

Article Carbon Emission Governance Zones at the County Level to Promote Sustainable Development

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Abstract: Low-carbon governance at the county level has been an important issue for sustainable development due to the large contributions to carbon emission. However, the experiences of carbon emission governance at the county level are lacking. This paper discusses 5 carbon emission governance zones for 1753 counties. The zoning is formed according to a differentiated zoning method based on a multi-indicator evaluation to judge if the governance had better focus and had formulated a differentiated carbon emission governance system. According to zoning results, there is 1 high-carbon governance zone, 2 medium-carbon governance zones, and 2 low-carbon zones. The extensive high-carbon governance zone and medium-carbon zones are key governance areas, in which the counties are mainly located in the northern plain areas and southeast coastal areas and have contributed 51.88% of total carbon emissions. This paper proposes differentiated governance standards for each indicator of the 5 zones. The differentiated zoning method mentioned in this paper can be applied to other governance issues of small-scale regions.



1. Introduction

Targeted climate change mitigation policies can have co-benefits and have led to an interest in sub-national climate action. In particular, there is a growing emphasis on low-carbon city construction in developing countries. To achieve the low-carbon goal announced by the Paris Agreement, China should take different types of domestic lowcarbon policies and actions into consideration. County is the basic administrative unit for the overall planning of Chinese urban and rural development. Different from city district, county is located in a more marginal area, and governs towns and villages. It usually has a lower level of industrialization and urbanization. However, it still plays a vital role in carbon control and emission reduction. In 2015, a total of 1929 counties, which covered 88% of the land area and contained 74% of the population, accounted for 60% of total carbon emissions. Carbon emission governance at the county level is very important for the achievement of low-carbon development goals. Compared with cities and regions, counties are smaller in size and face a more specific governance scenario. Most of the experiences of carbon emission governance in the typical large cities do not apply to the counties. Moreover, at the county level, there are great differences in carbon emission governance as a result of their wide differences between populations, distribution regions, and levels of urbanization. Therefore, at the county level, carbon emission governance needs to build a more detailed and systematic method of assessment for addressing more specific issues of low-carbon development. According to the systematic characteristics of low-carbon development issues, the counties should be classified into different zones as a basis on which a systematic and differentiated carbon emission governance path for Chinese counties can be constructed.



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In the past decades, scholars from different disciplines have conducted a large number of carbon emission governance studies in different regions and on different spatial scales, and the studies mainly focus on the following three categories: low-carbon city indicators, governance methods, and case studies. First, a large number of studies on low-carbon indicators have been conducted on urban clusters [1-3], large cities [4,5], and other largescale objects, such as research on low-carbon urban assessment [6,7] and carbon emission estimation methods [8,9]. Second, studies on governance methods have proposed some carbon emission governance tools [10,11] or models [12–15], targeting one aspect, such as production or building, of governance, at the city level [16–18]. Third, many carbon emission governance case studies have been conducted on small-scale objects, such as urban centers [19], communities [20-22], and industrial parks [23,24]. Also, more than 80 low-carbon pilots were set up in China from 2010 to 2017 and some research was conducted to analyze the carbon emission governance effects of the pilots. The studies attempted to realize the universal application of carbon emission governance through the governance method in a case-study city or the governance mode of a specific topic. To date, the research on carbon emission governance has focused on large scales, such as cities and regions, or some specific small-scale areas, and has provided many theoretical and methodological bases. However, the main drivers of carbon emissions in cities and counties are different because the overall levels of the development of the cities are higher than those of the counties whose levels of development are varied. It is indicated that the proposed low-carbon city indicators were not completely applicable to counties and that the policy tools and governance models for low-carbon cities could not work for all counties. To draw on the experiences of low-carbon cities, carbon emission governance for the counties requires further discussion considering the characteristics of the county.

On the county level, there are two difficulties in carbon emission governance. The large number of counties means that it is unrealistic to achieve targeted governance, such as pilot establishment. The huge differences in geographical locations and the levels of economic development among the counties have caused differences in the carbon emission drivers and have resulted in the consequence of applying uniform standards of low-carbon constraints in all counties during unified governance. However, based on preliminary estimates of the counties' carbon emissions combined with the conclusions of some scholars on the counties' economic and social development, this study found that the counties in the neighboring areas had similar levels of low-carbon development [25]. It provides for the possibility of classified governance. For example, the average carbon emissions of the construction sector in counties north of the heating demarcation line (the north-south demarcation line, where the Chinese government subsidizes central heating in winter) were nearly twice those of the counties in the eastern region are nearly three times that of the less developed counties in the western region [26].

Due to the above difficulties and findings, this study attempted to introduce the classification approach toward achieving differentiated carbon emission governance for counties. The specific goal of the study is to analyze the regional differences of the carbon driving factors and further establish a zoning system for carbon emission governance based on these factors. It will be helpful for the country to carry out macro-level regulation, and convenient for local governments to formulate specific and feasible low-carbon management measures based on local conditions, thereby reducing carbon emission in counties nationwide. To achieve the above goals, the study needs to solve the following problems: (1) identify the carbon emission governance elements in counties by formulating a cause-effect chain among the county's level of development, carbon emission governance, and carbon emissions, and (2) classify all counties according to their performances on carbon emission governance elements in order to propose differentiated carbon emission governances and planners.

Considering the two problems above, methods for establishing a low-carbon evaluation indicator system and for zoning by geographical type have been extensively discussed. For the first method, scholars have mainly used literature inquisition [27,28], Triple Bottom Line, pressure-state-response (PSR) framework and its expansion framework, such as the driving force-pressure-impact-state-response (DPISR) framework [29] and driving force-pressure-state-impact-response-management (DPSIRM) framework [30], to formulate the indicator system. For example, Yang set up a three-tier low-carbon city evaluation indicator system with the PSR model and calculated the low-carbon city comprehensive score for Beijing in 2009 [31]. Song and Li used the DPSIR model to build a low-carbon city indicator system and assessed the low-carbon development of the Yangtze River Delta [32]. The PSR and its expansion framework have been widely used in research on city carbon emission governance [33] and have proven advantages in building indicator systems and developing political goals related to environmental issues [30]. For geographical zoning, the classical zoning methods can be categorized as clustering analysis [34–36], spatial auto-correlation [37,38], and analytic hierarchy process (AHP) [39,40]. More suitable for governance-oriented zoning, clustering analysis is used mostly for multi-factor integrated zoning because it can reflect the differences and convergences among regions by integrating many governance elements. The zoning method is widely used in research on geographical zoning, such as geological zoning [41,42], climate zoning [35,43,44], and ecological functional zoning [45–48], but rarely used in research on carbon emission governance. Moreover, most zoning research has focused on reflecting the external differences in the carbon emissions of regions directly [49] but has disregarded the differences in the internal motivations. In general, both the PSR framework and clustering analysis have solid application foundations. The PSR framework is widely used to establish a carbon emission evaluation system, which can identify the cause-effect chain of governance indicators and carbon emissions to establish a carbon emission governance indicator system at the county level. Clustering analysis is used mainly in multi-factor comprehensive classification, which is suitable for carbon emission governance zoning. It is worth mentioning that the zoning in previous studies was mainly cognitive-oriented zoning rather than governanceoriented zoning. The zoning's results do not reflect the internal differences in governance elements that could affect external differences in carbon emissions, so it was difficult to derive a governance strategy. In fact, governance elements such as population, land use, and facilities, can affect carbon emissions by affecting the energy consumption of the building and transportation sectors [50–53]. Therefore, to establish a zoning system oriented toward carbon emission governance, it is essential to find the effects of governance elements on carbon emissions. This study attempted to reflect the differences in the counties' carbon emissions through the governance elements, then guide the counties' low-carbon development by the governance elements. Finally, to derive differentiated governance standards, the current Code for County Management, which has set the standard thresholds for most governance elements, can be referenced. Although this document does not consider carbon emission governance, a comparison of its proposed standard scenarios and the realistic scenarios of the counties in different zones is of much relevance to clear, differentiated carbon emission governance targets for the counties.

The framework of "identifying the cause-effect chain among county development, carbon emission governance, and carbon emissions—establishing carbon emission governance indicator and carbon emission governance zoning systems for the counties—setting a differentiated governance system" consisted of the following steps (Figure 1): (1) introduce the county governance elements into the PSR framework and identify the cause-effect chain so that the governance elements in the chain would be used to build the initial carbon emission governance indicator system, (2) further screen the initial governance indicators that do affect carbon emissions by analyzing their carbon effects to establish a modified indicator system, (3) collect data for the counties' indicators and classify all the counties with the clustering analysis method to draw a carbon emission governance zoning map at the county level, and (4) reference the current Code for County Management, so that the

differentiated governance system, including key governance indicators and the low-carbon target thresholds of the indicators, would be established for each zone.



Figure 1. Research framework.

This paper intends to construct a governance-oriented carbon emission zoning at the county level. This research will help policymakers develop differentiated and locally applicable strategies for controlling and reducing carbon emissions, which is important for sustainable development. The zoning presented in this paper can help to clarify the differences in carbon management among the counties and the directions of governance for the counties in different zones. The proposed differentiated zoning method is based on multi-indicator evaluation and optimizes the classical zoning method to establish governance-oriented zones that can reflect the differences in both external carbon emissions and internal motivations, as well as provide new ideas for the carbon emission governance of small-scale regions with large populations.

2. Materials and Methods

2.1. Data Sources

The statistics of the counties' energy consumption in 2015 are relatively complete for 1753 of the 1903 counties (county-level cities) in China, so these counties were selected for this study. The data of both the planning indicators (such as socio-economic development, and urban and rural construction) and the energy consumption used for carbon emission estimation were obtained from the "China County (City) Social and Economic Statistical Yearbook 2016", "China County Construction Statistical Yearbook 2015", "China County Statistical Yearbook 2016", China Energy Statistical Yearbook 2016", and "Statistical Communiqué on Economic and Social Development 2015".

The Intergovernmental Panel on Climate Change (IPCC) is the current, mainstream regional Greenhouse Gas (GHG) accounting system. In this study, the IPCC's emission inventory method was applied to estimate the counties' carbon emissions for an analysis of the carbon effects of the indicators.

2.2. PSR Framework for Low-Carbon Counties

PSR is an environmental model proposed by the Organization for Economic Cooperation and Development (OECD) in 1993 [54]. The framework is a common method used by policymakers to measure climate adaptation [55] and has evolved expansion frameworks.

Carbon reduction should not only control energy consumption directly but also reduce energy consumption by changing people's production and living styles, as well as improve energy efficiency, from the perspective of urban governance. Reducing energy consumption through carbon emission governance requires clarifying the causal relationships among city governance, human activities, and carbon emissions. The pressures of county development (e.g., population increase, land expansion, and economic development) have led to environmental changes, i.e., carbon emissions. The governance sector improves urban construction (infrastructure improvement, energy efficiency improvement, ecological environment protection, etc.) for controlling carbon emissions. Such improvement in urban construction affects the socio-economic development of the counties. Both urban construction and socio-economic development are covered by the content of county governance. The classic PSR framework can provide a systematic and complete representation of the causal relationship analyzed above. The cause-effect chain for low-carbon county governance based on the PSR framework is shown in Figure 2. "P" represents the pressure of the county's development that affects carbon emissions, "S" represents the environmental state of the carbon emissions, and "R" represents the governance response for carbon reduction.



Content of county governance

Figure 2. Pressure-state-response (PSR) framework for county-level carbon measurement.

By the sorting and classifying of the contents of county governance, as well as the introducing of the governance indicators into the cause-effect chain [56], governance indicators that constituted a causal relationship with carbon emissions were found and formed the initial county-level carbon emission governance indicator system, as shown in Table 1. To ensure that the selected indicators were representative and justified, this study referred to the low-carbon planning indicators in 15 typical papers on low-carbon city indicator systems [7,49,57–69]. The initial indicators' reference rates in the 15 references were counted and most were higher than 30%. In addition, the indicator of total investment in fixed assets, which reflects the reproduction of fixed assets in the county governance content, was added to economic development. Combined with the indicator of the density of heating pipelines, the indicator of the floor-area ratio of heating was added to the low-carbon building sector in order to reflect building heating in both the density and intensity dimensions.

Group	Sector	Indicator	Reference Rate
Environmental State	Carbon emissions	Carbon emissions	60.0
		Built-up areas	26.7
	Seels and structure	Land urbanization rate	33.3
	Scale and structure	Population	20.0
		Population urbanization rate	33.3
		Gross domestic product (GDP)	33.3
Pressure from development	Economic development	Gross domestic product (GDP) per capita	40.0
	*	Proportion of secondary industry to gross domestic product (GDP)	40.0
		Proportion of tertiary industry to gross domestic product (GDP)	60.0
		Total investment in fixed assets	-
		Coverage rate of population with access to gas	13.3
	Buildings	Density of heating pipelines	20.0
		Living density	40.0
		Density of road network	20.0
		Public transportation vehicles per 10,000 people	86.7
	Transportation	Possession of motor vehicles per capita	40.0
Governance response		Parks per 10,000 people	60.0
		Matching ratio of hospital accommodations	20.0
-		Matching ratio of educational facilities	20.0
		Proportion of sidewalk area	13.3
	Ecology	Carbon sink capacity	60.0
	Energy efficiency	Ton of standard coal equivalent (TCE) per unit gross domestic product (GDP)	66.7

Table 1. Initial carbon emission governance indicators for counties.

Note: After a consideration of the matching ratio of facilities, such as hospitals and schools, which affect the carbon emissions of the transportation sector and the efficiency of residents' access to the facilities, such indicators were included in the transportation sector.

2.3. Carbon Emission Governance Indicator System for Counties

To ensure that each selected indicator did affect carbon emissions, the carbon effect analysis of the indicators was conducted for screening the initial indicators. The methods of the logarithmic mean weight division Index (LDMI) model [51], stochastic impacts by regression on population, affluence, and technology (STIRPAT) model, decoupled model [70,71], regression analysis, and correlation analysis [51,64,72] were usually used in previous research to analyze the carbon effects of multi-indicators. Correlation analysis is a more suitable method for judging the correlation between a comprehensive multi-indicator and carbon emissions. In addition to the carbon emission indicator, all 22 indicators in the "P" and "R" groups in the initial indicator system belonged to the county's direct governance content, whereas the carbon emission indicator was an environmental indicator indirectly affected by carbon emission governance. The carbon effects of 20 governance indicators were analyzed by the correlation analysis method, but the other 2 indicators of carbon sink capacity and energy intensity were not analyzed because they were absolute effect indicators of low-carbon development. The results show that some of the indicators widely used in the urban carbon emission evaluation of the transportation sector were not significantly related to carbon emissions at the county level but may have

been related to the lower levels of the development of the counties rather than those of the cities. The number of motor vehicles in the counties is lower than in the cities, traffic congestion is not as widespread, and the construction of public transport systems is also less complete. Therefore, some indicators, such as the number of motor vehicles per capita, in the transportation sector had little effect on carbon emissions, but other indicators related to rigid travel demand still had close relationships. In addition, according to the county governance content, the calculations of the 3 indicators that reflected the services of parks, schools, and medical facilities in the initial indicator system were adjusted. The attributes of the T_2 indicator were different from those of T_3 . This difference may be due to the tendency of most residents to choose hospitals with the best service quality. This tendency weakens the indicator's effect on carbon emissions; however, a county with a high hospital matching ratio tends to have a higher level of economic development, which has a positive effect on carbon emissions according to the Kaya Identity. When the effect of the indicator is weakened, the positive effect of socio-economic development factors on carbon emissions is revealed.

Finally, the carbon emission governance indicator system was set up to reflect the carbon emission governance problem. Each indicator has its own meaning and affects carbon emissions in different ways. Table 2 shows the final indicators, the results of the correlation analysis, and the attributes of the indicators. The attribute of "+" represents its positive effect on carbon emissions. The higher the indicator's value, the more critical is the governance problem. The indicator attribute of "-" means the opposite of "+". The 17 governance indicators with carbon effects constitute the final indicator system (Table 2). The measurement methods of some indicators can be seen in Appendix A. The 6 indicator sectors to which they belong can separately reflect the internal carbon emission governance problems in 6 aspects and the indicator in the "CE" sector directly shows the external carbon emissions affected by governance problems.

Sector	Indicator	Unit	Sig.	Attribute
Carbon emissions (CE)	Carbon emissions (CE)	10,000 tons	/	/
	Built-up area (S1)	km ²	0.0001 **	+
Scale and structure (S)	Population (S_2)	10,000 people	0.0001 **	+
	Population urbanization rate (S_3)	%	0.0001 **	+
	$GDP(ED_1)$	\$	0.0001 **	+
Economic development	Proportion of secondary industry to GDP (ED ₂)	%	0.0001 **	+
(ED)	Proportion of tertiary industry to GDP (ED_3)	%	0.0001 **	—
	Total investment in fixed assets (ED ₄)	\$	0.0001 **	+
	Coverage rate of population with access to gas (B_1)	%	0.0980 *	+
Buildings (B)	Density of heating pipelines (B_2)	km/km ²	0.0880 *	—
Dununigs (D)	Floor-area ratio of heating (B_3)	-	0.0001 **	_
	Living density (B ₄)	10,000 people/km ²	0.0001 **	-
	Average service area per park (T ₁)	hm ²	0.0030 **	+
Transportation (T)	Average service population per medical bed (T_2)	person	0.0200 **	—
	Average service area per educational facility (T_3)	hm ²	0.0140 **	+
	Proportion of sidewalk area (T_4)	%	0.0430 *	_
Ecology (EC)	Carbon sink capacity (EC ₁)	ton	/	_
Energy efficiency (EE)	GDP per tce (EE_1)	\$/tce	/	_

Table 2. Carbon emission governance indicator system for counties.

Note: The significance (Sig) of "*" means a significant correlation with carbon emissions, "**" means a very significant correlation. The attribute of "+" represents positive effect on carbon emissions and "-" represents negative effect on carbon emissions.

2.4. Clustering Analysis

Clustering analysis was used to classify the carbon emission governance of the 6 sectors in 1753 counties in 2015 with the clustering analysis. The weights of the 17 indicators and the 6 governance sectors to which they belong needed to be clarified. The entropy weight method is a mathematical method for calculating the weights of the indicators according to the comprehensive consideration of the amount of information provided by various factors [73] and is widely used in the weight calculations of low-carbon city evaluation indicators [59]. A larger difference in the values of an indicator means that it plays a greater role in the comprehensive evaluation and has a higher indicator weight. AHP is a simple, flexible, and practical multi-criteria decision-making method for quantitative analysis of qualitative problems. It is convenient to comprehensively judge the carbon effect of the indicators and the degree of difficulty in governance. The combination of the two models is helpful to comprehensively judge the weight of governance indicators. The specific steps are as follows:

 Suppose that there are m counties and n indicators. R_{mn} is the value of county M under indicator N. An original matrix R is established:

$$\mathbf{R} = \begin{bmatrix} \mathbf{R}_{11} & \cdots & \mathbf{R}_{1N} \\ \vdots & \ddots & \vdots \\ \mathbf{R}_{M1} & \cdots & \mathbf{R}_{MN} \end{bmatrix}_{\mathbf{m} \times \mathbf{n}}$$
(1)

(m = 1, 2, ..., 1753; n = 1, 2, ..., 17)

(2) Suppose that the normalized value of R_{MN} is Q_{MN} , which is calculated by the min-max normalization method. For indicators with the "+" attribute:

$$Q_{MN} = (R_{MN} - \min|R_{MN}|) / (\max|R_{MN}| - \min|R_{MN}|)$$

$$(2)$$

For indicators with the "-" attribute:

$$Q_{MN} = (\max|R_{MN}| - R_{MN}) / (\max|R_{MN}| - \min|R_{MN}|)$$
(3)

(3) Calculate P_{MN} of Q_{MN} :

$$P_{\rm MN} = Q_{\rm MN} / \sum_{\rm M=1}^{\rm m} Q_{\rm MN} \tag{4}$$

(4) Calculate the entropy value e_N of indicator N:

$$e_{\rm N} = -1/\ln m \times \sum_{\rm M=1}^{\rm m} \left(P_{\rm MN} \times \ln P_{\rm MN} \right) \tag{5}$$

When $P_{MN} = 0$, suppose $P_{MN} \times \ln P_{MN} = 0$.

(5) Determine the entropy weight α_N of the indicator N:

$$\alpha_{\rm N} = (1 - e_{\rm N}) / \sum_{\rm N=1}^{\rm n} (1 - e_{\rm N})$$
(6)

(6) Suppose that the comprehensive weight is W_N. The index weight obtained according to the AHP is determined as βN. The W_N can be calculated by combining α_n and β_n.

$$w_{\rm N} = \alpha_{\rm N} \, \beta_{\rm N} / \sum_{\rm N=1}^{n} \alpha_{\rm N} \, \beta_{\rm N} \tag{7}$$

Suppose Z_{JM} is the value of county M under sector J, which has i indicators. Calculate Z_{IM} to determine the sector level's entropy weight:

$$Z_{JM} = \frac{1}{I} \sum_{N=1}^{n} (W_N \times Q_{MN})$$

$$\tag{8}$$

Determine the entropy weight of sector J, W_J , with Equations (4)–(7). The entropy weight of each indicator and sector was derived as shown in Table 3.

Table 3. Entropy weight statistics.

Sector	WJ	Sector	WJ	Sector	WJ
Scale and structure (S)	0.1649	Economic development (ED)	0.1657	Buildings (B)	0.1681
Transportation (T)	0.1678	Ecology (EC)	0.1673	Energy efficiency (EE)	0.1671

The linear weighted summation model was used to calculate the values of each county in the 6 sectors. Suppose that the value of county M under sector J is S_{IM} :

$$S_{JM} = W_J \times Z_{JM} \tag{9}$$

The linear weighted values of the 6 governance sectors were used to classify the 1753 counties with the K-means clustering analysis method. Euclidean distance and betweengroups linkage were used to measure the similarity and form classification, respectively. The results of the geographic classification were visualized by geographic information system (GIS).

3. Results

3.1. Overall Analysis of Zoning Results

Following the differentiated zoning method mentioned above, 1753 counties were taken as the objects and the values of the 6 sectors were taken as the classification variables for clustering. When the number of clusters is 5, the classification results can reflect the differences in the governance problems among the zones relatively clearly and reasonably. Table 4 lists the 5 zones and some of the included counties.

Table 4. County data description in 5 zones.

Zone	Number	County
1	390	Taikang, Weishi, etc.
2	212	Zhangjia Gang, Gaozhou, etc.
3	686	Wuqi, Dingbian, etc.
4	325	Maqin, Dari, etc.
5	140	Jingdong, Menyuan, etc.

In every zone, the average and total value of each sector of the counties were calculated to reflect the zones' carbon emission governance problems in each sector and the overall level of low-carbon development. The higher the average value of the sector, the more critical is the governance problem in it. For a zone as a whole, a high total value means relatively high carbon emissions. The table in Figure 3 shows the average and total values of the 5 zones in the 6 sectors.





There are wide gaps between the total value and the coverage area of the 5 zones. The first zone, whose total value is significantly higher than the other districts, is identified as a high-carbon governance zone. It covers 22.25% of the counties. The second and third zones, with a medium total value, are identified as medium-carbon governance zones, covering 12.09% and 39.13% of the counties, respectively. The fourth and fifth zones, which have the lowest total value, are identified as low-carbon governance zones. The two zones cover 18.54% and 7.99% of the counties, respectively.

3.2. Map of Carbon Emission Governance Zones at the County Level

The classification results were visualized into a zoning map by GIS and the values of the 6 sectors in each zone were displayed with radar charts for an analysis of the differences, which together form the map of the county-level carbon emission governance zones (Figure 4). The high-carbon problems and governance focuses of each zone were analyzed according to the total value and sector value of each zone.

The first zone is revealed as the high-carbon governance zone, in which the counties are located mainly in the Northeast Plain and the North Plain Area. Each sector value is high in the zone. The sector values of "Scale and structure (S)", "Ecology (EC)", and "Buildings (B)" are the highest of the 5 zones and the sectors value of "Economic development (ED)" and "Transportation (T)" are the second highest. The large-scale developments, ecological erosion, and housing energy consumption mainly caused the carbon-intensive model of development. Meanwhile, economic development and transportation play an important role. It could be inferred as these counties adopt the development path of expansion. They have expanded production through extensive land expansion to drive the growth of the secondary industry. This growth caused the erosion of carbon sink resources as a result of the lack of attention paid to ecological protection. In addition, extensive land expansion has led to the selection of bigger houses and the scattered distribution of buildings, resulting in high energy consumption caused by residential heating and long-distance transportation.



Figure 4. Map of county-level carbon emission governance zones.

The second zone is a medium-carbon governance zone with low buildings value and high economy development value. It is widely distributed in the south and clustered in the southeast coastal area. The sector value of "B" of this zone is the lowest among the 5 zones, however, the sector value of "ED" is the highest. Meanwhile, the sector value of "S" is only second to the first zone. The value of "Energy efficiency (EE)" and "T" is also high. It can be concluded that the county housing energy consumption is low lie, due to two reasons: First, most of these areas do not have heating demands in winter. Second, the higher residential density in these region leads to higher residential energy efficiency. Meanwhile, the counties in this zone have a strong economic development orientation. It can be inferred that they take the mean of land expansion to promote the development of the secondary industry.

The third zone is revealed as medium-carbon governance zone of low scale and structure value and high energy efficiency value. The counties are mainly gathered in Inner Mongolia and the Loess Plateau Area. The sector value of "S" is the lowest in the 5 zones. However, the sector value of "EE" is the highest. The values of "B" and "T" are also high. Because of the limitation of plateau terrain, these counties tend to have less land expansion and less population concentration. Thus, the characteristics of scale and structure are not obvious, and the associated carbon emissions are less. But, at the same time, these areas have a high proportion of fossil energy applications, resulting in a large amount of energy consumption.

The fourth zone is revealed as a low-carbon governance zone with high transportation value. The counties belonging to the zone are mainly gathered in the western region and northeast border. They receive the lowest sector values of "S", "ED", "EC", and "EE". But, they also have a high sector value of "T", which causes much carbon emissions. The low emissions of these counties can be inferred as backward economic development, lower modernization and urbanization level, and less population concentration. However, most of these counties have complex terrain and large land area, resulting in high energy consumption of long-distance transportation.

The fifth zone was revealed as the efficient low-carbon zone. The counties of the zone are scattered across the Northeast and Midwest. The sector values of "S", "ED", "EC", "EE", and "T" are all very low and the sector value of "T" "is the lowest of the 5 zones. The low-carbon development of such areas benefits from a compact land-use model, perfect public facilities, and soothing economic growth. This zone has a low potential for further emission reduction through governance.

4. Discussion

4.1. The Availability Analysis of the Zoning Results

From the use of the grading symbol to show the differences in the carbon emissions from the first to the fifth zones, it can be seen that the spatial distribution of carbon emission governance zones had a high coupling degree with the 3 classical Chinese geographical zonings. The first zone is a high-carbon zone, the second and third zones are mediumcarbon zones, and the fourth and fifth zones are low-carbon zone. And the Chinese graphical zoning are the winter heating demarcation line based on the Qinling-Huaihe line [74] (Figure 5a), the comparison line proposed by Huanyong in 1935 to divide the population density [75] (Figure 5b), and the Chinese geomorphic zones to distinguish the overall topography of the country [76] (Figure 5c). The Qinling-Huaihe Line (north area) and the heating demarcation line (winter heating area) (Figure 5a) are the important dividing lines that distribute the main areas of the high-carbon zone and medium-carbon zone. The high-carbon zone and medium-carbon zone are mainly distributed in the east of Hu Line (high population density area) (Figure 5b) and the third step area (flat terrain area) (Figure 5c). According to the conclusions of Qin [77], Wang (2017) [27], and Yang [78], differences in carbon emissions due to heating and population density have been supported. This comparison reflects not only the differences in the carbon



emission governance demands due to winter heating, population density, and geographical conditions, but also partly reflects the reasonableness of the zoning results.

Figure 5. Comparison of 3 classical Chinese geographical zoning and carbon emission governance zones. Comparison of winter heating zone (**a**), comparison of population density zone (**b**) and comparation of geomophic zone (**c**).

Compared with the previous research on the low-carbon development of major urban clusters or provinces in China in 2015 [79,80], the spatial distribution of the carbon emission levels indicated by the carbon emission governance zones has a high consistency with the conclusions of the existing results of research at the provincial and municipal levels. This comparison verifies the accuracy of the zoning results to some extent. In addition, the present study's conclusion about the carbon effects of some indicators can be confirmed by the previous research on the low-carbon indicator system and its carbon effects. However, compared with such research, which usually contains only indicators of the productive or household sectors [81], this study has formulated a sector-wide, governance-oriented indicator system based on the PSR framework. The carbon emission governance-oriented zones simultaneously compensate for the deficiency of most of the existing research, which has focused only on cognizing carbon emissions but has ignored the differences in the carbon emission drivers, and thus, has resulted in different carbon emission governance focuses [28,82].

4.2. The Carbon Emission Governance System at the County Level

The carbon emission governance zones established by this study can reflect the differences in the carbon emission governance of the zones, as well as help to identify the key sectors and areas for governance at the macro-level, so that it can be used by policymakers to formulate a carbon emission governance system.

Zoning is a process of reflecting the qualitative differences in county governance by the analysis of quantitative data, so differentiated zoning governance strategies should be pushed back by the analysis of qualitative differences. Since zoning governance should consider the difficulty of both the emission reduction of different indicators and of steady socio-economic development, it is obviously unreasonable and incomplete to put forward completely quantitative or qualitative strategies for all the indicators. Following the current county governance document, this study divided all the indicators into target-controlled indicators and guided indicators. Sector in a zone would be considered a high carbon sector if its value were higher than the average value of the 5 zones; otherwise, it is a non-high carbon category. The standard threshold of target-controlled indicators can be calculated by taking population as a benchmark (population indicator would not be considered in the adjustment strategy because of the small elasticity of population growth). The guided indicators do not have a standard threshold, but the national average value or the mean rate of change can be used as a reference. Therefore, according to the levels of the low-carbon development of the 5 zones and their various governance problems, this study formulated quantitative goals and qualitative guidance objectives respectively, for the two types of indicators, thereby forming a differentiated carbon emission governance system. Among the zones, the high-carbon zones were assigned reduction and optimization. The medium-carbon zones took optimization as the governance direction. The low-carbon zone was not adjusted. Figure 6 shows the governance strategies for the indicators marked "+" in Table 2. The opposite governance strategies were adopted for indicators marked "-". The zoning governance strategy is shown in Table 5.

department	High carbon department of a zone			Non high carbon department of a zone			
threshold indicator] (Compared w C	Farget-controlled ind vith the threshold stipu ode for County Mana	licators alated by the current gement)	Guided indicators	Target-contro (Compared wi stipulated by the County M	Iled indicators th the threshold current Code for anagement)	Guided indicators
Zones and governance direction	>standard threshold	Estandard threshold *	<standard threshold *</standard 		€standard threshold	<standard threshold</standard 	
High carbon zones: reduction and optimization	standard threshold	Minimum standard value, average value of the zone	The optimal value of the zone, Minimum standard value	Reference to national average	90% of Minimum standard value, average value of the zone	The optimal value of the zone, 90% of Minimum standard value	Reference to national average value or annual growth rate
Medium carbon zones: Optimization and maintenance	(non- existent)	90% of Minimum standard value, average value of the zone	The optimal value of the zone, 90% of Minimum standard value	value or annual growth rate		_	
Low carbon zone: Maintenance				_			

Guided indicators: S₃, ED₁, ED₂, ED₃, ED₄, B₂, B₃, EC₁, EE₁

Figure 6. Differentiated carbon emission governance strategies by zone. The superscript of "*" means that the current governance standard may not be suitable for low-carbon development. In this case, adjustment recommendations should be proposed.

 Table 5. County low-carbon planning and governance strategies by zone.

Indica	ators	Zone 1	Zone 2	Zone 3
	S_1 (per capita)	(65,85)	(25,72)	-
	B ₁	(90%, 100%)	-	(90%, 100%)
	B_4	(2.7, 4.2)	-	(2.7, 4.2)
Target- indicators	T_1	(200,700)	-	-
	T ₃	(100,240)	-	-
	T_4	$\geq 25\%$	\geq 23%	-
	S ₄	Annual growth rate should be controlled below 0.10% except for less developed counties	Pe pt 0.10% except for less developed counting	

Indicators		Zone 1	Zone 2	Zone 3
	ED_2	Reference to 40%	Reference to 40%	-
Guided indicators	ED ₃	Reference to 50%	-	Annual growth rate should be controlled below 0.10% except for less developed counties
	ED_4	Annual growth rate should be controlled below 10%	Annual growth rate should be controlled below 10%	-
	B ₂	Reference to 3.90 for heating area	-	-
	B ₃	Reference to 0.40	-	-
EC ₁ Referen		Reference to 15.20 m ² green space per capita	Reference to 15.20 m	² green space per capita
	EE_1	Annual growth rate should be higher than 5%		Annual growth rate should be higher than 5%

Table 5. Cont.

The population was used as the benchmark for calculating the standard thresholds of the other indicators. For social and economic development to be unaffected, the gross domestic product (GDP) should not be restricted. The attribute of the T_2 indicator is obviously influenced by residents' special needs for medical treatment. The carbon emission governance strategy for this indicator requires further discussion. So, the indicators of S_2 , T_2 , and ED₁ are not in the scope of governance. The reasonable threshold of built-up areas (S_1) should be determined according to the population, so it is adjusted by the per capita built-up area indicator. According to the governance system, the current Code for County Management should adjust the standard thresholds of the B_4 and T_4 indicators. It is recommended that the standard threshold of the B_4 indicator should be adjusted to (2.70, 4.20) and the lower limit of the T4 indicator should be adjusted to 25%.

The first zone and the second zones are typical high-carbon zone and medium-carbon zones and should be considered as a key carbon emission governance area. The 34.33% of the counties covered by the zones have been emitting 51.88% of carbon emissions at the county level, indicating that the potential for carbon reduction is relatively high, so higher carbon reduction targets for the zones should be set at the national level. If the county-level average carbon emissions were referenced to set carbon reduction targets for the counties in the first and second zones, then the first and second zones' total carbon emissions would fall by 33.8% and the counties' total carbon emissions would achieve a 17.54% reduction.

5. Conclusions

This study constructed a cause-effect chain for low-carbon county development and proposed a differentiated zoning method based on a multi-indicator evaluation to establish carbon emission governance zones for 1753 counties and reflect the differences in carbon emissions through governance elements. The results show: (1) there are 5 governance zones, in which 22.25% of the counties are located in 1 high-carbon governance zone, 51.23% are in 2 medium-carbon governance zones, and 26.53% are in 2 low-carbon zones, and (2) the first zone and the second zones, which are mainly clustered in North China Plain and Southeast China Coastal Area, should be treated as the key governance area. According to the zoning results, this study proposed a county-level governance system, which is obviously different from the carbon emission governance strategies for cities proposed in the previous study. The difference occurs in the governance approach: compared to the governance approach by pilots and sectors at the city level [83,84], the classified governance method is more suitable for low-carbon county governance. The difference also occurs in the governance indicators, which have been shown in the analysis of the carbon effects of the indicators: some important low-carbon city governance indicators, such as the number of motor vehicles and public transportation vehicles [58,59], are not critical for

the counties. Presumably, most counties are at an earlier urbanization stage and a lower level of economic development than the cities. The lifestyles of the residents are also different, so the main carbon emission drivers are different. Therefore, the experience of carbon emission governance for cities is not fully applicable to towns or villages. However, towns and rural areas, which have made large contributions to carbon emissions, cannot be ignored and should be targeted for carbon reduction.

The differentiated zoning method can type regions with large diversity, forming a basis for the regional governance policy. The zoning results can help policymakers identify the key governance sectors and areas, as well as develop differentiated governance strategies for each type of area. The application of the zoning results can provide new ideas to address the carbon emission governance issues of other towns or villages. However, the zoning results have certain limitations and there is still improvement needed in future applications. It is a static system because only the cross-sectional data from 2015 were used rather than the panel data in a larger time span. The carbon emission governance zoning can be further extended to a dynamic system that analyzes and monitors the changes in the differences between the zones and the year-by-year feedback on carbon emission governance effects.

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Appendix A

Table A1. Measurement methods of some indicators.

Indicator	Measure Method	Unit
Population urbanization rate (S_3)	Urban Population/population $ imes$ 100%	%
Coverage rate of population with access to gas (B_1)	Population with access to gas/population $\times 100\%$	%
Density of heating pipelines (B_2)	Length of heating pipelines/builtup area	km/km ²
Floor-area ratio of heating (B_3)	Floor area of heat – supply service/area of heat – supply service	-
Living density (B_4)	Population/area of residential land	people/km ²
Average service area per park (T_1)	Builtup area/number of parks	hm ²
Average service population per medical bed (T_2)	Population/number of medical beds	person
Average service area per educational facility (T_3)	Builtup area number of educational facilities	hm ²
Proportion of sidewalk area (T_4)	Sidewalk area/road area \times 100%	%

The measurement of carbon sink capacity (EC_1) is based on the land-use map identified by the environment for visualizing images (ENVI) using Landsat satellite imagery. The four land-use types of forest land, grassland, and water body are used to calculate the carbon sink capacity by:

$$C_{s} = \sum S_{i} = \sum_{i=1}^{3} A_{i} a_{i} \; (i = 1, \; 2, \; 3)$$

 C_s : carbon sink capacity, i: land-use type, S_i : the ith land-use type, A_i : area of the ith land-use type, and a_i : the carbon fixation coefficient of the ith land-use type.

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