Study on provincial decomposition method of total carbon emission control target based on greenhouse gas inventory

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Abstract: Realizing the transformation from "dual control of energy consumption" to "dual control of carbon emissions" is the inherent requirement of realizing the "dual carbon" goal. Scientific planning of the provincial decomposition method of total carbon emissions is an important content of the top-level design of carbon emissions management, and an important support for the implementation of total carbon emissions control. Based on the application research of greenhouse gas inventory in all fields, this paper conducts a full factor analysis of the total carbon emissions of the whole society, establishes a comprehensive decomposition index system, and proposes a simple and transparent provincial decomposition method of the total carbon emissions control target, which considers fairness and efficiency. The simulated decomposition results show that the decomposition method is scientific and operable and can be used as an important reference for future practical decomposition operations.

1. Introduction

The 2021 Central Economic Work Conference pointed out that conditions should be created to realize the transformation from energy consumption "dual control" to total carbon emission and intensity "dual control" as soon as possible, which is the inherent requirement to achieve carbon peak carbon neutralization and promote high-quality development. Carbon reduction and carbon control at the provincial level is the key link and fundamental guarantee to achieve the national goal of "dual carbon". Currently, there is no direct measurement or monitoring of carbon emissions in China, and most studies on total carbon emissions are based on energy consumption[1]. As the carbon emission space obtained by decomposition means the local development space in the future, it is extremely critical to carry out the research on the decomposition of provincial carbon emission control and to find a relatively fair, reasonable, intuitive, transparent and operational decomposition method.

The total carbon emission decomposition methods are generally divided into top-down and bottom-up decomposition methods[2], in which the former can be divided into two categories (structural decomposition method and exponential decomposition method)[3], while the latter is represented by the three-sector method of the European Union, which is one of the few carbon reduction target decomposition methods that have been applied in practice. Since its establishment, the method has been extended on a large scale because of the increasing complexity of factors, such as the three sectors themselves are more detailed. Subsequently, it was extended to 48 countries around the world [4]. The bottom-up approach sets different parameters for each country, calculates the carbon emission limits of the three sectors respectively, and finally adds up to the total target of each country[5]. The early three-sector approach focused on energy structure in electricity and energy efficiency in industry, while in other industries, it focused on per capita GDP and per capita CO_2 emissions, GDP scheme characterized by per capita GDP and per capita cumulative emissions, and FAIR2.0 model based on emission reduction cost because these industries are mainly related to living welfare[6]. Since then, the three-sector method has been significantly developed, and the factors of consideration are becoming more and more complex[7].

During the 12th Five-year Plan period, China issued the *Work Plan for Controlling Greenhouse Gas Emissions During The 12th Five-Year Plan*. First of all, 31 regions in China are divided into three categories, based on the declining index of energy consumption intensity in each region, and the adjustment related to the classification of each region is added to get the declining index of carbon intensity in each region[8]. However, the research on the decomposition of total carbon emissions is only in the exploratory stage. In recent years, researcher focused attention on the decomposition of total carbon emissions in China, most of them are based on the principles of fairness and efficiency, such as the decomposition method based on cluster analysis[9]. model prediction method based on the difference of

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emission reduction potential of different provinces[10], data envelopment analysis based on relaxed variables or zero-sum income[11], decomposition method based on carbon emission environment learning curve model[12], CGE model decomposition method based on consumption and so on.

At the same time, some scholars decompose China's total carbon emission control target to provinces through FCAM-based ZSGDEA model, Lorentz curve, DDF model[13] and and regional decomposition model based on vertical increment of carbon emissions[14]. These studies provide effective scientific support for provinces to achieve greenhouse gas emission reduction targets. However, the existing research results still lack a scientific and reasonable basis for decomposition, and there are great differences in the core issues such as allocation objects, principles, factors, models and the reliability of results, which indirectly imply the need for a set of decomposition methods that are more simple, transparent and easy to discuss[15]. The research on the decomposition of total carbon emission control at the provincial level not only helps to enrich the theoretical research on carbon emission decomposition, but also makes the work of carbon reduction and carbon control at the provincial level more targeted and operational. This work conducts a full factor analysis of the total carbon emissions of the whole society, establishes a comprehensive decomposition index system, and develop a simple and transparent provincial decomposition method of the total carbon emissions control target.

2. Target Region Decomposition Model

From the main practices of the decomposition of total carbon emission control objectives at home and abroad, "giving consideration to fairness and efficiency" is a common feature. At the same time, the decomposition method should also reflect China's basic policy orientation of "controlling increment first and reducing stock as a supplement". Combined with the existing research results and according to the actual situation in China, a simple and transparent decomposition method of total carbon emission control target is proposed, which takes into account both fairness and efficiency.

The total carbon emission decomposition model is mainly divided into three types: direct distribution of total carbon emissions; allocation of carbon emission increment space; and "increment + partial stock" distribution mode. The third mode takes into account the advantages of both total and incremental allocation, which is relatively fair and reasonable, and is more operable, and the scheme is more practical and effective[16].

The basic principles of regional decomposition of total carbon emissions have the following four parts: The first is the principle of fairness, which is decomposed by comprehensively considering the differences in the number of population and the stage of development between regions; The second is the principle of efficiency, which is helpful for the country to produce more development benefits under the set total carbon emission target; The third is the principle of feasibility to enhance the acceptability of the selected indicators and the accessibility of data; The fourth is the principle of effectiveness to ensure the realization of the total carbon emission control target.

3. Construction of Target Decomposition Model and Index System

3.1. Provincial Decomposition Index System of Total Carbon Emissions

The index system is based on the principles of fairness, efficiency, feasibility and effectiveness. In terms of equity, first of all, we should ensure that the population in the region enjoy equal rights to greenhouse gas emissions, that is, interpersonal equity, and secondly, we should ensure that the stage of economic development is fair, that is, the allocation of space in economically developed fields is less than that in fields in need of development. The principle of efficiency means that the decomposition results should maximize the economic output in the region. The feasibility first refers to the policy feasibility, and the distribution scheme can be accepted by various local governments; the second is the technical feasibility, which mainly refers to the difficulty of the model and the availability of relevant data of the existing statistical system, so that the construction of total control target decomposition system is more operable and closer to the needs of government decision-making.

Based on the guidelines for the preparation of greenhouse gas emissions inventory, the research scope of the proposed index system includes five major fields of activities of the whole society, namely, energy activities, industrial production processes, agricultural activities, land use change and forestry, and waste disposal (Table 1)[17].

Table 1. Comprehensive index system based on greenhouse gas emission inventory

First-level index	Second-level index	Note
Energy	Greenhouse gas emissions per unit of industrial value added energy activities	efficiency-related index
	Greenhouse gas emissions per unit of gross domestic product of construction energy activities	

	Greenhouse gas emissions from energy activities per unit value added of tertiary industry	
	Greenhouse gas emissions from energy activities per unit of passenger traffic	
	Greenhouse gas emissions per unit of freight transport energy activities	
	The expected speed of regional economic development	fairness-related index
	Per capita GDP	
	Proportion of tertiary industry	
Industry	Greenhouse gas emissions per unit of industrial value added	efficiency-related index
	Growth of per capita disposable income of urban residents	fairness-related index
Agriculture	Greenhouse gas emissions per unit added value of agriculture, forestry, animal husbandry and fishery	efficiency-related index
	Intensity of agricultural support (per capita agricultural government subsidy)	fairness-related index
Forestry	Standing stock volume	efficiency-related index
	Support for forest cultivation (proportion of forestry investment in GDP)	fairness-related index
Waste disposal	Per capita waste treatment greenhouse gas emissions treatment	efficiency-related index
	Urban resident population	fairness-related index

3.2. Total Carbon Emission by Regional Decomposition

For the comprehensive index system, the hierarchical assignment method is adopted. First of all, each field is assigned according to the proportion of greenhouse gas emissions in different fields in the total emissions of the whole society; on this basis, the quantitative values and expert opinions are comprehensively considered for each index item in each field, and the values are assigned one by one according to its influence.

(1) Weights of index in different fields ωk.

$$E = \sum_{k=1}^{5} E_k = \sum_{k=1}^{5} E \times \omega_k$$

$$\sum_{k=1}^{5} \omega_k = 1$$

Where, E represents the total greenhouse gas emission control target in the region; k represents five different fields, namely, energy activities, industrial production processes, agricultural activities, land use change and forestry, and waste disposal, and E_k represents the total greenhouse gas emission control targets in different fields.

(2) Weight of index in a single field $\beta_{j.k}$.

$$E_{j.k} = E_k \times \beta_{j.k}$$

$$\Sigma_j E_{j.k} = E_k$$

$$\Sigma_{j.k} \beta_{j.k} = 1$$

Wherein, $E_{j,k}$ represents the greenhouse gas emission control sub-goal of the j index in the k-th field, and $\beta_{j,k}$ represents the weight of the j-th index of the k-th activity in the total greenhouse gas emission control target of the whole province.

(3) Weight of each region $\gamma_{i.j.k}$

$$E_{i.j.k} = \gamma_{i.j.k} \times \beta_{j.k} \times \omega_i \times E$$

Wherein, $E_{i.j.k}$ represents the greenhouse gas emission control target of the j index part of the k activity field broken down to a region i at the next level.

(4) Decomposition results of greenhouse gas emission control targets in various regions E_i

$$\mathbf{E}i = \sum_{j.k} E_{i.j}$$

4. Decomposition of Total Carbon Emission Control Target

4.1. Normalization of Carbon Emission Index Data

In order to eliminate the influence of dimension, integrate positive index and negative index, and solve the problem of orientation and value of each index in the index system, the index data are normalized. For a certain index X_i (where i represents a region at the next level in the region), the maximum value X_{max} and the minimum value X_{min} are identified, and then normalized according to the orientation of the index.

For positive indicators, the values after normalization are:

$$\Phi_i = \frac{X_i - X_{min}}{X_{max} - X_{min}}$$

For negative indicators, the values after normalization are:

$$\Phi_i = \frac{X_{max} - X_i}{X_{max} - X_{min}}$$

In the index system, except for forestry, efficiency-related index in other fields are regarded as negative indicators, that is, the larger the greenhouse gas emissions per unit added value (population), the smaller the emission space, while for carbon sinks, standing stock volume is a positive index, that is, the larger the standing stock volume of a region, the stronger the carbon sequestration capacity, the larger the distributable emission targets, which reflects the incentive orientation of the policy.

4.2. Simulation Total Carbon Emission Decomposition Index

Reasonable weight distribution starts from the overall optimization goal and objectively reflects the difference of the importance of each index. In turn, weight can also play a guiding role. Different empowerment can be used to reflect the policy orientation and guide the behavior of local governments. The assignment of the index system is shown in Table 2.

Table 2. Assignment of th index systems.

First-level index	Weight	Second-level index	Weight
Energy	0.75	Greenhouse gas emissions per unit of industrial value added energy activities	0.3
		Greenhouse gas emissions from energy activities per unit of value added of construction industry	0.1
		Greenhouse emissions from value-added energy activities per unit of tertiary industry	0.1
		Greenhouse gas emissions per unit of passenger traffic	0.05
		Greenhouse gas emissions per unit of freight transport	0.05
		Proportion of tertiary industry	0.15
		The expected speed of regional economic development	0.1
		Per capita GDP	0.15
Industry	0.15	Greenhouse gas emissions per unit of industrial value added	0.6
		Growth of per capita disposable income of urban residents	0.4
Agriculture	0.05	Greenhouse gas emissions per unit added value of agriculture, forestry, animal husbandry and fishery	0.6
		Intensity of agricultural support (per capita agricultural government subsidy)	0.4
Forestry	0.03	Greenhouse gas absorption per unit standing stock	0.6
		Support for forest cultivation (proportion of forestry capital investment in GDP)	0.4
Waste disposal	0.02	Greenhouse gas emissions per capita (waste disposal)	0.6
		Urban resident population	0.4

Considering the share of total carbon emissions in different fields, such as the largest emissions from energy activities, the indicators in this field should be set to the maximum. According to the proportion of greenhouse gas emissions in different fields of a province, the weight values of energy, industrial production process, agriculture, forestry and waste disposal are assigned to 0.75, 0.15, 0.05, 0.03, 0.02 respectively, and the index items in each field are evaluated and scored, and the Weight value of each index item is determined reasonably.

4.3. Determination of Distribution Target of Total Carbon Emission Control

During the 14th five-year Plan period, reserved indicators were set to take into account the fact that provincial governments would arrange major projects for prefectural and municipal governments on the basis of strategic considerations. The total carbon emission target for major projects will be set in accordance with the 10% target for the total carbon emission control of the whole province. Provincial governments can allocate reserved carbon emission targets to relevant local governments according to the landing of key projects, which will enable the energy-based decomposition scheme more flexible.

At present, the regional distribution of carbon emissions (stock) is not in line with the principle of "fairness and efficiency", and it takes some time to adjust its pattern. Therefore, it is suggested that the method of "increment + partial stock" should be adopted for the allocation object in accordance with the principle of "controlling increment first and subtracting stock as auxiliary".

Provinces are also advised to give full play to the role of strategic reservation indicators and establish a "reservation" or "reservation" system, that is, prefectures and cities are allowed to "reserve" part of the carbon emission space targets for the next year, or only the current year's surplus indicators are "reserved" to the next year. In a word, the results of this study creatively provide a fair, efficient and feasible scheme for the prefecture-city decomposition of the total carbon emission control target in the province.

4.4. Explanation of decomposition cases

For validating the rationality and operability of the above decomposition method, a total carbon emission control target for a certain province is selected for

decomposition and validation. The closest and relatively complete information is the carbon emission data of ten regional-level cities from 2010 to 2014 through a search of the available literature and database such as the statistical yearbook of the province and the Chinese Carbon Emission Accounts &Datasets (CEADs). 2010 is the base year and 2014 is the target year, and the above method is used for simulated decomposition. The comparison of decomposition values and actual emission values of carbon emission targets in various regions and cities in this province is shown in Table 3.

It can be found that the difference between the actual carbon emission and the local carbon emission target of each municipality is getting smaller as the years increase, with a deviation of -9 ~ 7% and an absolute error of -4.10 ~ 4.14 million tons. Six cities have achieved the carbon emission control targets, and three cities are within the controllable scope although they have not fully completed the carbon emission control targets, indicating that the carbon emission space decomposed by this method is basically in line with the actual situation. This decomposition method is more operable and scientific, which is consistent with the regional development policy orientation of the province.

5. Conclusion

A target decomposition method for total carbon emission control with fairness and efficiency, simplicity and transparency are proposed in this thesis according to the actual situation in China. Based on the greenhouse gas emission inventory preparation guide, this decomposition method covers five major activities throughout society, such as energy activities, industrial production processes, agricultural activities, land-use change and forestry, waste processing, etc. 16 indicators are weighted through the hierarchical value assignment method and verified for the actual carbon dioxide emission of a province, which shows that the decomposition method of carbon emission indicators proposed in this thesis is highly operable and scientific.

Table 3 Data Validation Results Comparison

City	2010	2011			2012			2013			2014			
	Actual emission	Actual emission	Completion	Deviation	Actual emission	Completion	Deviation	Actual emission	Completion	Deviation	Actual emission	Decomposition value	Completion	Deviation
A	10.56	11.15	-0.05	-0	10.48	0.62	6%	12.51	-1.41	-11%	12.2	**11.1**	-1.1	-9%
B	63.72	64.45	4.52	0.07	66.48	2.49	4%	64.14	4.83	8%	64.83	**68.97**	4.14	6%
C	30.4	29.01	-2.88	-0.1	26.75	-0.62	-2%	26.74	-0.61	-2%	27.53	**26.13**	-1.4	-5%
D	22.52	28.43	9.29	0.33	32.83	4.89	15%	39.56	-1.84	-5%	39.7	**37.72**	-1.98	-5%
E	81.12	82.44	-3.57	-0	81.26	-2.39	-3%	84.12	-5.25	-6%	82.97	**78.87**	-4.1	-5%
F	57.95	54.3	16.51	0.3	57.62	13.19	23%	63.25	7.56	12%	67.66	**70.81**	3.15	5%
G	12.9	13.98	8.18	0.59	17.96	4.2	23%	19.16	3	16%	20.71	**22.16**	1.45	7%
H	30.32	39.49	-7.52	-0.2	38.07	-6.1	-16%	31.18	0.79	3%	29.88	**31.97**	2.09	7%
I	32.35	35.49	-3.87	-0.1	33.94	-2.32	-7%	32.62	-1	-3%	31.3	**31.62**	0.32	1%
J	96.49	98.33	11.43	0.12	101.16	8.6	9%	102.54	7.22	7%	108.67	**109.76**	1.09	1%
K	N/A	N/A	/	/	N/A	/	/	N/A	/	/	N/A	**14.64**	/	/
L	N/A	N/A	/	/	N/A	/	/	N/A	/	/	N/A	**12.19**	/	/
M	N/A	N/A	/	/	N/A	/	/	N/A	/	/	N/A	**10.46**	/	/
N	N/A	N/A	/	/	N/A	/	/	N/A	/	/	N/A	**8.25**	/	/
Total	458.76	471.24			481.32			502.56			506.39	**534.65**		

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