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Extended exergy-based fossil fuels resource accounting in spatial distribution in 2007, China

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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 extended exergy based indicators of fossil fuels in 2007 for 30 provinces in mainland of China, and to reveal the spatial distribution of ecological investments. This present situation of distribution may be helpful in recognizing spatial resource depletion and efficiency distinction, so as to make reasonable decision and holistic method as well as path in making planning and regulation with respect to environmental management.

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1. Introduction

The human society is now facing severe ecological crisis, such as global warming, environmental pollution, mineral as well as water resources shortage, all of which are directly related to people’s excessive exploitation and inefficient allocation or utilization of natural resource. At the same time, exergy, representing the maximum work of its reference environment, has been considered to be the fundamental biophysical resources in the field of all processes and the unitary measurement of ecological scarcity. Therefore, exergy analysis method, initially employed in engineering thermodynamics, has received widely acceptance in resources accounting, environmental assessment, ecological value accounting and comparison.

It is indisputable that the scarcity and utility of exergy resource prove the correctness of exergy-based assessment in ecological economy [1-5]. As the basic natural resource in human society, systematic accounting of exergy flux built in different temporal and spatial level can clearly reveal the utilization and efficiency of natural wealth, which is critical in socio-economic diagnosing and decision making. Furthermore, social exergy exhausting is an unified metric for artificial ecological influences, and its minimized and high-efficient usage will be of vital importance in sustainable developing pattern based on social-economic-ecological harmony.

Closely related to the utility as the central concept of macroeconomics, exergy analysis has already been combined with the economic analysis to quantify the cost of the exergy destruction and losses and the cost of

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products, thus optimizing various stages of the life cycle of the product and improve the thermal-economic performances of each stage to facilitate the decision-making procedure [5-10]. Szargut et al. [11] suggested cumulative exergy consumption as an ecological cost indicator to quantify the loss of exergy of deposit resources over time connected with the fabrication of the considered production and the network of production processes. A series of social exergy based analysis has been performed for different economies and countries [12-18]. The exergy-based comparisons of different countries are also conducted to reveal the various structures of the society in the thermodynamic sense and the potential direction towards increased thermo-economic efficiency [19-20].

Extended exergy, proposed by Sciubba, is an extension of traditional exergy analysis to highlight the primary production factors, including two of neo-classical economics, i.e., labor and capital, and the other three ones, i.e., the exergy, necessary materials and environmental remediation, thus bridging the gap concerning the ‘production of value’ between the majority of economists and energists [21]. Despite the cost of a product or service is expressed as a compound function of the production factors, EEA is the first theory to unify them in view of the value production chain associated with the concrete production process with the linearizing and exergeticizing efforts using the additive exergy metric. Particularly, labor acts as the important and unique media to drive the whole value production chain and creates surplus values to each sector of the chain. In comparison to the previous quantification of labor in terms of financial market, the extended exergetic content of labor is decided by the social-economic, production technical and environmental management factors, through exchange of commodities produced by labor that acquires such a compound character as which people are working in the social economy context and conserving the environment supporting the society. In essence, EEA is a socio-economic construct with biophysical references, intending to bring the labor theory of value and the current thermodynamic theory into harmony, which is indicative of a possibility that it can be used as a goal function to optimize the allocation and distribution of the involved values to reach a delicate balance amongst the development of society, economy and environment towards the long-term sustainability. Therefore, it can be used as a good tool to measure the cost to achieve sustainability, for sustainability efforts may in some cases require greater resource consumption than less [22].

Fossil fuels 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 fossil fuels 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 us to use extended-exergy analysis as the tool to revalue the synthetic consumption of fossil resource in China with a view to natural, economical and social aspects.

Generally speaking, this study is primarily a case study about fossil fuels consumption based on EEA method within the mainland of China. Fossil fuels 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. In view of the energy department is playing an essential role in social development process, however, the relation to future usefulness of fossil fuels 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 us to use extended-exergy analysis as the tool to revalue the synthetic consumption of fossil resource in China with a view to natural, economical and social aspects. In addition, it may also contribute to the development of the method and to the discussion of some implications by using it.

2. Methodology and data used

2.1 Method(system boundary)

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 [23]. The calculation of EE value is formulated by Sciubba as follow,

\[ EE = CEC + E_C + E_W + E_R \]  

where CEC represents the cumulative exergy consumption, \( E_{\text{Capital}} (E_C) \) represents the exergy equivalent of monetary flows, \( E_{\text{Labor}} (E_W) \) 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 [24], the accounting value of \( E_C \) and \( E_L \) are precisely given, respectively,

\[
E_C = C \frac{E_{in}}{C_{ref}}
\]

\[
E_W = n \frac{E_{in}}{n_{tot}}
\]

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.

In this research, by overall consideration of the study object and the case country, we modified that EE accounting is divided into three parts, the exergy of fossil fuels, capital exergy and labor exergy. Meanwhile, the exergy part can be calculated by exergy factors and the conversion efficiency from Kotas [25] in Table 1; 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; \( C \) refers to the capital flux into fossil industry, is corresponding to yearly input of capital asserts. Suppose that all the people have a same work-hours in different professions, people proportion of those who work in the field of fossil resource to total working people can stand for the ratio of \( n \) to \( n_{tot} \).

Table 1 Exergy factors of fossil fuels

| Fuel form     | Exergy factors | Exergy (J/t or J/m3) |
|--------------|----------------|----------------------|
| Coal         | 1.06           | \( 2.79 \times 10^{10} \) |
| Crude oil    | 1.08           | \( 4.52 \times 10^{10} \) |
| Natural gas  | 1.04           | \( 4.05 \times 10^{10} \) |

Major natural resources entering the economic production mainly include three parts, they are mineral resources, biomass resources, and water resources. To be concrete, in this study, \( E_{in} \), total natural exergy influx, contains fossil fuels, metal minerals, nonmetallic minerals, agriculture, forestry, livestock, fishery, biomass fuels, chemical water exergy and waterpower. The value of \( E_{in} \) comes from the references of Chen [26-29]. By analyzing the ratio of fossil fuels exergy to total natural resource exergy during the year from 1980 to 2002, \( E_{in} \) in 2003 to 2007, therefore, can be estimated by the average value based on the ratio and yearly fossil fuels exergy.

2.2 System boundary

In this study, the chosen object referred to the consumption of fossil fuels, which was one kind of common natural resource, and the research boundary was limited within the region of mainland China except Tibet, because of its unavailable data in long time series. The detailed numerical values would be listed in the part of Results and Discussion.

2.3 Date collection
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, China Statistical Yearbook, China Foreign Economic Statistical Yearbook, China Environment Yearbook, China Macroeconomic Information Network and so on.

3. Results

This part mainly displays spatial distribution of extended-exergy based indicators in 30 provinces of mainland China in 2007. Table 1 is the whole basic statistic conditions of different provinces in 2007 and Fig.1 demonstrates a clearly extended-exergy based fossil fuels accounting in different provincial areas. Analysis over the whole country, east region obviously consumed more extended-exergy of fossils than west parts, especially Shanxi province and Shandong province which due to their abundant natural reserve as well as corresponding energy based economy and industry pattern. Moreover, Beijing, Shanghai and Guangdong province play important roles in China’s social and economic development, therefore, the area around these three points cover a highly depletion of extended-exergy resource.

Table 1 Analysis of extended-exergy in fossil fuels accounting in 30 provinces of mainland China in 2007

| Year 2007 | Total exergy of fossil fuels(J) | Population (10^4person) | Provincial GDP(10^8Yuan) | Capital exergy(J) | Labor exergy(J) | extended-exergy (J) |
|-----------|-------------------------------|-------------------------|-------------------------|-------------------|----------------|--------------------|
| Beijing   | 1.19E+18                      | 1633                    | 9353.32                 | 4.13E+11          | 2.32E+11       | 1.19E+18           |
| Tianjin   | 1.38E+18                      | 1115                    | 5050.4                   | 9.00E+12          | 5.01E+10       | 1.38E+18           |
| Hebei     | 6.77E+18                      | 6943                    | 13709.5                  | 2.20E+12          | 3.11E+11       | 6.77E+18           |
| Shanxi    | 9.37E+18                      | 3393                    | 5733.35                  | 1.62E+14          | 3.32E+12       | 9.37E+18           |
| Inner Mongolia | 5.24E+18                  | 2405                    | 6091.12                  | 8.69E+13          | 5.97E+12       | 5.24E+18           |
| Liaoning  | 6.39E+18                      | 4298                    | 11023.49                 | 3.82E+13          | 2.63E+11       | 6.39E+18           |
| Jilin     | 2.66E+18                      | 2730                    | 5284.69                  | 2.22E+13          | 2.7E+12        | 2.66E+18           |
| Heilongjiang | 3.98E+18                   | 3824                    | 7065                     | 2.67E+13          | 3.4E+11        | 3.98E+18           |
| Shanghai | 1.91E+18                      | 1858                    | 12188.85                 | 4.34E+11          | 0              | 1.91E+18           |
| Jiangsu   | 6.25E+18                      | 7625                    | 25741.15                 | 2.61E+12          | 4.59E+09       | 6.25E+18           |
| Zhejiang  | 4.62E+18                      | 5060                    | 18780.44                  | 6.78E+11          | 2.02E+11       | 4.62E+18           |
| Anhui     | 2.95E+18                      | 6118                    | 7364.18                  | 2.34E+13          | 1.08E+11       | 2.95E+18           |
| Fujian    | 1.84E+18                      | 3581                    | 9249.13                  | 1.86E+12          | 3.66E+11       | 1.84E+18           |
| Jiangxi   | 1.50E+18                      | 4368                    | 5500.25                  | 3.44E+12          | 6.78E+09       | 1.50E+18           |
| Shandong  | 1.14E+19                      | 9367                    | 25965.91                 | 3.69E+13          | 1.15E+13       | 1.14E+19           |
| Henan     | 7.74E+18                      | 9360                    | 15012.46                 | 5.08E+13          | 2.7E+11        | 7.74E+18           |
| Hubei     | 3.01E+18                      | 5699                    | 9230.68                  | 5.05E+12          | 7.61E+11       | 3.01E+18           |
| Hunan     | 2.99E+18                      | 6355                    | 9200                     | 8.26E+12          | 1.43E+10       | 2.99E+18           |
| Guangdong | 4.70E+18                      | 9449                    | 31084.4                  | 2.03E+12          | 2.68E+11       | 4.70E+18           |
| Guangxi   | 1.29E+18                      | 4768                    | 5955.65                  | 3.86E+12          | 3.96E+09       | 1.29E+18           |
| Hainan    | 4.84E+17                      | 845                     | 1223.28                  | 3.32E+11          | 8.16E+10       | 4.84E+17           |
| Chongqing | 1.16E+18                      | 2816                    | 4122.51                  | 3.60E+12          | 1.12E+10       | 1.16E+18           |
| Province | Exteneded-energy (PJ) | Population | Energy Consumption (TJ) | Exteneded-energy (TJ) | Exteneded-energy (TJ) |
|----------|-----------------------|------------|-------------------------|-----------------------|-----------------------|
| Sichuan  | 2.80E+18              | 8127       | 10505.3                 | 9.27E+12              | 1.27E+12              |
| Guizhou  | 3.31E+18              | 3762       | 2741.9                  | 2.75E+13              | 7.66E+10              |
| Yunnan   | 2.08E+18              | 4514       | 4741.31                 | 1.05E+13              | 8.68E+11              |
| Shaanxi  | 2.89E+18              | 3748       | 5465.79                 | 3.03E+13              | 2.88E+12              |
| Gansu    | 1.84E+18              | 2617       | 2702.4                  | 3.23E+12              | 1.36E+10              |
| Qinghai  | 3.30E+17              | 552        | 783.61                  | 3.52E+12              | 1.52E+11              |
| Ningxia  | 1.54E+18              | 610        | 889.2                   | 2.60E+13              | 2.04E+11              |
| Xinjiang | 2.22E+18              | 2095       | 3523.16                 | 5.06E+13              | 2.66E+12              |

**Fig.1 Spatial distribution of extended-exergy in fossil fuels accounting in 30 provinces of mainland China in 2007**
Inner Mongolia consumed more extended-exergy compare with the national level in Fig.1, besides, Fig.2(2) tell us that its EECI is the highest in China. This phenomenon can attribute to low technical level and efficiency caused by non-intensive life style with much land and few people. This reason is same true for Ningxia area, because they both developed on the basis of weak infrastructure industries and a relatively backward scientific and technological level, under special national and historical conditions. Moreover, the EECI in northern China were higher than those in southern area on average, which partly associated with natural reserve and their energy based industry, besides, fossil fuels are absolutely necessary for people’s daily life in winter for north China.

![Extended-exergy consumption intensity (J/person) in different provinces in mainland of China in 2007](image)

**Fig.2(1)** Extended-exergy consumption intensity (J/person) in different provinces in mainland of China in 2007

![Extended-exergy consumption intensity (J/person) in different provinces in mainland of China in 2007](image)

**Fig.2(2)** Extended-exergy consumption intensity (J/person) in different provinces in mainland of China in 2007
Fig. 3(1) and Fig 3(2) reflected the special distribution of economic productivity, EEP, accounting based on extended-exergy. Ningxia, Shanxi and Guizhou are the obviously top three in EEP, indicating that they need more row resource in transferring material into monetary, and there was still sufficient space compared with other region in China to improve their efficiency of resource consumption. Meanwhile, from north to south in China, EEP mainly has a descent by stages or steps, which showing no difference of national conditions in the field of provincial economy and productive efficiency.
4. Conclusion and discussion

In the spatial distribution part, on one side, economic dynamic areas in China, such as Beijing, Shanghai, Guangzhou, and the surrounding areas use more extended-exergy of fossil fuels; on the other side, some abundant resources provinces, such as Shanxi, Shandong, Inner Mongolia, consumed lots of local resource. Generally speaking, north China depleted more fossils than south in both total and per capita extended-exergy. But south regions own a comparative high efficiency of monetary transferring by material using, because of their low EEP value compared with northern area in China. More quantity demand and inefficiency compel north half to change energy consuming pattern from extensive to intensive, find alternative energy sources as well as replace high-performance technology. Only in this way, can avoid accelerated depletion of fossil resource in north China.

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, emerg analysis, and embodied energy analysis and also this analysis is more suitable to act as a second-law efficiency metric.

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