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Driving factors of China's energy-related CO_2 emissions

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ABSTRACT

In this paper, logarithmic mean Divisia index (LMDI) method was used to analyze China's energy-related CO_2 emissions from 1980 to 2019. Four contributing factors including energy intensity, carbon intensity, economic development and population size were selected. The results show that China's CO_2 emissions increased from 1.49Gt to 9.68Gt from 1980 to 2019. Per capita GDP is the dominating positive factor, accounting for 293.51%, while energy intensity is the major negative factor, contributing -189.91%. Thus the efforts for carbon peak and neutrality in China should be focused on economic structure adjustment and energy efficiency promotion.

Keywords: CO_2 emissions, energy consumption, driving factor analysis

1.INTRODUCTION

According to the fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), the concentration of greenhouse gases (GHG) such as carbon dioxide in the atmosphere has increased by 40% since industrialization revolution [1,2]. Carbon emission has thereby been the core of a series of environmental issues such as climate change. In 2018, the IPCC proposed to limit global warming to 1.5 ° C [3], and China set the goal of achieving carbon peak by 2030 and carbon neutral by 2060 [4]. In the 14th Five-Year Plan, China had set a target of reducing energy consumption and carbon dioxide emissions per unit of GDP by 13.5 percent and 18 percent respectively by 2025. However, large-scale combustion of fossil fuels may impede the achievement of such ambitious goal [5]. Controlling and reducing energy-related carbon emissions and clarifying their driving factors are of great significance to figure out the proper pathway of carbon emission mitigation.

China is now the world's largest energy consumer and emitter of CO_2, accounting for about 30% of global emissions [6]. In China, the most important cause of anthropogenic CO_2 emissions is the burning of energy-related fossil fuels, which will occupy the primary position in China's energy share for a long time [7]. In order to achieve stable economic growth, it is necessary to control the use of fossil energy so as to reduce CO_2 emissions. Li analyzed the carbon flows of China from 2008 to 2012 [8]. Zheng accounted the energy-related CO_2 emissions in China and analyzed the impact of policy changes on energy-related CO_2 emissions [9]. Cai also explored the spatio-temporal changes of carbon emissions in China by constructing a high-resolution spatio-temporal data set [10].

The most commonly used methods of decomposition analysis in existing literatures include structural decomposition analysis (SDA) and index decomposition analysis (IDA) [11]. IDA originated from energy system analysis and was characterized by low data consumption, easy access, easy time series and cross-country comparison. The logarithmic mean Divisia index (LMDI) method, as one of the IDA, has been preferred to investigate the driving factors of energy use and CO_2 emissions [12]. It can qualitatively decompose CO_2 emissions into a set of several driving factors, and then describe their positive or negative impacts.

In this paper, CO_2 emissions under energy consumption in China are studied and decomposed from four aspects of energy intensity, carbon emission intensity, economic development and population size by using LMDI decomposition analysis. The driving effect of each factor on CO_2 emissions is analyzed in order to provide scientific basis for carbon emission planning and energy policy making in China.

2. MATERIAL AND METHODS

2.1 Data

The study used 1980-2019 energy and economic data obtained from National Bureau of Statistics of China Statistical Yearbook (1980-2020) [13], China Energy Statistical Yearbook (1980-2020) [14]. Among them, the GDP data were unified at constant prices in

2000. The accounting of carbon emissions caused by energy consumption refers to the IPCC Greenhouse Gas Inventory Emission Accounting Guidelines [15]. The carbon emission coefficients of various energy sources in the carbon emission calculation followed the carbon emission coefficients adopted by the Energy Research Institute of the National Development and Reform Commission [16].

2.2 Methods

2.2.1 CO_2 emissions accounting

The following formula was used to calculate the CO_2 emissions, and only three main fossil fuels (coal, oil and natural gas) were considered. The specific calculation formula [17] is as follows:

$$CO_2 = \sum_{i=1}^{3} F_i \times E_i \tag{1}$$

where, CO_2 is carbon emissions; E_i represents the consumption of primary energy of i type of energy; F_i represents the emission factor of i type of energy.

2.2.2 Decomposition model

The CO_2 emissions were decomposed from four aspects: CO_2 emission intensity, energy intensity, per capita GDP, and population size. These four indexes can not only be used to assess the decisive factor but also set different policy change scenarios. Specific formula [9] is given as follows:

$$CO_2 = \frac{CO_2}{E} \times \frac{E}{GDP} \times \frac{GDP}{P} \times P = CI \times EI \times PCG \times P \tag{2}$$

where, CI is carbon intensity, EI represents energy intensity, PCG denotes Per capita GDP, and P denotes population.

Using the following formula to obtain the change in CO_2 emissions over a period of time:

$$\Delta C = C_T - C_0 = \Delta CI + \Delta EI + \Delta PCG + \Delta P \tag{3}$$

where, ΔC is the total effect of CO_2 emissions, C_T is the CO_2 emissions in target year, C_0 is the CO_2 emissions in base year, ΔCI is carbon intensity effect, ΔEI is energy intensity effect, ΔPCG is Per capita GDP effect, and ΔP denotes population effect.

The relative contribution of each indicator was calculated separately by Eqs. 4 to 7.

$$\Delta CI = \sum \frac{CO_2(t) - CO_2(t-1)}{\ln CO_2(t) - \ln CO_2(t-1)} \times \ln\left(\frac{CI(t)}{CI(t-1)}\right) \tag{4}$$

$$\Delta EI = \sum \frac{CO_2(t) - CO_2(t-1)}{\ln CO_2(t) - \ln CO_2(t-1)} \times \ln\left(\frac{EI(t)}{EI(t-1)}\right) \tag{5}$$

$$\Delta PCG = \sum \frac{CO_2(t) - CO_2(t-1)}{\ln CO_2(t) - \ln CO_2(t-1)} \times \ln\left(\frac{PCG(t)}{PCG(t-1)}\right) \tag{6}$$

$$\Delta P = \sum \frac{CO_2(t) - CO_2(t-1)}{\ln CO_2(t) - \ln CO_2(t-1)} \times \ln\left(\frac{P(t)}{P(t-1)}\right) \tag{7}$$

3 RESULTS

3.1 Dynamics of energy-related CO_2 emissions in China

China's total energy consumption increased rapidly from 586 million tce in 1980 to 4.476 billion tce in 2019, with an annual growth rate of 5.21%. Related CO_2 emissions increased from 1.49Gt in 1980 to 9.68Gt CO_2 in 2019, with an annual growth rate of 4.78%. As can be seen in Fig. 1, China's CO_2 emissions are generally divided into three stages :(1) 1980-2001, slow growth stage; (2) Rapid growth stage from 2002 to 2014; (3) Regulating and optimizing the development stage after 2015. The average annual growth rate of the three stages showed obvious changes, which were 4.15%, 7.05% and 0.60%, respectively.

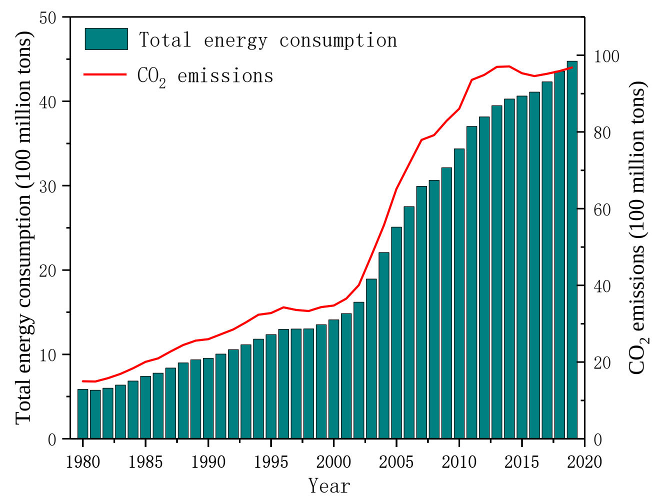

Fig 1 China's total energy consumption and CO_2 emissions

3.2 Driving factors of CO_2 emissions

From the analysis of CI, EI, PCG and P, it is found that PCG is the main positive driving factor, and EI is the main negative driving factor. Since 1980, PCG has made positive contributions to CO_2 emissions, and the contribution has shown an increasing trend. Since 2010, the contribution has shown a decreasing trend year by year; The negative driving force of EI on CO_2 emissions has increased year by year. Only in 2003, the positive driving force appeared. The contribution rate varies greatly from year to year, and the overall trend is increasing, indicating that the dependence of economic development on primary energy is gradually decreasing; Since 1980, the negative drive of CI in energy consumption CO_2 emissions has become more and more significant, indicating that the use and promotion of non-fossil energy has a positive role in promoting CO_2 emissions reduction.

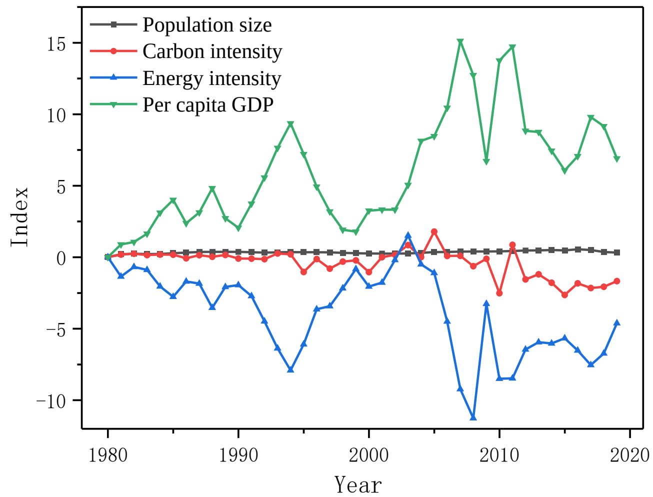

Fig 2 Cumulative contribution values of influencing factors of the energy-related industrial CO_2 emissions.

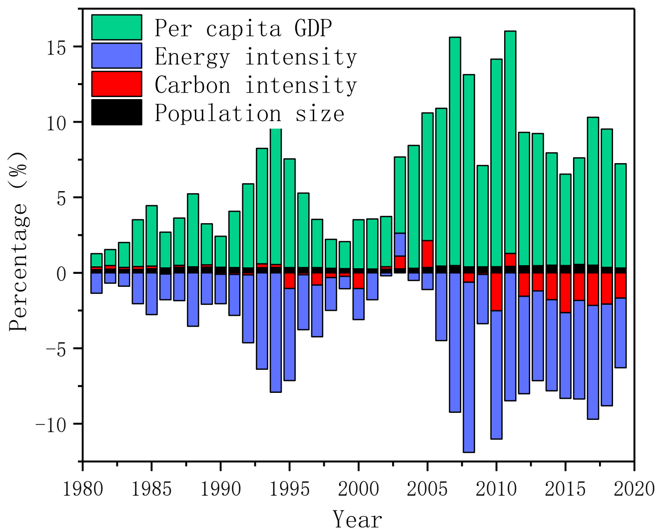

Fig 3 Cumulative contribution rates of influencing factors of the energy-related industrial CO_2 emissions.

Policy drives in different time periods affect the changes in the contribution of driving factors. By integrating the time process, the overall driving effect of different driving factors on CO_2 emissions can be more significantly discovered. From 1980 to 2019, primary energy consumption increased 7.6 times, while CO_2 emissions increased 6.5 times. Economic development contributed 293.51 percent of the growth, while population only contributed 16.67 percent. EI and CI contributed -189.91% and -20.28% to CO_2 emission, respectively.

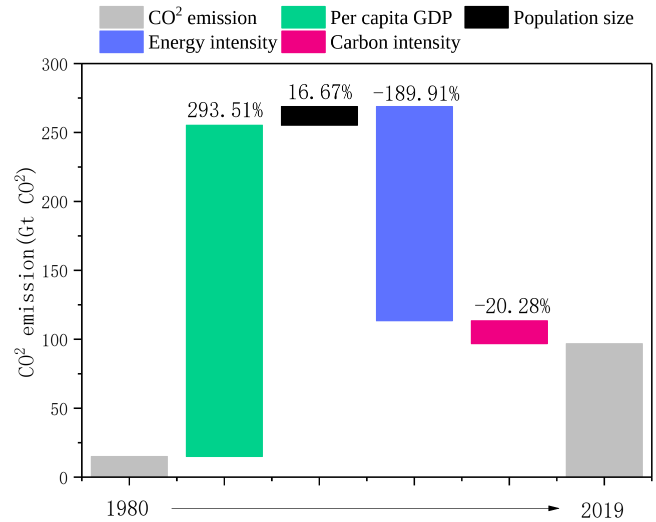

Fig 4 Cumulative determinant effects of 4 indicators from 1980 to 2019. The percentages above the y axis refer to the determinant's contributions to the changes in CO_2 emissions.

4 DISCUSSION

Since 1980, China's economy has undergone three stages of extensive, intensive and high-quality development. Economic growth has played the most important driving role in the expansion of energy demand and the increase of CO_2 emissions. Meanwhile, the development of clean energy makes the proportion of China's primary energy consumption decline year by year. With the development of cleaner technology, the optimization and adjustment of energy efficiency and industrial structure, China's economic growth, energy consumption and CO_2 emissions would show a new steady state and development.

Moreover, the results will help us predict and evaluate China's CO_2 emissions in the future. Driven by policies, China's economic growth and energy efficiency promotion are at a critical stage, and population policy stimulus has failed to bring significant population growth in the breaking point, Meanwhile, with the development of clean energy and the increase in its proportion in the entire energy consumption system, the CO_2 emissions of China's energy consumption will see a new steady state and balance at some points in the future, helping to achieve the goal of carbon peak and carbon neutrality.

Based on the analysis of China's energy consumption CO_2 emissions in the past 40 years, as well as the goals and plans proposed for carbon emissions in the future, policies should be driven from the following aspects:

(1) Strengthen carbon emission mitigation and develop zero-carbon economy.

The premise of developing low-carbon economy is to clarify the relationship between energy consumption, economic growth and carbon emissions, carry out the transformation of energy structure, strictly control the consumption of primary energy, and find the carbon emission path to achieve high-quality economic development while considering the contradiction between economic development demand and strict control of energy consumption.

(2) Formulate regional emission reduction policies according to local conditions.

Different regions in China differ greatly in terms of development stage, economic strength and resource endowment. We should adhere to the principle of common but differentiated responsibilities, strengthen coordination at the national level, put forward phased-in emission reduction roadmap for different regions, and specify time limits and key tasks for each region's emission reduction.

(3) Increase energy technology development in different industries and improve energy efficiency.

Industry is the main field of carbon dioxide emissions in China, accounting for about 80% of the country's total emissions. For different industrial technologies, investment of scientific and technological research should be increased to promote the improvement of energy efficiency, so as to achieve scientific and technological emission reduction.

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