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Analysis of Hefei city's ecological economic system---based on Morlet wavelet transformation

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ABSTRACT

Based on the energy theory, this paper researches Hefei city's 1991-2012 urban eco-economic system energy indices, adopts Morlet wavelet transformation to empirically study the environmental load ratio (ELR). The results show that Hefei's current urban eco-economic system is characterized by typical high environmental pressure load, and the ELR has a 12-year characteristic time scale, and that the environmental load mutated intensely in 1994, 2002 and 2010. The paper also analyzes the mutation causes and puts forward the corresponding countermeasures.

KEYWORDS

Energy analysis; Morlet wavelet transformationation; UEES; Hefei.

INTRODUCTION

Urban eco-economic environment is a complicated system and also the basis for human sustainable development. However, with the development of social progress and economic development, environmental problems, such as urban smog, industrial waste water, trash, noise, gets more and more worsened and poses a threat to human being's survival and development. Therefore, people begin to re-evaluate the urban development theory, and pay close attention to urban eco-economic environment.

Based on current literature, scholars worldwide, using energy analysis methods, have practically and theoretically researched ecological economic systems in respect of policy making, land developing, index selection and urban ecological function[1]. In addition, countries, such as Canada, American, have constructed a variety of evaluation methods for evaluating urban ecoeconomic system. For instance, America and Canada used three-component model (economy, society, environment) to study the complex ecosystem and ecological security of Ottawa. In china, the construction of the urban eco-economic system has not been under way until recently, but gets great attention. Under the regional development guidelines of the central government and local governments, China has continuously established a series of ecological developement cities teaming with local characteristics, such as the "Mountain and River Garden Ecological City" as exemplified by Guangzhou, the "Coastal Ecological City" by Tianjin, the "Sunshine Ecological City" by Rizhao, the "Tourism Ecological City" by Guilin and the "Lake and Shore Ecological City" by Wuxi. As far as the methodology is concerned, the Chinese literature mostly uses energy analysis[2,3] and ecological trace methods[4,5].

In summary, the energy method provides a new thinking for people to do the quantative analysis of an ecological economy system, but within this theory, energy value is non-linear, and would be affected by population, economy, technology, etc.. However, an urban eco-economic system is a dynamic system, and the research and evaluation should accordingly be adjusted over time. Therefore, this paper, taking Hefei city (Anhui province's capital city) of China as an instance, and applying energy theory, tries to explore the status quo and development process of its eco-economic system, and to provide theoretical support for its urban eco-economic development.

RELEVANT CONCEPTS AND STUDY AREA

Relevant concepts

Urban eco-economic system (UEES) is not a new concept. Some scholars believe that UEES is an artificial ecosystem, consisting of the mutual coupling of urban economic system, urban social system and urban ecological system, which is similar to the "urban complex ecosystem"; some scholars suppose that UEES is a kind of urban economic system which takes human as the center and has the typical consumptive structure. When it comes to manipulating this system, it needs to safeguard the sound function of the inner system, and to decrease the entropy outflow as well. This paper agrees with the latter explanation of UEEES, and takes total energy inflow (U), net energy yield rate (NEYR), environmental load rate (ELR), energy investment rate (EIR) and energy sustainable index (ESI) as UEES indices. The specification can be seen in TABLE 1. This index system can present the inner operating status of urban eco-economy, demonstrate the restrictions of urban and social development on economy, and illustrate the effect of urban eco-economic system on the outer system.

TABLE 1 : Urban eco-economic system indices

Index	Formula	Implication
total energy inflow (U)	U=R+N+IMP	The total of renewable resource, non-renewable resource and inflow resource from outside
net energy yield rate (NEYR)	NEYR=(R+N+IMP)/IMP	The measure of whether economic process would provide the basic energy for economic activities
environmental load rate (ELR)	ELR=(IMP+N)/R	The measure of energy use and environmental pressure
energy investment rate (EIR)	EIR=IMP/(R+N)	The required energy investment to measure local resources
energy sustainable index (ESI)	ESI=NEYR/ELR	The comparison between net energy yield rate and energy sustainable index

Note: R is renewable resource; N is local non-renewable resource and consumption; IMP is imported inflow

TABLE 2 : The energy of Hefei eco-economic system in 2012

Specification	Original data	Energy transformation rate (sej/unit)	Solar energy (sej)
Renewable resource	\	\	8.57 E+20
Local renewable resource products			
Grain (g)	303.38 E+10	18.20 E+04	55.22 E+16
Cotton	3.36 E+10	1.9 E+06	6.38 E+16
Oil	33.47 E+10	6.9 E+05	23.09 E+16
Meat (g)	47.21 E+10	79.20 E+04	37.39 E+16
Aquatic products (g)	21.57 E+10	196.00 E+04	42.28 E+16
Milk (g)	11.17 E+10	82.20 E+04	9.18 E+16
Subtotal			173.54 E+16
Local non-renewable resource products			
Coal (g)	1021.96 E+10	3.92 E+04	0.40 E+18
Gasoline (g)	2.59 E+10	6.47 E+04	0.17 E+16
Kerosene (g)	0.04 E+10	6.47 E+04	0.26 E+14
Diesel (g)	6.98 E+10	6.47 E+04	0.45 E+16
Fuel oil (g)	0.1 E+10	6.47 E+04	0.65 E+14
Liquefied petroleum gas (g)	0.12 E+10	4.71 E+04	0.57 E+14
Electric power production (J)	548.28 E+14	17.00 E+04	93.21 E+20
Steel production (g)	238.49 E+10	33.80 E+08	80.61 E+20
Cement production (g)	1585 E+10	30.90 E+08	489.77 E+20
Plastic production (g)	47.87 E+10	27.10 E+08	12.97 E+20
Subtotal			676.56 E+20
Import flow			
Imports ($)	40.14 E+08	5.79 E+12	232.41 E+20
Tourism Foreign Exchange Income ($)	2.30 E+08	5.79 E+12	13.32 E+20
Foreign direct investment ($)	16.01 E+08	5.79 E+12	92.70 E+20
Subtotal			338.43 E+20
Export flow			
Total exports ($)	136.28 E+08	1.20 E+12	163.54 E+20
Subtotal			163.54 E+20
Waste flow			
Solid waste (g)	0.11 E+18	1770.00 E+04	1.95 E+24
Wastewater (g)	4.35 E+18	65.30 E+04	2.84 E+24
Industrial wastewater (g)	0.60 E+18	65.30 E+04	0.39 E+24
Exhaust gas (m^3)	2.77 E+11	65.30 E+04	0.18 E+18
Subtotal			5.18 E+24
Local resource storage			
Natural gas (m^3)	3.26 E+06	4.71 E+04	15.35 E+10
Land			
Cultivated land (m)	3.37 E+09	1.60 E+12	53.92 E+20(sej/year)
Residents and independent industrial and mining land (m)	1.73 E+09	35.50 E+12	614.15 E+20(sej/ year)
Traffic land (m)	0.14 E+09	46.00 E+12	64.40 E+20(sej/ year)
Water conservancy facilities land (m)	0.02 E+09	1.90 E+12	0.38 E+20(sej/ year)
Population (person)	0.71 E+09	211.00 E+04	14.98 E+14(sej/ year)
Subtotal			747.83 E+20

Note: the relevant data from TABLE 2, Figure 1, 2, 3, 4, 5, 6 and 7 are from Hefei Statistical Yearbook from 1991 through 2012; energy transformation rate is from Reference 13.

Study area

Hefei is the capital and largest city of Anhui Province in Eastern China. As a political, economic, and cultural centre of Anhui, it is located in the central part of the province. To the southeast is Chao Lake, a lake 15 km, one of the largest fresh water lakes nationally. Hefei has an area of 11,323 km and, as of 2013 Census, a population of 7,611,000 inhabitants. Its built-up area is home to 3,352,076 inhabitants encompassing all urban districts. Hefei has acheived a remarkable economic and social development in recent years, developing into a second-tier city of China, and considered as one of the world's fastest growing cities.

HEFEI'S URBAN ECO-ECONOMIC SYSTEM ENERGY ANALYSIS

Current status of Hefei's urban eco-economic system

As shown from TABLE 2, Hefei's staple renewable resource products are mainly agricultural products. The consumption structure of Hefei is of the medium level, which meets the consumption requirement for a second-tier city. Waste flow is the largest energy flow, high up to 5.18E+24sej, much larger than the other energy flow, but the total value of the local renewable resource energy flow, local non-renewable resource energy flow and total import and export flow stream is only 0.12E+24sej, meaning Hefei's waste flow has significantly exceeded the required standard, and there exists serious imbalance in its urban eco-economic system. Based on the energy index calculation method in TABLE 1, the net energy output rate was up to 3.02 in 2012, presenting that the system production efficiency is relatively high. However, the energy investment ratio (EIR) was only 0.49, showing that Hefei's economic development depends on itself more than on the outside, and also that the needs for energy input is low in exploring local resources. The environmental load ratio (ELR) was up to 118.44, revealing Hefei's energy is used in a disproportionate way and the environmental pressure is rather high. The sustainable development index (ESI) was low down to 0.0255, and based on the original definition of Ulgiati[6], Hefei's UEES is obviously a typical high environmental pressure load consumption economic system.

Energy analysis of Hefei's urban eco-economic system

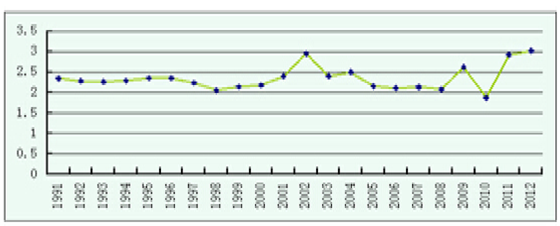

Figure 1 Hefei's NEYR from 1991 to 2012

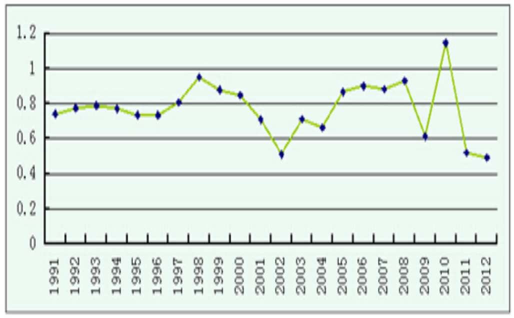

Figure 2 Hefei's NIR from 1991 to 2012

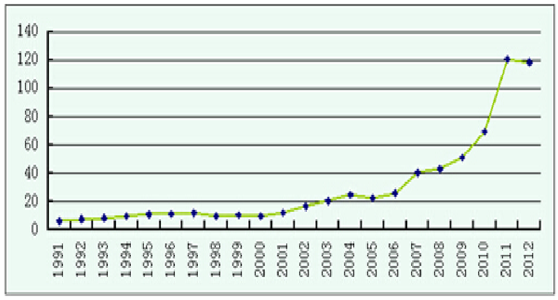

Figure 3 Hefei's ELR from 1991 to 2012

Figure 4 Hefei's ESI from 1991 to 2012

Hefei's net energy yield rate (as seen from Figure 1) from 1991 to 2012 overall ranges between 2 and 3, showing that Hefei had a high efficiency in system production during these years. In 2012, the NEYR had increased to 3.02, the maximum value within all the statistical years. It is clear from Figure 2 that Hefei's energy investment ratio (EIR) oscillated up and down from 1991 to 2012. In terms of environmental load ratio (ELR), Hefei's energy use intensity is becoming smaller and smaller as the environmental pressure is becoming bigger and bigger. As seen from Figure 3, the ELR remained relatively stable between 1991 and 2006, but presented an almost complete upward trend starting from 2006. From Figure 4, Hefei's sustainable development index (ESI) between 1991 and 2012 has an almost complete downward trend, and the biggest figure is no more than 0.4. Based on the ESI theory, if ESI value ranges between 1 and 10, the economic system is full of vitality and potential development ability, and if ESI>10, the economic system may be underdeveloped. Hefei's eco-economic system is now at a stage lacking vitality potential development ability.

MORLET WAVELET TRANSFORMATION ANALYSIS BASED ON ELR ENERGY INDEX

Method

Wavelet transformation is currently the most popular method for time frequency transformations. In 1984, Jean Morlet introduced Gabor's work to the seismology community and, with Goupillaud and Grossmann, modified it to keep the same wavelet shape over equal octave intervals, resulting in the first formalization of the continuous wavelet transformation. In mathematics, Morlet wavelet (or Gabor wavelet) is a wavelet composed of a complex exponential (carrier) multiplied by a Gaussian window (envelope). This wavelet is closely related to human perception, both hearing and vision. Currently it is mainly through the error between signal processing results by means of wavelet analysis and theoretical results to determine the quality of wavelets and thus select wavelets. Considering the amount of data in this article is not much, and wavelet coefficients of each scale have a strong correlation, the artical uses continuous Morlet wavelet transformation.

Morlet wavelet is a commonly used non-orthogonal wavelet, having no scaling function, and its general mathematical representation is

$$\varphi(t) = e^{jw_0 t} e^{-\frac{1}{2}t^2}$$

Among which, w_0 is wavelet center frequency. Its Fourier transformation is

$$\phi(w) = \sqrt{2\pi}\, e^{-\frac{1}{2}(w-w_0)^2}$$

Morlet wavelet is a single-frequency sinusoidal modulation Gaussian wavelet, and is also a common complex value wavelet, and its time domain representation and complex domain are as follows:

Time domain relation:

$$\varphi(t) = \pi^{-1/4}(e^{-iw_0 t} - e^{-w_0^2/2})e^{-t^2/2}$$

Complex domain relation: $\psi(w) = \pi^{-1/4}\left[e^{-(w-w_0)^2/2} - e^{-w_0^2/2}e^{-w^2/2}\right]$

Morlet wavelet analysis of ELR for Hefei

Characteristic analysis

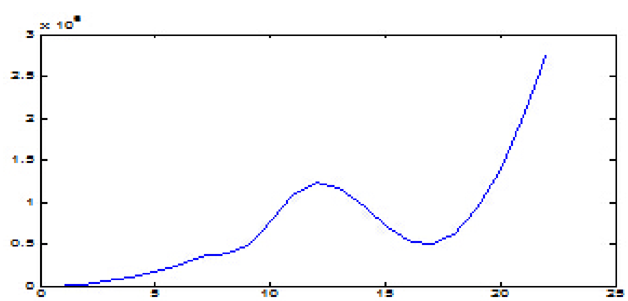

Figure 5 Wavelet variance of ELR sequences

Figure 5 shows the wavelet variance picture that is formed by making Morlet wavelet transformation on the ELR sequence (as seen in Figure 5). The map can be used to determine the relative intensity of different scales disturbing a certain time series. Therefore, through the wavelet variance figure can we find out the main scale (cycle) that plays the major role in a time series, that is, the peak of the scale is the main characteristic time or the main cycle of the time series. In Figure 5, there is an obvious peak corresponding to 12, implying that there is a 12-year period oscillation for ELR changes in Hefei.

Mutation analysis

Wavelet transformation has the ability of mathematically diagnosing mutations, so it has a unique advantage of finding out the mutation point quickly through analyzing the local scalability of a function. Because a Sub-Morlet wavelet is a symmetric wavelet function, based on the wavelet theory, if the wavelet coefficient curve crosses zero on the occassion of characteristic time scale, then the zero point is the mutation point. Figure 6 shows the wavelet coefficient with 12-year characteristic time scale.

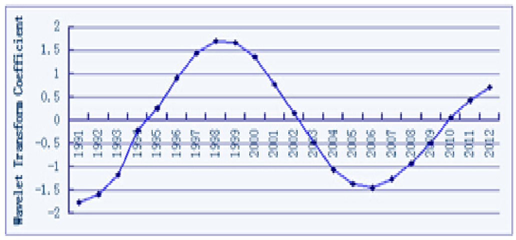

Figure 6 Morlet wavelet transformation coefficent for Hefei's ELR change

As shown from Figure 6, Hefei's ELR within the 12-year characteristic time scale has three mutations, respectively in 1994, 2002 and 2010. There exist substantial range of change between 1991 and 1994, 1994 and 2002, and 2002 and 2010. Therefore, we can categorize the time period into the following 2 sections.

(1) Gradually developing period (1991-2010). During this period, the ELR moves comparatively slightly, but its cycle is relatively long. Thus, even though the mutations occur around 1994 and 2002, the mutation extent is not big. Within this period, Hefei's industrial structure was experiencing upgrade, and accordingly its economy developed steadily, growing into a second-tier city in China from an obscure place.

(2) Rapid developing period (2010-2012). Following the steady development of the previous stage, after 2010, Hefei's UEES indicators, like local non-renewable resource, consumption energy value flow, export flow, import flow and waste value, grew substantially, almost twice as much as before. It indicates that as Hefei entered into the stage of extraordinary rapid development, and in the meanwhile, the ELR greatly increased.

CONCLUSION

Hefei's renewable resource energy flow will maintain stable within a short period of time; then the changes of non-renewable resource products, consumption and import energy flow are the major causes of ELR growth. However, the development of economy will undoubtedly lead to the increase of exported and imported trade, so the fundamental way to reduce environmental load is to reduce local non-renewable resource products and consumption. Accordingly, It is significant for Hefei to develop science and technology so as to change the traditional development mode of consuming non-renewable resources; it is also significant for Hefei to develop recycling economy to intergrate ecological construction with industrial structure adjustment and optimization, to improve resource utilization rate, to increase the added value of products, and to promote the sustainable development of eco-economic system health.

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