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Regional Disaggregation of Energy Consumption Target: The Case of Henan Province

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Abstract

An approach to determine energy consumption control target allocation based on analytic hierarchy process, Ward's clustering algorithm, and differential adjustment method is proposed in this study. A case study of the allocation of control targets in Henan by 2020 is then conducted via the proposed method. The results show that: The per capita added value of the secondary industry is the primary factor for the increasing carbon emissions in provinces. Regions with high cardinality of energy consumption have to shoulder the largest reduction, whereas regions with low energy intensity and poor economic conditions met the minimum requirements for energy consumption in 2020.

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Keywords: Energy consumption; Analytic hierarchy process; Target allocation.

1. Introduction

China's energy consumption and related emissions have attracted attention worldwide. It is learned from 11th and 12th Five-Year Plan period that decomposing the energy intensity reduction targets to local areas and establishing a local supervising system are effective energy-saving means in China [1]. The cumulative reduction rate of energy intensity is 18.2% in 12th Five-Year Plan period, suppressing the original 16% target [2]. Apart from the energy intensity target, total energy consumption controlling has been put forward in the "Strategic action plan for energy development (2014-2020)" issued by General Office of the State Council issued, in which the national total energy consumption should be controlled at 4.8 billion tce by 2020. Therefore, it is necessary to set up the decomposition mechanism of total energy consumption target during the 13th Five-Year Plan period (2016–2020). With the increasing efforts in

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energy conservation and the challenging energy-saving targets proposed in China, the regional decomposition of energy-saving targets have attracted more and more domestic scholars to research. Zhou et al. analysed approaches for reducing carbon emissions and put forward a disaggregation model to decompose the China's national carbon intensity reduction target during 12th FYP period [1]. Yu et al. applied the PSO–FCM–Shapley method to solve the China's regional emission intensity reduction target allocation and suggest that provinces with large carbon emissions should bear the biggest burden [3]. Yi et al. constructed a top–down allocation approach based on emission abatement responsibility, capacity and potential to decompose the national carbon intensity reduction target [4]. Wang et al. used the analytic hierarchy process (AHP) approach to allocate the Sichuan's energy intensity target from province to city [5]. Sun and Tao allocated Jiangsu's energy intensity target in 2010 by setting a reduction benchmark based on the decomposition of total reduction target (20%) into basic and floating energy-saving rate [6]. However, most of these studies usually do not pay attention to the regional decomposition of energy consumption control targets that can comprehensively consider the regional circumstances in energy use, social economy and industrial structure. The aim of this paper is to address this gap by establishing comprehensive indicator evaluation system reflecting the regional development stage by taking Henan Province as a case.

The paper is structured as follows: section 2 illustrates the methodology of energy consumption target allocation. The results are discussed in section 3. Finally, the conclusion is given in Section 4.

2. Methodology

2.1. Comprehensive index construction

The comprehensive index ECI_i is constructed based on the three indicators of necessity, capacity and difficulty to quantify the energy consumption cap and allocate the controlled target of growth rate, providing overall analysis of all three indicators. Based on the standardized indicators and the corresponding indicator weights, the values of the comprehensive index of the 18 regions are obtained by the linear weighted method as following equation:

$$ECI_i = W_n N_i + W_c C_i + W_d D_i \tag{1}$$

Where ECI_i is the comprehensive index for i region; Ni, Ci, Di are the values of energy-saving necessity, capacity and difficulty respectively, which could also be calculated by the linear weighted method; i represents 18 regions of Henan (i=1,2,⋯,18); W_n, W_c, W_d are the weights for the three indicators the sum of which equals one.

2.2. Determining weights through the AHP approach

The basic thought of AHP is to decompose the research object into various factors by several levels according to the characteristics of the object and the research target [7-9]. Generally, the AHP method reflects people's basic characteristics of thinking: decomposition, judgment, and synthesizing. The range variation method is applied to standardize the evaluation indicators of 18 cities in Henan province [10].

2.3. Ward's hierarchical clustering method

To allocate the control target of energy consumption to various regions, this study proposes a Ward's hierarchical clustering algorithm considering the squared Euclidean distance as a measure of difference[11]. Detailed descriptions can be found in the literatures[12].The Ward's hierarchical clustering algorithm, which is a bottom-up cluster method, has been widely used in explore the characteristics of research objects[13].

2.4. Differential adjustment method

The classified growth rates obtained by the allocation model are not entirely consistent with the actual situation of each region. For balancing the differences between the actual situation and the classified growth rates in various regions, an adjustment variable a_{ij} is introduced to balance the differences in this study. Therefore, the final target of growth rate can be expressed:

$$v_{ij} = V_j + a_{ij} \tag{2}$$

Wherev_{ij} represents the energy consumption growth rate of i^{th} city in j^{th} category during 13th FYP period, and V_j denotes the classified growth rate of i^{th} city.

The classified growth rate during 13th FYP period of each region can be adjusted by analyzing the historical difference between historical growth rate and classified growth rate during 12th FYP period, which reflected the actual situation of each region.

$$\varepsilon_{ij}(12) = v_{ij}(12)\text{-}V_j(12) \tag{3}$$

Where $\varepsilon_{ij}(12)$ is the difference between energy consumption growth rate $v_{ij}(12)$ and classified growth rate $V_j(12)$ during 12th FYP period.

Based on the historical data of energy consumption, the growth trend in each city during 13th FYP period can be predicted via trend analysis method. The difference between predicted growth rate and classified growth rate could be expressed as follows:

$$\varepsilon_{ij}(13) = v_{ij}(13)\text{-}V_j(13) \tag{4}$$

Where $\varepsilon_{ij}(13)$ is the difference between predicted growth rate $v_{ij}(13)$ and classified growth rate $V_j(13)$ during 13th FYP period.

Then, according to the Eqs. (3) and (4), the adjustment variable a_{ij} could be calculated as follows:

$$a_{ij} = \sigma \times \frac{1}{2} \times \left\{ \varepsilon_{ij}(12) + \varepsilon_{ij}(13) \right\} \tag{5}$$

Where, σ is 0.2 which is an adjustment factor.

Based on Eqs. (2)–(5), Eq. (6) can be derived as follows:

$$v_{ij} = V_j + \sigma \times \frac{v_{ij}(12) - V_j(12)}{2} + \sigma \times \frac{v_{ij}(13) - V_j(13)}{2} \tag{6}$$

3. Results and discussion

3.1. Comprehensive evaluation results

Based on the above-mentioned AHP method, each indicator is weighted as shown in Table 1. Comprehensive index can be obtained from Eq. (1). The comprehensive energy conservation evaluation scores of 18 regions are ranged from the highest 0.622 to the lowest 0.192. Analyzing the results by integrating the indicators of the regions, Zhengzhou and Luoyang are regions with higher values of energy conservation necessity and capacity and lower energy conservation difficulty values; whereas Anyang, Hebi and Jiaozuo have great values of energy conservation necessity and lower energy conservation capacity and difficulty; Zhoukou and Zhumadian have high energy conservation difficulty, but low values for capacity and necessity; Jiyuan stands out with high values of energy conservation necessity and capacity, but low energy conservation difficulty.

Table 1. Indicator weights of energy consumption comprehensive evaluation system.

First hierarchy index	Weight	Second hierarchy index	Weight
Energy conservation necessity	0.45	Per capita energy consumption	0.3
		Energy consumption per unit of industrial add-value	0.3
		Energy intensity	0.3
		Tertiary industry proportion	0.1
Energy conservation capacity	0.35	Per capita local fiscal revenue	0.375
		R&D expenditure proportion of GDP	0.375
		Fixed-asset investment proportion of GDP	0.25
Energy conservation difficulty	0.2	Export trade proportion of GDP	0.4
		Industrial added value proportion of GDP	0.6

3.2. Clustering results

Based on the comprehensive evaluation results and the Ward's clustering method, the 18 regions in Henan are classified into five categories, as shown in Fig. 1. The samples in each category are generally stable and have significant category features. The features of the four categories of 18 regions are obvious. For example, Luohe and Zhoukou (agriculture-based region)are in class one, with lowest values of comprehensive index resulting from the poor economic condition and energy consumption. Undeveloped secondary industry regions belong to class two, which include Zhumadian, Shangqiu, Kaifeng, Nanyang, Xuchang and Puyang. Most resource-based regions such as Anyang, Jiaozuo, Sanmenxia, Hebi and Pingdingshan constitute class three, which represents the highest energy consumption. Advanced northern regions of Henan province, Zhengzhou, Xinxiang and Luoyang are clustered into class four. As a heavy industry city, Jiyuan city belong to class five.

Fig. 1. Clusteringresultsof18 regions in Henan province.

3.3. Regional allocation of energy consumption control target

As shown in Table 2, the relationship between regional growth rate v_i (i is the region) and provincial growth rate V in 12th FYP can be observed. If $v_i \geq V$, most regions (more than 80%) meet $v_i \leq 1.62V$. On the other hand, if $v_i < V$, most regions (more than 80%) meet $v_i \geq 0.51V$. Therefore, the growth rates of energy consumption in most regions are in the range of 0.51-1.62 times of the provincial annual average (4.2%) during 12th FYP period. Based on the historical trend and partitioning results, the control target of growth rate of each category in 13thFYP period could be initially set to 0.51, 0.755, 1, 1.31 and 1.62 times more than the provincial average level.

Table 2. Allocation of energy consumption in 13th FYP in 18 regions

Region	Annual growth rate of energy consumption in 12th FYP	Classified region group	Calculated annual growth rate of energy consumption in 13th FYP	Energy consumption in 2020 (Mtce)
Zhengzhou	5.13%	1	3.50%	42.01
Kaifeng	9.33%	2	5.35%	10.40
Luoyang	4.32%	2	3.22%	25.81
Pingdingshan	-1.37%	2	2.65%	15.14
Anyang	3.17%	2	3.03%	21.71
Hebi	6.09%	2	4.55%	8.43
Xinxiang	6.62%	3	3.58%	17.29
Jiaozuo	5.11%	3	4.02%	18.88
Puyang	7.67%	3	4.35%	12.05
Xuchang	7.33%	3	5.74%	15.84
Luohe	4.62%	3	6.42%	8.67
Sanmenxia	4.91%	3	4.31%	13.11
Nanyang	2.09%	3	3.80%	14.06
Shangqiu	-2.94%	3	3.53%	13.66
Xinyang	4.62%	4	4.28%	13.00
Zhoukou	5.48%	4	6.49%	10.83
Zhumadian	6.91%	5	5.54%	13.15
Jiyuan	5.21%	5	3.25%	8.33
Henan Province	4.11%	/	/	282.38

The regional allocation of energy-consuming growth rates and regional allocation results of provincial energy consumption in 13th FYP is described in Table 2.With the advantages of geography and policies, the economy of resource-based and industrial regions such as Jiyuan, Zhengzhou, Luoyang have greatly outperformed agricultural regions. From Table 2, we find that the overall regional allocation of the energy consumption growth rates present a sight of "lower growth rate in industrial regions(Jiyuan, Anyang and Luoyang), higher growth rate in agricultural regions (Zhoukou, Luohe and Zhumadian)," which is consistent with the current economic and energy development layout of Henan province. Compared with 2015, there is not big change in the energy consumption of 18 regions in 2020. The energy consumption of the regions which are assigned low energy consumption growth rates will decrease in 2020, while the remains will increase.

4. Conclusions

This paper has developed a top-down model consisting of AHP, Ward's clustering and differential adjustment method to allocate the provincial energy consumption control target among regions. The following conclusions and implications are drawn from the results:

(1) The 18 regions of China can be clustered into five classes. The categories are tertiary industry-

developed regions, the resources-based and high energy consumption regions, the highest energy intensity and industrial energy intensity region, the agricultural regions and (v) the rest of the provinces.

(2) To achieve energy consumption control targets, all regions of Henan should limit the growth rate of their secondary industries.

(3) Eight regions are expected to be lower than the provincial average energy consumption growth rate (4.2%) from 2015 to 2020. Several developed regions, such as Anyang and Luoyang, should adjust their economic structures, strictly restrict the energy consumption of their second industry, and further improve their energy efficiency.

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