protected plants.

As a famous landscape garden in Nanjing city, this paper selects Nanjing Green Expo Park as the research object, aiming to evaluate its ecological sustainability. Due to the wide variety of plants in the Green Expo Park, the main plant types were extracted as the basis for the calculation of non-renewable energy values. The specific names and pictures of several plants can be seen in Table 1.

Table 1. *The main plant species in Nanjing Green Expo Park.*

1. Rudbeckia		*2. Canna*	

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3. Cinnamomum		*4. Magnolia*	
5. Yucca gloriosa		*6. Diospyros*	
7. Liriope		*8. Nymphaea*	
9. Cunninghamia		*10.Rhododen dron*	
11. Tulip		*12. Fraxinus*	
13. Metasequoia glyptostrobides		*14. Pinus Linn*	

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15. Coconut tree		*16. Hosta*	
17. Ophiopogon		*18. Hedera*	

A total of 18 plants have been selected as the basis for this calculation, including Rudbeckia, Canna, Cinnamomum, Magnolia, Yucca gloriosa, Diospyros, Liriope, Nymphaea, Cunninghamia, Rhododendron, Tulipa, Fraxinus, Metasequoia glyptostroboides, Pinus Linn, Coconut tree, Hosta, Ophiopogon and Hedera.

2. Emergy Methodology

2.1. Method Introduction

In the 1990s, based on the integration of system ecology, energy ecology and ecological economic principles, H. T. Odum developed new scientific concepts and metrics -the emergy concept and created the emergy theory and analysis method [24].

Emergy is a scientific concept and metric. The essence of emergy is the inclusion of various energy. It is assumed that any form of energy is directly or indirectly derived from solar energy. Therefore, solar energy is often used as a benchmark to measure the emergy of various energies [25]. The amount of solar energy required for any resource, product or service, is the solar emergy, which is in solar emjoules (sej).

Up to now, the theory of emergy method has developed for 30 years. Emergy theory was produced in the United States, and then spread around the world. At present, there are several major countries to study the emergy method in the world involving USA, China, Italy, UK, Spain, Norway, Canada, Japan, Sweden, Denmark, France, Brazil, etc. As the birthplace of emergy theory, the development of emergy theory has shown an extension of depth and breadth in the U.S, especially the perfection of emergy theory.

A complete emergy assessment process can be divided into 5 items, including renewable energy, nonrenewable resources, output and input resources, labor & service and output emission and system simulation part. In order to assess the sustainability of a system, first of all, the boundary conditions should be confirmed so as to apply emergy method [30]. Then on the basis of calculated procedures to get the results of assessment.

The value of Geobiosphere Emergy Baseline (GEB) is 12 E+24 sej/year that comes from research by other scholars [26].

2.2. Calculated Steps, Formulas and Indicators

2.2.1. Basic Formula [27-29]

Emergy (sej) = energy (J) × unit emergy value (sej/J)
Emergy (sej) = mass (g) × unit emergy value (sej/g)
Emergy (sej) = value ($) × unit emergy value (sej/$)

2.2.2. Relevant Ecological Indicators

Table 2. *Emergy indicators list [27-29].*

No.	Emergy indicator	Code
1	Renewable Energy	R
2	Non-renewable Energy	N
3	External input emergy	F
4	Total emergy usage	U
5	Total input emergy	I=U
6	Per capita emergy intensity	U/P
7	Unit currency emergy	U/M
8	Emergy density	U/S
9	Environmental load rate	ELR=N/R
10	Net emergy output rate	NEYR=(R+N+F)/F
11	Emergy sustainability index	ESI=NEYR/ELR

3. Results and Discussion

3.1. Renewable Emergy Calculation

Renewable resources consist of five sources of energy, including wind energy, rainwater chemical energy, rainwater gravity potential energy and earth's rotational energy. The specific calculated process is as follows:

1. Solar energy
   = (Green Expo Park area) x (Total annual solar radiation)
   = (7.7 x 10^5m^2) x (5.65 x 10^9J/m^2/yr)
   = 4.35E+15 J/yr
2. Wind energy
   = (height) x (Air density) x (Eddy diffusion coefficient) x (Wind speed gradient)^2 x (The total area)
   = (20m) x (1.23kg/m^2 x 12.95m^3/sec) x (3.39 x 10^{-3}m/sec/m)^2 x (3.154 x 10^7sec/a) x (7.7 x 10^5m^2)
   = 2.62E+13J/yr
3. Rainwater chemical energy
   = (Green Expo Park area) x Average precipitation) x (Gubs free energy of rain)
   = (7.7 x 10^5m^2) x (1.1m/yr) x (4.94J/g) x (1 x 10^6g/m^3)
   = 4.18E+12 J/yr
4. Rainwater gravity potential energy
   = (Green Expo Park area) x (average altitude) x (Average rainfall) x (Rain density) x (Gravity acceleration)
   = (7.7 x 10^5m^2) x (13m) x (1.1m/yr) x (1 x 10^6g/m^3) x (9.8m/sec^2)
   =9.81E+12J/yr
5. Earth rotation energy

= (Green Expo Park area) x (Heat flux)
= $(7.7 \times 10^5 m^2) \times (1 \times 10^6 J/m^2/yr)$
= 7.7E+11J/yr

As can be seen from Table 3, there are the proportions of the five types of emergy involving solar energy, wind energy, rainwater chemical energy, rain energy potential and earth's rotational energy in the Green Expo Park. Based on the five emergy, finally the total renewable resource is 2.43E+17sej.

Table 3. *Renewable emergy calculated result.*

No.	Item	Annual Energy Consumption (Per Year)	Unit emergy value (sej/j)	Emergy (sej)	Total emergy (sej)
1	Solar energy	4.35E+15 J	1	4.35E+15	2.43E+17
2	Wind energy	2.62E+13 J	1.5E+03	3.93E+16	
3	Rainwater chemical energy	4.18E+12 J	1.8E+04	7.52E+16	
4	Rainwater gravity energy	9.81E+12 J	1.0E+04	9.81E+16	
5	Earth rotation energy	7.7E+11 J	3.4E+04	2.62E+16	

According to the renewable emergy data in Table 3, the emergy of proportion change diagrams about five natural energy sources are obtained. As been shown in Figure 1.

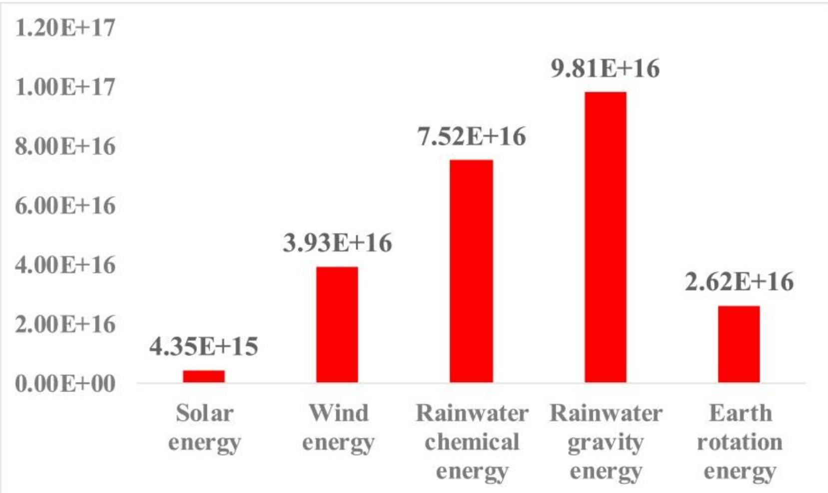

Figure 1. *Nanjing Green Expo Park renewable emergy comparison chart.*

The maximum rainwater potential emergy is 9.81E+16sej, the others include 7.52E+16sej of rainwater chemical emergy; 3.93E+16sej of rainwater chemical emergy; 2.62E+16sej of rainwater chemical emergy; 4.53E+15sej of rainwater chemical emergy.

3.2. Calculation of the Emergy of Non-Renewable Resources

Based on the collected data and the results of the survey, the compiled data are shown, including names, quantities, unit energy, and corresponding unit emergy values of the 18 major green garden plants in Table 4.

Table 4. *The calculated table of various plant emergy.*

No.	Name	Number	Unit energy (Mitchell,1975)	Unit emergy values	Emergy (sej)	Total emerg

				sej/unit (Odum,1996)		(sej)
1	Rudbeckia	1000		8.3E+04	1.45E+18	
2	Canna	300		8.3E+04	4.36E+17	
3	Cinnamomum	1500		5.3E+05	1.39E+19	
4	Magnolia	1500		8.3E+04	2.18E+18	
5	Yucca gloriosa	30		8.3E+04	4.36E+16	
6	Diospyros	40		5.3E+05	3.71E+17	
7	Liriope	1400		8.3E+04	2.03E+18	
8	Nymphaea	300		2.7E+04	1.42E+17	
9	Cunninghamia	20	1.75E+10 (Kcal/unit)	5.3E+05	1.86E+17	7.02E+19
10	Rhododendron	3		5.3E+05	2.78E+16	
11	Tulip	10		2.7E+04	4.73E+19	
12	Fraxinus	10		5.3E+05	7.05E+16	
13	Metasequoia	15		5.3E+05	1.79E+17	
14	Pinus Linn	6		5.3E+05	5.57E+16	
15	Coconut tree	15		5.3E+05	1.79E+17	
16	Hosta	200		2.7E+04	9.45E+16	
17	Ophiopogon	2000		2.7E+04	9.45E+17	
18	Hedera	2000		2.7E+04	9.45E+17	

On the basis of the data, unit energy can be obtained, so that all the emergy are calculated. However, due to the wide variety of plants and the cross -growth of various plants, it is difficult to distinguish. The number is calculated by the author on site and the data are approximate.

On the basis of Table 4, a comparison chart of the emergy of various plants in the park is obtained. In Figure 2, we can clearly see that the maximum emergy is Tulips (more than 100,000); followed by Cinnam omum. There are some plants with obvious emergy, including Magnolia, Liriope, Rudbeckia, Ophiopogon and Hedera. The remaining plant species have a small proportion of emergy.

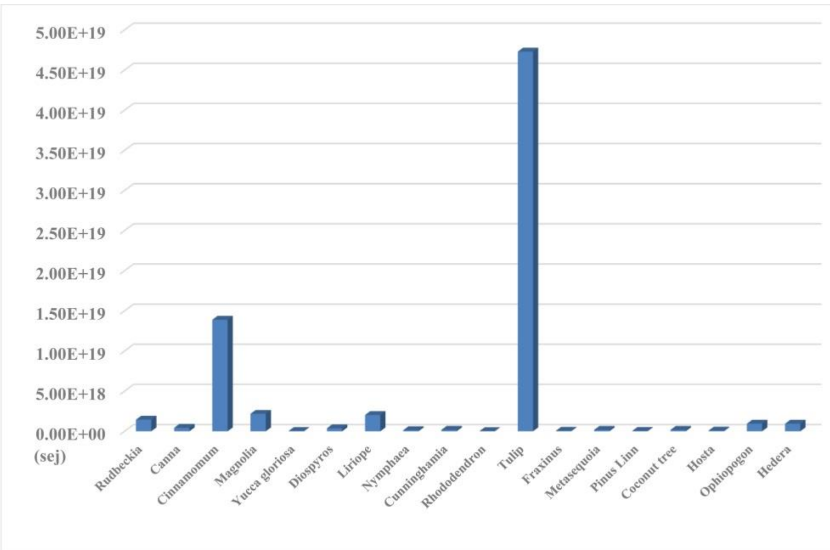

Figure 2. *Comparison of various plant emergy of Nanjing Green Expo Park.*

3.3. Evaluation of Sustainable Indexes of Nanjing Green Expo Park

Based on the collection and calculation of various plant data in Green Garden, the green sustainability assessment of Nanjing Green Expo Park can be obtained. The specific indicators are shown in Table 5.

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Table 5. *Evaluation of Sustainable Index of Nanjing Green Expo Park [30-40].*

No.	Emergy indicator	Code	Emergy	Unit
1	Renewable Energy	R	2.43E+17	sej
2	Non-renewable Energy	N	7.02E+19	sej
3	External input emergy	F	7.02E+19	sej
4	Total emergy usage	U	7.02E+19	sej
5	Total input emergy	I=U	7.04E+19	sej
6	Per capita emergy intensity	U/P	1.41E+14	Sej/person
7	Unit currency emergy	U/M	7.04E+09	Sej/money
8	Emergy density	U/S	1.42E+13	Sej/area
9	Environmental load rate	ELR=N/R	289	-
10	Net emergy output rate	NEYR=(R+N+F)/F	2.01	-
11	Emergy sustainability index	ESI=NEYR/ELR	0.007	-

Note: 1. it is estimated that 500,000 people will be visited each year. 2. Total building area 7.7E+05M2. 3. The total cost is estimated to be 1 billion yuan.

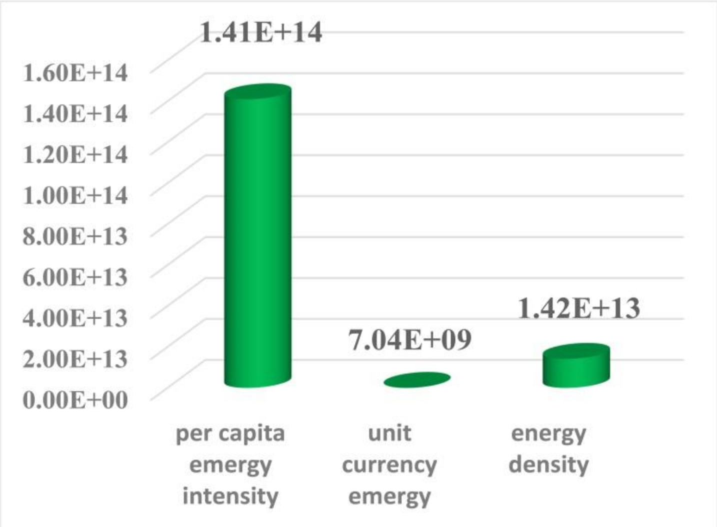

Figure 3. *The unit emergy.*

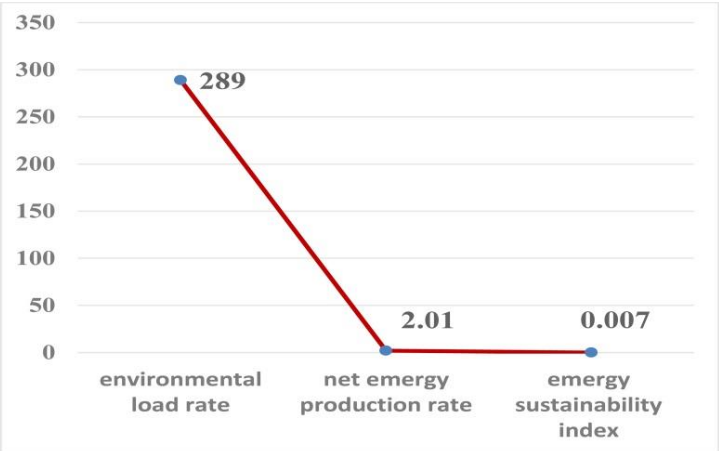

Figure 4. *Ecological Sustainable Indicators.*

The emergy index calculations are divided into two categories in Table 5. One is the unit emergy based on people, currency and area, and the analysis have been shown in Figure 3. Due to the high construction cost of the park, the unit currency emergy is the least (7.04E+09sej/money), followed by the emergy density (1.42E+13sej/area). The highest value is the per capita emergy intensity (1.41E+14sej /person).

In addition to the unit emergy indicators in Figure 3, the most important indicators have three types of ecological sustainability indicators, namely environmental load rate (ELR), net emergy production rate (NEYR) and emergy sustainability index (ESI). The three indicators represent the pressure of the environment and the ecological sustainability status of the entire assessment.

Table 6. *Sustainable indicator level.*

Level	ESI	Sustainable capacity
1	>10	Strong
2	1-10	Medium
3	0.1-10	Weak
4	0-0.1	Very weak

There are three indicators of emergy in Table 5, involving: ELR=2.21; NEYR=2.46 and ESI=1.12. As can be seen from Table 5 and Figure 4, based on the emergy method, the environmental load rate of Nanjing Green Expo Park is too high and causes unsustainability for the entire park. The net emergy production rate is small and the situation indicates that the overall non-renewable resource investments is large and have a negative influence. According to these two points, the sustainable index of Nanjing Green Expo Park is only 0.007. Based on the standard in Table 6, the sustainable development capability is in a very weak state.

3.4. Sensitivity Analysis of Various Plant Landscapes in Nanjing Green Expo Park

According to the emergy calculation of 18 plants landscape in Nanjing Green Expo Park, there several plants that account for the most emergy, such as Tulip, about 67% and others are 20%, 3%, 3%, involved with Cinnamomum, Magnolia and Liriope.

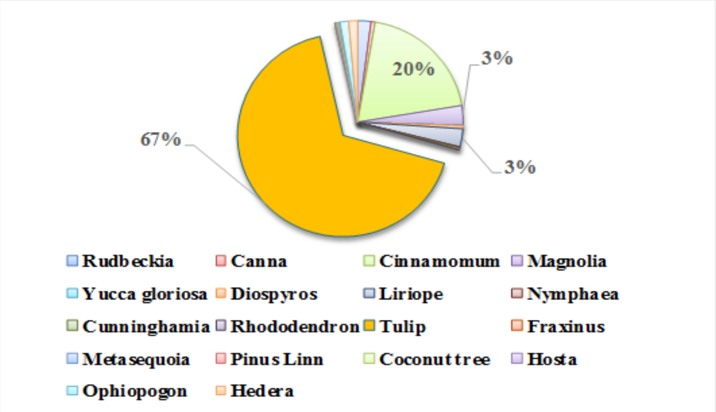

Figure 5. *Sensitivity analysis of various plant landscapes.*

Two reasons contribute to the phenomenon, including plant number and unit emergy value. Because of the insufficient statistics and regional problem of unit emergy value, sensitivity analysis should be considered carefully.

4. Conclusions

In view of the final evaluated results, it can provide a reference for government departments and park staff, and provide theoretical support for the sustainable development of Nanjing Green Expo Park. But there are also two problems that need to be improved so that the following issues can be addressed to improve the accuracy of sustainable indicators.

4.1. Complete Plant Data Collection

Because the overall area of the Green Expo Park is very large, there are many kinds of plants and it is impossible to cover all of them. In this paper, only some of the main plants are extracted and the cross-growth of plant species cause partial deviation of the data.

4.2. Evaluated Method Selection

This paper adopts the emergy method to carry out the ecological sustainability assessment of Green Expo Park. The assessment results may be quite different from other methods of assessments. By combining multiple ecological sustainability methods, more accurate sustainable indicators of the Green Expo Park will be obtained.

Conflicts of Interest

The author declares that there is no conflict of interest regarding the publication of this article.

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References

[1] Angelstam P.; Elbakidze M.; Axelsson R.; Koch NE.; Tyupenko TI.; Mariev AN.; Myhrman L. Knowledge Production and Learning for Sustainable Landscapes: Forewords by the Researchers and Stakeholders. *Ambio.* 2013, 42, 111-115.

[2] Axelsson R.; Angelstam P.; Myhrman L.; Sädbom S.; Ivarsson M.; Elbakidze M.; Andersson K.; Cupa P.; Diry C.; Doyon F.; Drotz MK.; Hjorth A.; Hermansson JO.; Kullberg T.; Lickers FH.; McTaggart J.; Olsson A.; Pautov Y.; Svensson L.; Törnblom J. Evaluation of multi-level social learning for sustainable landscapes: Perspective of a development initiative in Bergslagen, Sweden. *Ambio.,* 2013, 42(2), 241-53, DOI: 10.1007/s13280-012-0378-y.

[3] Katsue Fukamachi. Sustainability of terraced paddy fields in traditional satoyama landscapes of Japan. *Journal of Environmental Management,* 2017, 202, 543-549.

[4] Takeuchi, K.; Ichikawa, K.; Elmqvist, T. Satoyama landscape as socialecological system: historical changes and future perspective. *Curr. Opin. Environ. Sustain.,* 2016, 19, 30-39.

[5] Kurotaki, S.; Sugawara, Y.; Ogawa, S. Conservation of traditional “rice terraces” and the significance of environmental rejuvenation from the viewpoint of biodiversity. *J. Okhotsk Bus. Sci.,* 2014, 23(1), 63-77.

[6] Christa Renetzeder, etc. Can we measure ecological sustainability? Landscape pattern as an indicator for naturalness and land use intensity at regional, national and European level. *Ecological Indicators,* 2010, 10(1), 39-48.

[7] Hongyan Gu; Suneetha M. Subramanian. Drivers of Change in Socio-Ecological Production Landscapes: Implications for Better Management. *Ecology and Society,* 2014, 19(1), 1-13.

[8] Feng Wu, etc. Assessing agricultural system vulnerability to floods: A hybrid approach using emergy and a landscape fragmentation index. *Ecological Indicators*, 2017, DOI: https://doi.org/10.1016/j.ecolind.2017.10.050.

[9] Adade, R.; Nyarko, B.K.; Aheto, D.W.; Osei, K.N. Fragmentation of wetlands in the south eastern coastal savanna of Ghana. *Reg. Stud. Mar. Sci.*, 2017, 12, 40-48.

[10] Chang, L.F.; Huang, S.L. Assessing urban flooding vulnerability with an emergy approach. *Landscape Urban Plann.*, 2015, 143, 11-24.

[11] Guo, E.L.; Zhang, J.Q.; Sun, Z.Y.; Lan, W.U.; Zhu, M. A Review of Agricultural Flood Risk Assessment, the Meeting of Risk Analysis. Council of China Association for Disaster Prevention, 2014.

[12] Jenkins, K.; Surminski, S.; Hall, J.; Crick, F. Assessing surface water flood risk and management strategies under future climate change: insights from an Agent-Based Model. *Sci. Total Environ.;* 2017, 595, 159-168.

[13] Liu, J., Shi, Z.W. Quantifying land-use change impacts on the dynamic evolution of flood vulnerability. *Land Use Policy Int. J. Covering Aspects Land Use.*, 2017, 65, 198-210.

[14] Zhang, G.; Huo, Z.; Li, W.U.; Wang, H.; Yang, J. The temporal and spatial variations of agricultural flood disaster over the middle and lower reaches of the Yangtze river from 1961 to 2010. *Geogr. Res.*, 2015, 34(6), 1091-1108 (in Chinese).

[15] Zou, T.; Yoshino, K. Environmental vulnerability evaluation using a spatial principal components approach in the Daxing'anling region. *China. Ecol. Indicators.*, 2017, 78, 405-415.

[16] Stevanović, M.; Popp, A.; Lotze-Campen, H.; Dietrich, J.P.; Müller, C.; Bonsch, M.; Schmitz, C.; Bodirsky, B.L.; Humpenöder, F.; Weindl, I. The impact of high-end climate change on agricultural welfare. *Sci. Adv.*, 2016, 2(8), 1-9.

[17] Su, M.; Zheng, Y.; Hao, Y.; Chen, Q.; Chen, S.; Chen, Z.; Xie, H. The influence of landscape pattern on the risk of urban water-logging and flood disaster. *Ecol. Indic.*, 2018, 92, 133-140, DOI: https://doi.org/10.1016/j.ecolind.2017.03.008.

[18] Ward, P.J.; Jongman, B.; Aerts, J.C.J.H.; Bates, P.D.; Botzen, W.J.W.; Diaz Loaiza, A.; Hallegatte, S.; Kind, J.M.; Kwadijk, J.; Scussolini, P.; Winsemius, H.C. A global framework for future costs and benefits of river-flood protection in urban areas. *Nature Clim. Change.*, 2017, 7, 642-646.

[19] Shu-Li Huang, etc. How vulnerable is the landscape when the typhoon comes? An emergy approach. *Landscape and Urban Planning*, 2011, 100 (4), 415-417.

[20] Salvatore Mellino; Sergio Ulgiati. Mapping the evolution of impervious surfaces to investigate landscape metabolism: An Emergy–GIS monitoring application. *Ecological Informatics*, 2015, 26(1), 50-59.

[21] Mellino, S.; Ripa, M.; Zucaro, A.; Ulgiati, S. An Emergy–GIS approach to the evaluation of renewable resource flows: a case study of Campania Region, Italy. *Ecol. Model.* 2014, 271, 103-112.

[22] Ying-Chieh Lee; Shu-Li Huang. Spatial emergy analysis of agricultural landscape change: Does fragmentation matter? *Ecological Indicators*, 2018, 93, 975-985.

[23] Lee, Y.-C.; Ahern, J.; Yeh, C.-T. Ecosystem services in peri-urban landscapes: the effects of agricultural landscape change on ecosystem services in Taiwan's western coastal plain. *Landscape Urban Plann.*, 2015, 139, 137-148.

[24] Odum.H.T. Environmental Accounting. Emergy and Environmental Decision Making. NewYork: John Wiley, 1995, ISBN: 978-0-471-11442-0.

[25] Lan Shengfang, etc. Emergy analysis of Ecological economic system. Beijing: Chemical Industry Press, 2002, 5.

[26] Brown, M.T.; Campbell, D.E.; De Vilbiss, C.; Ulgiati, S. The geobiosphere emergy baseline: a synthesis. *Ecol. Modell.*, 2016, 339, 92-95.

[27] Brown, M.T.; Ulgiati, S. Energy quality, emergy, and transformity: H.T.Odum's contributions to quantifying and understanding systems. *Ecological Modelling*, 2004, 178(1), 201-213.

[28] Srinivasan, R.S.; Braham, W.W.; Campbell, D.E.; Curcija, C.D. Re(De)fining net zero energy: renewable emergy balance in environmental building design. *Build. Environ.*, 2012, 47, 300e315.

[29] Lan, S.; Odum, H.T. Emergy evaluation of the environment and economy of Hong Kong. *J. Environ. Sci.*, 1994, 4, 432-439.

[30] Buranakarn V. Evaluation of Recycle and Reuse of Building Materials Using the Emergy Analysis Method. PhD Paper, University of Florida, FL, 1998.

[31] Ling Shao, G.Q.Chen. Renewability assessment of a production system: Based on embodied energy as emergy. *Renewable and Sustainable Energy Reviews*, 2016, 57, 380-392.

[32] Zhang, Y.; Yang, Z.; Yu, X. Evaluation of urban metabolism based on emergysynthesis: a case study for Beijing (China). *Ecol. Modell.*, 2009, 220, 1690-1696.

[33] Kampeng Lei; Lu Liu; Dan Hu; Inchio Lou. Mass, energy, and emergy analysis of the metabolism of Macao. *Journal of Cleaner Production*, 2016, 114, 160-170.

[34] S. Mellino; M. Ripa; A. Zucaro; S. Ulgiati. An emergy–GIS approach to the evaluation of renewable resource flows: a case study of Campania Region, Italy, *Ecol. Model.*, 2014, 271, 103-112.

[35] Huang, S.-L.; Hsu, W.-L. Materials flow analysis and Emergy evaluation of Taipeis urban construction. *Landscape and Urban Planning*, 2003, 63, 61-74.

[36] Lan, S.; Odum, H.T. Emergy evaluation of the environment and economy of Hong Kong. *J. Environ. Sci.*, 1994, 4, 432-439.

[37] Brown, M.T.; Ulgiati, S. Energy quality, emergy, and transformity: H.T.Odum's contributions to quantifying and understanding systems. *Ecological Modelling*, 2004, 178(1), 201-213.

[38] Odum, H.; Brown, M.; Brandt-Williams, S. Handbook of Emergy Evaluation: a Compendium of Data for Emergy Computation in a Series of Folios, Folio.# 1.Center for Environmental Policy, University of Florida, Gainesville, FL, USA, 2000.

[39] Brown, M.T.; Herendeen, R.A. Embodied energy analysis and emergy synthesis: a comparative view. *Ecol. Econ.* 1996, 19, 219-235.

[40] Brown, M.T.; Ulgiati, S. Emergy-based indices and ratios to evaluate sustainability: monitoring economies and technology toward environmentally sound innovation. *Ecol. Eng.*, 1997, 9, 51-69.