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Original Research Paper

Study on National Energy Consumption Allocation Based on Fair Interval Under Pollution Control

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ABSTRACT

A concept of "fair interval" has been proposed and applied into the energy consumption allocation problem under pollution control. A comprehensive evaluation for energy consumption is used to calculate the fair interval by obtaining the coefficient and increment of energy consumption allocation, on the basis of evaluation index system of energy consumption under pollution control. The ultimate allocation scheme of national energy consumption is obtained by comprehensively considering the original energy consumption of the base year and the increment allocation of the expected year, and the fair interval for energy consumption allocation can ensure the equity on energy allocation effectively.

INTRODUCTION

In the past few years, rapid development of Chinese economy brings serious environmental issues, and the energy consumption is one of the core reasons resulting in pollutant emission and the decline on environmental quality. For total energy consumption, control is the key way to adjust energy structure, the five-year plan for 2011 to 2015 of China indicates that it is necessary to control total energy consumption in a reasonable pathway, and the total-amount-control target and decomposition scheme should be clear.

Before the proposal of total energy consumption control in the five-year plan for 2011 to 2015, only a few researches have been launched in this field (Wang & Mu 2010, Yue & Long 2010, Zhou 2010). After the proposal of total energy consumption control, more studies have been carried out around total energy consumption control. Wu propounded suggestions on total energy consumption control from four aspects of resource endowment, environmental protection, structure adjustment and energy security and analysed driving factors of national energy consumption increase (Wu et al. 2011). Bai (2011) put forward an objective of energy consumption in 2015, which is far insufficient for allocating to the regions under the present development level of economy and intensity of energy consumption. Jin (2011) analysed the probable efficient improvement on energy utilization, adjustment on energy price and effective on resident income from energy supply control by mathematics model.

Nevertheless, how to propose a relatively fair allocation for energy consumption while considering pollution control is the biggest difficulty. Previously, the allocation based on the principle of "efficiency comes first, balances fairness" makes the collective interest stand out and relatively ignore the individual requirements, which is extremely easy to result in the contradict from unfair allocation, and the total energy consumption control is hard to implement smoothly. However, few studies have applied the "fair interval" into the energy consumption allocation research, and the attempt in this article would like to save as a discovery on fair interval method applying into the energy study field.

METHODS

Evaluation Index System for Energy Consumption Allocation

Establishment of index system for energy consumption allocation under pollution control: An evaluation index system for energy consumption allocation has been established following the principles of comprehensiveness, representativeness, systematicness and feasibility, and taking fairness, resources endowment, potential of energy saving and resource consumption reducing, technical ability into account, which has summarized the experiences of predecessors and the indices of atmospheric pollutants (Li & Deng 2010, Ren et al. 2010, Zhuang et al. 2011). The index system takes the representativeness of indices and availability of data into account and composed of 16 indices, which can be divided into energy consumption,

Table 1: The evaluation index system for energy consumption allocation.

The first class	The second class	Interpretation
Energy consumption indices	Energy consumption per person	Reflecting the historical responsibilities on energy consumption control. Lower energy increment will allocate to the province with higher energy consumption per people, which has heavier responsibility.
	Energy consumption of each province	Reflecting the energy consumption level of each province. The higher energy consumption level is, the greater the potential of emission reduction is.
	Energy consumption/ industry increment	Reflecting the energy consumption efficiency of industrial sector. The reduction of energy consumption/ industry increment and the increase on energy consumption efficiency are encouraged.
	Local energy supply	Reflecting the supply situation of each province. The high energy supply, the more flexible of the energy consumption structure is.
	Energy consumption per GDP	Reflecting the efficiency of energy consumption. The reduction on energy consumption per GDP and the increase of energy consumption efficiency are encouraged. Controlling on energy consumption per GDP can make full use of "Forced" mechanism to improve industrial transformation and upgrading.
	Power consumption per person	Reflecting the utilization of energy. The more power utilization is, the better the environment is.
	Energy consumption in industry/total energy consumption	Reflecting the proportion of productive energy. The higher the proportion, the higher the responsibility, which embodies the ideology that necessity of survival is prior to development demand.
Social economy indices	GDP per people	Limitation is needed in the region, which has high GDP per person, in order to protect the economic development right of less developed regions.
	Provincial GDP	A typical index for reflecting regional economic development.
	Level of the resident consumes	For level of the resident consumes, the potential and responsibility of emission reduction are high in the region, which has high level of the resident consumes.
	Proportion of the tertiary industry	Reflecting the support for the tertiary industry. The higher the proportion of the tertiary industry is, the higher the energy consumption allocation will be.
	Urbanization rate	High urbanization rate reflects high development level and high responsibility of energy consumption control.
Environment indices	Emission of industrial waste gas Emission of SO_2 Emission of NO_x Soot emission	Environment indices are the indices of environmental control, reflecting the impact degree from energy consumption of the region. Among the environment indices, emission of SO_2 and NO_x are the atmosphere pollution control indices. The inclusion of the above indices in the evaluation index system reflects the consideration of pollution control ideology, and pollution emission level is an important evaluating direction of energy consumption allocation for different provinces.

development of society and economy, and environmental protection (Table 1). The index system is the foundation for comprehensively evaluating the situation of energy consumption in every region, and the higher the evaluation result is, the higher the responsibility on energy consumption controlling for the region is.

Calculation on Energy Consumption Allocation

Calculation on regulatory factor and allocation factor of energy consumption allocation: The regulatory factor calculation is based on entropy method, which can obtain the standard values and the weighted values, in order to conduct a comprehensive analysis on the energy consumption situation of each province, providing the foundation for acquiring the fair interval of total energy consumption allocation (Yuan et al. 2003, Antoniou et al. 2002).

***Standardization of data*:** In this study, there are n provinces as evaluation objects and m evaluation indices, therefore, the decision matrix can be presented as:

$$X = \left(x_{ij}\right) \quad ...(1)$$

Where, x_{ij} is the eigenvalue for index i and province j ($i=1, 2,..., m; j=1, 2,..., n$).

For eliminating the impact from different dimensions of different indices, standardization for original data is necessary before the calculation and analysis. The standardization can be expressed in the following forms in the two situations:

Standardization 1, when the indices have positive influence on the evaluation result:

$$r_{ij} = \frac{x_i - x_{\min}}{x_{\max} - x_{\min}} \quad ...(2)$$

Standardization 2, when the indices have negative influence on the evaluation result:

$$r_{ij} = \frac{x_{\max} - x_i}{x_{\max} - x_{\min}} \quad ...(3)$$

Where, r_{ij} is the standardization value, x_i is the original value, x_{max} is the maximum of index i, and x_{min} is the minimum of index i.

The membership matrix gained from standardization eigenvalue through equations (2) - (3) can be expressed as follows:

$$R = \left(r_{ij}\right) = \begin{bmatrix} r_{1,1} & r_{1,2} & \cdots & r_{1,n-1} & r_{1,n} \\ r_{2,1} & r_{1,2} & & r_{1,n-1} & r_{2,n} \\ \vdots & & & & \vdots \\ r_{m-1,1} & r_{m-1,2} & & r_{m-1,n-1} & r_{m-1,n} \\ r_{m,1} & r_{m,2} & \cdots & r_{m,n-1} & r_{m,n} \end{bmatrix} \quad ...(4)$$

***Calculation on weighted value*:** In entropy method, "information entropy" is an important concept, which is introduced from thermodynamics to information science by Shannon. Low information entropy represents high variation and amount of information, and the weight of the index with lower information entropy will be higher. The calculation method of information entropy can be presented as follows:

$$E_j = -(\ln m)^{-1} \sum_{i=1}^{m} p_{ij} \ln p_{ij},\ j = 1, 2, \ldots, n \quad ...(5)$$

Where, m is the number of evaluation objects, n is the number of index; p is the number of the second class.

$$p_{ij} = \frac{d_{ij}}{\sum_{i=1}^{m} d_{ij}}, \text{ and when } p_{ij}=0,\ \lim_{p_{ij} \to 0} p_{ij} \ln p_{ij} = 0$$

The weight values of the indices can be calculated as follows:

$$W_j = \frac{1 - E_j}{n - \sum_{j=1}^{n} E_j} \quad ...(6)$$

Where, $0 < w_j < 1$; $\Sigma w_j = 1$. And the weight vector of the index can be express as follows:

$$W = \begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ w_{n-1} \\ w_n \end{bmatrix} \quad ...(7)$$

The weight vector presents the weight of index in the energy consumption allocation process, which is the adjustment function in the process.

***Regulatory factor of energy consumption allocation*:** In this research, regulatory factor of energy consumption allocation is presented as comprehensive evaluation result, which can be calculated by multiplying standardization matrix and weight matrix. The adjustment situation of energy consumption allocation of each province can be reflected by assemble A, which is obtained by multiplying standardization matrix and weight matrix of the evaluation index.

$$A = \begin{bmatrix} a_1 \\ a_2 \\ \vdots \\ a_{m-1} \\ a_m \end{bmatrix} = \begin{bmatrix} r_{1,1} & r_{1,2} & \cdots & r_{1,n-1} & r_{1n} \\ r_{2,1} & r_{2,2} & \cdots & r_{2,n-1} & r_{2,n} \\ \vdots & \vdots & & \vdots & \vdots \\ r_{m-1,1} & r_{m-1,2} & \cdots & r_{m-1,n-1} & r_{m-1,n} \\ r_{m,1} & r_{m,2} & \cdots & r_{m,n-1} & r_{m,n} \end{bmatrix} \times \begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ w_{n-1} \\ w_n \end{bmatrix} = R \times W \quad ...(8)$$

***Allocation factor of energy consumption allocation*:** Allocation factor reflects the responsibility of energy consumption allocation control, and the responsibility is higher when the region has high allocation factor. The allocation factor of energy consumption allocation can be presented as follows:

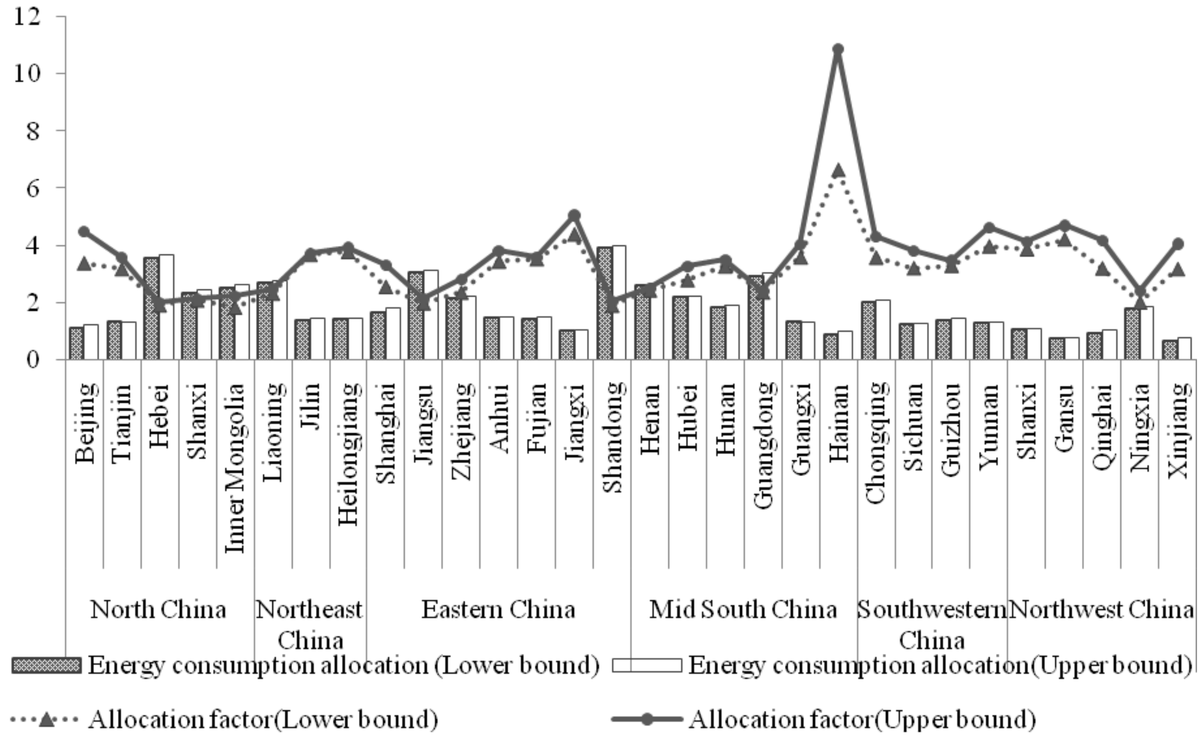

Fig. 1: Fair interval of energy consumption allocation.

$$K_i = 1/a_i \qquad ...(9)$$

Calculation on increment of energy consumption allocation: The increment of energy consumption allocation can be calculated by multiplying the allocation factor and energy consumption of base year (the year 2010).

$$\Delta N_i = N_{i,0} \times K_i \qquad ...(10)$$

According to the national acquirement of total energy consumption, the sum of increment allocation for the provinces should be in accordance with the national increment objective.

$$N_t - N_0 = \sum_i \Delta N_i \qquad ...(11)$$

The adjustment coefficient should be introduced to avoid the situation that the sum of the total increment of energy consumption is higher than the objective increment of the expected year (the year 2020).

$$\beta = \Delta N / \sum_i \Delta N_i \qquad ...(12)$$

Therefore, the increment of energy consumption allocation for the expected year can be calculated as follows:

$$\Delta N_i = \Delta N_{i,0} \times \beta \qquad ...(13)$$

In the above formula, ΔN_i is the initial allocation of energy consumption, $\Delta N_{i,0}$ is the energy consumption of the base year for province i, N_0 is energy consumption of the base year, and N_i is the energy consumption of the expected year.

Calculation on fair interval of total energy consumption allocation: The energy consumption allocation of the expected year can be calculated according to equations (10) to (13), with the addition of energy consumption of the base year and increment of the expected year.

$$N_{i,t} = N_{i,0} + \Delta N_i = N_{i,0} + N_{i,0} \times K_i \times \beta \qquad ...(14)$$

Where, $N_{i,t}$ is the energy consumption allocation for each province of expected year, K_i is allocation factor of energy consumption allocation and β is the adjustment coefficient of energy consumption allocation. In this research, original data are presented as interval values, which are gained from previous years, for avoiding loss of information and maintaining the flexibility of decision-making. The original interval values are sorted out from the year 2005 to 2011, taking from authoritative data sources, such as The China Statistical Yearbook, Energy Statistics Yearbook and so on.

CASE STUDY AND DISCUSSION

Fair interval of total energy consumption allocation

under pollution control for the provinces: The fair interval of total energy consumption allocation under pollution control for each province can be obtained by the above equations, based on energy consumption of the previous year and control objective of the expected year. The fair interval can reflect the energy consumption level and satisfy the increasing demand under national planning requirements at the same time. The fair interval of energy consumption allocation is shown in Fig. 1.

Allocation factor for the provinces: Fig. 1 indicates that, Hebei, Shandong, Jiangsu and Inner Mongolia are with low allocation factors, which are [1.9346, 2.0134], [1.9208, 2.0547], [1.9995, 2.1484] and [1.8461, 2.2335], respectively. For low allocation factor reflecting the high reduction responsibility, the provinces with low allocation factor will take higher emission cuts and lower increments in the expected year, in order to limit the rapid increase of energy consumption in the above provinces.

From the perspective of the regions, the highest average of allocation factor is in mid-south China, followed by northwest China and northeast China; the lowest average is in north China and eastern China. For mid-south China, energy consumption level is relatively low, and the economy development level is low accordingly. On the contrary, north China and eastern China contain most of the developed economic provinces, such as Beijing, Shanghai, and main provinces of energy consumption, such as Shandong and Inner Mongolia, therefore, the allocation factors are low in general. This indicates that, energy consumption is encouraged in the relative backwardness regions and is limited in the regions of high consumption, from which the advantages of fairness can be shown explicitly.

The provinces with low allocation factor mainly distribute in north China and east China, while Hainan province is with the highest allocation factor [6.6458, 10.8865], which is in mid-south China. The allocation factor of provinces distributed in north China are with great differences, for instance, the allocation factors of Hebei and Inner Mongolia are relatively low, while the allocation factors of Beijing and Tianjin are high. The factors of east China are with larger span that Shandong and Jiangsu are in relatively low level, while Jiangxi is in high level [4.4017, 5.065]. There is an obvious uptrend from north to south in mid-south China, and the factors of provinces in northeast China are with similar levels. The factors in southwestern China and northwestern China are universally higher than the national average.

Allocations of increment and the gross for the provinces: Shandong province gains the highest allocation of all the Chinese provinces. Although the allocation factor of Shandong province is low, which leads to its increment of energy consumption in a low level, the high original energy consumption still results in its highest allocation, for the ultimate allocation scheme is the sum of original energy consumption of base year and the increment of the expected year. The highest allocation for Shandong province demonstrates that the energy demand, that is the dependence on energy, is high for the region. On the other hand, the potential downside of energy consumption is also high for Shandong province. The total energy consumption can be adjusted by controlling the increment of energy consumption through promoting efficiency of energy utilization, structural adjustments on energy use, and popularization on new energy resources. On the contrary, Qinghai gains the lowest allocation, since its energy consumption of the base year is the lowest among all the Chinese provinces. Although the allocation coefficient is relatively high, the low original energy consumption of the base year leads to the low energy consumption. The low energy consumption demonstrates that the dependence on energy is low for Qinghai province, and the potential downside of energy consumption is also low in this region.

Among all the regions, north China has the highest level of energy consumption, followed by northeast China, while northwest China ranks last. North China and northeast China have the similarities of large population and high percentage of primary industry and secondary industry, which result in large increment and total consumption of energy. The lowest increment is allocated to the northeast China, which has the smallest density of popularity, leading to high level of energy consumption per person. Therefore, the increment is still low in this region, though the nation has enhanced exploit power on West China Development Strategy.

Overall, the increment of energy consumption shows a downtrend from north to south in each region, except northeast China. According to the allocation coefficient of each province, most of the low allocation coefficients are concentrated in the northern regions, indicating that although the northern regions own relatively high values of original energy consumption, the percentage of increment for such regions has declined constantly in accordance with the allocation coefficients obtained from fair interval method, and the increment and total allocation of energy consumption will get balance gradually.

CONCLUSIONS

The fair interval method has been proposed and applied into the energy consumption allocation problem under pollution control. The result indicates that, although some provinces still own high allocation, resulting from their large original consumption of the base year, the increment is maintained in a low level because of their relatively negative situation of energy consumption, mirrored by low evaluation result. This reflects that the fair interval for increment of energy consumption can adjust the proportion of the whole increment to balance the energy consumption variation tendency for different provinces. The fair interval for the total energy consumption allocation provides a flexible decision-making scheme for allocating the energy consumption gross of the expected year under a relatively fair principle.

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