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Exploring the analysis of the impact of Tianjin's economic development on carbon emissions

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Abstract:

Amid the swift expansion of the global economy, environmental issues in China have garnered increasing scrutiny. Along with the increase in China's economic development level, the total amount of carbon emissions in China is also rising. As one of the economically developed cities in northern China, Tianjin will inevitably impact the environment during its development. This paper explores the factors affecting carbon emissions in Tianjin through relevant data from 2002 to 2021, based on the Kaya constant equation and using the LMDI model. It learns that economic development is the main contributing factor to carbon emissions and further compares and analyzes the GDPs of various industries in terms of economic benefits. In order to promote the low-carbon development of Tianjin, it should maintain sustained and stable economic growth, formulate low-carbon policies that are tailored to its actual situation, transform the economic development model, restructure the industry, and promote the ideology of sustainable consumption, among other measures.

Keywords: economic development, carbon emissions, kaya constant equation,driving factor

1. Introduction

As the global problem of climate change becomes increasingly serious, the issue of carbon emissions has received widespread attention. China, being the largest emitter of carbon globally, plays a pivotal role in global climate initiatives through its efforts to reduce emissions. As an important industrial city and port city in China, Tianjin's economic development and energy consumption have a direct impact on carbon emissions. Consequently, examining the relationship between economic development and carbon emissions in Tianjin is crucial for devising effective strategies to mitigate emissions and advance sustainable development.

2. Literature review

In studies exploring the relationship between economic development and carbon emissions, the Kaya constant has been widely used due to its simplicity and practicality. The equation provides a clear framework for analyzing carbon emissions by linking them to factors such as population, GDP, and energy intensity [1]. However, the Kaya Constant Equation has limitations in explaining changes in carbon emissions, as it fails to account for differences between different energy types and industrial sectors [2]. To analyze the influencing factors of carbon emissions more precisely, the LMDI model was introduced and has since been widely adopted. This model attributes changes in carbon emissions to multiple factors, including energy structure, energy intensity, economic development, and population size, through a decomposition method [3]. The application of the LMDI model has enabled researchers to more accurately identify and assess the specific impacts of economic development on carbon emissions [4]. Within the specific context of Tianjin, numerous investigations have delved into the impact of diverse industrial sectors on carbon emissions. For instance, some studies have pointed out that the industrial sector in Tianjin is the primary source of carbon emissions, while the development of the service sector contributes to the reduction of carbon intensity [5]. Additionally, Tianjin's rapid urbanization has also had an impact on carbon emissions, with urban expansion and infrastructure development increasing energy demand and, consequently, carbon emissions [6]. In studies analyzing the effects of economic growth on carbon emissions, some scholars have also considered factors such as technological progress, energy prices, and policy changes [7]. These factors have influenced the energy consumption patterns and carbon emission levels in Tianjin to varying degrees. Overall, the existing literature provides a rich theoretical foundation and empirical analyses that elucidate the dynamics between economic progress and carbon emissions. Nevertheless, there is a scarcity of in-depth quantitative analyses focusing specifically on the carbon footprint of industrial hubs like Tianjin. This study aims to fill this gap by adopting the LMDI model and combining data from Tianjin spanning from 2002 to 2021 to analyze in depth the impact of economic growth on carbon emissions. The ultimate goal is to provide a scientific basis and policy recommendations for the low-carbon development of Tianjin and similar cities.

3. Study area, methodology and data sources

3.1 Study area

Situated in the northeastern sector of the North China Plain, Tianjin, a pivotal port city in northern China, is flanked by the Bohai Sea to its east, Yanshan Mountain to the north, and Beijing to the west, constituting a significant component of the Bohai Rim Economic Zone. The city has witnessed swift industrial and urban development in recent years, leading to a substantial increase in its economic output.

3.2 Research methodology

Calculate the carbon emission data of Tianjin according to IPCC carbon emission with the following formula:

$$C = \sum_{i=1}^{n} E_i F_i$$

In this context, C denotes the emissions of carbon resulting from the consumption of diverse energy sources. E_i is energy consumption, dominated by standard coal; F_i is the carbon emission factor for each type of energy; and i is the type of energy.

The Kaya Constant Equation, proposed by Japanese scholar Yoichi Kaya, is used to analyse and predict carbon dioxide emissions, linking carbon emissions to factors such as population, economy and energy, with the following basic formula:

$$C = POP \frac{GDP}{POP} \frac{ENERGY}{GDP} \frac{C}{ENERGY}$$

With C for total carbon emissions, POP for total population, GDP for GDP, and ENERGY for total energy consumption.

The LMDI method can provide residual-free decomposition results and is suitable for time-series analysis, which can ensure a high degree of consistency among the decomposition indicators. As a result, it has become a prevalent method for investigating carbon emission decomposition in recent years. To conduct a more granular analysis of the individual impacts of various factors on carbon emission fluctuations, this study employs the LMDI additive model to assess the effects of energy structural intensity, energy consumption intensity, economic growth, and demographic scale. The decomposition expressions are as follows:

$$C_t - C_0 = \Delta C = \Delta c + \Delta e + \Delta g + \Delta p$$

$$\Delta c = \frac{C_t - C_0}{lnC_t - lnC_0} ln\left(\frac{c_t}{c_0}\right)$$

$$\Delta e = \frac{C_t - C_0}{lnC_t - lnC_0} ln\left(\frac{e_t}{e_0}\right)$$

$$\Delta g = \frac{C_t - C_0}{lnC_t - lnC_0} ln\left(\frac{g_t}{g_0}\right)$$

$$\Delta p = \frac{C_t - C_0}{lnC_t - lnC_0} ln\left(\frac{P_t}{P_0}\right)$$

where Δc denotes that energy structure intensity effect, the Δe denotes the energy consumption intensity effect, and Δg denotes the economic development effect, and Δp denotes the population size effect.

3.3 Data sources

Within the scope of this research, the datasets pertaining to population demographics, Gross National Product, overall energy usage, and the consumption of fossil fuels have been extracted from the Tianjin Statistical Yearbook spanning the years 2001 to 2021.

4. Findings

4.1 Analysis of changes in total carbon emissions in Tianjin

Figure 1 shows the trend of carbon emissions in Tianjin from 2001 to 2021, from which it can be seen that the total amount of carbon emissions in Tianjin shows an overall steady upward trend during the 20 years without large fluctuations. Carbon emissions increased by 238,203,200 tonnes from 2001 to 2021. Among them, between 2015 and 2016, Tianjin's carbon emissions had a relatively large increase. Between 2017 and 2018, carbon emissions decreased significantly by 14,718,600 tonnes. The trajectory of carbon emissions in Tianjin is closely related to the intensity of energy structure, energy consumption intensity, economic expansion and demographic size. In order to deeply understand and explore the specific impacts of these elements on the alterations in carbon emissions in Tianjin, we will then conduct a detailed analysis using the LMDI decomposition method to reveal whether each factor plays a driving or inhibiting role in the growth of carbon emissions.

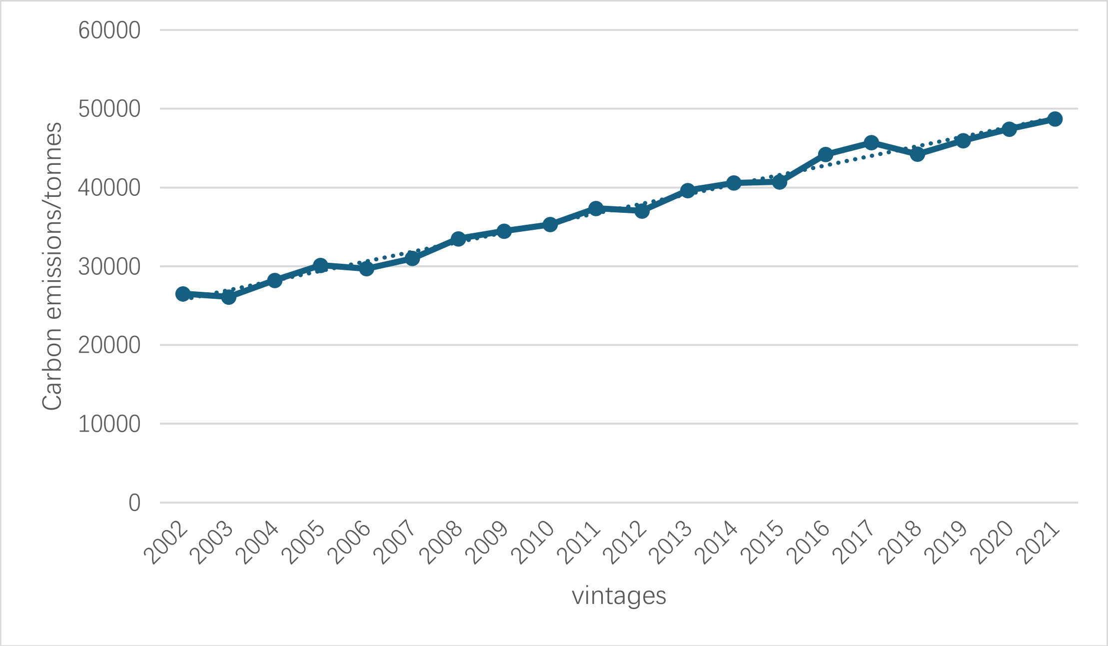

Figure 1 Carbon Emissions in Tianjin, 2002-2021

4.2 Analysis of LMDI model results presentation

The LMDI model is employed to process the data for Tianjin spanning from 2001 to 2021, using 2001 as the base year for decomposition, to ascertain the effect values of energy structure intensity, energy consumption intensity, economic development, and population size in Tianjin during this period, as illustrated in Table 1. Analysis of the data presented in Table 1 reveals that from 2001 to 2021, economic development and population size had a positive average effect, serving as the primary drivers of carbon emissions growth, with average contributions of 3,263.01 and 497.30, respectively. In contrast, the intensity of the energy structure exhibited a negative average impact, contributing an average of -2,115.84. Furthermore, the energy structure's effect on carbon emissions fluctuated across different years, with an overall negative impact and an average contribution of -453.46.

Table 1 Decomposition of factors affecting carbon emissions in Tianjin, 2002-2021

vintages	Energy structure intensity effects	Energy consumption intensity effects	Economic development effects	Population economies of scale
2002	728.07	-1456.62	2292.83	79.71
2003	-2042.75	-2537.76	4063.06	107.43
2004	-1749.64	-186.46	3721.86	330.14
2005	-1129.07	-2410.03	4895.10	545.63
2006	-3285.03	-536.41	2490.82	904.01
2007	-1365.19	-2228.50	3793.53	1108.85
2008	-140.91	-4463.57	5380.29	1717.30
2009	-2125.16	-202.27	1817.15	1474.83
2010	-4365.18	-1055.76	4290.34	1963.96
2011	-1881.14	-2310.08	5098.27	1147.60
2012	1045.56	-5399.76	3026.78	1012.45
2013	-215.67	-840.40	2765.43	879.72
2014	-364.11	-1392.17	2172.87	536.82
2015	-419.75	-332.34	619.19	283.54
2016	3544.42	-2349.38	2152.11	117.82
2017	3814.95	-5968.58	4698.74	-1039.85
2018	-2277.40	-2374.27	4049.19	-869.38
2019	244.32	-790.89	2213.27	65.16
2020	2239.36	-871.40	39.91	53.91
2021	675.20	-4610.11	5679.55	-473.70
Average contribution effect	-453.46	-2115.84	3263.01	497.30
Average contribution rate	14.93 per cent	22.77 per cent	45.82 per cent	16.48 per cent

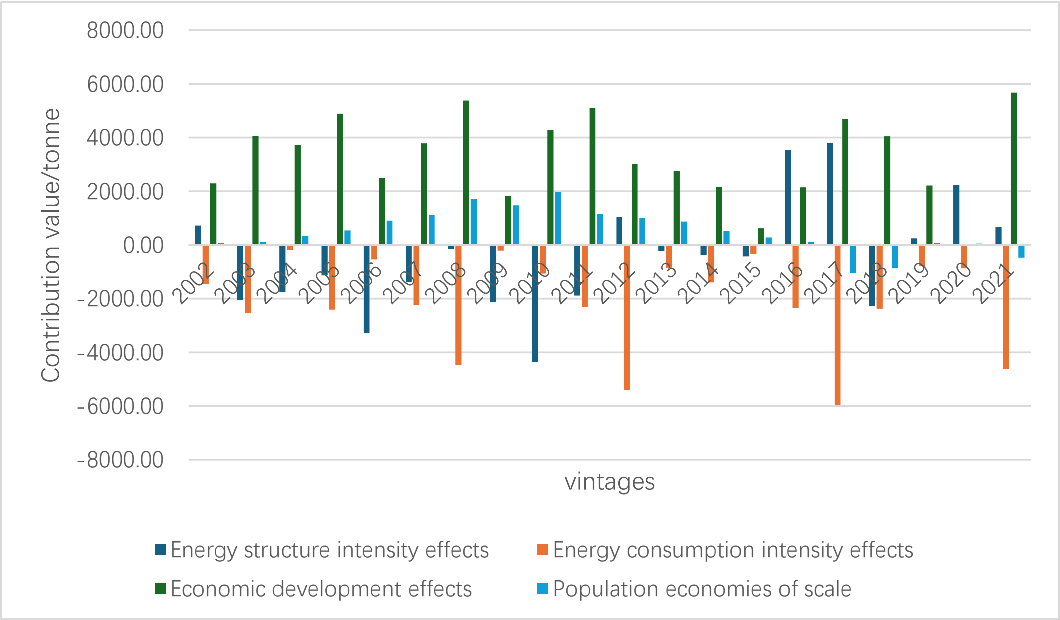

Figure 2 Contribution value of the four effects affecting carbon emissions in Tianjin, 2002-2021

4.3 Analysis of influencing factors

As can be seen from Figure 2: during the period 2001-2021, there is a great difference between the four factors explored in this paper that have an impact on carbon emissions: the energy structure intensity effect, the energy consumption intensity effect, the economic development effect, and the population scale efficiency. The average annual impact of each factor is summarized below: the population effect reaches 4,973,300 tonnes, and the economic effect is 32,630,100 tonnes, which are all positive; while the intensity effect and structure effect are -21,158,400 tonnes and -4,534,600 tonnes, respectively, which are all negative.

The economic development effect has the highest value of contribution to carbon emissions, which fluctuates considerably during the study period. For instance, economic development peaked with a substantial positive impact of 5679.55 on carbon emissions around the year 2021, while in 2020, this effect is the lowest, only 39.91. This indicates that the relationship between economic growth and carbon emissions is complex and may be influenced by a variety of factors. Overall, economic growth's influence on Tianjin's carbon emissions surpasses that of other elements, emerging as the predominant contributor. Population size's influence on carbon emissions has relatively smoother fluctuations and a relatively smaller contribution value. In most years, population growth has a positive contribution to carbon emissions, so the population size effect also contributes to carbon emissions. Conversely, the intensity of energy structure typically exhibits mixed positive and negative impacts on carbon emissions. However, in most years, the contribution value is negative, and it generally plays a suppressive role on carbon emissions in Tianjin. Between 2016 to 2017 and 2019 to 2021, the intensity of the energy structure positively influenced carbon emissions. Conversely, the intensity of energy consumption had a predominantly negative impact on carbon emissions throughout the research period. This indicates that the improvement of energy use efficiency is a key factor in suppressing the rise in carbon emissions in Tianjin. The average contribution of the structure effect is low, suggesting that changes in the energy consumption structure have a limited effect on carbon emissions. Despite some shifts towards cleaner energy sources, the dominance of coal implies that the fundamental structure of energy consumption has not yet seen transformative changes. As a result, the escalation in Tianjin's carbon emissions is predominantly shaped by energy usage efficiency and economic development patterns, with the influence of population growth and adjustments in energy structure being comparatively marginal.

5. Economic development analysis

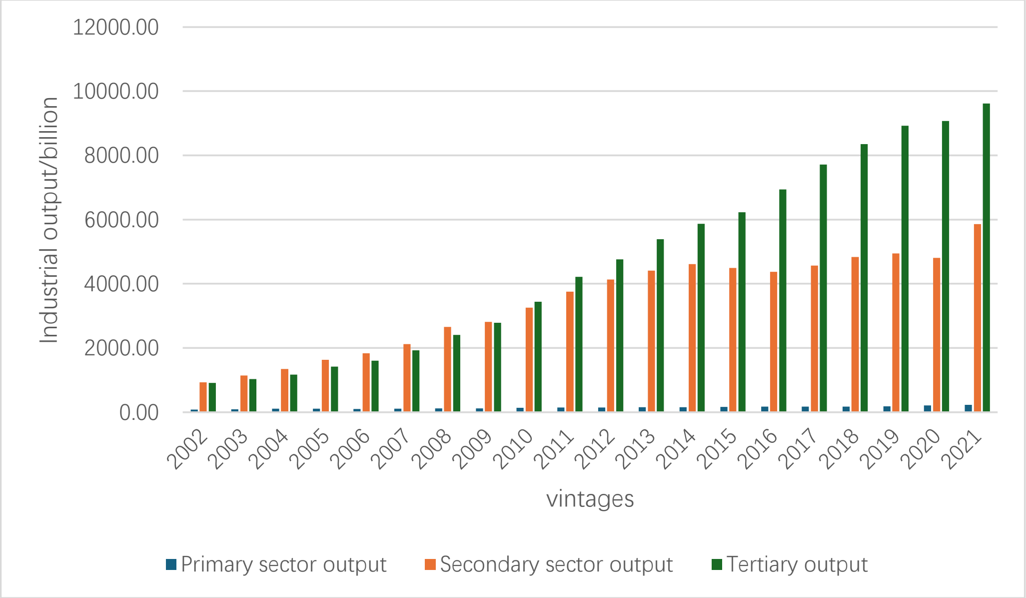

Figure 3 Output Value of Various Industries in Tianjin, 2002-2021

Analysis of the LMDI model findings reveals that economic development is the predominant force behind the escalation of carbon emissions in Tianjin. From 2001 to 2021, economic development contributed positively to carbon emissions, with the most substantial impact observed among all factors. To further dissect the specific influence of economic development on carbon emissions, we have categorized the economic output into primary, secondary, and tertiary sectors. Figure 3 illustrates that the secondary and tertiary sectors are the most significant contributors to Tianjin's economic growth, whereas the primary sector's share is comparatively minor. As an industrial city and a port city, Tianjin is weak in agricultural development. With the acceleration of urbanisation in Tianjin, agricultural land is converted into urban construction land, leading to a decrease in the proportion of agricultural output value. Meanwhile, the increase of employment opportunities in cities and the migration of rural populations to cities have led to a decrease in the agricultural labour force. As an important pillar of Tianjin's economy, fluctuations in the output value of the secondary industry have a significant impact on carbon emissions. In 2014-2016 and 2020, the reduction in the value of secondary industry output significantly contributed to the decrease in carbon emissions. With the increase in demand for the service industry as a result of economic development and higher per capita income, the Tianjin municipal government has implemented various policies and initiatives to foster the service sector's development. Consequently, the value added by the tertiary industry has experienced a steady increase.

6. Conclusions and recommendations

Utilizing data spanning 2002 to 2021, this research undertook a comprehensive examination of the carbon emissions in Tianjin and the elements that influence them, employing both the IPCC carbon accounting system and the LMDI model. It is found that the total carbon emissions in Tianjin have shown a steady upward trend in the past two decades, in which the Economic development has emerged as the primary driver of this upward trajectory, whereas the intensity of energy structure and energy consumption have acted as restraining factors. As an important pillar of Tianjin's economy, fluctuations in the output value of the secondary industry have a significant impact on carbon emissions. Especially in 2014-2016 and 2020, the decline in the output value of the secondary industry plays a key role in the reduction of carbon emissions. The growth of the tertiary industry has a positive significance for the low-carbon transformation of Tianjin's economy. Policy support, urbanisation, infrastructure development, opening up to the outside world, consumption upgrading and scientific and technological innovation have combined to drive the development of the tertiary industry. While promoting economic development, Tianjin needs to pay more attention to the optimisation of industrial structure and cleaner energy consumption in order to foster a harmonious balance between economic progress and environmental conservation. In the future, it is imperative for Tianjin to persist in enhancing the industrial structure, hastening the modernization of service sectors, and high-tech industries, while diminishing dependence on carbon-intensive industries. Improve the efficiency of energy use, promote the use of clean and renewable energy sources, and reduce the consumption of fossil energy, thereby lowering the intensity of energy intensity and carbon emissions. Encourage technological innovation and investment in research and development, and promote industrial upgrading and carbon emission reduction through technological progress. Also formulate and implement more proactive green policies to incentivise enterprises and individuals to adopt low-carbon behaviours. Vigorously strengthen education and publicity campaigns to raise public awareness of environmental protection and low-carbon lifestyles, and advocate green consumption and low-carbon travel. Establish and improve a carbon emission monitoring and assessment system to regularly evaluate the effectiveness of policies and to adjust and optimise emission reduction strategies in a timely manner.

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