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Abstract: Since the resources from environment are in short supply, it is necessary to alleviate the conflict between high-speed economic construction and limited resources in the Chinese society. This paper aims to analysis the variation of natural resources input into China during 2000-2007 based on extended exergy as an eco-centric metric. With the materials, labor, capital and environmental renovation quantified by exergy numeraire grounding on the second-law metric in view of ecological accounting, the composition and proportion of extended exergy clearly revealed the whole condition of available energy input into society in China. Moreover, two indexes, i.e., extended exergy consumption intensity and extended exergy productivity of natural resources, are proposed to depict the contribution of four different production factors from economic, social and environmental aspects, respectively. Moreover, the extended exergy based analysis of the Chinese society may be helpful in uncovering the long-term resource depletion and promoting efficiency of the resource transformation in the social-economic-environmental system, thus providing holistic method and systematic view for the decision makers with respect to environmental management.

Keywords: Extended exergy, ecological accounting, natural resource, China

1. Introduction

The depletion of non-renewable natural resources is very dangerous for the future existence of the mankind. The consumption of natural resources, and deleterious impacts on the environment should be evaluated in a unified criterion to describe and quantify the variation and direction in order to reflect the macrocosm situations in the process of energy and resource exploitation, especially taking into account humans involvements. At the same time, the thermodynamic evaluation of the environmental losses and natural resources has been considered as a useful tool in the field of natural resource accounting (Frangopoulos, 1992; Sciubba, 1998; Szargut et al., 2002).

The concept of exergy, which is firstly proposed by Wall (1977), is represented as the maximum work performed by a system in the process to get in equilibrium with its reference environment (Wall, 1987; 1990; Chen, 2005). It (exergy) is considered to be the basic physical resource of social processes and the scientific unitary measurement of utility and scarcity. For a given system, exergy is defined as the maximal amount of work that can be extracted from the system in the process of reaching equilibrium with its local environment, chosen to have a direct bearing on the behavior of the system with respect to the time and length scales, depending on the observer's objectives and knowledge (Szargut 1971,1980,2004; Morris and Szargut, 1986; Chen, 2005; 2006).

Therefore, exergy method, initially employed in thermal and thermo-chemical systems, has developed into a widely accepted approach for the account of large complex societal systems and different natural resource. It has also been adopted to reveal the characteristics of resource availability, buffering capacity and environmental impact for ecological system when preliminarily combined with the systems ecology (Cai et al., 2009). The advantage of exergy based analysis compared with traditional energy analysis is that, exergy reflects the internal irreversibility of a system, which may depict the real thermodynamic conversion coefficient. Besides, exergy accounting provides a convenient way to unify and measure different types of materials, energy and information and evaluate the quality of the resources and degradation in the conversion.

Usually, exergy is referred to standard chemistry exergy, which is a state function, to consider the previous pathways of exergy utilization. Szargut and his colleagues subsequently proposed cumulative exergy as the total consumption over time of the exergy of fossil resources connected with the fabrication of the considered production and the network of production processes (Morris and Szargut, 1986), which view the ecological cost as the cumulative consumption of non-renewable exergy. Later, to extend the traditional exergy analysis based on

exergy biophysics and labor theory of value, the concept of extended-exergy, proposed by Sciubba, is to highlight the primary production factors, including labor, capital, exergy, necessary materials and environmental remediation (Sciubba, 2001; Sciubba and Cutler, 2004), and firstly applied to the Italian society 1996 by Milia and Sciubba (Milia and Sciubba, 2006). This approach is a systematic attempt to integrate into a unified coherent formalism both cumulative exergy consumption and thermo-economic methods, and constitutes a generalisation of both, in that its framework allows for a direct quantitative comparison of non-energetic quantities like labor and environmental impact (Sciubba, 2001). By using this method, "extended exergy accounting", which includes in the exergy "balance" nonmaterial and nonenergetic production factors like labor, capital, and environmental remediation costs, it can be shown to provide a good measure of the amount of primary exergy resources "used up" in the life cycle of a material or immaterial commodity (Sciubba et al., 2008), which can indicate the comprehensive statement of socially necessary, economically feasible and environmentally cost. Compared with traditional exergy analysis, the advantage of extended-exergy analysis (EEA) is that, it allows for the calculation of the conversion coefficient of the domestic sector by considering the working hours as its product (Chen and Chen, 2009). As extended-exergy is a path function, it is different from the state function of standard chemical exergy.

Therefore, it can be concluded that EEA results are more reasonable and directive for the resource policy constitution of the whole country. As mentioned, the EEA is an integration of life cycle analysis, classical exergy analysis, cumulative exergy analysis, emergy analysis, and embodied energy analysis at the base of the classical exergy analysis, which is more suitable to act as the second-law efficiency metric.

Society EEA is considered as an effective method to reveal the energy quality and degradation in the resource conversion process at the national level. The comparison of social resource accounting among different societies by using diverse index can not only obtain information about diagnosis of production conversion coefficient, assessment of environment impact and ecological dysfunction (Reistad, 1975; Ertesvag, 2005; Chen and Chen, 2006; Chen et al., 2006), but also reveal the intrinsic societal resource utilization structure and its temporal and spatial allocation.

Generally speaking, natural resource analyses are conducted regularly by the official statistical agencies and included in the official statistical reports. Usually, these statistical analyses tend to be summarized and quantified in terms of monetary values or weight analysis. However, in view of the relation to future usefulness of natural energy and the irreversibility associated with the use, the growing discomfort in the processes of evaluating resource where money or weight is the common metric is lack of exactitude, which lead to use EEA as the tool to revalue the synthetic consumption of natural resource in China with the view to natural-economical-social aspects.

This study is primarily a case study about resource consumption where the EEA is employed within the mainland of China. It may also contribute to the development of the method and to the discussion of some implications by using it.

2. Methodology

2.1. Method

By Sciubba's method of EEA, extended-exergy (EE) values are assigned to labor and capital fluxes in addition to thermomechanical and chemical exergy values (Ertesvag, 2005). The calculation of EE value is formulated by Sciubba as follow,

$$EE = CEC + E_{Capital} + E_{Labor} + E_R \tag{1}$$

where CEC represents the cumulative exergy consumption, $E_{Capital}$ (E_C) represents the exergy equivalent

of monetary flows, E_{Labor} (E_W) is the exergy equivalent of human labor, and E_R stands for the environmental

clean-up or remediation cost. Generally speaking, E_C, E_W and E_R all are path functions, so the extended-exergy in fact is a path function, which is different from the state function of standard chemical exergy.

In the reference (Milia and Sciubba, 2006), the accounting value of E_C and E_L are precisely given, respectively,

$$E_C = C \cdot \frac{E_{in}}{C_{ref}} \tag{2}$$

$$E_W = \eta \frac{E_{in}}{n_{tot}} \tag{3}$$

where E_{in} is the exergy influx to the society, C is the monetary flux in a relevant currency and C_{ref} is a proper measure of the "monetary flux", in which the choice of C_{ref} is considered to be arbitrary and depended on the conditions in different countries. Besides, n is the flux of work-hours into a sector, and n_{tot} is the total amount of work-hours.

To different study objects, E_R is sometimes contained in CEC as a part of cumulative exergy consumption in the aspect of environmental cost，so that it is quite difficult to evaluate the ecological exergy expense. In this paper, we consider the economic cost devoted on environmental remediation and management as the environmental exergy consumption parts, the calculate formula is:

$$E_R = C_E \frac{E_{in}}{C_{ref}} \tag{4}$$

In this study, for the EEA, each flux is assigned an exergy value. The annual energy balances or energy accounting and the calorific values of fuels were published by the National Statistical Bureau. In order to obtain exergetic value of the flux, exergy factors from Kotas, Ertesvag, Wall, Chen and Qi(Kotas, 1985; Ertesvag, 2000;Chen and Qi,2007;Wall, 1986;)were adopted; gross domestic product (GDP) is chosen as C_{ref} due to the assumption that the equivalent exergy of GDP was equal to the exergy values of energy carriers and materials, at the same time, Chen (2009) had proposed that owing to large portion of the global monetary circulation (M2) in China is time deposits and saving deposits, which was not suitable like other countries to choose M2 as C_{ref}; C, refers to the capital flux into resource production process, is corresponding to yearly input of capital asserts and also contains the total salary of practitioners in the relevant vocations; C_E is money invested on environmental pollution and ecological improvement in the process of natural resource production and consumption. In addition suppose that all the people have a same work-hours in different professions, people proportion of those who work in the field of natural resource production to total working people can stand for the ratio of n to n_{tot}, which in this study is built on the assumption that the average working hours in different industry are identical and the total

working hours in a certain department is depended on the number of practitioners.

Major natural resources entering the economic production mainly include three parts, mineral, biomass, and water resources. To be concrete, all kinds of natural resources talked above are divided into three classes, they are mineral resources, biomass resources as well as water resources, which contains 41 kinds of material resources yearly input into China. To put it more specifically, all the chosen items are the mainly articles of consumption, because they all take over the largest amount in different statistical information. Therefore, other small consumables with small quantity are omitted in this research. The detailed division is listed in Table 1 as follow:

Table 1 Detailed division of all natural resources in this paper

Resources	Detailed sort
Mineral	Coal, Petroleum, Natural gas, Nuclear power, Iron, Other metal ores, Pyrite Ore, Phosphorus Ore, Sodium Salt NaCl, Magnesite Ore
Biomass	Rice, Wheat, Corn, Beans, Tubers, Peanuts, Rapeseeds, Sesame, Cotton, Fiber Corps, Sugarcane, Beetroots, Tobacco, Silkworm Cocoons, Tea, Fruits, Honey, Lumbering, Bamboo, Meat, Milk, Sheep wool, Goat wool, Cashmere, Poultry eggs, Aquatic products, Marsh gas, Straws, Fuel wood
Water	Water Use (Agriculture, Industry, Consumption, Ecological Protection), Waterpower

In particular, water resource was included in the accounting process, which usually excluded in the traditional classification of ecological resources based on the mainstream economics. Chemical exergy of water can be acquired by the exergy factors listed in Table 1, but potential and phase transformation exergy cannot be calculated in the national scale at this moment due to the difficulty of statistic data and standard resulted in geographical difference as well as space-time complexity.

2.2 System boundary and data collection

In this study, the chosen object referred to the consumption of common ecological resources, and the research boundary was limited within the region of China, which mainly because of the availability of data in time series and same statistic criterion. The detailed numerical values would be listed in the part of Results and Conclusions.

All the data sources available are acquired from standard yearbooks and publications compiled by the central government and its subordinate ministries, such as Energy Statistical Yearbooks (2001-2008), Statistical Yearbooks of China (2001-2008), National Statistical Bureau and correlative published articles.

3. Results

3.1 Total natural resource exergy input

According to the classification of different kinds of natural resource exergy contribution, we got the CEC distribution in China from 2000 to 2007 listed in Fig.1. Generally, Total CEC exergy was increasing persistently, with its value 1.72 times in 2007 than that in 2000. Specifically, mineral exergy consumption owned a high speed expansion, while biomass energy was briefly declining and water resource exergy input was basically smooth and steady. This situation indicated that energy using speed on mineral resources was in accelerated depleted condition, which also reflected that the accelerated economic development and social construction was mainly depended on extensive mineral and fossil energy input in the national level.
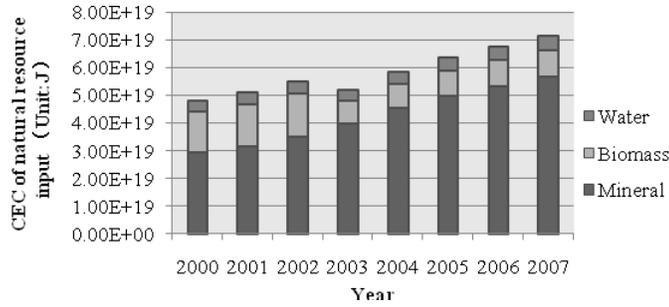
Fig. 1 CEC of natural resource input in China during 2000-2007

Fig.2 clearly demonstrated the three kinds of CEC's proportional relation. It is obviously that the mineral input occupied the largest continent, and its percentage was gradually enlarged from 2000 to 2007. Biomass input had a distinct shrinking trend, which attributed to itself reduce and growth of total natural resource consumption.
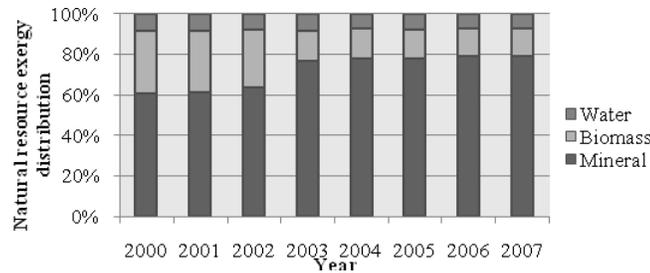

Fig. 2. Natural resource exergy distribution in China during 2000-2007

3.2 Capital exergy input

Table 3 are the economic information used in accounting capital exergy during 2000-2007. The results showed that capital exergy input of EEA in Table 3 was greatly increased during 2000-2007, which meant economic behavior played an important role in available energy input in the whole society. This part reflected that capital exergy nearly has the same significance with natural resource in maintain the normal operation of China's society.

Table 3 Catital exergy input of EEA

	2000	2001	2002	2003	2004	2005	2006	2007
Total capital input (10^8 RMB)	12054.69	13121.84	15299.82	15299.48	18700.21	24116.57	29764.89	36196.68
GDP (10^8 RMB)	98000.45	108068.22	119095.69	135173.97	159586.74	184088.60	213131.70	259258.90
Total natural exergy input (J)	5.07E+19	5.39E+19	5.80E+19	6.37E+19	7.12E+19	7.77E+19	8.24E+19	8.71E+19
Catital exergy input (J)	5.07E+19	5.39E+19	5.80E+19	6.37E+19	7.08E+19	7.64E+19	8.00E+19	8.42E+19

3.3 Labor exergy input

And Table 4 provided a detailed description of employment variation in correlative production departments. The increasing trend of employment population lead to an accelerated change of labor exergy input, which was 4.33E+19 in 2007, 1.79 times compared with the value in 2000 (see Table 5). In view of that China is a country with intensive population, to take full advantage of human resources is a realistic approach in taking place of non-renewable natural exergy consumption and operating the sustainable developing mode.

Table 4 The employed population in the vocation of natural resource production and management

Unit: 10^4

	2000	2001	2002	2003	2004	2005	2006	2007
Agriculture, Forestry, Animal	33354.63	32973.61	32487.24	45970	43812.77	41421.57	40214.51	38550

	2000	2001	2002	2003	2004	2005	2006	2007
Husbandry, Fishery Mining	597	561.46	558.49	481	491.15	497.59	518.05	523.8
Production and Distribution of Coal and Electricity, Gas and Water	283.85	287.80	289.57	292.3	293.98	293.73	296.40	297.7
Management of water Conservancy, Environment and Public Facility	110.21	104.94	97.74	163.88	164.57	170.34	175.64	180.6
Work population in the field of ecological resource	34345.69	33927.82	33433.05	46907.18	44762.47	42383.23	41204.60	39552.1

Table 5 Labor exergy input of EEA

	2000	2001	2002	2003	2004	2005	2006	2007
Work population in the field of ecological resource (10^4)	34345.69	33927.82	33433.05	46907.18	44762.47	42383.23	41204.61	39552.10
Total working population (10^4)	72085	73025	73740	74432	75200	75825	76400	76990
Total natural exergy input (J)	5.07E+19	5.39E+19	5.80E+19	6.37E+19	7.12E+19	7.77E+19	8.24E+19	8.71E+19
Labor exergy input (J)	2.42E+19	2.50E+19	2.63E+19	4.01E+19	4.21E+19	4.27E+19	4.31E+19	4.33E+19

3.4 Environmental exergy input

To evaluate the environmental pollution and ecological risk is a lengthy task, its cumulative influence in temporal and special skill cannot be calculated precisely. In view of the difficulty in data procurability here, we chose the economic input on environmental governance as the determinant in accounting the environmental exergy. The results showed in Table 6 reflected the input of environmental exergy raised evidently, which depicted people in China accords more and more importance to the ecological and environmental disturbance.

Table 6 Environmental exergy input of EEA

	2000	2001	2002	2003	2004	2005	2006	2007
Environmental renovation input(10^8RMB)	1014.9	1106.6	1367.2	1627.7	1909.8	2388.00	2566	3387.3
GDP(10^8RMB)	98000.45	108068.22	119095.69	135173.98	159586.75	184088.60	213131.70	259258.90
Environmental exergy input	5.25E+17	5.52E+17	6.66E+17	7.67E+17	8.47E+17	9.91E+17	9.63E+17	1.10E+18

3.5 Extended exergy input

From Table 7, we obtained that extended exergy of natural resource input in China during 2000-2007 was enlarged 1.71 times, with natural energy input as the largest contribution. At the same time, capital and labor import into society was partly influence the movement of total extended exergy. Whereas, environmental restoration had little impact on total input, which not meant small environmental destruction or disturbance, but pay less attention to renovate by exergy input from human in China.Table 8 showed that, material resource exergy invested into China owned approximately 60% of total extended exergy during 2000-2007, and other 1/3 of total available energy came from capital devotion. Though four kinds of exergy changed obviously during 2000-2007, their proportion varied slightly, maintaining a comparatively stable situation.

Table 7 Total extended exergy input in China during 2000-2007 (Unit:J)

	2000	2001	2002	2003	2004	2005	2006	2007
Natural	5.07E+19	5.39E+19	5.80E+19	6.37E+19	7.08E+19	7.64E+19	8.00E+19	8.42E+19
Capital	2.42E+19	2.50E+19	2.63E+19	4.01E+19	4.21E+19	4.27E+19	4.31E+19	4.33E+19
Labour	6.24E+18	6.54E+18	7.46E+18	7.21E+18	8.29E+18	1.00E+19	1.12E+19	1.13E+19
Environmental	5.25E+17	5.52E+17	6.66E+17	7.67E+17	8.47E+17	9.91E+17	9.63E+17	1.10E+18

|								
Total	8.17E+19	8.60E+19	9.25E+19	1.12E+20	1.22E+20	1.30E+20	1.35E+20	1.40E+20

Table 8 The proportion of different part in total extended exergy input in China social consumption during 2000-2007

|	2000	2001	2002	2003	2004	2005	2006	2007
Natural	62.12%	62.65%	62.76%	56.97%	57.99%	58.72%	59.14%	60.01%
Capital	29.60%	29.11%	28.46%	35.90%	34.52%	32.82%	31.89%	30.83%
Labour	7.64%	7.61%	8.06%	6.45%	6.80%	7.69%	8.26%	8.38%
Environmental	0.64%	0.64%	0.72%	0.69%	0.69%	0.76%	0.71%	0.78%

6 Economic and social index of extended exergy

Two indexes, extended-exergy consumption intensity (EECI) and extended-exergy productivity (EEP), are chosen in this research to present the interaction between EE consumption and social system. EECI is an indicator that can reveal the level of per capita resource which can reflect the personal access to natural resource in China. EEP, an economic value produced by unit natural substance, is a key indicator in measuring the inter connection between available extended-exergy resource and social economy. This index can tell the transfer ability from row material into monetary value, which usually represents the efficiency of resource consumption. The statistics of both two which calculated from 2000 to 2007 are showed in the Fig. 7 to depict the total variation trend in China. On the whole, EECI kept sustained and rapid growth, with its value 1.64 times in 2007 than that in 2000; and EEP declined noticeably, which was only 64.77% in 2007 compared with that in 2000. Both of the transformations indicated expansion of per capita share on available natural energy, as well as the efficiency improvement of power production on unit currency.

In Fig. 7(1), the increasing trendline of EECI had close relationship with social and economic situation in China. During the study era, industrial restructuring and deeply implement of the thorough transconformation of marketing economy were important elements in effecting economical construction, which finally lead to an undulation era in resource consumption and EECI. Wholly speaking, the increasing EECI implied that a great demand beyond necessaries had become life pursue after China progressively entering into affluent society. After the optimization of industrial structure since enter into 21th century, the enormous requirements for private car, energy-consumption electronic products, high quality of material requirements made life quality improve deeply on the one hand, and on the other hand extremely aggravated natural resources depletion, especially for non-renewable material resources. The only solution to avoid energy crisis, especially for limited energy, is to elevate utilization efficiency and attempt new renewable energy. In addition, China is the most populous developing country, its contradiction between large energy-needed population and low per capita energy possession is always restricting the whole national development in social and economic fields. The Fig.7(2) showed that EEP was falling basically during 2000-2007, which means a gradually improving transfer ability from extended exergy based of row material consumption into monetary value.
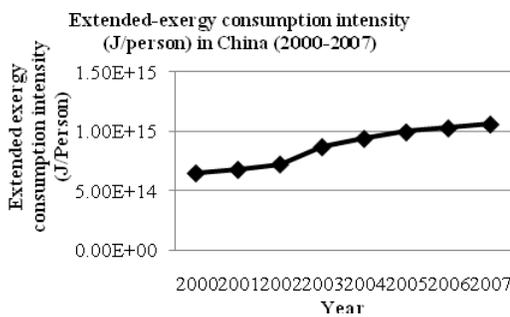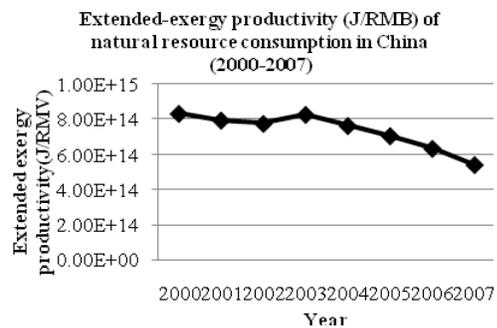
(1)   (2)

Fig. 7 Economic and social index of extended exergy in China during 2000-2007

4. Conclusion and discussion

In country level, extended exergy of natural resource consumption in China was always increasing from 2000 to 2007 with an accelerate speed. The changing of extended exergy on natural resource that basically agree with the trend of economic growth and new situation of social develop can clearly proclaim that natural energy is particularly important element in the process for one country's development. Furthermore, the rising degree of extended-exergy was more distinctive, and the significance of capital and manpower input became stronger than ever before, and should not be omitted anymore, besides, we should devote much non material object instead of natural resource to relief energy depletion.

Both increasing EECI and decreasing EEP demonstrate a positive conversion in transferring quantity and efficiency from material energy to economic output. But in order to develop in a sustainable pattern, production sectors and administration sections should devote more efforts on bettering workpiece ratio other than go in for extensive production with massive resource consuming.

It can be concluded that EEA results are more reasonable and directive for the resource policy constitution of the whole country. As mentioned, the EEA is an integration of life cycle analysis, classical exergy analysis, cumulative exerg analysis, emergy analysis, as well as embodied energy analysis, moreover, this analysis is more suitable to act as a second-law efficiency metric. Whereas, the accounting of F_R still has some problems, on the one hand, it was included in $CExC$ as a part of cumulative exergy consumption in the aspect of environmental cost, on the other hand, economic devotion on environmental pollution and ecological destruction cannot be evaluated straightforwardly on capital investment, because some long temporal range and spacial interaction in large scale cannot be characterized in currency substitution and estimation.

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