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Impact of district-level decomposition policies to achieve a post-fossil carbon city: A case study of Beijing, China

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A B S T R A C T

China promised to achieve CO_2 emissions peak by around 2030. Beijing, as a pilot low carbon cities, has announced to reach carbon emissions peak by around 2020. It is expected to play a leading role and to enter into a post-fossil carbon society earlier than others. The analysis revealed that Beijing should control its future emissions by primarily controlling total energy consumption and expanding the scale of imported green electricity. The energy intensity reduction targets are predicted to be 17% and 20% during the 14th Five-Year Plan period. Decomposing targets to districts has been approved to be one of the most effective ways. However, most of relative studies adopt a state-to-provincial level of analysis and few could balance theoretical analysis and practical allocation. Considering equity, operability and feasibility, reduction pathway method, type assignment method, and average adjustment method are applied for Beijing. The methods have obvious effects on energy consumption in Shunyi, Chaoyang, Fengtai, and Haidian, which energy consumption is almost half of Beijing's total. The differences in carbon emissions for districts are less than 4% of the highest in 2025, while decomposition targets differ 0 to 3 percentage points. If Beijing is required to peak around 2020, then Tongzhou, Shunyi, and Daxing would peak later than 2025. However, if Beijing should peak earlier, then all districts except Shunyi should peak earlier than 2020 or even earlier than 2015. This assessment framework could be applied in other regions or countries to help local governments to make a more reasonable and compromising carbon mitigation plan.

1. Introduction

The Chinese government signed the Paris Agreement on Climate Change in 2016 and promised to cut its carbon emissions per unit of GDP by 60–65% by 2030 based on 2005 level. In Copenhagen in 2009, emission intensity was set to achieve 40–45% of the 2005 level by 2020 (Xinhua, 2016). China proposed to achieve a peak level of total carbon dioxide emissions by around 2030 and outlined its commitment which is raising the proportion of non-fossil energy consumption to around 20% by 2030 (IEA, 2015). The Chinese central government has both the policies and the will to convert the current energy system into a more sustainable one and more non-fossil energies will be consumed due to the pressure from global climate change and national environmental protection. For this ambitious objective, further research and additional measures should be encouraged for greenhouse gas (GHG) emissions reduction in individual cities in China by adopting a range of perspectives.

Some cities, such as Beijing, will enter into a development phase of a post-fossil carbon society earlier. Beijing is China's capital and also one of the pilot low carbon cities promoted by the Chinese government. Its GDP per capita is nearly 20 thousand US dollar/per capita in 2017, which could be compared with some developed countries. The urbanization rate has achieved 87.6% in 2017 which is the highest in China. And its level of industrialization is also much higher than the national average level. Beijing is expected to play a leading role in national CO_2 emission reduction by both scholars and government. Although Beijing's energy consumption will continue to increase for at least ten years, Beijing has made a commitment to reach a peak level of total carbon dioxide emissions by 2020 and to achieve this target as soon as possible.

Some studies have been carried out to explore the potential emissions or energy consumption for Beijing in the future. Based on the Energy Plan model, the categorized energy consumption of Beijing was predicted by outlining three possible scenarios in 2030 (Zhao et al., 2017). The BP Neural Network prediction model was

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Nomenclature

AA	Average adjustment method
D	The actual data
EI	Energy intensity, which is energy consumption per unit of GDP
E	Energy consumption (tons of coal equivalent)
F	Emission factor (tCO_2/t)
G	GDP (Yuan RMB)
g	the annual GDP growth rate
IE	Imported electricity (tons of coal equivalent)
INT	The rounded integer-value function
ktce	Thousand tons of coal equivalent
L	The limit of each target or annual target
Mtce	Million tons of coal equivalent
R	The reduction target of a period
R_0	The basic reduction target of a period
r	Annual decline rate of energy intensity
ΔR	The adjustment amount for reduction target of a period
RP	Reduction pathway method
T	The city's expected reduction target of energy intensity for the next five years
TA	Type assignment method
TE	Total energy consumption (tons of coal equivalent)
TC	Total CO_2 emission (ton)
w	Weight of the indicators
θ	An approximation of the quotient for the maximum and expected value of the reduction rate for the districts
α	An approximation of the quotient for the minimum and expected value of the reduction rate for the districts

Superscript and subscript

c	The whole city
i	The i-th district
j	The j-th aspect of certain indicators, which is the potential, responsibility, or capacity
k	The k-th indicator for a certain aspect of the indicators in reduction pathway method
m	The number of type of reduction pathways
max	The maximum value
min	The minimum value
n	The n-th indicator in average adjustment method
p	The reduction pathways
p_1	Structural energy conservation pathway
p_2	Technical energy conservation pathway
t_0	The starting year of a period
t_1	The ending year of a period
y	The number of years in a period

constructed to study carbon emission scenarios for Beijing in 2020 (Liu et al., 2018). The future energy consumption of each district based on the SD-GIS model was predicted (Wu and Ning, 2018). A system dynamics model was developed to simulate energy consumption and Beijing's carbon emissions trends for the period 2005–2030 (Feng et al., 2013). The LEAP model was used to predict the reduction effect of GHG between 2010 and 2020 by examining two scenarios (Pan et al., 2013). Other issues are also discussed, including predictions and analyses for sectors (Ma et al., 2015), the driving factors of historical emissions in different periods, like 1995–2009 (Zhang et al., 2013), 1995–2012 (Fan and Lei, 2017) and 1995–2014 (Shen et al., 2018), the calculation of historical carbon emissions data, etc (Shao et al., 2016).

However, few studies have developed predictions at the district-level and to examine the relationship between the emissions reductions in all districts and emissions reductions for the city as a whole (Wu and Zeng, 2013). In order to achieve Beijing's low carbon development target, different districts should undertake different targets and tasks. By taking advantage of a centralized political system, the implementation of carbon intensity targets or energy intensity targets decomposition at district level has been approved to be effective policy measure. At the same time, reasonable objectives and appropriate regulatory means can assist the effective implementation of this measure. By taking China's energy intensity decomposition targets and carbon intensity decomposition targets for the period of the 11th and the 12th Five-Year Plans as an example, the state or local governments have adopted corresponding supervision measure. The announcement has been published by the National Development and Reform Commission, outlining the assessment results of total energy consumption and energy intensity target completion for provinces, autonomous regions, and municipalities directly by the central government (NDRC, 2018). The assessment revealed that these regulatory measures have yielded favorable results.

As one of the largest cities in the world, there are 16 districts in Beijing. And there are substantial differences in the economic development level and development conditions among these districts. In 2016, the GDP of Haidian district was more than 40 times that of Yanqing; the population of Chaoyang was more than 12 times that of Mentougou; the GDP per capita of Chaoyang district was more than three times that of Yanqing district; the total energy consumption of Shunyi district was more than 18 times that of Mentougou; the industrial proportion of Daxing district was above 50%, while the industrial proportion of Dongcheng district was only about 2% (BMBS, 2017a). Therefore, the reduction target of energy intensity or carbon intensity for each district should be different, and at the same time, the decomposition scheme should be an equitable, reasonable, and acceptable solution.

Currently, most of existing relative studies are associated with emission-reduction allocations for greenhouse gases (GHG) (Ringius et al., 2002) and CO_2 emissions allowance (Wang, 2013b). Some researchers discussed the principles that should be followed in the allocation, like per capita allocation (Grubb, 1990), the cumulative emission per capita concept (Yu et al., 2011) and so on. Many kinds of allocation models and schemes have been also developed, like Triptych approach (Groenenberg et al., 2001). The existing models and schemes could be classified into four groups, which are indicator, optimization, game theoretic and hybrid approaches (Zhou and Wang, 2016), and it is found that the fairness principle and the efficiency principle have been found to be paid more attention. Such study has been applied in the design of EU ETS. In 2003, the EU passed the Greenhouse Gas Emissions Allowance Trading Act and established the greenhouse gas emissions trading system. In general, the initial allocation mechanism of EU national indicators was relatively simple, and the three indicators which are GDP per capita, GDP, and total emissions were primarily taken into account, as shown in Fig. 1.

To allocate the national emission reduction target or energy saving target, scholars have also done many discussions by learning from the allocation experiences of different countries. A sectoral

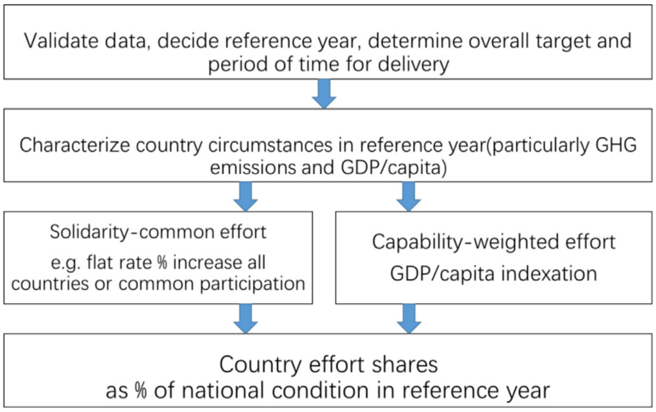

Fig. 1. Allocation mechanism of EU national indicators (Paul and Jonathan, 2010).

methodology was provided for allocating national energy-intensity targets among China's provinces in the 12th Five-Year Plan using the European Union (EU) Triptych approach (Ohshita and Price, 2011). Principles for the disaggregation of targets were developed and a carbon intensity disaggregation model was proposed (Zhou et al., 2014). An abatement capacity index based on weighted equity and efficiency index was construct (Wei et al., 2012). A framework for provincial-level disaggregation of energy-saving targets in China was presented (Zhang et al., 2015). A top-down model was developed to allocate the national CO_2 intensity-reduction target among regions (Yi et al., 2011). An approach was proposed based on improved fuzzy cluster and Shapley value decomposition (Yu et al., 2014). Energy use cap among China's provinces was disaggregated (Guo et al., 2016). A DEA-based approach to allocate China's national CO_2 emissions and energy intensity reduction targets over Chinese provincial industrial sectors was proposed (Wu et al., 2016). Three equity principles were applied to allocate CO_2 reduction targets at the provincial level considering both equity and efficiency (Dong et al., 2018). All of these studies have provided a methodological basis for the disaggregation of national targets among provinces or regions. Generally, most of current study is based on multi economic or social evaluating indicators and relative weights set by the AHP, experts' interview and so on.

However, most of these studies adopt a state-to-provincial level of analysis, and few studies have examined district decomposition in terms of a specific province or region. Only a few regions have carried out similar studies, such as Henan (Wang et al., 2016), Sichuan (Wang et al., 2013a), etc. Although many factors could be considered in the allocation, it can be found that the results based on theoretical analysis are always different from actual allocation plan, as operability and feasibility are insufficient. One of the reasons is some compromise are inevitable in the actual allocation process. Learning from published disaggregated targets announced by government (NDRC, 2018), the regions are always classified into several groups, and a same target is set for each group. The aim of this article is to address this gap by proposing three methods of district-level target decomposition reflecting both theoretical and practical aspects by taking Beijing as a case. Based on the prediction of carbon emissions and energy consumption in Beijing, the study examines how relatively reasonable district tasks may be determined to ensure that Beijing becomes a post-fossil carbon city and achieves the carbon emissions reduction target early.

2. Methodology

The design of disaggregation process is based on different design concepts. Equity, operability and feasibility are always the main concern in such design. However, it's rather hard to have a perfect method to balance these three aspects at the same time. In this study, three methods of district-level target decomposition are proposed. Average adjustment method emphasizes more on equity and operability. Type assignment method emphasizes more on operability and feasibility. And reduction pathway method emphasizes more on equity and feasibility. Although each could only balance two of above three aspects better, the comparison and discussion could help policy makers to choose a more reasonable and compromising plan.

2.1. Emissions predictions for Beijing

The consumption of coal, oil, natural gas, imported electricity, green electricity, and other energy types in Beijing over the years are investigated from energy balance tables (BMBS, 2017b). The equations are as follows:

$$TE = Coal + Oil + NG + IE + others \quad (1)$$

$$IE = IE_{green} + IE_{other} \quad (2)$$

$$TC = Coal * F_{Coal} + Oil * F_{Oil} + NG * F_{NG} + IE_{other} * F_{IE} \quad (3)$$

Where TE indicates total energy consumption, IE indicates imported electricity, TC indicates total CO_2 emissions, and F indicates the emissions factor. Others in energy balance table is mainly municipal solid waste, biomass waste, other industrial wastes, marsh gas and so on. The detailed composition and relative amount is not published. So it is assumed that the emissions factor for other energy sources is zero. The emissions factor for green electricity is also zero. The average carbon emissions factor and the electric power emissions factor for different types of energy are as follows: F_{Coal} is 2.64tCO_2/t, F_{Oil} is 2.08tCO_2/t, F_{NG} is 1.63tCO_2/t (Zhou et al., 2014), and F_{IE} is 9.913 tCO_2/ten thousand kwh (CCDM, 2015). Then the total carbon emissions in Beijing were estimated.

Based on historical trend analysis of Beijing's energy consumption, the investigation on economic planning studies and other institutional researches, Beijing's energy consumption with respect to different energy types from 2020 to 2030 is predicted. Based on predicted GDP growth rate of the whole city, it is possible to predict the reduction targets for carbon intensity or energy intensity for Beijing in order to achieve the carbon emissions peak in the future.

By referring to the Beijing Statistical Yearbook (BMBS, 2017b), different types of energy consumption and carbon emissions for Beijing are calculated for the past ten years. Emissions factors of imported electricity are estimated based on the emissions factors of the North China Power Grid in 2013 published by National Development and Reform Commission (CCDM, 2015). The results are as shown in Fig. 2 and Fig. 3. It is obviously that there was rapid short-term growth in 2008 and 2009 as a result of Beijing's successful bid to host the Olympic Games. The overall trend of Beijing's total energy consumption is rising steadily. Since 2005, total coal consumption has decreased annually, while natural gas consumption has continued to increase. Beijing's total energy consumption is 69.2 million tons of coal equivalent (Mtce) in 2016. The proportion of coal consumption for Beijing is now less than 10% and there is little room for improvement in the structure of fossil fuel consumption in the near future.

The trends in CO_2 emissions can be roughly divided into two stages. Prior to 2014, the overall trend in total CO_2 emissions is rising. In 2015, there were substantial reductions in CO_2 emissions per unit of energy due to the import of green electricity as well as

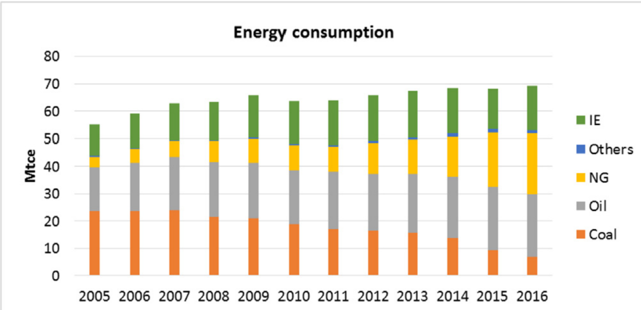

Fig. 2. Historical consumption of different energy types in Beijing.

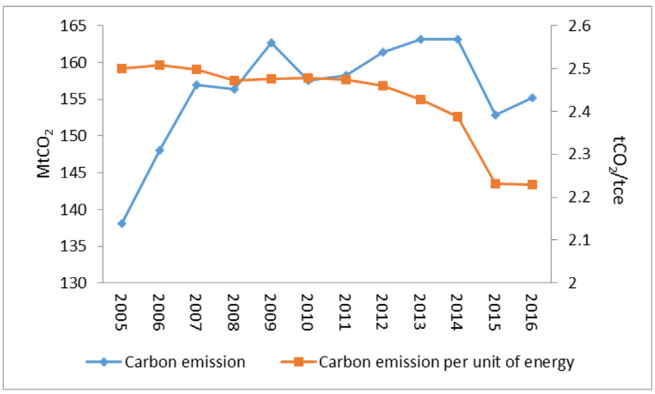

Fig. 3. Historical CO_2 emission levels in Beijing.

active efforts to improve the energy consumption structure. Due to such efforts, the total amount of CO_2 emissions had greatly been reduced. However, in 2016, improvements on the green electricity and fossil energy consumption structure were not enough to offset the increment of energy consumption. Total CO_2 emissions in 2016 were even higher than that in 2015.

2.2. Average adjustment method

Learning from the experiences of European Union's agreement on responsibility sharing (Paul and Jonathan, 2010), Beijing's energy intensity reduction targets are divided into two parts. The first part is one basic reduction target for all districts, which is also the expected reduction target for the whole city. The second is the adjustment value for each district, validated in accordance with indicators and weights.

The targets consist of two parts as shown in equation (4).

$$\mathrm{R_i} = \mathrm{INT}(\mathrm{R_0} + \Delta \mathrm{R_i}) \tag{4}$$

where R represents the reduction target, INT means the rounded integer-value function, ΔR represents the adjustment value, R_0 is the basic reduction target for energy intensity for the whole city, i represents the i-th district.

$$\Delta \mathrm{R_i} = \sum (\Delta \mathrm{R_i^n} \times w^n) \tag{5}$$

where w denotes the corresponding weight, n is the n-th indicator.

2.2.1. Adjustment value of single indicator

The adjustment value of the single indicator ΔR_i is determined according to the actual data of indicators and the upper and lower limits of indicators. First, this method determined the upper limit of each indicator according to the reduction target for the whole city. Then, the lower limit of each indicator was calculated to ensure completion of the expected target for the whole city by based on targets for districts.

$$\Delta R_i^n = \frac{\max(D_i^n) - \min(D_i^n)}{L^{\max} - L^{\min}} \times [D_i^n - \min(D_i^n)] + L^{\min} \tag{6}$$

where D represents the actual data, L represents the limit, max and min represent the maximum value and minimum value separately.

During the 13th Five-Year Plan period, the maximum reduction value of energy intensity for each district is assumed to be no more than 4 percentage points compared with the city's expected target, which is learned from allocation plans of energy intensity reduction target in the 12th and 13th Five-Year periods.

$$\max(R_i) \le (R_c + 4) \tag{7}$$

where c represents the whole city.

Using the equations outlined above, the upper and lower limit values under certain city's targets and weights can be calculated. The reduction target of energy intensity for each district can then be obtained.

2.2.2. Indicators and weights

In order to reflect equity and operability, typical indicators are chosen reflecting economic development level, development demand and energy utilization efficiency. The type of indicators should be as less as possible and the weights should be as simple as possible. GDP per capita and population are selected for economic development level and the economic demand. Energy consumption per unit of added value is selected for energy utilization efficiency. Relative weights are obtained from experts' interview, including the policy makers of Beijing and a project named Guidelines for the Decomposition of Carbon Emission Indicators. The economic development level is the most important one, and the other two are considered slightly unimportant and as important as each other. As the final reduction target is a rounded integer-value, tiny changes in weight values have limited impact on final results. The indicators and simplified weights are shown in Table 1.

2.2.3. Verification of the districts' targets

In this study, data verification is essential to ensure coordination between the target for each district and the target for the whole city. The calculation methods are outlined below.

The relationship between energy intensity (EI) reduction for the whole city and each district is as follows. And the calculated energy intensity reduction value of the whole city should be slightly larger or equal to the expected target.

$$\Delta EI_c = \frac{EI_c^{t_0} - EI_c^{t_1}}{EI_c^{t_0}} = 1 - EI_c^{t_1}/EI_c^{t_0} = 1 - \frac{\sum\left[(1-\Delta EI_i)\frac{E_i^{t_0}}{G_i^{t_0}} \cdot G_i^{t_1}\right]}{\sum G_i^{t_1}} \times \frac{G_c^{t_0}}{E_c^{t_0}} \tag{8}$$

Table 1
Indicators and weights used for average adjustment method.

Indicators	Weights
GDP per capita of each district	0.4
Energy consumption per unit of added value of districts divided by average value of Beijing	0.3
Population of each district	0.3

$$\varDelta \mathrm{EI}_c \geq \mathrm{T} \tag{9}$$

where EI indicates energy intensity, $\varDelta$EI is the reduction of energy intensity, E denotes energy consumption, G denotes GDP, T presents the city's expected reduction target of energy intensity for a period, t_0 and t_1 represents the starting year and ending year of the period which are 2020 and 2025 in this case.

The relationship between the GDP of each district in 2020 and 2025 is shown in Equation (10). g_i indicates the annual GDP growth rate of i-th district and y indicates the number of years in a period, which is five in this case.

$$G_i^{t_1} = G_i^{t_0} \times (1 + g_i)^y \tag{10}$$

2.3. Type assignment method

As learned from current policy design, districts are classified into a few groups in the type assignment method. This study largely utilizes former classification, which can be obtained from energy intensity reduction targets assigned for the 13th Five-Year Plan period in Beijing (PGBM, 2016). Based on the analysis, there are four groups. The energy intensity reduction target for each group is then assigned and the energy intensity reduction target for each group varies by certain percentage points. The reduction target for districts in the first group is set to be the highest, and the value for the fourth is set to be the lowest. The difference in the reduction target between the contiguous two groups is 0 or 1 percentage point Table 2.

In this method, data verification is also required and it is the same as the calculation used in the average adjustment method.

2.4. Reduction pathway method

In the reduction pathway decomposition method, it is aimed to analysis two energy-saving pathways in each district, which are structural and technical energy conservation, and consider responsibility, potential, and capability, which are the main aspects that provincial governments concern (Zhou et al., 2014). Based on historical data, the annual decline rate of energy intensity, due to structural and technical energy conservation in each district, is estimated for a future time period, and the energy intensity reduction target for each district for a future time period is then obtained.

The energy intensity reduction target for each district for a period can be calculated using equation (11)

$$R_i = INT\left\{[1 - (1 - \frac{\mathrm{r}_i}{100})^5] \times 100\right\} \tag{11}$$

where INT means the rounded integer-value function, r indicates the annual decline rate and i indicates the i-th district.

2.4.1. Expected annual decline rate of energy intensity for the whole city

It was assumed that the contribution of structural energy conservation is the same as that of technical energy conservation for the total energy intensity reduction (Zhou et al., 2014). Based on expected reduction target of energy intensity for the whole city, it is then possible to calculate the expected annual average decline rates for energy intensity reflecting structural and technical energy conservation respectively for Beijing.

$$r_c = \sum r_c^{p_m} = r_c^{p_1} + r_c^{p_2} \tag{12}$$

$$r_c^{p_1} = r_c^{p_2} = \frac{1}{2}\mathrm{r}_c = \frac{1}{2}\left[1 - \sqrt[y]{1 - T}\right] \tag{13}$$

where r represents the annual decline rate, p represents the reduction pathways, m represents the number of type of reduction pathways, p_1 and p_1 represent structural and technical energy conservation pathways, respectively, T indicates the expected reduction target of energy intensity for a period and the whole city, and y is the number of years in this period, which is five years in this study.

2.4.2. Forecasted annual decline rate of energy intensity for districts

The calculation of the annual decline rate of energy intensity for each district over a given time period is similar as equation (12).

$$r_i = \sum r_i^{p_m} = r_i^{p_1} + r_i^{p_2} \tag{14}$$

The districts' annual decline rates due to structural and technical energy conservation can be calculated by following equations.

$$r_i^{p_m} = \sum_{j=1} w_i^{p_{m_j}} \cdot r_i^{p_{m_j}} \tag{15}$$

$$r_i^{p_{m_j}} = \sum_{k=1} w_i^{p_{m_{j,k}}} \cdot r_i^{p_{m_{j,k}}} \tag{16}$$

$$r_i^{p_{m_{j,k}}} = \frac{L^{\max} - L^{\min}}{\max\left(D_i^{p_{m_{j,k}}}\right) - \min\left(D_i^{p_{m_{j,k}}}\right)} \times \left[D_i^{p_{m_{j,k}}} - \min\left(D_i^{p_{m_{j,k}}}\right)\right] + L^{\min} \tag{17}$$

D represents the actual data; *L* represents the limit; *j* represents a certain aspect of certain indicators, which is the potential, responsibility or capacity; and *k* represents the *k-th* indicator for a certain aspect of the indicators.

θ and α are used to reflect the gap between the highest and the lowest reduction targets of the districts. It is assumed the calculated maximum annual decline rate caused by structural energy conservation or technical energy conservation for the districts equals θ times the expected value for the whole city (equation (18)). At the same time, the calculated minimum annual decline rate caused by

Table 2
Four groups of districts identified in the type assignment method.

	The 1st group	The 2nd group	The 3rd group	The 4th group
Districts	Dongcheng Xicheng	Chaoyang Haidian Fengtai Shijingshan.	Mentougou Fangshan Changping Huairou Pinggu Miyun Yanqing	Tongzhou Shunyi Daxing
Energy intensity reduction target in the 13th Five-Year Plan	19	18	17	16

structural energy conservation or technical energy conservation for districts shall be equal α times the expected value for the city (equation (19)). Then, the upper and lower limit which are L^{max} and L^{min} can be calculated. In addition, the reduction targets related to structural and technical energy conservation in each district can be obtained. The equations are as follows:

$$r_c^{p_m} \times \theta = \max\left[\sum_{j=1} w_i^{p_{m_j}} \cdot \left(\sum_{k=1} w_i^{p_{m_{j,k}}} \cdot r_i^{p_{m_{j,k}}}\right)\right] \tag{18}$$

$$r_c^{p_m} \times \alpha = \min\left[\sum_{j=1} w_i^{p_{m_j}} \cdot \left(\sum_{k=1} w_i^{p_{m_{j,k}}} \cdot r_i^{p_{m_{j,k}}}\right)\right] \tag{19}$$

In this case, the gas is assumed to be less than 4, which is learned from energy intensity reduction target allocation plans in the 12th and 13th Five-Year periods. The value θ is an approximation of the quotient for the maximum and expected value of the reduction rate, which is 1.2. The value α is an approximation of the quotient for the minimum and expected value, which is 0.9.

2.4.3. Indicators and weights

Three aspects which are responsibility, potential, and capacity are proposed in this study. There are three criterions considered in selecting indicators. First, indicators must reflect responsibility, potential, or capacity of the energy-saving and carbon reduction approaches; second, indicators should be representative; third, the indicator data can be obtained directly or indirectly from local statistical yearbooks. Then nine indicators are selected as shown in Table 3. Relative weights are obtained from experts' discussions and literature (Zhou et al., 2014).

2.4.4. Data verification

In this method, data verification is also required and is the same as the calculation used in the average adjustment method.

3. Results and discussion

3.1. Emission prediction for Beijing

According to the general plan for Beijing (BPLRMC, 2017), Beijing's total energy consumption will be limited to 76.5 Mtce by 2020 and to approximately 90 Mtce by 2035. By 2020, Beijing aims to cut total coal consumption in the city to less than 5 million tons and it is planned to eliminate coal by 2035. According to Beijing's energy development plan for the 13th Five-Year Plan period (PGBM, 2017), it is planned to maintain total energy consumption at approximately 76 Mtce by 2020. Total coal consumption will be controlled to be less than 5 million tons and total imported green electricity will reach 10 billion KWh in 2020. Total CO_2 emissions will peak by around 2020 and Beijing aims to realize this target as soon as possible. By 2020, energy consumption per unit of GDP will be 17% lower than that in 2015. According to Beijing's gas development and construction plan for the 13th Five-Year Plan period (PGBM, 2017), Beijing's natural gas consumption will reach 20 billion cubic meters by 2020, accounting for 33% of the city's total energy consumption.

Based on above 13th Five-Year plans, the CO_2 emissions peak target, and other reports (BECC, 2017; IEEE, 2016), the possible peak time and peak value for emissions and energy consumption for Beijing are predicted. In this study, two scenarios are considered. In scenario 1, it is assumed that Beijing could complete the binding indicators related to carbon emissions and energy consumption and the emissions peak will be reached in 2020. In scenario 2, Beijing would more actively promote industrial development, coal substitution, green electricity introduction and electric vehicle promotion, and emissions peak is assumed to be realized earlier than 2020. The different types of energy consumption for both scenarios are shown in Table 4 and Fig. 4.

Using the prediction method for carbon emissions outlined in section 2.1, Beijing's CO_2 emissions in the future can be obtained, as shown in Fig. 5. In scenario 1, the peak of Beijing's carbon emissions is realized by around 2020, with a peak level of 153$MtCO_2$, and it is supposed to reach 147$MtCO_2$ by 2030. In scenario 2, it is assumed that the peak value of Beijing's carbon emissions will occur before 2020. After 2015, total carbon emissions continue to decrease, and could be as low as 126$MtCO_2$ by 2030.

The prediction results have been compared with others. Feng (Feng et al., 2013) assumed the total energy consumption in 2020, 2025 and 2030 is 92, 104 and 114 Mtce and relative CO_2 emissions are 143, 158 and 170 $MtCO_2$. Some other earlier researches also predicted such high consumption level (Li and Xian, 2014). However, it should be noticed that prediction of 2015 in these research was higher than the actual data, as Beijing has taken more carbon reduction measures than expected. In some recent studies, Beijing Energy Conservation and Environmental Protection Center (Wang and Liu, 2018) predicted the total energy consumption in 2020, 2025 and 2030 is 75, 82 and 88.5 Mtce separately, which is rather similar with the results in scenario 1.

In order to achieve Beijing's low carbon development target, different districts should adopt different energy intensity targets and implement different measures to reduce emissions. In recent years, both the state and local governments announced the decomposition of energy intensity targets or carbon intensity targets, and the assessment was carried out revealing good results. During the 14th Five-Year Plan period, the decomposition remains one of the most effective measures to control CO_2 emissions by allocating Beijing's emissions reduction target to districts.

The analysis outlined above proposes that the main method for controlling Beijing's future carbon emissions is to control total energy consumption to around 80 Mtce in 2030 and to increase the scale of imported green electricity to about 40 billion Kwh in 2030.

Table 3
Indicators and weights used for reduction pathway method.

Aspects		$w_i^{p_{m_j}}$	Indicators	$w_i^{p_{m_{j,k}}}$
Structural Energy Conservation	Potential	0.3	Pulling rate of tertiary industry of districts from 2015 to 2020	1
	Responsibility	0.4	GDP per capita of districts in 2020	0.5
			GDP growth rate of districts from 2015 to 2020	0.5
	Capacity	0.3	Industrial proportion of districts in 2020	1
Technical Energy Conservation	Potential	0.4	Residential electricity consumption per capita of districts divided by average of Beijing in 2020	0.5
			Energy consumption per unit of added value of districts divided by average of Beijing in 2020	0.5
	Responsibility	0.4	Total energy consumption of districts divided by total energy consumption of Beijing in 2020	1
	Capacity	0.2	Total profit rate of secondary and tertiary industries of districts in 2020	0.5
			• Residential consumption expenditure per capital of districts in 2020	0.5

Table 4
Scenario forecast of different types of energy consumptions.

		Coal	Oil	NG	Others	IE	IE_{green}	Total
	Unit	Mtce	Mtce	Mtce	Mtce	Mtce	10^8Kwh	Mtce
	2015	9.37	22.98	19.85	1.55	14.77	45	68.53
Scenario one (S1)	2020	3.80	23.00	25.00	1.20	23.00	100	76.00
	2025	2.00	23.50	27.00	2.00	28.00	250	82.50
	2030	1.00	23.00	29.00	2.00	32.00	400	87.00
Scenario two (S2)	2020	2.50	22.00	25.00	1.50	22.00	150	73.00
	2025	0.50	21.00	27.00	2.50	25.00	300	76.00
	2030	0.00	20.00	28.00	2.00	28.00	400	78.00

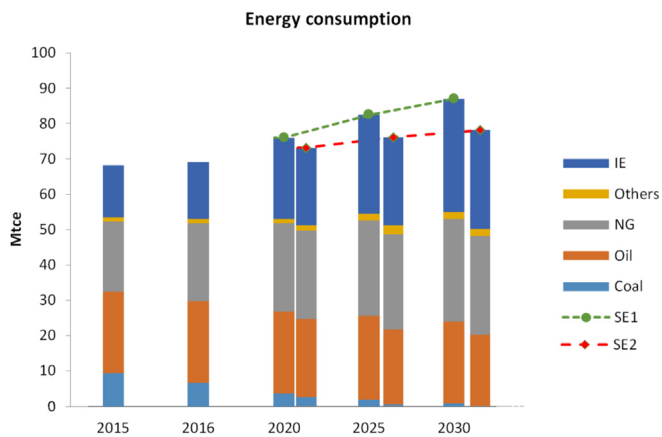

Fig. 4. Forecast of different types of energy consumption for the two scenarios.

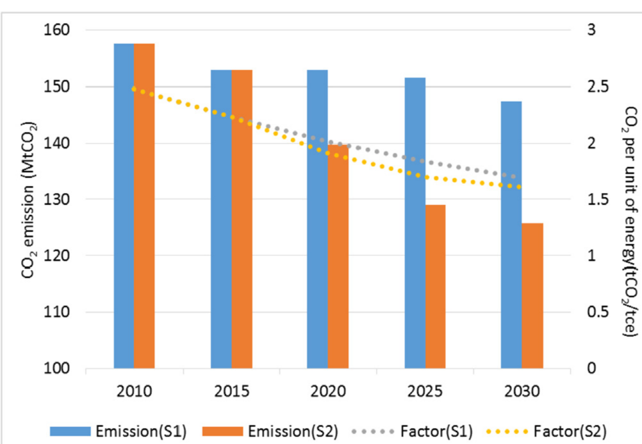

Fig. 5. Forecast of CO_2 emissions in Beijing.

As the scale of green electricity is principally determined by provincial government, the influence of the district administrative departments is rather limited. Thus, setting energy intensity targets for each district represent one of the positive measures aimed at controlling total energy consumption. The emissions factor of imported electricity is assumed to be invariable, and it is also assumed that Beijing's GDP growth rates in 2015–2020, 2020–2025, and 2025–2030 will be 6.5%, 5.5%, and 4.5% (BECC, 2017), respectively. The expected reduction rates for energy intensity in the two scenarios were then calculated as 17% and 20% for the period 2020 to 2025, respectively.

3.2. *Target decomposition results*

In order to do the decomposition, it is necessary to predict the indicators' data for 2020. Considering data variations trend for Beijing in recent years, the data for 2020 is predicted by referring to the variation trend from 2013 to 2016. At the same time, it is assumed that districts can achieve their economic development targets, total energy consumption targets, and energy intensity reduction targets for the whole city. Table 5 shows the predicted data for each district in 2020.

The decomposition results, obtained from above three methods are compared in Table 6.

Due to the design of decomposition methods, the characteristics and factors that can be taken into account are limited, and the results obtained from different decomposition methods are somewhat varied. Only a few districts, such as Fangshan, has the same result in all three methods. The maximum variance in the results from different decomposition methods in Dongchen, Xichen, Haidian and Daxing districts is 1%; the maximum difference among Shunyi is 3%; and the maximum difference among other districts is 2%. Each scenario and decomposition plan yields a difference in the predicted total energy consumption for each district. The change in the proportion of energy consumption for each district within the whole city from 2015 to 2025 in two scenarios could be calculated.

The results show that the change in the trend of energy consumption proportions for each district is largely consistent. The change in the proportion is less than ±0.1% for eight districts, which means the methods have limited effect on these districts. For the other eight districts, the effect is a little more obvious. Fig. 6 shows the change in the proportion of energy consumption for latter eight districts. The abbreviations AA, TA, and RP are used to represent the three methods, namely, average adjustment, type assignment, and reduction pathway. The total energy consumption and proportions for the major economic growth districts including Shunyi, Daxing, and Tongzhou will be further increased over a future time period. However, with respect to further optimization of the industrial structure, the proportion of energy consumption for relatively developed regions such as Dongcheng, Xicheng, and Chaoyang will be further reduced. Fangshan and Fengtai are not developed districts, and the expected economic growing rates are slower than that of Shunyi and other regions. Under similar targets of energy intensity, although total energy consumption is still higher, the range of the increment is slightly smaller.

At the same time, Fig. 7 shows predicted energy consumption of each region in 2025 in different scenarios and using different methods.

Figs. 6 and 7 show that different decomposition targets have the most obvious effects on the proportion of energy consumption in Shunyi, Chaoyang, Fengtai, and Haidian. The change in the proportion of energy consumption is as follows: Shunyi, 0.69%; Chaoyang, 0.32%; Fengtai, 0.18%; Haidian, 0.15%. At the same time, the maximum difference in total energy consumption of Shunyi

Table 5
Predicted indicators' data for districts in 2020.

Indicators*	1	2	3	4	5	6	7	8	9	10
Unit	%	Thousand Yuan RMB/Person	%	%	–	–	–	%	Yuan RMB	Thousand People
Dongcheng	5.99	296.6	6.35	1.89	1.26	0.53	4.25	38.83	104,787	848
Xicheng	5.40	360.6	6.25	5.89	1.07	0.41	5.65	41.52	118,777	1216
Chaoyang	6.21	160.8	6.05	4.58	1.07	0.61	12.12	15.62	87,987	3871
Fengtai	4.13	70.4	6.05	9.59	1.15	1.31	6.57	7.17	69,332	2249
Shijingshan	5.63	95.1	6.25	13.34	0.86	0.80	1.51	21.63	96,194	624
Haidian	6.99	179.7	6.65	7.69	0.76	0.51	10.44	23.83	98,684	3610
Fangshan	3.17	63.2	7.05	48.38	1.03	4.02	9.56	45.59	39,588	1189
Tongzhou	5.22	57.5	6.25	29.42	1.19	1.47	4.11	9.23	41,591	1538
Shunyi	2.69	175.6	8.25	36.23	1.21	2.89	18.93	9.52	36,282	1176
Changping	2.49	42.4	7.45	34.77	0.92	1.67	4.79	5.19	49,652	2139
Daxing	3.06	122	6.65	55.80	0.86	0.94	6.93	5.04	47,128	1904
Mentougou	3.25	61.1	7.85	36.69	1.27	1.55	0.96	1.15	54,827	319
Huairou	1.85	80.7	6.25	50.01	1.08	1.38	1.42	4.34	34,979	404
Pinggu	4.88	59	6.85	30.69	1.13	1.95	1.65	5.72	37,002	453
Miyun	3.06	63.5	6.25	31.63	1.00	1.82	1.80	2.39	34,472	490
Yanqing	2.22	45.2	6.55	28.04	0.72	2.13	1.03	8.14	36,613	338

* 1) Pulling rate of tertiary industry of districts from 2015 to 2020; 2) GDP per capita of districts in 2020; 3) GDP growth rate of districts from 2015 to 2020; 4) industrial proportion of districts in 2020; 5) residential electricity consumption per capita districts divided by average of Beijing in 2020; 6) energy consumption per unit of added value of districts divided by average of Beijing in 2020; 7) total energy consumption of districts divided by total energy consumption of Beijing in 2020; 8) total profit rate of secondary and tertiary industries of districts in 2020; 9) residential consumption expenditure per capita of districts in 2020; and 10) population of districts in 2020.

Table 6
Comparison of decomposition results of energy intensity reduction targets for districts.

Unit: %	S1			S2		
	Average adjustment	Type assignment	Reduction pathway	Average adjustment	Type assignment	Reduction pathway
Dongcheng	18	19	18	21	22	21
Xicheng	18	19	18	21	22	21
Chaoyang	19	18	17	22	21	20
Fengtai	17	18	16	20	21	19
Shijingshan	16	18	17	19	21	20
Haidian	19	18	18	22	21	21
Fangshan	18	18	18	21	21	21
Tongzhou	17	17	19	20	20	22
Shunyi	18	17	19	21	20	23
Changping	17	18	16	20	21	19
Daxing	17	17	18	20	20	21
Mentougou	16	18	17	19	21	19
Huairou	16	18	17	19	21	20
Pinggu	16	18	17	19	21	20
Miyun	16	18	16	19	21	19
Yanqing	16	18	16	19	21	19

district in 2025 is 563 thousand tons of coal equivalent (ktce), which accounts for approximately 0.8% of total energy consumption in 2025; the maximum difference of Chaoyang district is 234ktce, which represents approximately 0.3% of its total energy consumption in 2025; the maximum difference of Fengtai district is 128ktce, which accounts for more than 0.2% of its total energy consumption in 2025; the maximum difference for Haidian district is 106ktce, which represents approximately 0.2% of its total energy consumption in 2025.

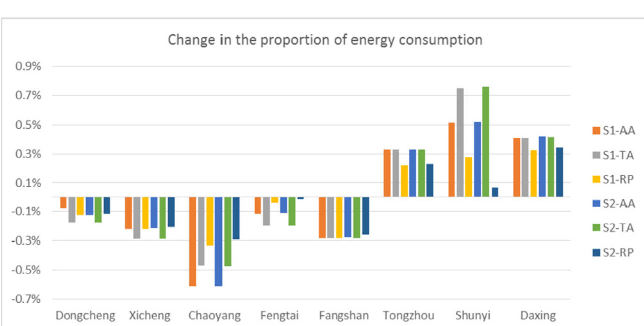

Fig. 6. Forecasted proportion of energy consumption of eight districts in Beijing from 2015 to 2025.

Fig. 8 shows the predicted total energy consumption for these four regions. The total energy consumption of these four districts in 2015 is almost 50% of Beijing's energy consumption. Considering methods and other assumptions like economic growth rate, the difference in the decomposition schemes actually reflects the possible range of energy consumption within this district in the future.

As the proportion of coal consumption in Beijing is relatively low in 2025 (i.e., lower than 3%), the differences in carbon emissions per unit of energy among districts is rather limited. Thus, it could be assumed that the carbon emissions per unit of energy for these districts could be the same as that of Beijing. In this case, it is possible to predict the carbon emissions of these districts. Taking in the first scenario as an example, the emissions for each district are shown in Fig. 9. The results show that the emission peak time for Tongzhou, Shunyi, and Daxing will be later than other regions, which will be later than 2025. These three districts are also the

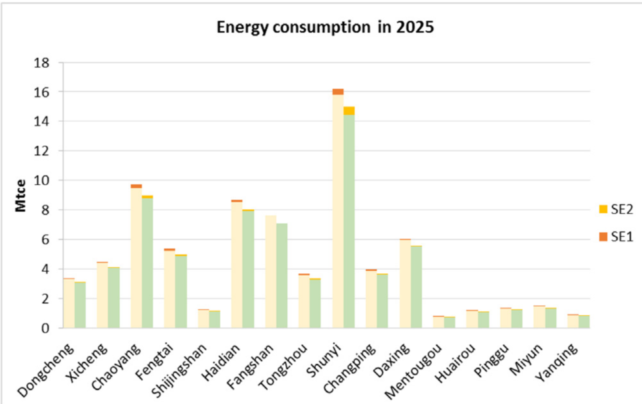

Fig. 7. Predicted ranges of energy consumption for districts in 2025.

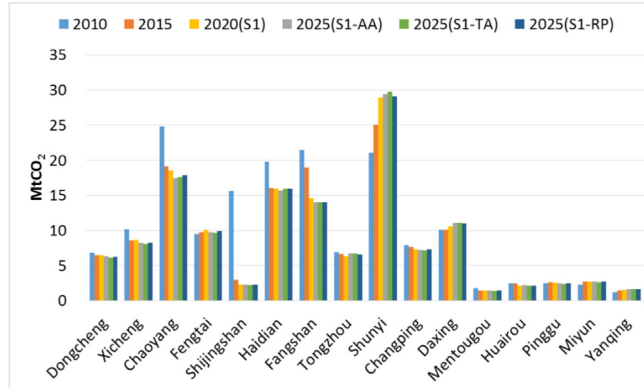

Fig. 9. Forecasted carbon emissions of districts in 2020 and 2025.

fourth group in type assignment, which means more room is needed for their further development. It is showed that Yanqing will achieve peak later than 2025 using the AA and RP method, while peak by around 2020 using TA method. Peak time of some regions, such as Dongcheng, Xicheng, Chaoyang, Shijingshan, Haidian, Fangshan and Changping will be even earlier than 2015. In 2025, emissions could be approximately 29.1–29.8 $MtCO_2$ for Shunyi, 17.4–17.9 $MtCO_2$ for Chaoyang, 15.7–15.9 $MtCO_2$ for Haidian, and 9.7–9.9 $MtCO_2$ for Fengtai. If the emission peak is achieved earlier, only Shunyi could achieve peak emissions by around 2020, while others should peak earlier than 2020, or even earlier than 2015. The peak value could be about 24.5–25.5 $MtCO_2$ for Shunyi. The differences in peak time and peak value reflect development stages and the development orientation of these districts.

4. Conclusions and policy recommendations

Beijing is going to reach total carbon dioxide emissions peak by 2020 and it is likely to be one of the first post-fossil carbon cities. By analysis of Beijing's energy consumption and carbon emissions over the past ten years, two principal measures to control total carbon dioxide emissions in the future are identified. One is to control total energy consumption, and the other is to expand the scale of green electricity imported to Beijing. As district-level measures cannot influence the scale of green electricity, the primary measure of reducing emissions is to control the intensity and amount of energy consumption for districts. Therefore, in order to achieve Beijing's emissions target, each district should realize different energy intensity targets.

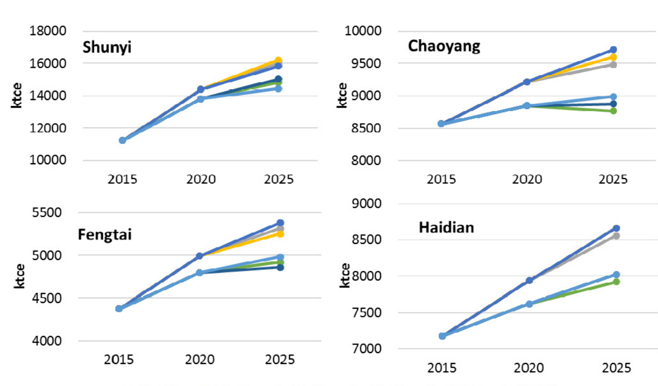

Fig. 8. Forecasted total energy consumption in Shunyi, Chaoyang, Fengtai and Haidian in 2020 and 2025.

This study analyzed energy consumption and the corresponding carbon emissions by evaluating two particular scenarios. In scenario one, the peak value of carbon emissions in Beijing is reached by around 2020, with a peak level of 153$MtCO_2$. In scenario two, the peak value may be achieved before the year 2020. If Beijing's GDP growth rates for 2015–2020, 2020–2025, and 2025–2030 are 6.5%, 5.0%, and 4.5%, respectively, the reduction rates of energy intensity from 2020 to 2025 would be 17% and 20% respectively. Considering equity, operability and feasibility, three types of energy intensity target decomposition methods were proposed for districts, namely, the reduction pathway method, type assignment method, and average adjustment method.

Different decomposition methods have the most obvious effects on energy consumption in Shunyi, Chaoyang, Fengtai, and Haidian, while the energy consumption of these four districts is nearly 50% of Beijing's consumption. Different distribution plans actually reflect the city's development expectations for each district, which then affects the specific development decisions taken by the districts. If the peak time is around 2020 for Beijing, the increment of energy consumption of these four districts should be controlled to a level of 2,838ktce to 3,047ktce during the period of the 14th Five-Year Plan. If the peak is achieved earlier, the increment of energy consumption should be controlled to a level of 1,337ktce to 1,677ktce. That is to say, controlling the increment of energy consumption in these four areas is the main task for controlling the increment of energy consumption of Beijing. More attention should be paid in actual allocation to these four areas.

Relative carbon emissions for districts are also analyzed. Three decomposition methods in two scenarios yield different emissions peak time and peak value for districts. The differences in the emissions value for districts is less than 4% of the highest value in 2025, while the difference found among targets using three decomposition methods is 0–3%. If the peak time is around 2020 for Beijing, the peak time for Tongzhou, Shunyi, and Daxing could be later than 2025, while some districts may reach a peak earlier than 2015, such as Dongcheng, Xicheng, Chaoyang, Shijingshan, Haidian, Fangshan and Changping. Actually, Tongzhou, Shunyi, and Daxing are major economic growth areas of development in the future. Tongzhou will become a sub center of Beijing, which investment in fixed assets would take up a higher proportion of the city; Shunyi has capital airport, international exhibition hall and is the main location for the 2022 Winter Olympics which could promoting sports economy and tourism economy; Daxing has Yizhuang economic and technological development zone, which is the only one under preferential policies of state-level economic and technological development zones and national high-tech industrial parks in Beijing. The decomposition results reflect the regional developmental stages and development orientation properly. If the peak is achieved earlier, only Shunyi could achieve peak emissions by around 2020, while others should be earlier than 2020, or even earlier than 2015. This means future economic growth and relative increment of energy consumption will rely more heavily on non-fossil fuel and imported green electricity. Beijing's non fossil resources are mainly wind power, solar energy, geothermal energy and so on. The development potential is limited as a city. Green electricity should be largely expanded by actively developing green electricity transmission channel construction, building green electricity trading system, and other measures. The high dependence on external energy could become one of the main risks of achieving carbon emissions peak in Beijing as early as possible.

It should be also mentioned that the indicators are all obtained from statistic data. The content of them are already achieved consensus and there is no argument. Unless other complex theoretical models or mathematical methods, calculation approach and weights of these three methods are quite transparency. The basis and meaning behind the final indicators could be easier to be understood. It is really helpful for the comparison among districts and the communications between districts and provincial government. And It can greatly enhance the practicability of the methods. It should be also noted that, in this study, the estimates of future economic growth for each district are based on historical data, and there is some uncertainty about the future economic development of each district. In the actual decomposition process, data related to indicators should be also updated to be the latest. At the same time, the existing methods are mainly designed to evaluate historical development, which cannot reflect the big changes that may take place in the economy, industrial structure, population, energy, and other variables over a short time period like large new projects and major industrial structure adjustments. According to the Five-Year Plan in the future, it is possible that some new and substantial projects might be constructed in certain districts, although the total energy consumption of these districts is relatively small. In the process of dissolving the non-capital functions of Beijing, the industrial structure within some districts may be greatly affected within a short period of time. These factors should be taken into account by adding 1 or 2 percentage points to the decomposed targets for some districts, and reducing relative points for other districts.

In conclusion, this article adopts district-level decomposition methods for energy intensity targets. Such decomposition methods have been utilized for national carbon intensity decomposition as well as Beijing's carbon intensity decomposition, as outlined in the 13th Five-Year Plan. Similar methods and indicators could also be used for other regions or countries by adjusting few indicators and weights according to the characteristics of these areas. In other words, these methods may not only assist in evaluating Beijing's districts in achieving the carbon emissions peak target and to become a post-fossil carbon city, but can also offer a frame for other provinces and cities or even other countries, that seek to implement target decomposition measures for energy conservation and carbon emission reduction.

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