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Carbon dioxide emission reduction quota allocation study on Chinese provinces based on two-stage Shapley information entropy model

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Abstract Chinese central government made a commitment to achieve a 40–45% reduction in carbon dioxide (CO_2) per unit of GDP by 2020 compared with 2005. This targeted reduction was allocated averagely among all the provinces rather than individually according to different situations of each province. Though some research has been done regarding this rough allocation, two shortcomings in previous studies exist: Firstly, CO_2 marginal abatement cost (MAC) has been ignored as one of the CO_2 emission reduction allocation indexes. Secondly, either subjective or objective method has been used rather than comprehensively of both subjective and objective method to calculate the weight of each index in the previous studies. In order to fill the gaps, this paper builds a two-stage Shapley information entropy model to allocate CO_2 emission reduction quota among the Chinese provinces based on the equity and efficiency principles. Afterward, three CO_2 emission reduction quota allocation scenarios have been proposed. The results show that the CO_2 MAC is an indispensable index in CO_2 emission reduction quota allocation, because its value of CO_2 Shapley information entropy is the highest among five indexes. CO_2 emission reduction quota of lower-MAC provinces should be allocated larger, while the quota of higher-MAC provinces should be allocated smaller. Therefore, two suggested policies have been proposed: First, differential CO_2 emission reduction quota allocation should be proposed. Second, synergetic development should be promoted.

Keywords Two-stage Shapley information entropy model · Carbon dioxide · Emission reduction quota allocation · Marginal abatement cost · Policy suggestion

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1 Introduction

Carbon dioxide emission reduction is one of the hot issues in China. Chinese government issued "13th Five-Year" CO_2 emission reduction allocation plan for 30 Chinese provinces in 2016 based on each province's CO_2 emission reduction accomplishment during the "12th Five-Year" plan. This plan classifies the 30 provinces' CO_2 carbon intensity reduction plan into five categories, and it shows that the eastern provinces have higher CO_2 reduction goal than the western provinces. This classification can reduce some developing provinces' CO_2 reduction pressure. However, MAC will increase as the CO_2 reduction burden aggravates (Yang and Lei 2016), which would lead to heavier pressure for high-MAC provinces. To allocate CO_2 emission reduction quota rationally among Chinese provinces, this paper thoroughly considers characteristics of each province. Based on our findings, the previous studies on CO_2 emission reduction quota allocation typically chose population, CO_2 emission quantity, GDP and carbon intensity as their reduction indexes (Welsch 1993; Baer et al. 2008; Yi et al. 2011; Zhou et al. 2014a; Zhou and Wang 2016). However, the MAC has been ignored by the previous studies as one of the CO_2 emission reduction allocation indexes. The CO_2 MAC showing the challenge level of CO_2 emission reduction has not been included in the index system. Besides, the index distribution method has been widely used in CO_2 emission reduction quota allocation. However, subjective and objective methods are used separately to calculate the weight of each index in previous studies. Indexes' weights are set based on distributor's willingness in subjective methods and set as its own importance by objective methods' calculation. Because of the large development gap among Chinese provinces, the combination of subjective and objective methods will thoroughly allocate CO_2 emission reduction quota fairly and effectively among Chinese provinces.

This paper builds a two-stage Shapley information entropy model, with the combination of subjective and objective methods at the same time to allocate CO_2 emission reduction quota among Chinese provinces. Besides, the CO_2 MAC is brought into the index system to allocate CO_2 emission reduction quota scientifically.

This paper has five sections. Section 2 introduces the literature review of CO_2 emission reduction quota allocation. Section 3 describes the model and method. Section 4 depicts the results and discussion. The conclusion and policy suggestions are illustrated in Sect. 5.

2 Literature review

Index allocation method is a commonly used method for CO_2 emission reduction quota allocation. According to the previous studies, equity and efficiency have been considered as the principles of making the index allocation choices (Zhou and Wang 2016). The principle of efficiency also has been considered as certain type of equity principle by some scholars (Welsch 1993; Zhou et al. 2014a).

The equity principle has been widely used in CO_2 emission reduction quota allocation and can be divided into grandfather principle, historical responsibility principle (also called polluters pay principle), egalitarianism principle, ability-to-pay principle, economic index principles, horizontal equity principle and vertical equity principle (Rose and Stevens 1993; Rose et al. 1998; Rose and Zhang 2004; He et al. 2009; Zhou and Wang 2016). Table 1 shows the description and indexes of each principle.

Table 1 Principle of equity

Principles	Description	Indexes
Grandfather principle	All the distributors have the equal emission rights	Proportion of historical emissions
Historical responsibility principle	Bigger historical emitter takes more responsibility	Proportion of accumulated emission
Egalitarianism principle	All people have equal emission rights	Proportion of population and per capita emissions
Ability-to-pay principle	Higher economic ability takes more responsibility	GDP and per capita GDP
Economic index principles	Emission reduction will not affect the standard of living	Proportion of GDP
Horizontal equity principle	Every region has same responsibility	The value of change of net benefits divide GDP of each province is equal
Vertical equity principle	Take more attention on under-performed region	Net revenue is negatively related to per capita GDP

The principle of efficiency is to optimize the resource allocation from the perspective of efficiency. It can be divided into three types: environmental efficiency principle, energy efficiency principle and the ecological efficiency principle (Zhou and Wang 2016). Carbon intensity has been typically used as the efficiency index.

2.1 Per capita carbon emission and per capita accumulated CO_2 emission

Per capita carbon emission is one of the most commonly used CO_2 quota allocation indexes. Grubb (1990) emphasized that everyone shares the equal resource utility right. He suggested that CO_2 emission should be based on principle of equity, and he chose the per capita CO_2 emission as reduction quota allocation index. However, some scholars believed that the per capita accumulated CO_2 emission, which reflects the historical responsibility principle, is a more appropriate index (He et al. 2009; Hu et al. 2009; Kartha et al. 2009; Ding et al. 2010). Scholars from Tsinghua University proposed the "two convergence" method to allocate CO_2 emission reduction quota. The main idea of the "two convergence" method is to choose the per capita accumulated CO_2 emission as the allocation index (Chen et al. 2005). Besides, the "compression and convergence" method which was proposed by British, Indian and Brazilian scholars also chose the per capita accumulated CO_2 emission as the index (Mayer 2000). Yu et al. (2010) pointed out that population is always changing so the per capita accumulated CO_2 emission is not the most appropriate index.

2.2 CO_2 emission and accumulated CO_2 emission

CO_2 emission has been considered as the grandfather principle's index (Ferng 2003; Bastianoni et al. 2004). Miketa and Schrattenholzer (2006) compared the accumulated CO_2 emission and CO_2 intensity separately as reduction quota allocation indexes. They found that the developing counties would gain more CO_2 emission quota based on the accumulated CO_2 emission principle. Zhou et al. (2013) compared five indexes: CO_2 emission, energy consumption, GDP, population and per capita GDP. The results show that CO_2 emission and population are two relatively fair factors. Chen and He (2016) subjectively set weight of three indexes: accumulative CO_2 emission, industry added value and carbon intensity to allocate CO_2 emission reduction quota of each different kind of Chinese industries. The result shows that four high accumulative CO_2 emission sectors: manufacture of raw chemical materials and chemical products, manufacture of non-metallic mineral products, smelting and pressing of ferrous metals, and other services, have more CO_2 emission reduction quota than other sectors.

2.3 GDP and per capita GDP

GDP and per capita GDP have been considered as the indexes of ability-to-pay principle, economic index principles and horizontal equity principle (Rose et al. 1998; Rose and Zhang 2004). Wu et al. (2010) chose each province's historical emissions, population and per capita GDP proportion to allocate the quota. They found per capita GDP proportion of each province is more appropriate for CO_2 emission allocation than the other two indexes.

2.4 Population

Population has been considered as the egalitarianism principle's index. Xu et al. (1997) compared three allocation scenarios with different indexes: population, GDP and population–GDP. The results show that allocation based on population index is beneficial for developing countries, while the allocation of GDP is for developed countries.

2.5 Carbon intensity

Carbon intensity always has been considered as the efficiency principle's index (Xia and Chen 2012). Liu et al. (2008) allocated the CO_2 emission quota of China, North America, the European Union, Russia and the developed countries in the Asia and Pacific areas under the following six indexes: CO_2 emission, carbon intensity, per capita GDP, per capita CO_2 emission, accumulated per capita CO_2 emission and the import and export trade. China, according to the results, attained high CO_2 emission quota when accumulated per capita CO_2 emission and per capita CO_2 emission indexes were adopted. And under carbon intensity index, China would be allocated low CO_2 emission quota.

Some scholars composited several indexes to allocate CO_2 emission quota. Phylipsen et al. (1998) proposed an equal weight allocation model to allocate the CO_2 emission quota for 16 European countries. The weight of per capita CO_2 emission, per capita GDP and the CO_2 emission per GDP were subjectively set as 1/3 equally. The result shows that most of the European countries will reduce its CO_2 emissions in 2010. The Luxembourg, which is the biggest reducer, will reduce 20.8% of its CO_2 emission compared to 1990. However, some European countries have little historical CO_2 emission so they have large CO_2 emission quota. For instance, the Ireland will increase 3% of its CO_2 emission compared to 1990. Gupta and Bhandari (1999) believed that to attain the "common but differentiated responsibilities" CO_2 emission reduction quota allocation, each country's quota should be allocated based on the per capita accumulative CO_2 emission. They used the multi-objective programming approach to allocate CO_2 emission reduction quota of 14 countries. The result shows that USA and Canada will be allocated large CO_2 emission reduction quota, while Spain, Sweden and Switzerland will be allocated small CO_2 emission reduction quota.

Several studies did researches on rational allocation of CO_2 emission reduction quota among Chinese provinces. The objective model: China Regional Burden Differentiation Model (CRBDM), was built to allocate CO_2 quota of Chinese provinces by Wang et al. (2011). He chose five allocation indexes: per capita GDP, per capita CO_2 emissions, industrial added value of energy consumption, trend of energy consumption of industrial added value and the proportion of non-fossil fuel consumption. The result shows that Shanxi is the largest CO_2 emission reducer which will reduce 1.55% of its CO_2 emission in 2020 compared with 2005, while Sichuan has the largest increment and it will increase 1.18% its CO_2 emission in 2020 compared with 2005. Yi et al. (2011) selected per capita GDP, accumulative CO_2 emissions and energy consumption per unit of industrial added value as the CO_2 quota allocation indexes based on equity principle. They analyzed the CO_2 emission quota allocation among 30 Chinese provinces under four scenarios with subjectively set biased weight on each index. The result shows that Beijing, Shanghai and Xinjiang will have large CO_2 emission quota under preferring capability scenario. Under preferring potential scenario, Shanxi and Ningxia will have large CO_2 emission quota. Hebei, Shanxi, Liaoning and Shandong will be allocated large CO_2 emission quota under preferring responsibility scenario. LMDI model was used by Chen and Lin (2015) to objectively allocate CO_2 emission reduction quota for Chinese provinces. From the LMDI structure, CO_2 emission, energy structure, energy intensity, economic output and population are chosen as the indexes based on the equity principle. The result shows that Shanxi and Liaoning will have largest CO_2 emission quota, while Qinghai and Ningxia will have the smallest CO_2 emission quota in 2020. Han et al. (2016) chose accumulative CO_2 emission, per capita GDP and unit of industrial added value of energy consumption as indexes to allocate CO_2 quotas of Beijing, Tianjin and Hebei Provinces. And the directional distance function value of each index was objectively taken as the index weight. The result shows that Hebei has the largest CO_2 reduction quota which is equal to 1.4 times the sum of Beijing and Tianjin. Sun et al. (2011) objectively allocated the Chinese provinces' CO_2 emission reduction quota based on per capita GDP and carbon intensity of each province. The result shows that Shanxi and Hebei Provinces have the largest CO_2 emission reduction allocation quota, while Qinghai, Hainan and Guangxi Provinces have the smallest CO_2 emission reduction allocation quota. Thirty Chinese provinces were clustered into four groups by using particle swarm algorithm and fuzzy clustering methods by Yu et al. (2014). GDP, energy endowment, living level and carbon intensity were chosen as the indexes to objectively allocate 30 Chinese provinces' CO_2 emission quota by using the Shapley information entropy method. The result shows that Shandong and Henan Provinces are the largest CO_2 emission quota reducers, while Beijing, Jiangxi and Hainan Provinces are the smallest CO_2 emission quota reducers. Index allocation methods are the most commonly used methods for CO_2 emissions quota allocation in the previous literature. Mostly, the previous literature chose population, CO_2 emissions (per capita), accumulative CO_2 emissions (per capita), GDP and carbon intensity as the allocation indexes based on both the equity and effective principles. MAC, which depicts the decrement amount of GDP when reduced to the last unit of CO_2 emissions in a certain abatement technology status (Chen 2010; Ba and Wu 2010; Matsushita and Yamane 2012; Garg et al. 2014; Wang and Wei 2014), is an important effective index for CO_2 emissions allocation quota system. However, MAC had been always ignored by previous studies. The CO_2 macro-abatement costs are defined as the decrement of GDP when imposing CO_2 emission reduction measures in a certain period. And the MAC can express the difficulty of CO_2 reduction more directly than the macro-abatement cost (Gao et al. 2004; Chen et al. 2005, 2007; Ko et al. 2010). Moreover, without a comprehensive determination, the weight of indexes was always calculated subjectively or objectively separately.

In order to overcome previous studies' shortcomings, this paper established a two-stage Shapley information entropy model to allocate CO_2 emission reduction quota among Chinese provinces. In the first stage, we set the subjective weight of equity and effective principles. In the second stage, we established Shapley information entropy to objectively calculate the weight of each specific index. We chose historical accumulative CO_2 emissions, MAC and carbon dioxide as the equity principle index, and MAC and carbon intensity as the effective principle index. The Shapley information entropy model is established to consider the internal relationship between the indexes, so as to reflect the influence of the indexes more comprehensively.

3 Models and methods

3.1 Two-stage Shapley information entropy model

As previous studies have ignored MAC as one of the CO_2 emission reduction quota indexes, we overcome the drawback and set MAC as one of the efficiency principle indexes. Historical accumulative CO_2 emissions (C), population (P) and GDP (GDP) are chosen as indexes of equity principle, while MAC and carbon intensity (CI = C/GDP) are chosen as efficiency principle indexes.

The previous studies, respectively, build subjective or objective model to allocate CO_2 mission reduction quota. To combine the advantages of these two models, we build a two-stage Shapley information entropy model to allocate the CO_2 emission reduction quota of Chinese provinces.

First of all, we establish the first stage of Shapley information entropy model with the forementioned selected indexes. We set a decision matrix X, and each x_{ij} of X represents index value. And n and m are the numbers of provinces and indexes, respectively.

$$X = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1m} \\ x_{21} & x_{22} & \cdots & x_{2m} \\ \cdots & \cdots & \cdots & \cdots \\ x_{n,1} & x_{n,2} & \cdots & x_{n,m} \end{bmatrix} \quad (n = 1, 2, \ldots, 30,\ m = 1, 2, \ldots, 5),$$

where x_{ij} represents the historical accumulative CO_2 emissions, population, GDP, MAC and carbon intensity of each one of the 30 Chinese provinces. The calculation of CO_2 emission and MAC followed the models in the previous literature (Yang and Lei 2016).

The proportion of each index of each province is calculated by the following equation:

$$v_{ij} = \frac{x_{ij}}{\sum_{i=1}^{n} x_{ij}}. \tag{1}$$

The decision matrix is obtained as follows:

$$V = \begin{bmatrix} v_{11} & v_{12} & \cdots & v_{1m} \\ v_{21} & v_{22} & \cdots & v_{2m} \\ \cdots & \cdots & \cdots & \cdots \\ v_{n,1} & v_{n,2} & \cdots & v_{n,m} \end{bmatrix} \quad (n = 1, 2, \ldots, 30,\ m = 1, 2, \ldots, 5).$$

The Shapley value of each index can be calculated by the following equation:

$$e_j = \frac{\sum_{i=1}^{n} v_{ij} \ln v_{ij}}{\ln n} \quad (j = 1, 2, \ldots, m). \tag{2}$$

And the information entropy of each index are measured by Eq. 3:

$$w_j = \frac{1 - e_j}{m - \sum_{j=1}^{m} e_j} \quad (j = 1, 2, \ldots, m). \tag{3}$$

The second stage of Shapley information entropy model is established based on equity and efficiency principles to allocate CO_2 emission quotas:

$$S_i = \sum_{j=1}^{m} \alpha_j \times w_j \times v_{ji} \quad (i = 1, 2, \ldots, n; j = 1, 2, \ldots, m), \tag{4}$$

where S_i is the allocation weight of province i and α_j denotes the subjective allocation weight of equity and efficiency principle subject to $\sum_{j=1}^{m} \alpha_j = 3$.

Besides, we set three scenarios based on whether there are biases of each principle:

Scenario 1: Equal distribution of equity and effective principles. Then:

$$\alpha_j = 1, \quad j = 1, 2, \ldots, 5.$$

Scenario 2: Have bias on equity principle. Then:

$$\alpha_j = 1.5,\ j = 1, 2, 3; \quad \alpha_j = \frac{w_4 + w_5}{1 - \sum_{j=2}^{3} w_j} w_j, \quad j = 4, 5.$$

Scenario 3: Have preference on effective principle. Then:

$$\alpha_j = 1.5,\ j = 4, 5; \quad \alpha_j = \frac{\sum_{j=1}^{3} w_j}{1 - (w_4 + w_5)} w_j, \quad j = 1, 2, 3.$$

3.2 CO_2 emission reduction quota allocation of Chinese provinces in 2020

First of all, we predict the CO_2 emission of China in 2020 according to the Chinese target of 45% carbon intensity reduction in 2020 compared to 2005:

$$C_{2020} = (1\text{–}45\%)\ \mathrm{CI}_{2005} \times \mathrm{GDP}_{2020} \tag{5}$$

According to the GDP growth rate tendency in recent years, we set the GDP growth rate of 6% in 2015 to 2020.

The CO_2 emissions in 2015–2020, C'_{2020}, is predicted according to the 2000–2014 CO_2 emissions data trend. Then, the total CO_2 allocation quota is calculated by Eq. 6:

$$C_{\mathrm{reduction}} = C'_{2020} - C_{2020}. \tag{6}$$

According to Eq. 4, the CO_2 emission reduction allocation quota of each Chinese province can be obtained as follows:

$$m_i = S_i \times C_{\mathrm{reduction}},\ i = 1, 2, \ldots, 30. \tag{7}$$

3.3 Data

The inputs in this study included capital, labor and energy. The perpetual inventory method, which was proposed by Goldsmith in 1951, is generally accepted by previous studies to measure capital stoke. The perpetual inventory method was widely used in the measurement of Chinese capital stoke (Zhang et al. 2004; Shan 2008; Xiang and Ye 2011; Fan 2012). The labor, energy consumption and GDP are derived from the *2015 China Statistic Yearbook (CSY)*, *2000–2015 China Energy Statistic Yearbook (CESY)* and 2000–2015 *China Statistic Yearbook (CSY)*. Moreover, the energy consumption is estimated as standard coal by considering the standard coal coefficient. GDP is converted into comparable prices in 2000. And the historical accumulative CO_2 emission is calculated by CO_2 emissions from energy consumption of each province from 2000 to 2015. The data of Tibet, Hong Kong, Macau and Taiwan are not included in this research.

4 Results and discussion

4.1 Shapley information entropy of each index

Table 2 shows the results of the information entropy of each index. The Shapley information entropy value of MAC is significantly higher than other indexes. It means that MAC is critical for CO_2 reduction allocation quota. So it is scientifically meaningful to bring MAC into the index system in this paper.

The values of carbon intensity, GDP and historical accumulative CO_2 emissions' Shapley information entropy are close to each other in Table 2, which means these three indexes are equally important under scenario with no bias. Population, on the other hand, has smallest Shapley information entropy value and least importance under no-bias scenario.

4.2 CO_2 emissions reduction quota allocation of Chinese provinces

Figure 1 shows the real and fitted CO_2 emissions of China from 2000 to 2014 and predicted CO_2 emissions from 2015 to 2020.

Figure 2 shows the GDP from 2000 to 2014 and the predicted GDP (with 6% GDP growth rate).

Under 45% reduction in carbon intesity scenario, the total CO_2 emission reduction allocation quota allocation quota calculated by Eqs. 11 and 12 is 570.1493 million tons.

Table 2 Shapley information entropy of each index

Principle	Index	Shapley information entropy
Equity principle	Historical accumulative CO_2 emissions	0.1773
	Population	0.1421
	GDP	0.1886
Efficiency principle	MAC	0.2944
	Carbon intensity	0.1975

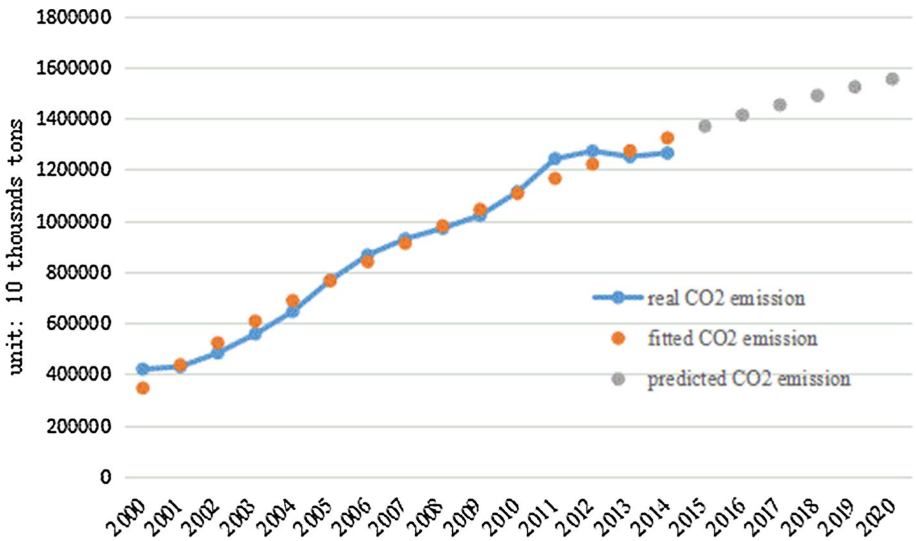

Fig. 1 Real, fitted and predicted CO_2 emission (unit: 10 thousand tons)

The CO_2 emission reduction allocation quotas of each Chinese province can be calculated in three scenarios (see Fig. 3).

As shown in Figs. 3 and 4, provinces like Xinjiang, Heilongjiang, Shandong and Shanxi have larger CO_2 emission allocation quota (occupied 10.37, 8.63 and 6.95% of total quota, respectively), while provinces like Beijing, Tianjin, Hainan and Qinghai have smaller CO_2 emission allocation quota (occupied 0.72, 1.11, 0.23 and 1.15% of all quota, respectively) under scenario of *equal distribution of equity and effective principles*. The result is similar to previous studies. From the previous studies, provinces like Shandong, Shanxi and Hebei have larger CO_2 emission reduction quota, while provinces like Hainan, Beijing and

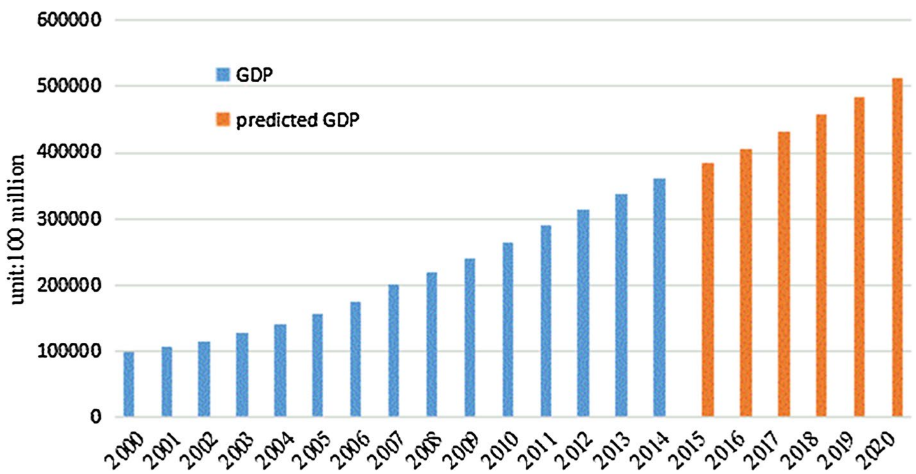

Fig. 2 GDP and predicted GDP (unit: 100 millions)

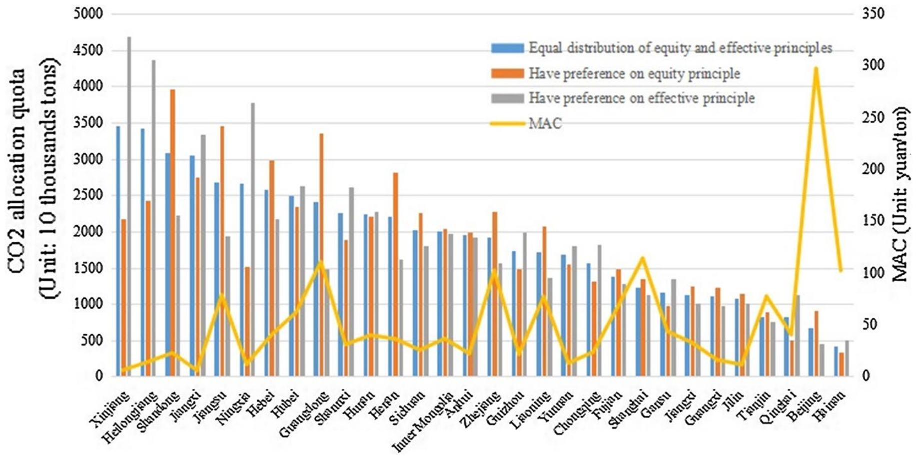

Fig. 3 CO_2 allocation quota of Chinese provinces under three scenarios (unit: 10 thousand tons) and MAC of each province (unit: yuan/ton)

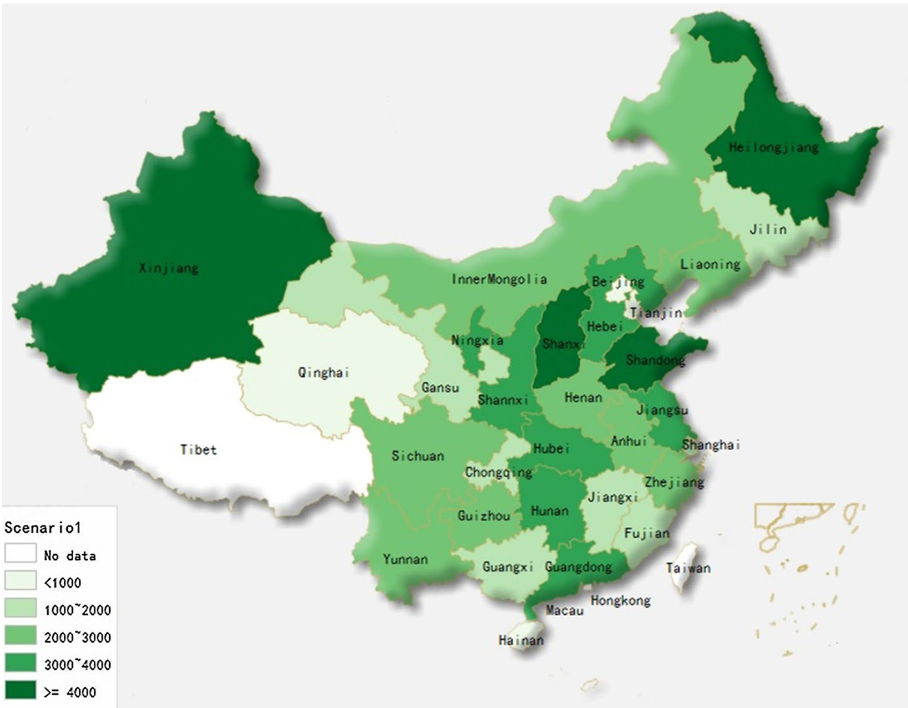

Fig. 4 CO_2 allocation quota of Chinese provinces under scenario 1 (unit: 10 thousand tons)

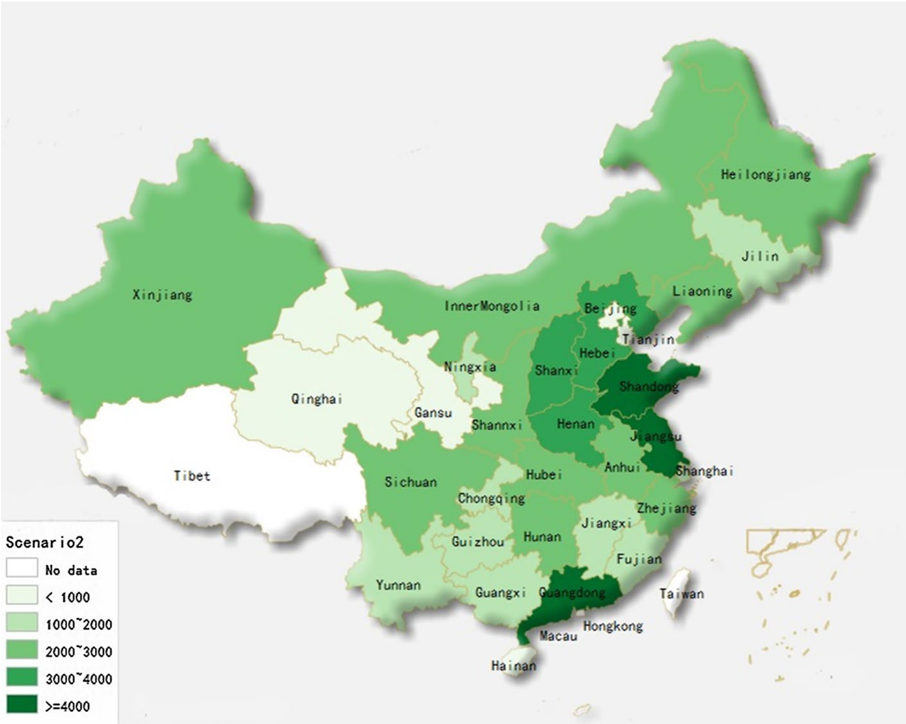

Fig. 5 CO_2 allocation quota of Chinese provinces under scenario 2 (unit: 10 thousand tons)

Qinghai have smaller CO_2 emission reduction quota (Wang et al. 2011; Yi et al. 2011; Sun et al. 2011; Yu et al. 2014; Chen and Lin 2015; Han et al. 2016).

However, in our paper, the MAC, of which the Shapley value occupies 29.44%, as the most important factor of CO_2 emission quota allocation system, is the main cause of the different CO_2 emission quota allocation among Chinese provinces. Therefore, the allocation result in this paper shows that the larger allocation quota provinces have lower MAC, while the smaller allocation quota provinces have higher MAC in scenario of equal distribution of equity and effective principles. This also illustrates the differences the previous researches and the recent one. In our research, under the scenario of equal distribution of equity and effective principles, provinces with high MAC like Xinjiang, Jiangxi and Ningxia (MACs are 24.66 yuan/ton, 21.53 yuan/ton and 12.21 yuan/ton, respectively) have large CO_2 emission quota (occupied 10.37, 6.95 and 5.53% of total quota, respectively).

Figure 5 shows that Shandong, Jiangsu and Guangdong provinces have the heavy CO_2 emission reduction burden (occupied 7.23, 8.38 and 5.15% of total quota, respectively) under the scenario of *have preference on equity principle*. Table 2 shows that historical accumulative CO_2 emissions and GDP have higher CO_2 Shapley information entropy value in equity principle. And the historical accumulative CO_2 emission is the driving factor of Hebei and Shandong Provinces, while the proportion of GDP has major influence in Jiangsu and Guangdong Provinces.

Figure 6 shows that Xinjiang and Heilongjiang have extremely heavy CO_2 emission reduction quota (occupied 14.52, 9.09 and 8.85% of all quota, respectively) under scenario

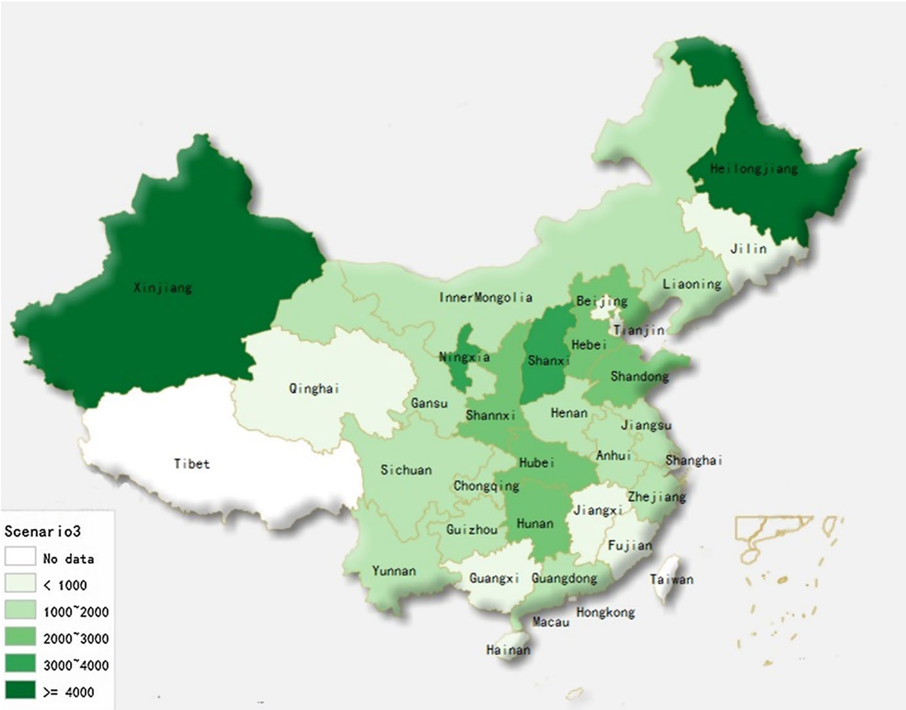

Fig. 6 CO_2 allocation quota of Chinese provinces under scenario 3 (unit: 10 thousand tons)

of *have preference on effective principle*. And lower-MAC provinces such as Shanxi, Ningxia, Shaanxi, Guizhou, Qinghai also share large reduction burden. Larger CO_2 emission reduction quota means heftier economic burden and is likely to impede the economy development of these developing provinces. Taking Xinjiang, Ningxia and Heilongjiang Provinces for example, the CO_2 emission allocation quota of these provinces under scenario 3 will bring extra 12.32 million tons, 11.12 million tons and 9.49 million tons, which are 4.51, 3.73 and 2.10% of total quota CO_2 emission reduction, respectively, and will cause 74.61 million yuan, 131 million yuan and 13 million yuan extra cost, respectively (equal 0.1, 0.5 and 0.08% of each province's GDP) than scenario of *equal distribution of equity and effective principles*.

Therefore, we think scenario 1 (equal distribution of equity and effective principles) and scenario 2 (have preference on equity principle) are more appropriate than scenario 3 (have preference on effective principle).

5 Conclusion and policy suggestions

5.1 Conclusion

1. MAC has the highest Shapley information entropy value. Hence, MAC is an indispensable index for CO_2 emission reduction quota allocation.

2. MAC index plays a vital role in allocating CO_2 emission reduction quota. In all the three set scenarios, lower-MAC provinces should be allocated larger quota, while higher-MAC regions should be allocated smaller quotas.
3. The scenario of equal distribution of equity and effective principles considers equity and effective principles equally, and the scenario of have bias on equity principle is more appropriate approach than the scenario of have bias on effective principle.

5.2 Policy suggestions

At the national level, a fair and effective CO_2 emission reduction quota allocation system is the foundation for stable economic development. Different CO_2 emission reduction quota targets for each Chinese province should be made based on historical accumulative CO_2 emissions, population, GDP, MAC and carbon intensity. Two policy suggestions are made as follows:

5.2.1 The central government should chose an allocation principle from scenario 1 (equal distribution of equity and effective principles) or scenario 2 (have preference on equity principle) based on the actual situation of China.

MAC plays an important role in CO_2 emission reduction quota allocation. It appears that lower-MAC provinces have higher quota, while higher-MAC provinces have lower quota. However, lower-MAC provinces mostly are developing provinces and higher CO_2 emission reduction quotas become a hefty burden for them. In order to encourage the economic development for the developing provinces, scenarios 1 and 2 are more appropriate approach than scenario 3 (have preference on effective principle).

Under scenario 1, Xinjiang, Heilongjiang, Shandong and Jiangxi Provinces will be allocated higher CO_2 emission reduction quota, while the quotas of Beijing, Tianjin, Hainan and Qinghai Provinces will be lower. The result shows that MAC is the major contributor for allocation. Economically, lower-MAC provinces with higher reduction quota and higher-MAC provinces with lower reduction quota are reasonable.

The central government can choose scenario 2 to focus on equity. Because of the higher historical accumulative CO_2 emission proportion of Shandong, Hebei, Henan and Liaoning Provinces, higher quotas will be allocated for those provinces. In contrast, Beijing, Jiangsu, Guangdong and Zhejiang Provinces have prosperous tertiary industry which consumed lots of energy conveyed from lower-MAC regions. From the perspective of equity, it is also reasonable to allocate more emission reduction quotas to those provinces.

5.2.2 Reasonable quotas will promote coordinated development between the provinces

It can be seen from the result that most developing provinces would undertake more CO_2 emissions reduction quota because of their lower MAC. To promote stable development of high-quota provinces, the central government should subsidize these provinces. In the meantime, developed provinces should play leading and model roles in order to promote the successful completion of the national emission reduction task. Developing provinces should be encouraged to improve their industrial structure, reduce high-carbon industries and develop low-carbon industries.

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Compliance with ethical standards

Conflict of interest The authors declare that there is no conflict of interest regarding the publication of this study.

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