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Research on carbon emissions of production-consumption sectors under the background of "Double Carbon"
——Take Beijing as an example

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Abstract: With the development of the Green and Low-carbon, Beijing has set a model for other provinces and cities in carbon emissions reduction, and it will help achieve the goal of carbon peaking rapidly. This paper studies various influencing factors of carbon emissions from both production and consumption by improving the Kaya identity. Through analyzing productive and consumptive CO2 emissions of Beijing with LMDI technology, this paper finds that: (1) For the production sectors in Beijing, the total carbon emissions exhibited a downward trend, and the energy intensity factor was the foremost factor to restrain the increase of carbon emissions, while the restraining effects of energy structure factors and industrial structure factors were limited, and the total production promoted emissions to increase significantly. (2) For the living sectors in Beijing, the total carbon emissions first increased and then decreased, and the urban and rural structural factor played a weak inhibitory role in the increase of CO2. The population and energy intensity were significantly promoted the increase of it. Therefore, this paper proposes to continue to adjust the structure of industry and urban, develop clear energy and make full use of energy, so as to realize the "dual-carbon" goal earlier.

Keywords: carbon emissions, urban structure, industrial structure, LMDI.

1. Introduction

On November 13, 2021, 197 countries signed a vital agreement of climate action on Glasgow, and it was aimed at climate protection. China owns the largest carbon emission in the world, and has formulated an ambitious Carbon reduction target: achieve carbon peak by 2030 and carbon neutrality by 2060. Under the guidance of this goal, many provinces and cities have begun to formulate relevant policies and guidelines to promote carbon emission reduction. As the economic, political and cultural center of the country, Beijing is also the pioneer of carbon peaking. In the Outline of the 14th Five-Year Plan of Beijing Municipality, it is proposed to improve and perfect the low-carbon governance system, and to achieve stable and moderate decline in total CO2 emissions during the "14th Five-Year Plan" period, laying a solid foundation for carbon neutrality. Therefore, the decomposition result can help to provide other provinces and cities useful recommendations to reduce CO2 emissions, achieve carbon peak goals, and promote high-quality economic development.

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In order to fully explore the influence of driving factors on CO2 emissions, as well as to more clearly compare the differences between the production-side and consumer-side carbon emission factors, this paper innovatively improves the "production-consumption Kaya identity" to more comprehensively the total CO2 emissions of production and consumption in Beijing from 2005 to 2019 are decomposed to avoid overly one-side analysis. By combining the characteristics of productive and consumptive carbon emissions, we can understand the unique and common driving factors of CO2, and clarify the different impacts of various factors on the two sides. The end-to-end carbon emission reduction policy has important practical significance. The follow-up arrangement of this paper is as follows: the second part summarizes the literature review of the research content and methods; the third part introduces the improved model; the fourth part introduces the selection of data and demonstrates the influencing factors of carbon emissions; the last part is the introduction of conclusions and useful recommendations.

2. Literature review

In last few years, more and more scholars have devoted themselves to studying the impact of carbon emission drivers on total CO2 emissions. The existing literature mainly focuses on the research methods and contents of impact factors of carbon emissions.

Factor decomposition methods are mainly divided into structural decomposition method and index decomposition method. Since the establishment of the environmental input-output model, the SDA has been applied in carbon emission influencing factors research. Dietzenbacher and Los (1998) perfected and developed the SDA. Scholars such as Zhu et al. (2018), Kulionis and Wood (2020), etc. have used this technology to analyze the carbon emissions and the energy use of India, and an empirical analysis of the carbon footprints of the UK, France, the US and Denmark respectively. The IDA determines the weights of different factors by determining the multiplier decomposition, including multiple types of exponential decomposition. LMDI technology is the most widely useful IDA method on carbon emission research. Olivera et al. (2019), Yang et al. (2020) used the LMDI method to decompose the driving factors of CO2 emissions in my country, and explore the economic, energy and the impact of other factors on carbon emissions. After discussing the advantages and disadvantages of the four index decomposition methods with Arithmetic Mean Divisia Index, Log Mean Divisia Index, Fisher ideal index method and Shaply method, Ang (2004) believed that compared with the other three IDA methods, LMDI could be well processed 0 and negative values without producing residual terms, making it fully decomposed. Meanwhile, compared with the SDA and the regression analysis, IDA is used in the field of carbon emissions more popularly. When comparing the SDA and IDA methods, Dutch scholar Rutger(2003) believes that although the data decomposed by the SDA method is more detailed, the IDA data base is easier to obtain and the data continuity is strong, with the characteristics of a unified form and a concise structure. At the same time, compared with regression analysis, IDA could intuitively find the most critical factor that affecting carbon emissions by quantifying the weight of every factor.

The research on the impact factors of carbon emissions mainly focuses on the sides of production and consumption. Scholars often study the impact factors of CO2 emissions of production from the macro level. Dong at al. (2013) studied the impact of productive CO2 emissions in different regions based on the regional level. Other scholars have decomposed the CO2 emissions of Chinese production side based on the industrial level, such as construction industry (MA at al. 2018), agriculture (Wang at al. 2020) and so on. Compared with the productive sectors, carbon emissions on the consumptive sectors are often researched at the micro level, and it was mainly focused on the impact of individual behaviors. Reinders at al. (2003) studied consumer carbon emissions from the perspective of micro-family in EU. In addition to micro-level research, O’Neill at al. (2012) also

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studied consumptive carbon emissions from the urban structure, and studied how urbanization affect carbon emissions. The studies believe that with the development of urbanization, household income level, consumption scale and energy consumption structure are all affected. The variety of income changes the consumption structure of residents, thus affecting the CO2 emissions.

In conclusion, the existing literature uses different methods to explore the impact of various factors on carbon emissions. Most scholars study the carbon emissions of the production side from the view of industrial sectors, or study the carbon emissions of the consumer side from the perspective of urbanization and household consumption. However, there are few studies that put the production-side and consumption-side carbon emissions in the same dimension at the same time. Different from the research of other scholars, the marginal contributions of this paper are: (1) In order to conduct a more comprehensive study of the carbon emission factors in Beijing, this paper will focus on decomposing these factors in Beijing from the urban structure while taking into account the influence of the industrial structure. (2) In terms of decomposition factors, this paper uses the LMDI addition model and innovatively construct a " production-consumption identity on carbon emission " based on the Kaya identity , so that to be more suitable for a comprehensive analysis of the decomposition of Beijing's carbon emission factors. It is decomposed into factors such as energy, population, economics, urbanization, and corresponding countermeasures are put forward.

3. Model and methodology

3.1. Kaya identity

In order to conduct a comprehensive study of CO2 emissions in Beijing, this paper separates the production sector from the living sector. This paper uses the LMDI two-layer complete decomposition method to construct a "production-consumption kaya identity" model through improving Kaya identity. As follows

$$C = \sum_{i=1}^{8} \sum_{j=1}^{17} \frac{C_{ij}}{E_{ij}} \times \frac{E_{ij}}{E_j} \times \frac{E_j}{Y_j} \times \frac{Y_j}{Y} \times Y + \sum_{i=1}^{8} \sum_{k=1}^{2} \frac{C_{ik}}{E_{ik}} \times \frac{E_{ik}}{E_k} \times \frac{E_k}{L_k} \times \frac{L_k}{L} \times L \quad (1)$$

In this model, i refers to the type of energy, there are 8 types of energy, namely raw coal, coke, kerosene, gasoline, diesel, fuel oil, liquefied petroleum gas and natural gas, j refers to the type of industry, there are the primary industry, secondary industry, and 17 sectors of the tertiary industry, k is the type of living sector, which are the consumption of rural and urban residents. C represents the total CO2 dioxide emissions about both the production and living sectors, E represents energy consumption, Y represents total production, and L represents population. $\frac{C_{ij}}{E_{ij}}$ and $\frac{C_{ik}}{E_{ik}}$ represent carbon emission intensity, changed by CI; $\frac{E_{ij}}{E_j}$ and $\frac{E_{ik}}{E_k}$ represent energy structure, changed by ES; $\frac{E_j}{Y_j}$ represents production energy intensity, changed by EI; $\frac{Y_j}{Y}$ represents industrial structure, changed by IS; $\frac{E_k}{L_k}$ represents life energy intensity, changed by EC; $\frac{L_k}{L}$ indicates the urban and rural structure, changed by LS. Therefore, the model can be re-expressed as:

$$C = \sum_{i=1}^{8} \sum_{j=1}^{17} CI \times ES \times EI \times IS \times Y + \sum_{i=1}^{10} \sum_{k=1}^{2} CI \times ES \times EC \times LS \times L \quad (2)$$

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3.2. LMDI model introduction

There are two models about LMDI technology, and they are the models of multiplication and addition, both of them are constructed based on IDA analysis. The models of multiplicative decomposition and additive decomposition are consistent' There is no residual error, and the factor decomposition can be carried out relatively completely. Each factor can be reflected. Therefore, the LMDI additive model is a very suitable method for carbon emission decomposition research.

In the additive model, we decompose the difference, and according to the derivation of the LMDI additive model, we can get equation 3.

$$\Delta M_{tot} = C_p^T - C_p^0 = \Delta C_{CI} + \Delta C_{ES} + \Delta C_{EI} + \Delta C_{IS} + \Delta C_Y \quad (3)$$

ΔM_{tot} represents the overall impact of the additive decomposition of carbon emissions per unit of GDP. The steps of decomposition in the living sectors are consistent with production sectors, so this paper will not repeat them here

Table 1: Decomposition results of carbon emissions.

Carbon Emissions Decomposition Factor	Productive sectors	Living sectors
ΔC_{CI}	$\sum_{ij} \frac{(C_{ij}^T - C_{ij}^0)}{(lnC_{ij}^T - lnC_{ij}^0)} ln(\frac{{CI_{ij}}^T}{{CI_{ij}}^0})$	$\sum_{ik} \frac{(C_{ik}^T - C_{ik}^0)}{(lnC_{ik}^T - lnC_{ik}^0)} ln(\frac{{CI_{ik}}^T}{{CI_{ik}}^0})$
ΔC_{ES}	$\sum_{ij} \frac{(C_{ij}^T - C_{ij}^0)}{(lnC_{ij}^T - lnC_{ij}^0)} ln(\frac{{ES_{ij}}^T}{{ES_{ij}}^0})$	$\sum_{ik} \frac{(C_{ik}^T - C_{ik}^0)}{(lnC_{ik}^T - lnC_{ik}^0)} ln(\frac{{ES_{ik}}^T}{{ES_{ik}}^0})$
$\Delta C_{EI}/\Delta C_{EC}$	$\sum_{ij} \frac{(C_{ij}^T - C_{ij}^0)}{(lnC_{ij}^T - lnC_{ij}^0)} ln(\frac{{EI_j}^T}{{EI_j}^0})$	$\sum_{ij} \frac{(C_{ij}^T - C_{ij}^0)}{(lnC_{ij}^T - lnC_{ij}^0)} ln(\frac{{EC_j}^T}{{EC_j}^0})$
$\Delta C_{IS}/\Delta C_{LS}$	$\sum_{ij} \frac{(C_{ij}^T - C_{ij}^0)}{(lnC_{ij}^T - lnC_{ij}^0)} ln(\frac{{IS_j}^T}{{IS_j}^0})$	$\sum_{ij} \frac{(C_{ij}^T - C_{ij}^0)}{(lnC_{ij}^T - lnC_{ij}^0)} ln(\frac{{LS_j}^T}{{LS_j}^0})$
$\Delta C_Y/\Delta C_L$	$\sum_{ij} \frac{(C_{ij}^T - C_{ij}^0)}{(lnC_{ij}^T - lnC_{ij}^0)} ln(\frac{Y^T}{Y^0})$	$\sum_{ij} \frac{(C_{ij}^T - C_{ij}^0)}{(lnC_{ij}^T - lnC_{ij}^0)} ln(\frac{L^T}{L^0})$

ΔC_X represents that the variation of CO_2 emissions which caused by X factor. The value of ΔC_X indicates the degree of influence of the X factor on the change of CO_2 emissions in Beijing. The larger the absolute value becomes, the deeper the impact represents. At the same time, if the value is positive, it means that the X factor affects CO2 positively and makes it increase clearly, or it has a negative effect. The meaning of each character is as follows (corresponding to the above):

Table 2: Symbol Notes.

Character	Meaning	Character	Meaning	Character	Meaning
CI	Carbon emission intensity	EC	Energy intensity of consumption	Y	Total production
ES	Energy structure	IS	Industrial structure	L	Population
EI	Energy intensity of production	LS	Urban structure		

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4. Empirical analysis

4.1. Data selection and calculation method

In 2009, Chinese government firstly promised to reduce CO2 emissions per unit of GDP by 40%-50% compared with 2005 by2020.In order to demonstrate the realization of this goal, combined with the data released by the Beijing Municipal Bureau of Statistics, this paper selects the 15 years data from 2005 to 2019. In order to make the research data more scientific and authoritative, the main data comes from the "Beijing Statistical Yearbook" every year from 2005 to 2019, and the "China Energy Statistical Yearbook" from 2005 to 2019 are used as auxiliary statistical research.

Table 3: Data on carbon emissions by sector.

Industry	2005	2010	2015	2019
Agriculture, forestry, animal husbandry and fishery	34.46	34.29	22.78	4.94
Industry	2029.83	1594.50	1006.64	911.36
Construction	32.81	55.10	32.82	29.39
Wholesale and retail	27.95	32.24	32.16	26.40
Transportation, Warehousing and Postal Industry	281.16	524.53	616.63	748.81
Accommodation and Catering	49.06	53.93	68.92	41.44
Information transmission, software and information technology services	4.37	4.79	5.91	5.66
Finance	3.54	3.46	3.51	2.37
Real estate	101.73	98.84	80.71	63.12
Leasing and business services	33.05	40.56	40.45	29.91
Scientific research and technical service industry	21.00	21.48	30.32	21.10
Water conservancy, environment and public facilities management industry	8.97	8.13	11.07	11.43
Residential Services, Repairs and Other Services	29.85	12.42	9.57	8.82
Education	47.51	43.96	39.68	28.48
Health and Social Work	18.32	13.29	12.60	8.45
Culture, Sports and Entertainment Industry	8.24	7.80	6.32	4.80
Public Administration, Social Security and Social Organization	21.51	21..9	18.01	10.41
Urban	154.00	231.16	314.74	287.15
Rural	94.07	82.73	101.28	41.51
Total	2966.81	2850.31	2429.33	2280.66

This paper calculates the CO2 emissions of different industries in Beijing from 2005 to 2019 by IPCC method, and lists the data for four years due to space reasons. From Table 3, it can be observed that in the past fifteen years, Beijing's total carbon emissions have shown a slow

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downward trend, while the CO2 emissions of the primary and secondary industries have shown a relatively strong downward trend. The tertiary industry has a trend of first rising and then stabilizing. However, specific to the sub-sectors of the tertiary industry, different sectors show different time trends. In terms of the living sector, the overall trend is on the rise, and the ratio of consumptive carbon emissions is lager. The CO2 emissions in both urban and rural areas basically displayed a trend of rising first and then falling, while the trend of changes in urban areas was more significant.

5. Decomposition results

This paper puts the data in 2005 as base period data, and LMDI is used to decompose CO2 emissions of the productive and consumptive sectors. Since the CO2 emissions per unit of energy is a constant, the carbon emission intensity is no longer studied. The main consideration is the impact of other factors on productive sectors and living sectors.

5.1.1. Decomposition of carbon emissions in the part of productions

According to the decomposition formula and the existing data, the CO2 emissions of each production sector in Beijing in the past 15 years were decomposed by LMDI. The decomposition results are shown in Figure 1:

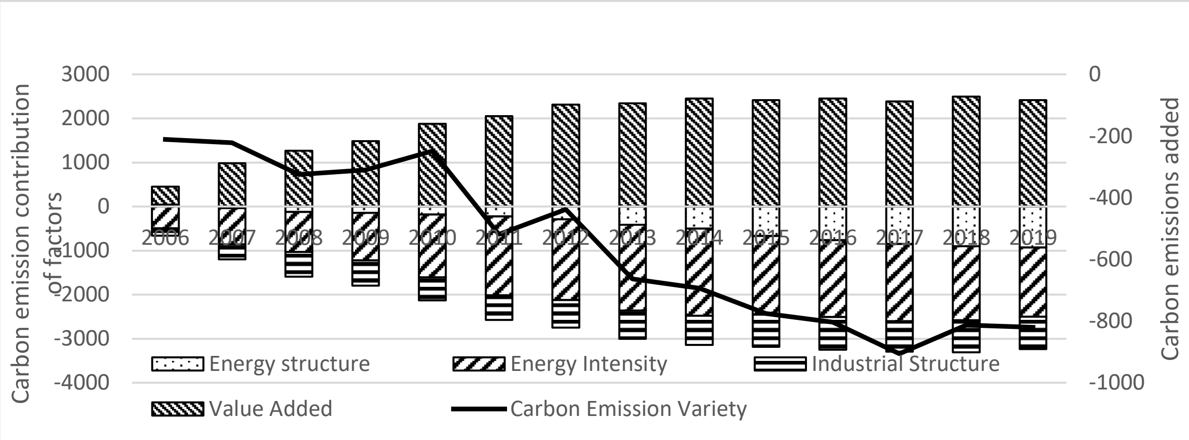

Figure 1: Decomposition trend of carbon emission factors in Beijing's production sector from 2005 to 2019.

Since the decomposition result is calculated based on the 2005 data, we can see a time trend. According to Figure 1, the overall carbon emissions in Beijing fluctuates gently and then decreases year by year, especially after 2010. There is a clear downward trend. It means that the government has paid more and more attention to ecological and environmental issues, and has gradually strengthened the control of carbon emissions. However, in 2018, there was a small increase in carbon emissions in Beijing. From Figure 1, it can be seen that the main reason is the weakening of energy intensity. For the four decomposition factors, they can be segmented into two categories, namely positive factors and negative factors. Among the four decomposition factors analyzed in this paper, the total production is a positive factor, while the structural factors and the intensity factors including energy structure, industrial structure and energy intensity are negative factors.

Figure 1 shows that economic development promotes the growth of CO2 emissions, and other impact factors inhibit the growth of carbon emissions. From 2006 to 2013, the contribution value added showed a linear increase trend, and maintained a relatively stable trend after 2013. Industrial structure and energy intensity are negative factors, and restrain emissions in Beijing. However, the inhibitory effect of structural factors is smaller than that of energy intensity factors from figure 1.

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The industrial structure showed a relatively obvious downward trend before 2010, and gradually became flat after 2010. The energy structure is slightly different from the trend of changes in the industrial structure. The energy structure declined slowly before 2010, and showed a more obvious downward trend after 2010. Comparing the proportion of energy used in different years, it is found that the use of coal energy has increased in recent years. The decline was significant within a decade, but it was replaced by other fossil fuels and some clean energy. After 2015, the ability of energy structure factors to restrain carbon emissions exceeds that of industrial structure factors.

The main factor that restraining Beijing's carbon emissions is the energy intensity factor. It can be clearly seen from the figure that the energy intensity curve first drops rapidly and then rises slowly, showing a "positive U-shaped" structure. After 2014, it began to rebound, indicating that energy intensity has a limited effect, and it is impossible to completely rely on energy utilization efficiency to suppress the growth of CO2 in Beijing.

5.1.2. Decomposition of carbon emissions in the part of consumers

The impact factors of carbon emissions are decomposed for the living sector (urban and rural) in Beijing with the data in 2005 as the base period by LMDI technology.

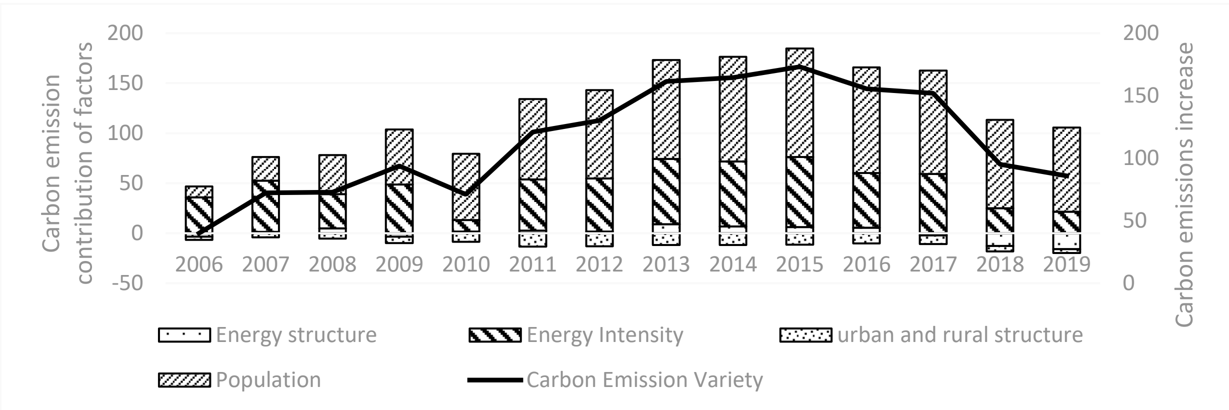

Figure 2: Decomposition trend of carbon emission factors in production sectors in Beijing from 2005 to 2019.

From Figure 2, CO2 emissions in the living sectors fluctuate greatly compared with the year-by-year decrease in productive sectors. The overall trend is to increase firstly and then begins to decrease. Population and energy intensity are main factors that increase CO2 emissions in the living sectors, while urban structure has a slight negative effect on its development.

The carbon emissions of the living sector in Beijing increased from 2006 to 2009, and dropped slightly in 2010, continued to rise from 2010 to 2015 and reached the highest value in 2015, and began to decline after 2015. However, the carbon emissions of the municipal living sector still increased by about 0.96 million tons of CO2 in 2019 compared with the base period.

The urban structure has always been a negative factor. Although it accounts for a small proportion, it has also played a necessary role in decreasing emissions in the living sector. The population is the largest positive factor contributing to the carbon emissions of the living sectors in Beijing, and the growth of the population also further increases the contribution to carbon emissions; the role of urban and rural structural factors on carbon emissions presents an "inverted U-shaped", that is, the inhibitory effect increases first and then decreases.

Life-energy intensity is also a positive factor, and the contribution to CO2 emissions first increases and then decreases. The energy structure factors were negative factors in 2007 and 2009-2016, and negative factors in other time periods. Especially since 2016, while the impact of the energy structure has changed from a promoting effect to a suppressing one, the negative impact has also increased.

6. Conclusion and Recommendation

This paper takes Beijing as the research object, and formulates the "production-consumption Kaya identity " which is suitable for a single area of Beijing, and studies the impact factors of productive and consumptive CO2 emissions in Beijing from 2005 to 2019 by LMDI method. By studying and comparing the productive and living sectors respectively, this paper obtains the similarities and differences between them, thus reflecting the characteristics of Beijing's CO2 emissions.

Firstly, from the perspective of total CO2 emissions in Beijing, there is a significant difference in it between production and consumption. Secondly, from the perspective of productive carbon emissions in Beijing, rapid economic development has contributed the most to the growth of emissions; the energy intensity is the important inhibiting factor. Finally, from the perspective of consumption, the population factor contributes the most to the increase in emissions; while changes in the urban structure play a weak inhibitory role in the increase in emissions.

To sum up, as Beijing's economy gradually shifts from high-speed to high-quality development, the main factor for carbon emission reduction has also shifted from the improvement of energy intensity to the optimization of structural factors. The following suggested countermeasures are proposed:

Government should adjust the energy structure and create a clean-efficient-modern energy system. In long run, the inhibitory energy structure has great potential. In the future, we can vigorously develop clean energy and expand the proportion of hydrogen energy, solar energy, and other clean energy in energy consumption. Accelerate the adjustment of industrial structure, attach importance to energy conservation and improve energy efficiency, and realize the transformation from "double control" of energy to "double control" of total carbon emissions. In terms of urbanization construction, the number of urban population should be controlled, and government should pay more attention to improvement of the energy consumption ways of residents.

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