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Regional allocation of energy intensity reduction target: The case of Henan province in China

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Using a sample of 18 prefecture-level cities in Henan province, this study explored the regional allocation of energy intensity reduction targets from the following three viewpoints: equity principle with common but differentiated responsibilities; intensity reduction target fulfillment; and economic differences and reduction potential among regions. Based on a preliminary decomposition model, an analytic hierarchy process (AHP) and Ward's hierarchical clustering, an intensity allocation method is proposed. First, the preliminary regional decomposition scheme is presented via the preliminary decomposition model. Then, a multi-criteria evaluation system consisting of four layers and covering 13 evaluation indicators is developed via the AHP method, and the evaluation results are analyzed via the cluster method to further improve the preliminary scheme. As decision makers may have different preferences when allocating the reduction burden, we allocate different weights to the indicators and analyze the results using a sensitivity analysis. The clustering results indicate that the 18 regions of Henan are divided into five categories, and each category has its own significant characteristics. Regions with high obligation and potential should share the largest reduction burden. The allocation results show that seven regions, including Zhengzhou and Luoyang, are expected from 2016 to 2020 to exceed the provincial average decrease rate of 16%. *Published by AIP Publishing.* [http://dx.doi.org/10.1063/1.4962416]

I. INTRODUCTION

As the largest developing country with flourishing economic growth, China relies heavily on energy consumption for economic strength. Energy consumption in China has involved issues such as having a coal-based energy mix and low energy efficiency, which threaten the long-term development of the country's economy. Growing intentions to reduce the energy intensity (EI) and control the total consumption have been indicated via the policies in China to ensure the economic sustainable development. According to the data published by the State, China's energy consumption per unit of gross domestic product (GDP) (energy intensity) in 2010 dropped by 19.1% compared with 2005.[1] To further improve the energy efficiency and achieve sustainable development, China's 12th Five-Year Plan (FYP) (2011–2015) set a challenging target of reducing energy intensity by 16% in 2015 compared with that of 2010.[2]

From the experience of 11th and 12th FYP period, one effective measure for energy conservation implemented by the government is the allocation of energy-saving targets to local governments and the creation of the target responsibility system for local government. In the upcoming 13th FYP (2016–2020), it should be continuously persevered and improved in achieving the energy intensity reduction targets by 2020.[3] To achieve the 2020 energy intensity reduction target successfully, the goal must be delegated among different regions under the principle of "common

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but differentiated responsibility" and according to the economic and technological development levels, energy consumption, economic structure, and environmental quality.

The question of how to allocate the energy-saving targets is always a popular research issue; the regional allocation of carbon intensity targets has especially been widely studied. Zhou *et al*.[4] proposed a regional disaggregation model, in support of energy restructuring, technological progress, and alternative energy, to decompose the 17% national carbon intensity reduction target. Yu *et al*.[5] allocated the 40%–45% of carbon emissions reduction target at the provincial level via a combination method formed by the particle swarm optimization algorithm, fuzzy c-means clustering algorithm, and Shapley decomposition. They suggested that provinces with high cardinality of emissions have to shoulder the largest reduction, whereas provinces with low emission intensity met the minimum requirements for emission in 2010. Zhang *et al*.[6] distributed the carbon emission quotas among the regions in China according to the cooperation relations of the China's eight regions, using the entropy method, the gravity model, and the Shapley value approach. They argue that provinces with higher GDP, carbon outflow, and carbon reduction connection may shoulder high proportions in the carbon quotas allocation. Wei *et al*.[7] employed an extended Slacks-Based Measure model incorporating an undesirable output to measure the CO_2 reduction potential and marginal abatement costs for 29 provinces in China. They assumed that the eastern region has the least inefficient emission and the highest marginal abatement cost, whereas the western region has the largest potential reduction capability and the lowest marginal cost.

In recent years, some researchers have begun to focus on the domestic allocation of energy intensity reduction targets among provinces. Wang *et al*.[8] constructed a comprehensive evaluation system consisting of three layers to decompose the energy intensity target of China's Sichuan province during 12th FYP (2011–2015). However, there are few descriptive indicators of the characteristics of energy intensity in the literature. More indicators reflecting the energy obligation and potential should be considered, such as SO_2 emission of energy consumption and R&D expenditure ratio to GDP. Bi[9] just analyzed the energy consumption of three industries and households by using the factor substitution method, not considering the principle of equity with common but differentiated responsibilities. Sun and Tao[10] divided the energy-saving target into the basic energy saving rate (ESR) and floating energy saving rate, ignoring the regional heterogeneity in the allocation process. This would lead to unfair distribution results among regions, for example, as undeveloped cities would bear a great burden. Lu and Xu[11] introduced a new decomposition method called "zero sum gains data envelopment analysis model" based on the principle of "efficiency" to achieve the target of reducing energy intensity by 16% from 2010 to 2015. They found that the energy intensity in some regions does not need to decline, concluding that the final target allocation needs to balance efficiency and fairness.

From the above analysis, it can be concluded that there is a need for further study on the following three areas. First, in the research of energy-saving target decomposition, most studies focus on allocating the CO_2 emission reduction target among nations or provinces. However, how the energy intensity reduction target should be distributed rationally among the various regions has not yet been determined. Second, after learning from the carbon intensity allocation, the principle of equity with common but differentiated responsibilities should be considered as the reasonable basis for decomposing the national reduction burdens at a provincial level. Without considering the principles, an unfair distribution will result. Therefore, in terms of energy intensity allocation, it is necessary to consider the principles. Third, the analytic hierarchy process (AHP) method is widely used to establish a comprehensive index system, which can reflect the economic development level, energy consumption, scientific and technological levels, and other indicators. According to the data availability and regional characteristics, it is necessary to improve the comprehensive index system to evaluate each region's energy-saving obligations, potential, and barriers.

Henan province is located in China's center and includes 18 cities, as shown in Fig. 1 (Appendix A provides the size of 18 cities, as shown in Table VIII). As China's most populous province, the Henan province is also a major agricultural, resource-rich, and emerging industrial province, which is currently in the middle stage of industrialization. From 2000 to 2013,

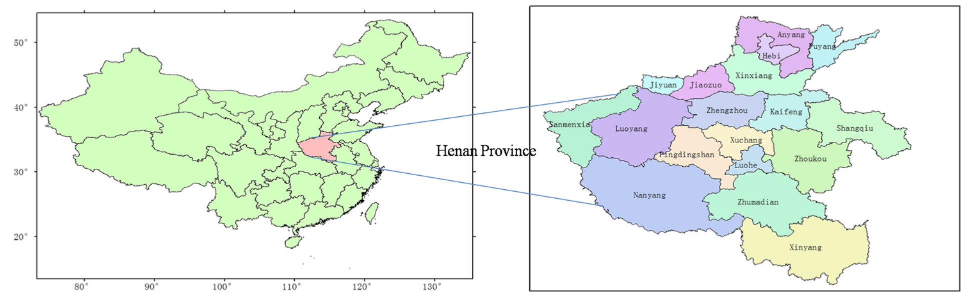

FIG. 1. Location of Henan province.

Henan's GDP maintained an average annual growth rate of 11.56%, and GDP reached 3200 billion RMB (Renminbi) in 2013 which is ranked fifth among all provinces in China. As a result, rapid economic development has also brought a sharp rise in energy consumption. From 2000 to 2013, the energy consumption of Henan province increased 9.16% annually, reaching 173 million tons of oil equivalent (Mtoe) in 2013, which is ranked fifth in all provinces of China. Compared with Zhejiang, one of the typically advanced provinces, Henan's GDP is 85% of Zhejiang's GDP, but energy consumption in the Henan province is 1.3 times that of Zhejiang, and its energy intensity is 51% higher than that of Zhejiang.[12,13] The regional allocation of energy-saving targets can provide useful decision-making support to improve energy efficiency. Based on the above discussion, the Henan province is chosen as the focus of our research to conduct empirical analysis of decomposition of the energy intensity target during 13th FYP period.

To allocate the energy intensity reduction burden rationally among regions, this paper proposed a regional decomposition method considering the principle of equity with common but differentiated responsibilities, which is based on the preliminary decomposition model, combined with AHP, Ward's hierarchical cluster method, as well as the sensitivity analysis carried out for weighting the indicators. Using the proposed method, Henan's energy intensity reduction target by 2020 is allocated from the provincial level to its 18 regions. Furthermore, some policy recommendations on setting emission reduction targets have been proposed based on the emission characteristics of different clusters. This method provides a more comprehensive index method and design system, enjoys better operability, and provides calculated data as a useful reference. A detailed regional target of energy intensity reduction in the 13th FYP can be provided in a scientific way.

II. METHODOLOGY AND DATA SOURCES

A. Energy-saving target: Preliminary decomposition model

Based on the decomposition methodology of the renewable energy target in the European Union,[14] a preliminary regional decomposition model of energy intensity reduction target is proposed. This model divides the total energy-saving target into two parts: basic and floating energy-saving rates.[10] The basic energy-saving rate is the mandatory target that must be met, which is determined by the industrial structure and the industrial energy-saving potential. On the other hand, the floating energy-saving rate is the adjustable target, which is determined by economic conditions and population. The regional energy intensity reduction target could be calculated by both the basic and floating energy-saving rates.[10]

1. Calculating the basic energy-saving rate

First, three basic equations related to energy intensity (EI), energy-saving rate (ESR), and energy-saving quantity in target year (ESQ) are expressed as follows:

$$EI = \frac{EC}{GDP}, \tag{1}$$

$$ESR = \frac{EI^o - EI^t}{EI^o}, \tag{2}$$

$$ESQ = G^t \times (EI^o - EI^t) = G^t \times ESR \times EI^o, \tag{3}$$

where EC (toe) is the energy consumption, EI^o (toe/10 000 RMB) and EI^t (toe/10 000 RMB) represent the EI in basic year o and target year t, **and** G^t (10^8 RMB) is the GDP in target year t.

Then, based on Eqs. (1)–(3), the basic ESR in target year D_i^t (%) could be represented as

$$D_i^t = \frac{E_i^t}{e_i^o \times G_i^t}, \tag{4}$$

where i represents city, the t denotes the target year, and the base year is expressed as o. E_i^t (10^4 toe) is the basic ESQ of i city in target year t. Similarly, G_i^t (10^8 RMB) represents GDP of i city in target year t and e_i^o (toe/10 000 RMB) denotes EI of i city in basic year.

Therefore, Eq. (4) can be represented as follows:

$$\mathrm{D}_i^t = \frac{\sum_{j=1}^{3} E_{ij}^t}{e_i^o \times G_i^t} = \sum_{j=1}^{3} \frac{E_{ij}^t}{e_{ij}^o \times G_{ij}^t} \times \frac{e_{ij}^o}{e_i^o} \times \frac{G_{ij}^t}{G_i^t} = \sum_{j=1}^{3} D_{ij}^t \times \frac{e_{ij}^o}{e_i^o} \times \gamma_{ij,}^t \tag{5}$$

where j represents three economic sectors (primary, secondary, and tertiary economic sector), e_{ij}^o (toe/10 000 RMB) is j industrial EI of i city in basic year o, and γ_{ij} (%) denotes j sector output proportion of GDP in i city. D_{ij}^t (%) represents j sector basic ESR in i city.

The sector basic ESR among regions (D_{i1}^t, D_{i2}^t, D_{i3}^t) could be calculated as in Eqs. (6)–(8),[9]

$$\sum_{j=1}^{3} G_j D_{ij}^t e_j = (EC - sP) \times N\%(i = 1, 2, \ldots, n), \tag{6}$$

$$G_j e_j = \sum_{i=1}^{n} E_{ij}(j = 1, 2, 3), \tag{7}$$

where i and j are represented as city and sector, respectively; $G_j\,(j = 1, 2, 3)$ (10^8 RMB) is j sector output value; and P (person) is the provincial population. e_j $(j = 1, 2, 3)$ (toe/10 000 RMB) is the j sector energy consumption per added-value. s (toe/person) is the provincial per capita residential consumption, EC (10^4 toe) is the provincial energy consumption, and $N\%$ denotes the total energy-saving target set by local government,

$$\frac{\omega_1}{D_{i1}^t} = \frac{\omega_2}{D_{i2}^t} = \frac{\omega_3}{D_{i3}^t} = \frac{\omega_4}{D_{i4}^t}, \tag{8}$$

where $\omega_j\,(j = 1, 2, 3, 4)$ is the weight of j factor (primary sector, secondary sector, tertiary sector, and residential) of energy consumption.

According to the mean square difference method, $\omega_j\,(j = 1, 2, 3, 4)$ is identified. The detailed calculation process can be expressed as follows:

$$\omega_j = \frac{v_j}{\sum_{j=1}^{m} v_j}, \tag{9}$$

where j represents the economic sector and the element v_j is obtained through formula (10),

$$v_j = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_{ij} - \overline{x_j})^2}, \tag{10}$$

where x_{ij} is the energy consumption of the j sector in i city, and the element $\overline{x_j}$ denotes the average of sector energy consumption and is obtained through formula (11),

$$\overline{x_j} = \frac{1}{n}\sum_{i=1}^{n} x_{ij}. \tag{11}$$

As the total basic ESQ of province is equal to the sum of the basic ESQ of each region, thus D_i^t also need to meet the next type

$$\sum_i D_i^t \times e_i^o \times G_i^t = D^t \times e^o \times G^t, \tag{12}$$

in which D^t (%) is the provincial basic ESR in target year, e^o (toe/10 000 RMB) is the provincial EI in basic year, and G^t (10^8 RMB) represents provincial GDP.

Generally, based on the above equations and related data, provincial and regional basic ESR are obtained.

2. Calculating the floating energy-saving rate

Based on Eqs. (5) and (12), the provincial basic energy-saving rate for the target year is obtained. Based on the provincial energy-saving target, the provincial floating ESR could be obtained. The floating ESR in various cities F_i^t can be identified by the provincial floating ESR F^t (%), GDP, population, and EI in each city. Detailed procedures are described as follows:

$$F_i^t = \frac{f_i^t \times P_i}{e_i^o \times G_i^t}, \tag{13}$$

where i is the city, t represents the target year, and o represents the basic year. P_i is the population in i city, and e_i^o is the EI of i city in basic year. f_i^t (toe) denotes the floating per capita ESQ of i city in target year t, which can be determined by

$$f_i^t = \frac{f^t \times g_i^o}{g^o}, \tag{14}$$

in which f^t (toe) is the provincial floating per capita ESQ in target year, g^o (10^4 RMB) represents the provincial per capita GDP in basic year, and g_i^o (10^4 RMB) is the per capita GDP of i city in basic year. The equation elements f^t can be calculated by

$$f^t = \frac{F^t \times e^o \times G^t}{P}, \tag{15}$$

where P (person) is the total population size in province.

Finally, according to the values of the basic ESR and the floating ESR, the regional ESR for the target year can be determined. This model allocates the reduction target for various regions by target year based on the decomposition of total EI into basic and floating ESR.

B. AHP method

Based on the processing of multiple attribute decision-making problems, AHP was first proposed by Saaty in the 1970s.[15] It is a systematic and hierarchical analysis method for processing multi-criteria systems quantitatively, and it can decompose the study object into various indicators by multiple levels according to the features of study object. Based on the mutual and subordinate relationship among various factors, each factor is then aggregated into an ordered hierarchical analysis structure model. Since its introduction, it has been widely applied to various fields such as social, industry, power sector, management, engineering, education, government, and so on.[16] Fields of application within the energy sector are as follows: for energy evaluation,[17,18] for energy conservation policy assessment,[19] for determining a priority analysis of equipment used in power plant,[20] for analyzing cost-benefit of hydrogen energy technologies,[21] and for prioritizing manufacturing sectors.[22] In addition, a number of improved AHP methods have been proposed, such as the Fuzzy AHP method[23] and the AHP-TOPSIS (technique for order preference by similarity to an ideal solution) approach.[24]

AHP is essentially a subjective weighting method. The index value of the judgment matrix determined by expertise or related professional knowledge reflects the importance between the two comparative factors.[25] In other words, the weights among different indices in the same level are determined through the pairwise comparison. Generally, the 9-point scale is used to represent such a relative importance, as shown in Table I. The numbers 1, 3, 5, 7, and 9 are used as scaling ratios, corresponding to the strength of importance for one element over another. For example, number 9 represents the extreme importance over another element.

Based on the AHP, a comprehensive evaluation system composed of several indicators can be established. However, each index cannot be directly added or integrated when calculating the comprehensive evaluation score because there are different units, dimensions, and orders of magnitude among various indicators. Therefore, the discrepancy among various indicators should be eliminated by the standardization method.[26,27]

In this paper, we employ the range transformation method to standardize the evaluation indicators. When the characteristic of the indicator is "higher is better," the indicator can be normalized as follows:

$$y_{ij} = \frac{x_{ij} - \min x_i}{\max x_i - \min x_i}(1 \le i \le m,\ 1 \le j \le n). \tag{16}$$

When the characteristic of the indicator is "lower is better," the normalization of the indicator can be written as follows:

$$y_{ij} = \frac{\max x_i - x_{ij}}{\max x_i - \min x_i}(1 \le i \le m,\ 1 \le j \le n). \tag{17}$$

In Eqs. (16) and (17), the i and j denote city and index, respectively. x_{ij} represents the original data for the j index in the i city. $\min x_i$ means the minimum value of original data in the ith row. Similarly, $\max x_i$ denotes the maximum of original data in the ith row.

After transformation, the standardized index can be expressed as y_{ij}, which also satisfies the condition of $0 \le y_{ij} \le 1$, which means that a higher index corresponds to a stronger comprehensive strength of the city.

TABLE I. 9-Point scale for pairwise comparison.

Importance scale	Representative	Explanation (*i* compared with *j*)
1	Equally important	*i* and *j* contribute equally to the target
3	Moderately important	Experience and judgment slightly favor *i* over *j*
5	Strongly important	Experience and judgment strongly favor *i* over another *j*
7	Very strongly important	*i* is very strongly more important than *j*
9	Extremely important	The evidence favoring *i* over *j* is of the highest possible order of importance
2,4,6,8	Intermediate values of adjacent judgments	Used to indicate compromise between the above-listed priorities
Reciprocal of the above values	If *i* has one of the above value (1–9) assigned to it when compared with *j*, then *j* has the reciprocal value when compared with *i*	A reasonable assumption

C. Ward's hierarchical cluster method

The considerable differences of socioeconomic history and conditions among the regions have led to regional disparities in economic development and energy consumption. According to the comprehensive evaluation score of each region, regions with the common characteristics are clustered into one group by using an intelligent clustering algorithm to embody the principle of equity with common but differentiated responsibilities in this study. The regions in the same category have the same reduction target that reflects "equity" and "common responsibilities." However, different categories should be allocated dissimilar reduction targets, thereby reflecting "differentiated responsibilities."

We employ Ward's hierarchical clustering algorithm to explore the regional characteristics,[28] which selects the squared Euclidean distance (SED) to measure the affinities among individuals. The Ward's method uses the analysis of variance at each merging step, considering all possible pairs of clusters and retaining the one with the smallest increase in the error sum of squares (ESS), which can be expressed by the following mathematical equations:

$$D_{ij} = ESS_{ij} - (ESS_i + ESS_j) = \frac{\|X_i - X_j{}^2\|}{\left(\frac{1}{n_i} + \frac{1}{n_j}\right)}, \tag{18}$$

$$D^2_{s,ij} = \frac{n_s + n_i}{n_s + n_i + n_j} D^2_{s,i} + \frac{n_s + n_j}{n_s + n_i + n_j} D^2_{s,j} + \frac{n_s}{n_s + n_i + n_j} D^2_{i,j}. \tag{19}$$

It is assumed that i and j belong to two groups, C_i and C_j, respectively. In Eq. (18), $\mathrm{ESS_{ij}}$, $\mathrm{ESS_i}$, and $\mathrm{ESS_j}$ are the ESS for the merged cluster of C_i with C_j, cluster C_i, and cluster C_j, respectively; D_{ij} is the distance between C_i and C_j; X_i and X_j are the mean vectors of groups C_i and C_j, respectively; n_i and n_j are the numbers of observations in groups C_i and C_j, respectively; and $\|\cdot\|^2$ is the SED. In Eq. (20), C_k is the group merged by groups C_i and C_j; the distance $D^2_{s,ij}$ refers to the distance between C_k and C_s. Detailed descriptions can be found in the literature.[29]

As a popular hierarchical cluster method, Ward mainly evolves by comparing the distance between self and surrounding classes. In terms of separation, this method outperforms other cluster algorithms such as Single linkage, Complete linkage, and K-means clustering, resulting in relatively dense clusters with small within-group variance.[30,31]

D. Data sources and assumptions

1. Data sources

Regional energy consumption data are taken from various versions of Henan Statistical Yearbook, including the 2010–2014 issues,[32–36] and the medium- to long-term development planning of energy in Henan province (2012–2030).[37] According to these data, the energy consumption per unit of GDP for three industries can be obtained. The basic energy-saving rate can also be calculated by using the data from the Henan Province. Based on the energy intensity of 18 cities in 2010, the energy intensity of each city in 2015 is calculated according to the energy intensity reduction rate for 2011–2015.[38,39] The unit of energy data is standard oil consumption in Mtoe. Regional population data and added value data of the three industries are obtained from the 2014 edition of the Henan Statistical Yearbook.[36]

According to the data availability, indicator values involved in the multi-criteria evaluation system can be found in the Statistical Communiqués of 18 regions on the National Economic and Social Development (2010–2014) which are supplied by the local Statistical Bureau of 18 cities in Henan province,[40–44] and the Henan province's 42 and 143 departments basic prolong of input-output table (2007).[45] The 18 regions in Henan province are listed in Appendix B.

2. GDP prediction

Henan province, with its rapid economic development, has made remarkable achievements in economic development. Since 2000, the average annual growth rate of GDP remained above 9% in Henan province. The historical GDP (2000–2014) of each region used in this study are from the national accounts section in the Henan Statistical Yearbook and Statistical Communiqués of 18 regions on the 2014 National Economic and Social Development. Based on the historical GDP, the annual GDP growth rate of each region is estimated for the period of 2016–2020. The total GDP of each region in 2020 is predicted according to the annual GDP growth rate, as shown in Table II. The GDP is converted into the constant price for 2010. The exchange rate between RMB and USD (United States Dollars) in 2010 derived from the Word Bank WDI Database is 6.77 Yuan per dollar.[46]

III. RESULTS AND DISCUSSION

Our study was in close collaboration with the planning for energy saving and emission reduction in Henan from 2016 to 2020, which is entitled, "Research on the decomposition and implementation of Henan province's energy intensity reduction target in the 13th FYP." The main purpose of the project is to allocate the provincial reduction target to 18 regions. Based on the Delphi method (the principles and philosophy of the method are given in Ref. 47),[47] we eventually selected a scenario in which energy intensity decreases by 16% from 2015 levels by 2020 according to the 16% energy-saving target of Henan in 12th FYP.[48] In this scenario, a program for allocating the provincial energy intensity reduction target at the interregional level in the 13th FYP period is proposed.

A. Preliminary regional decomposition scheme

Based on the energy-saving target decomposition model mentioned in Section II A, combining the 16% energy intensity reduction target, the preliminary regional decomposition scheme of Henan by 2020 is shown in Table III.

TABLE II. Provincial and regional GDP indices.

	Annual GDP growth rate (%)			
Region	11th FYP period	12th FYP period	13th FYP period	GDP (10^{12} RMB) In 2020
Zhengzhou	13.7	10.9	10	1.09
Kaifeng	12.8	10.7	10	0.25
Luoyang	14.6	9.5	9	0.56
Pingdingshan	13.4	8.2	8	0.29
Anyang	14.4	9.1	8.5	0.31
Hebi	15.3	11.2	10	0.12
Xinxiang	14.4	10.8	10	0.32
Jiaozuo	13.7	10.6	10	0.33
Puyang	13.2	11.3	10.5	0.22
Xuchang	13.7	11.3	10.5	0.37
Luohe	13.5	10.6	10	0.18
Sanmenxia	15.6	10.5	10	0.23
Nanyang	12.1	9.4	9	0.47
Shangqiu	11.9	10.1	9.5	0.29
Xinyang	12.5	9.7	9	0.27
Zhoukou	11.7	9.8	9	0.30
Zhumadian	12.4	9.7	9	0.26
Jiyuan	15.2	11.6	10	0.10

TABLE III. Preliminary regional decomposition scheme for Henan province in 2020.

	Energy-saving quantity (Mtoe)			Energy intensity reduction target (%)		
Region	Basic	Floating	Total	Basic	Floating	Total
Henan province	48.37	3.43	51.80	15.0	1.0	16
Zhengzhou	9.52	0.63	10.15	20.8	1.4	22
Kaifeng	1.68	0.14	1.82	18.1	1.4	20
Luoyang	4.55	0.35	4.90	15.3	1.1	16
Pingdingshan	2.10	0.21	2.31	10.7	1.0	12
Anyang	2.31	0.21	2.52	9.2	0.7	10
Hebi	1.40	0.07	1.47	12.7	0.7	13
Xinxiang	2.80	0.14	2.94	14.5	0.9	15
Jiaozuo	3.01	0.21	3.22	13.7	0.8	15
Puyang	2.10	0.14	2.24	15.4	0.8	16
Xuchang	3.50	0.21	3.71	20.9	1.1	22
Luohe	1.54	0.07	1.61	16.0	1.0	17
Sanmenxia	2.10	0.14	2.24	13.9	0.8	15
Nanyang	3.15	0.28	3.43	19.2	1.7	21
Shangqiu	1.89	0.14	2.03	11.8	1.0	13
Xinyang	1.61	0.14	1.75	12.8	1.2	14
Zhoukou	2.38	0.14	2.52	25.3	1.7	27
Zhumadian	1.75	0.14	1.89	14.8	1.2	16
Jiyuan	0.98	0.07	1.05	8.8	0.5	9

The amounts and targets of energy conservation are different among the 18 regions in Henan (see Table III). The results show that the cities of Zhoukou, Nanyang, Zhengzhou, Kaifeng, and Xuchang have to undertake a greater share of the burden to achieve the 16% intensity reduction target by 2020. This indicates that these regions have better economic conditions (manifested in per capita GDP), higher energy intensity, and greater energy consumption per unit of an industrial value added. By contrast, Jiyuan is allocated the lowest reduction target, a target decrease of only 9% by 2020, which is 33% that of Zhoukou. However, there is a serious imbalance between the distribution results and development level of cities for Jiyuan and Zhoukou. According to Eqs. (13)–(15), the imbalance may be caused by the inconsistent relation between the proportion of population and industrial structure. Jiyuan's population is the least significant, accounting for only 0.76% of the total population in Henan province, but the proportion of the secondary sector consumption, especially the heavy industry (manufacture of chemical raw material and chemical products, manufacture of non-metallic mineral, manufacture and processing of ferrous and non-ferrous metals, etc.) in its industrial structure, is the largest. In 2013, the primary, secondary, and tertiary economic sectors in Jiyuan accounted for 4.7%, 74.8%, and 20.5% of the total economy, respectively, further securing the industry sector's dominant position. Conversely, Zhoukou is one of the most populous cities in Henan, which is more than three times as populous as Jiyuan, but it is an underdeveloped city in which agriculture is the dominant sector of the economy. Therefore, based on the principle of equity with common but differentiated responsibilities, some of the distribution results are unreasonable.

To compensate for this deficiency on regional energy intensity allocation, the comprehensive evaluation of energy-saving target decomposition is carried out in Section III B.

B. Comprehensive evaluation results (CER)

In this section, we select energy, environment, economy, technology, and structure as indicators for energy intensity reduction obligation, potential, and barriers to establish the energy-saving target comprehensive evaluation system, based on the above-mentioned AHP method.

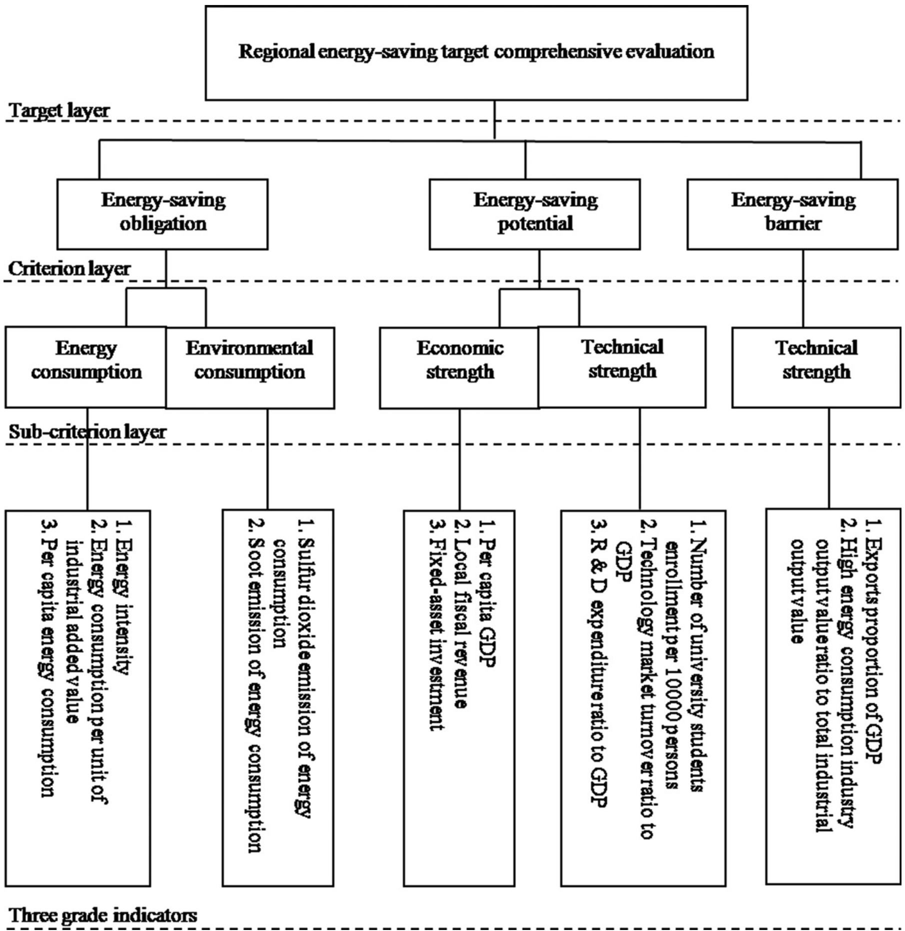

FIG. 2. Regional energy-saving target comprehensive evaluation system.

The comprehensive evaluation system is shown in Fig. 2. We weighted each indicator through the expert scoring method (also called Delphi method). Table IV shows the weight of each indicator. The comprehensive index is constructed based on the 13 indicators to quantify the burdens that each region might shoulder. The comprehensive index provides better and more integrated representation for equity and efficiency than a single indicator.[2,49]

Based on the standardized indicators and the corresponding indicator weights, the linear weighted aggregative method is used to calculate the comprehensive evaluation scores (see Table V). As the value of the comprehensive index increases, the burden the province may shoulder for the 2020 energy intensity reduction target increases.

Table V shows that the overall score of Luoyang is the highest, thereby indicating that it should be allocated the larger reduction burden. In contrast, Zhoukou and Shangqiu, with lower comprehensive scores, should be assigned smaller burdens. To further analyze the impact of obligation, potential, and barriers on the regional energy intensity allocation, a cluster analysis of the results of three indicators is carried out in Section III C.

C. Cluster analysis

Based on the data in Table V and the clustering method mentioned in the second part, the clustering results of obligation, potential, and barriers can be shown in Figs. 3–5, respectively. The red line in Figs. 3–5 represents the classification line, which can be clearly presented the classification of regions.

TABLE IV. Indicator weights of multi-criteria evaluation system of energy-saving target decomposition.

First grade index	Weight	Second grade index	Weight	Third grade index	Weight
Energy-saving obligation	1	Energy consumption	0.7	Energy intensity	0.25
				Energy consumption per unit of industrial added value	0.25
				Per capita energy consumption	0.2
		Environmental quality	0.3	Soot emission of energy consumption	0.15
				Sulfur dioxide emission of energy consumption	0.15
Energy-saving potential	1	Economic strength	0.6	Per capita GDP	0.25
				Per capita local fiscal revenue	0.2
				Fixed-asset investment per unit of GDP	0.15
		Technological power	0.4	Technology market turnover ratio to GDP	0.1
				Number of university students enrollment per 10 000 persons	0.1
				S R & D expenditure ratio to GDP	0.2
Energy-saving barrier	1	Structural adjustment	1	Exports proportion of GDP	0.5
				High energy consumption sector output value ratio to total industrial output value	0.5

Fig. 3 shows the classification of 18 cities in terms of energy-saving obligation. With the red line, we can see that the 18 cities in Henan are classified into five categories. The regions in each category are generally stable and have significant category features. The category attributions of most regions are relatively stable. For example, Jiyuan, with the highest level of energy consumption, is classified as a separate category; Zhoukou stands out with its lowest values of energy intensity, energy consumption per-unit of industrial added value, and per

TABLE V. Comprehensive evaluation score results of eighteen regions.

	Energy-saving obligation		Energy-saving potential		Energy-saving barrier	
Region	Energy consumption	Environmental quality	Economic strength	Technological power	Structural adjustment	Overall rating
Zhengzhou	0.30	0.06	0.43	0.36	0.23	1.38
Kaifeng	0.15	0.23	0.07	0.14	0.86	1.45
Luoyang	0.27	0.15	0.29	0.26	0.75	1.72
Pingdingshan	0.33	0.19	0.15	0.17	0.67	1.50
Anyang	0.41	0.20	0.15	0.09	0.62	1.46
Hebi	0.41	0.11	0.22	0.02	0.73	1.49
Xinxiang	0.28	0.03	0.22	0.23	0.76	1.52
Jiaozuo	0.33	0.07	0.27	0.18	0.62	1.46
Puyang	0.20	0.06	0.15	0.08	0.83	1.31
Xuchang	0.14	0.08	0.19	0.20	0.63	1.24
Luohe	0.14	0.02	0.14	0.08	0.95	1.33
Sanmenxia	0.31	0.25	0.37	0.04	0.67	1.64
Nanyang	0.09	0.15	0.12	0.08	0.81	1.25
Shangqiu	0.18	0.01	0.09	0.04	0.76	1.08
Xinyang	0.19	0.04	0.18	0.01	0.85	1.27
Zhoukou	0.00	0.06	0.01	0.01	0.98	1.06
Zhumadian	0.13	0.12	0.02	0.02	0.88	1.17
Jiyuan	0.62	0.09	0.40	0.20	0.36	1.66

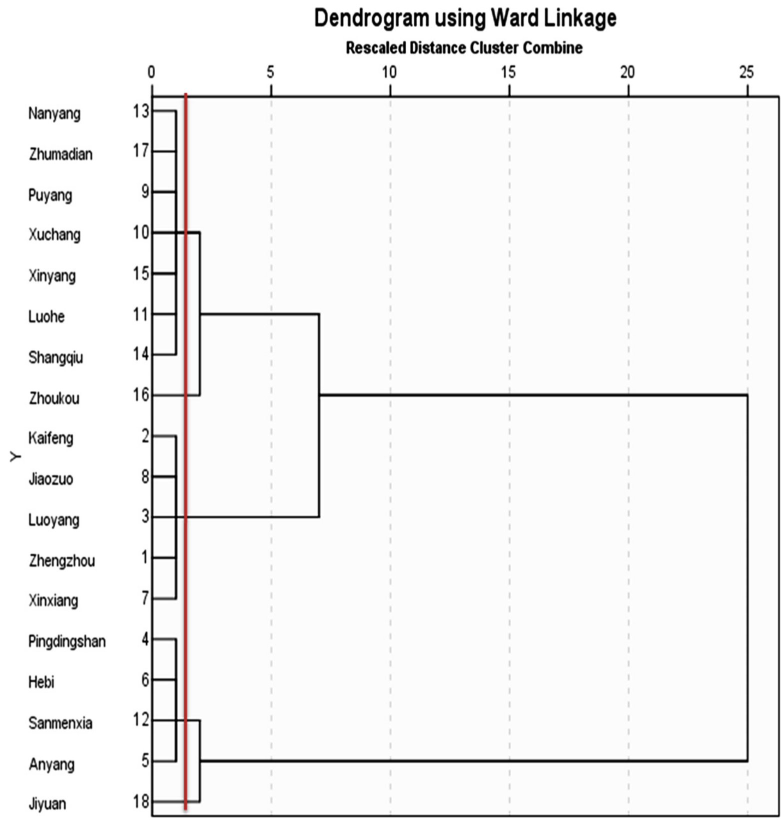

FIG. 3. Cluster analysis of energy-saving obligation.

capita energy consumption. Anyang, Pingdingshan, Hebi, and Sanmenxia, with their greater energy intensity, energy consumption per-unit of industrial added value, and per capita energy consumption, are classified into one category. Zhengzhou, Xinxiang, and Luoyang are the regions with higher per capita energy consumption, energy consumption per-unit of industrial added value, and lower energy intensity. Puyang, Luohe, and Shangqiu have high energy consumption per-unit of industrial added value and high energy intensity, but low values for per capita energy consumption and air pollution.

Fig. 4 shows the 18 cities are classified into five groups of high, medium, and low scores in energy-saving potential. The results reflect the regional economic and technological strength. Zhengzhou, with the highest economic strength and technological advantages, has the capacity for spending more on investing in an improvement of energy-saving technology, followed by Jiyuan and Luoyang. Jiyuan and Luoyang are clustered into one class, with great indicator values for energy-saving potential resulting from the high development of secondary sector. The regions with the lowest indicator values are Zhoukou and Zhumadian for economics and technology. Therefore, Zhoukou and Zhumadian possess poor economic and technological abilities to reduce energy intensity. Xinxiang, Pingdingshan, and Jiaozuo constitute another class. Regions with a large proportion of agricultural reliance are relatively backward for an economy, and industrial regions are relatively advanced. As the provincial capital of Henan, Zhengzhou is far ahead of other cities in Henan. Larger potential indicators correspond to greater reduction burdens.

According to the clustering results of the energy-saving barrier shown in Fig. 5, 18 regions can be classified into five groups: Zhengzhou and Jiyuan; Anyang and Jiaozuo, etc.; Kaifeng, Zhumadian, Nanyang, etc.; Hebi, Xinxiang, Luoyang, etc.; and Luohe and Zhoukou. Most of the cities' classification properties are relatively steady. From analyzing their industrial structure, we can observe that the agricultural or light industry sector in Luohe and Zhoukou

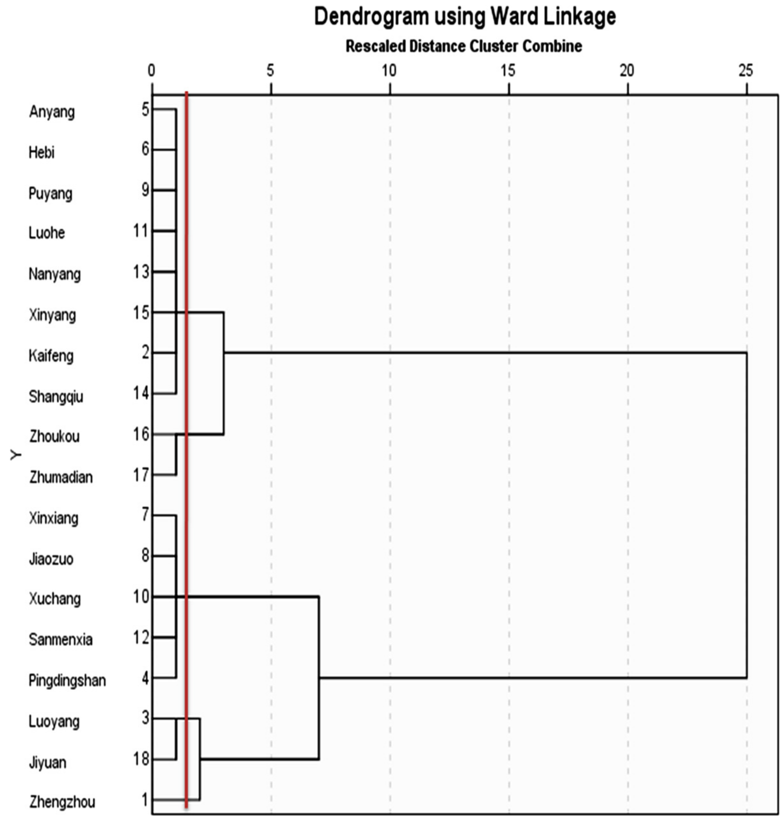

FIG. 4. Cluster analysis of energy-saving potential.

accounts for a larger proportion of the economy. However, the heavy industry in Zhoukou and Luohe accounts for only 31% and 25% of industry, respectively. Nanyang, Kaifeng, Xinyang, and Zhumadian, with lower proportions of energy-intensive industries, are classified into one category. Nanyang, Kaifeng, Xinyang, and Zhumadian also have weaker economic and technological strength. Anyang, Sanmenxia, Jiaozuo, and Pingdingshan have been dominated by heavy industry; in particular, the heavy industry in Sanmenxia and Pingdingshan accounts for 93% and 84% of the industrial sectors, respectively. Luoyang, Shangqiu, and Hebi are the regions with a high proportion of energy-intensive industries and a low proportion of tertiary sector. Advanced cities, such as Zhengzhou and Jiyuan, have a higher proportion of energy-intensive industries but a lower proportion of primary sector, at 3% and 5%, respectively. The export structure of Jiyuan and Zhengzhou is mainly based on heavy industry. The heavy industry in Jiyuan accounts for 89.7% of the industrial sector. The total volume of foreign exports in Zhengzhou increased significantly, with exports in 2013 valued at 153.2 billion RMB, representing an actual increase of 18.7%. Industrial structure adjustment is an important strategy to include in the economic development model for Henan. However, Henan is currently in the process of accelerating industrialization. The manufacturing sector, generally a relatively energy-intensive industry, is the main engine for economic growth. Therefore, the industry structure in the 13th FYP period will not change significantly.

The selection of indicators has a great influence on the final intensity reduction allocation results in our model. The regions that index highly based on the three indicators of obligation, potential, and barriers may shoulder greater burdens in the final intensity reduction target.

D. Sensitivity analysis

The indicator weighting of these indicators has a significant impact on the final intensity reduction results. To avoid the impact, according to expert opinions in the fields of energy,

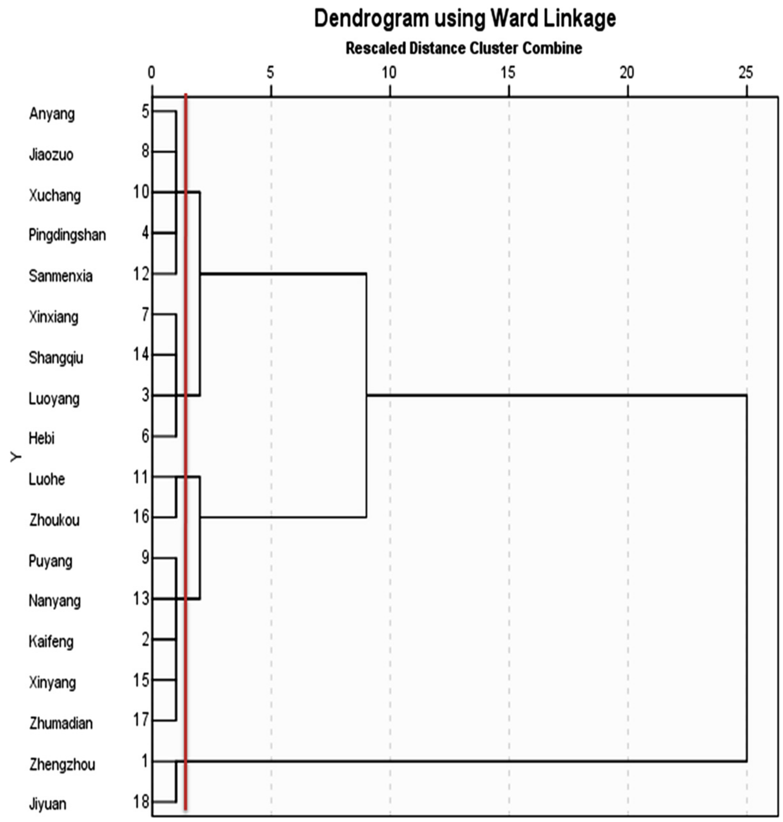

FIG. 5. Cluster analysis of energy-saving barrier.

environment, and economy, three indicators of energy-saving obligation, potential, and barriers are weighted in seven cases: 0.6:0.2:0.2, 0.6:0.3:0.1, 0.5:0.4:0.1, 0.4:0.5:0.1, 0.4:0.4:0.2, 0.3:0.6:0.1, and 0.2:0.6:0.2. Specifically, the indicators of potential and obligation are the most important factors for setting the energy-saving target. In the long term, industrial structure adjustment is conducive to the improvement of energy efficiency, but it is difficult to realize in the short term. In addition, there is limited scope in improving energy efficiency because of the constraints of industrial structure. Therefore, the impact of the energy-saving barrier is weakened, and its weight is limited in the range of 0.1–0.2. The comprehensive evaluation result (CER) can be calculated by the following equation:

$$CER = a * ECO + b * ESP + c * ESB, \tag{20}$$

where a, b, and c represent the weights of energy-saving obligation, potential, and barriers, respectively. ESO, ESP, and ESB are the values of energy-saving obligation, potential, and barriers, respectively. When the CER is carried out, the comprehensive evaluation results of seven groups of weights and corresponding sorting results can be described as shown in Figs. 6 and 7, respectively.

Fig. 6 shows the relationship between the energy-saving obligation and comprehensive evaluation results of seven cases. From 0.6:0.2:0.2 to 0.2:0.6:0.2 indicates that the weight of the energy-saving potential is gradually strengthened and the energy-saving obligation is constantly weakening. This indicates that regions should take the reduction burdens based on their own development level. Weakening the energy-saving obligation and enhancing the energy-saving potential, the comprehensive scores in developed regions are constantly increasing, while they are declining in undeveloped cities. Advanced regions have a stronger capacity for implementing more energy-saving projects, such as retrofitting appliances and introducing advanced technology to reduce energy intensity. Thus, the comprehensive evaluation results in developed

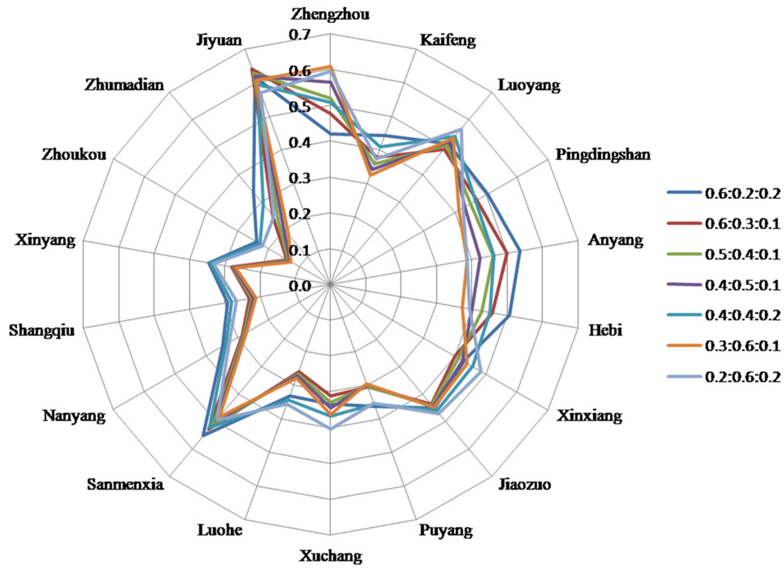

FIG. 6. Sensitivity analysis of comprehensive evaluation results in each city.

regions, such as Zhengzhou and Luoyang, are greatly affected by the energy-saving potential. On the other hand, undeveloped regions are greatly influenced by the energy-saving obligation because they are lagging behind in energy efficiency and industrial structure.

According to the regional sorting results shown in Fig. 7, Jiyuan always ranked in the top two in either weighting cases, while Zhumadian and Zhoukou always ranked in the last two. Jiyuan should take a greater intensity reduction target for all cases. Zhumadian and Zhoukou should be allocated the lower targets. Based on the principle of fairness, operability, and realizability, the evaluation results of two weights cases of 0.4:0.5:0.1 and 0.4:0.4:0.2 are selected as the reference object for modifying the energy-saving target decomposition scheme. In other words, the impact of energy-saving obligation and energy-saving potential on the distribution of the energy-saving targets are considered roughly equal.

We compare the sorting results of two weight cases of 0.4:0.5:0.1 and 0.4:0.4:0.2 with the preliminary decomposition scheme, as shown in Fig. 8. Overall, Zhengzhou, Jiyuan, and

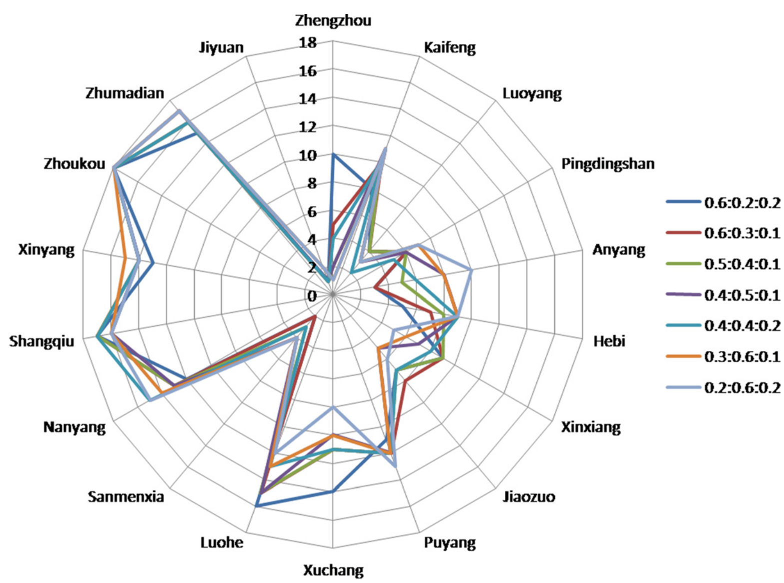

FIG. 7. Sensitivity analysis of the sorting results of cities.

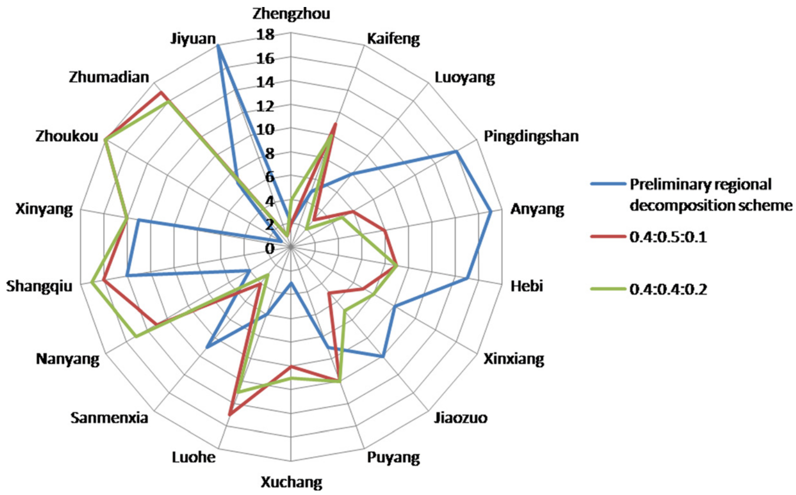

FIG. 8. A Comparison of ranking results with preliminary decomposition scheme.

Luoyang regions should undertake greater burdens to achieve the 16% intensity reduction target by 2020. These regions with higher values of CER result from having greater economic and technological conditions, as well as the highest level of energy consumption and energy intensity. Therefore, after considering the energy-saving obligation, potential, and barriers, these regions should be emphasized when allocating the energy-saving target. Resource-based regions, such as Anyang, Pingdingshan, Sanmenxia, and Jiaozuo, should be classified into class two, which represents the higher energy intensity and energy consumption per unit of industrial added value and a significant economic base. Kaifeng, Hebi, Xinxiang, Puyang, and Xuchang are the regions with high values of CER that should constitute class three. Luohe, Nanyang, Shangqiu, and Xinyang, with low economic and technological strength and low energy consumption, constitute class four, whereas underdeveloped agriculture-based regions, Zhoukou and Zhumadian, with lower energy intensity and poor economic conditions, belong to class five.

E. Regional allocation results of the intensity reduction target

According to the above analysis, the regional energy-saving targets in the preliminary regional decomposition scheme are reassigned. The regions in the same class have the same reduction target that reflects "common responsibilities." However, the reduction degree is dissimilar for different classes, thereby reflecting "differentiated responsibilities." Based on the principle of regional total energy savings equal to provincial energy savings and the target of reducing energy intensity by 16% for the Henan province in 13th FYP period, energy intensity reduction targets are set for each region ranging from 18% to 14% (see Table VI). Regions with the highest values of CER should shoulder greater burdens in the final intensity reduction target. Zhengzhou, Luoyang, and Jiyuan constitute class one.

These regions should lower their energy intensity by 18%. The decline in resource-based regions, such as Anyang, Pingdingshan, Sanmenxia, and Jiaozuo, is targeted at 17%, thus indicating that these regions should adjust their economic structures, strictly restrict the energy consumption of their secondary sector and further improve their energy efficiency to realize the provincial intensity targets. The regions in the third category have great economic and technological conditions. The energy intensity of some of the regions belonging to third category is higher than the average level of the 18 regions; therefore, these regions have the responsibility to undertake the target of reducing energy intensity by 16% compared to 2015. The characteristic of the regions belonging to fourth category is that the proportion of secondary sector is low, while the energy intensity is lower than the average level of Henan province. Thus, Luohe, Nanyang, Shangqiu, and Xinyang, with lower values of CER, should not bear a larger

TABLE VI. Energy-saving target decomposition scheme of Henan province during the 13th FYP period.

Region	Target (%)		Final rank	Final energy intensity (toe/10 000 RMB)	Energy-saving quantity in 2020 (Mtoe)	
	Preliminary	Final			Preliminary	Final
Province	16	16		0.46		51.5
Zhengzhou	22	18	2	0.34	10.15	8.2
Kaifeng	20	16	11	0.31	1.82	1.5
Luoyang	16	18	3	0.43	4.90	5.3
Pingdingshan	12	17	6	0.56	2.31	3.3
Anyang	10	17	7	0.67	2.52	4.3
Hebi	13	16	9	0.69	1.47	1.6
Xinxiang	15	16	8	0.48	2.94	2.9
Jiaozuo	15	17	5	0.56	3.22	3.8
Puyang	16	16	12	0.52	2.24	2.2
Xuchang	22	16	10	0.38	3.71	2.7
Luohe	17	15	15	0.45	1.61	1.4
Sanmenxia	15	17	4	0.55	2.24	2.6
Nanyang	21	15	13	0.29	3.43	2.6
Shangqiu	13	15	16	0.47	2.03	2.4
Xinyang	14	15	14	0.39	1.75	1.8
Zhoukou	27	14	18	0.27	2.52	1.3
Zhumadian	16	14	17	0.39	1.89	1.6
Jiyuan	9	18	1	0.91	1.05	2.0
Total					51.8	51.5

proportion of the reduction target, which is allocated at a 15% energy intensity reduction target for each region. The fifth category comprises the undeveloped regions with the lowest values of CER, such as Zhoukou and Zhumadian, who do not have abundant energy resources. Therefore, the reduction target in Zhoukou and Zhumadian is allocated at the lowest level, at only 14% when considering obligation, potential, and barriers. According to the 16% reduction target, the energy intensity of Henan province will be reduced to 0.46 toe/10^4 RMB in 2020. However, the 2020 level of energy consumption of Henan province is still higher than China's advanced provinces and municipalities during 2010–2014 (see Table VII).[50–54]

Comparing the preliminary and final decomposition results (see Table VI), some regions have significant differences in terms of energy-saving target and quantity. For example, the reduction targets in Zhoukou are significantly decreased, and are increased in Jiyuan, Anyang, and Pingdingshan. Jiyuan with the largest level of energy consumption is allocated the 9% lowest reduction target by 2020 compared with 2015 levels in preliminary allocation, which is 33% that of Zhoukou. Anyang and Pingdingshan with their greater energy intensity, energy consumption per-unit of industrial added value, and economic condition bear only 10% and 12% reduction targets in preliminary allocation scheme. Contrarily, Zhoukou is one of the most

TABLE VII. Energy intensity (toe/10^4 RMB) in China's advanced provinces and municipalities during 2010–2014.

Region	2010	2011	2012	2013	2014	Average
Beijing	0.35	0.32	0.31	0.27	0.25	0.30
Shanghai	0.44	0.41	0.39	0.37	0.34	0.39
Guangdong	0.34	0.33	0.32	0.30	0.29	0.32
Zhejiang	0.43	0.41	0.39	0.37	0.35	0.39
Jiangsu	0.44	0.42	0.40	0.37	0.35	0.40

populous cities in Henan, which is more than three times as populous as Jiyuan, but it is an underdeveloped city in which agriculture is the dominant sector of the economy. Zhoukou is allocated the largest reduction target in preliminary allocation. According to the results of comprehensive evaluation, cluster, and sensitivity analysis (Part B, C, and D), there is a serious imbalance between the preliminary allocation results and development level of cities for Nanyang, Xuchang, Jiyuan, Anyang, and Pingdingshan. This imbalance caused by the proportion of population and industrial structure results in large differences between the preliminary and final decomposition results in terms of energy-saving target and quantity.

IV. CONCLUSIONS AND IMPLICATIONS

This paper developed a decomposition method to set regional energy intensity reduction targets based on the preliminary decomposition model, AHP and Ward's cluster method, with a sensitivity analysis carried out for weighting the energy-saving obligation, potential, and barriers. With full consideration of the regional economic developmental level, industrial structure, and energy consumption level, the present paper proposes the key points and the extent of the energy and environmental policy required to accomplish the reduction target. The following conclusions and implications are drawn from the results:

(a) The 18 regions of Henan can be divided into five classes, each with distinct characteristics, according to the 13 indicators influencing energy intensity. These are the "higher obligation-higher potential-lower barrier" category, with a higher energy consumption and better economic conditions, but low energy-saving barrier, represented by the Zhengzhou and Jiyuan cities; the "high obligation-high potential-high barrier" category, represented by resource-based regions such as Anyang and Pingdingshan; the "high obligation-low potential-high barrier" category, represented by Hebi and Kaifeng; the "low obligation-low potential-higher barrier" category, with low economic and technological conditions and low energy consumption, but a higher energy-saving barrier, represented by the less developed regions such as Hebi and Kaifeng; and the "lower obligation-lower potential-higher barrier" category, represented by undeveloped regions such as Zhoukou and Zhumadian.

(b) The energy consumption per unit of industrial added value of the secondary sector has great effect on the regional energy intensity, especially in the heavy industrial cities such as Jiyuan and Jiaozuo. In other words, the industrial sector has an essential responsibility to reduce energy intensity. In the industrial sector, energy-intensive industries are mainly concentrated in eight industries: electric power, coal, iron and steel, chemicals, building materials (including cement industry), oil processing and coking, non-ferrous metals, and paper. Therefore, improving the energy efficiency of the eight energy-intensive industries will reduce the total energy consumption and aid in achieving the energy-saving targets faster and better.

(c) Different regions should shoulder different reduction burdens in terms of the 13 macro-influencing factors. High degrees of energy consumption reduction are required for regions with large total consumption. The allocation results of intensity reduction show that the largest reduction burdens should be shouldered by regions with a high cardinality of consumption and a strong regional economy, such as Jiyuan and Zhengzhou, as well as by resource-based regions with high energy intensities (at least a 17% reduction target). The minimum requirements for intensity reduction are met by fifth category regions, such as Zhoukou and Zhumadian, which have low cardinality of energy intensities and low energy-saving capacity.

(d) To meet the macro target of reducing energy intensity by 16% from 2015 levels by 2020 in the Henan province, this paper proposed the following suggestions looking at structure, management, and technology. First, the specific structural energy saving mainly includes the following points: deepening the elimination of backward production facilities, restricting the export of energy-intensive products, promoting the development of the tertiary sector, speeding up alteration of the economic development pattern of the Henan province, and limiting the growth rate of regional secondary industries, particularly those with high energy consumption. Second, the developmental direction of energy management is building the energy management system and developing the corresponding standards. Its specific measures can be concluded as follows: strengthening the management of enterprises at all levels, establishing energy-saving investment and financing a risk fund, widely implementing energy-saving transactions and contract energy management, and building an energy-saving information-sharing network platform. Third, the form of technological energy saving is developing and spreading energy-saving techniques: relying on the engineering centers and key laboratories to develop energy-saving technology; and improving energy efficiency in industry. Always governmental incentives are the key driving force for the industry to save energy.

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APPENDIX A: SIZE OF 18 CITIES

See Table VIII.

TABLE VIII. Size of 18 cities of Henan province in 2014.

				Economic sector (proportion %)		
Region	GDP (10^{12} RMB)	Population (10^6 persons)	EC[a] (Mtoe)	Primary	Secondary	Tertiary
Zhengzhou	0.62	9.38	25.06	2.17	51.46	46.37
Kaifeng	0.14	4.55	5.85	18.48	42.65	38.87
Luoyang	0.34	6.68	17.39	7.06	51.07	41.87
Pingdingshan	0.18	4.96	11.24	10.21	53.72	36.07
Anyang	0.19	5.09	15.07	11.45	52.36	36.19
Hebi	0.07	1.60	5.09	9.30	67.37	23.33
Xinxiang	0.18	5.71	10.63	11.64	51.77	36.59
Jiaozuo	0.19	3.52	12.29	7.42	61.80	30.78
Puyang	0.12	3.60	7.22	12.42	57.89	29.70
Xuchang	0.21	4.32	9.12	8.85	60.76	30.39
Luohe	0.10	2.60	5.38	11.59	63.71	24.70
Sanmenxia	0.13	2.25	8.72	8.98	62.52	28.50
Nanyang	0.28	9.99	9.51	17.52	46.50	35.98
Shangqiu	0.17	7.26	8.85	22.08	43.33	34.60
Xinyang	0.16	6.41	7.38	24.62	41.16	34.22
Zhoukou	0.18	8.80	5.54	22.47	47.26	30.27
Zhumadian	0.15	6.93	7.05	23.49	41.32	35.19
Jiyuan	0.05	0.72	6.17	4.52	68.12	27.36
Total	3.46	94.37	177.56			

[a]EC is the energy consumption.

APPENDIX B: COMPREHENSIVE EVALUATION INDICATOR VALUES

See Table IX.

TABLE IX. 13 Comprehensive evaluation indicator values of 18 cities in Henan province.

Unit	Energy consumption per-unit of GDP Toe/10 000 RMB	Energy consumption per-unit of industrial added value Toe/10 000 RMB	Per capita energy consumption Toe/person	Sulfur dioxide emission of energy consumption tSO_2/toe	Soot emission of energy consumption tSoot/toe	Per capita GDP 10 000 RMB/person	Per capita local fiscal revenue 10 000 RMB/person	Fixed-asset investment per-unit of GDP	Technology market turnover ratio to GDP	Number of university students enrollment per 10 000 persons person	R&D expenditure ratio to GDP	Exports proportion of GDP	High energy consumption sector output value ratio to total industrial output value
Zhengzhou	0.4736	0.7279	0.2505	0.0057	0.0027	5.2996	0.6182	0.6417	0.0039	766.0363	0.0151	0.1652	0.4358
Kaifeng	0.4327	0.8370	0.1931	0.0142	0.0056	2.3719	0.1228	0.6041	0.0007	174.6165	0.0104	0.0152	0.2298
Luoyang	0.5943	0.9794	0.2110	0.0119	0.0036	4.1449	0.2884	0.7200	0.0027	133.5662	0.0160	0.0290	0.3243
Pingdingshan	0.7687	1.1032	0.2046	0.0084	0.0061	3.0387	0.2043	0.6419	0.0008	124.0529	0.0126	0.0138	0.4970
Anyang	0.9030	1.4100	0.1989	0.0082	0.0067	2.9676	0.1554	0.6686	0.0002	106.7989	0.0080	0.0207	0.5312
Hebi	0.8962	1.1469	0.2187	0.0108	0.0028	3.2736	0.1926	0.7291	0.0000	64.8883	0.0036	0.0193	0.3917
Xinxiang	0.6465	1.0539	0.2040	0.0060	0.0018	2.5346	0.1758	0.8129	0.0002	222.7641	0.0179	0.0348	0.2805
Jiazuo	0.7464	0.9762	0.2168	0.0052	0.0034	4.2424	0.2272	0.7018	0.0016	213.6903	0.0110	0.0605	0.3634
Puyang	0.6895	0.8583	0.1834	0.0041	0.0034	2.5976	0.1240	0.7235	0.0001	31.8267	0.0081	0.0352	0.1963
Xuchang	0.5033	0.5897	0.1998	0.0073	0.0030	3.7295	0.1922	0.6372	0.0016	79.6514	0.0145	0.0562	0.3692
Luohe	0.5751	0.5064	0.1999	0.0051	0.0018	3.1964	0.1517	0.6386	0.0008	105.2065	0.0062	0.0172	0.1118
Sanmenxia	0.7319	0.9731	0.2104	0.0173	0.0051	4.6697	0.2880	0.7975	0.0000	65.4185	0.0052	0.0096	0.5038
Nanyang	0.3833	0.7085	0.1868	0.0071	0.0053	2.2424	0.0945	0.7214	0.0001	65.8824	0.0078	0.0257	0.2569
Shangqiu	0.6128	0.9364	0.1796	0.0031	0.0022	1.8152	0.0872	0.7168	0.0001	104.7212	0.0044	0.0075	0.4004
Xinyang	0.5075	0.9970	0.1898	0.0060	0.0020	2.0281	0.0804	0.8571	0.0002	87.3818	0.0023	0.0096	0.2744
Zhoukou	0.3486	0.3927	0.1794	0.0048	0.0032	1.6002	0.0630	0.6162	0.0001	40.2977	0.0029	0.0142	0.0807
Zhumadian	0.5186	0.8221	0.1795	0.0065	0.0044	1.7373	0.0765	0.6133	0.0001	27.8928	0.0034	0.0109	0.2210
Jiyuan	1.2592	1.6755	0.2225	0.0082	0.0028	6.0501	0.3998	0.6467	0.0002	153.9159	0.0161	0.0519	0.7414

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