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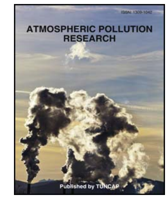

Impact of population aging and industrial structure on CO_2 emissions and emissions trend prediction in China

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A B S T R A C T

Along with the adoption of *the Paris Agreement* in 2015 and China's own action target, the emissions reductions in China, as the largest CO_2 emission country in the world, become extremely urgent. In terms of the current status of demographic and industrial structure, the impact factors of CO_2 emissions are analyzed by the ridge regression method based on an extended STIRPAT model in this study. The results show that population aging, industrial structure and per-capita wealth have a positive impact on CO_2 emissions growth, while energy intensity has a weakly negative effect on CO_2 emission. Based on the above studies, eight different scenarios are set to analyze the future energy CO_2 emissions. In addition, future CO_2 emissions in China are also predicted by the Grey System model. It concludes that CO_2 emissions will have an upward trend in the future. As a result, speeding up construction of the sanatoria industry as well as adjusting of the energy and industry structures is proposed as effective ways to control CO_2 emissions.

1. Introduction

According to *the Paris Agreement*, each country involved should spare no efforts to reduce the net CO_2 emissions to zero on a global scale in the second half of the 21st century, and the Chinese government has also made an action plan, with the goal of CO_2 emissions peaking around 2030. The US Energy Information Administration (EIA) states that over two-thirds of global emissions in 2014 came from just ten countries, with the shares of China (28%) and the United States (16%) far surpassing those of all others (EIA, 2016). China is the world's largest primary energy consumer and greenhouse gas emitter. In addition, its energy intensity is twice as high as the average global level. Therefore, China's CO_2 emissions reductions become very crucial to improve the global environment.

Research on CO_2 emissions originated during the 1950s when Revelle and Suess (1957) concluded that the large increase in CO_2 production by fossil fuel combustion should certainly cause some changes in weather and climate throughout the earth. In order to effectively control carbon emissions, many scholars have conducted lots of research to find the driving forces of CO_2 emissions. The focus of a great deal of research is on population, economic level, technology, and industrial structure. Ehrlich and Holdren (1971) initially proposed that population, per-capita wealth and technology level had an impact on environmental issues, and growing population was the significant contributor. Additionally, Jorgenson and Clark (2010) indicated that population size was the most important driving force of carbon emissions. The results also showed that population was one of the most important factors on CO_2 emissions (Zhu and Peng, 2012; Wang et al., 2012; Wang et al., 2013; Wang et al., 2015). Although demographic trends were considered to be key factors driving CO_2 emissions (O'Neill et al., 2001), the population-related factor was mainly represented by population size or population growth. Urbanization level, aging population, and household size also had great influence on CO_2 emissions (Liddle, 2014; Chikaraishi et al., 2015; Feng et al., 2011). Research involved in the role of any particular age cohort, especially the oldest cohort (65 years and above), in CO_2 emissions remains almost an unexplored field. The direct link between aging and CO_2 emission comes from the consumption pattern of the elderly people. Compared with the economically active or the young cohort, elderly people had different consumption needs, which affected energy requirements embodied in distinct goods (Schipper, 1996; Bin and Dowlatabadi, 2005). However, there are few studies of the impact of population aging on CO_2 emissions and scholars hold varied points of view. O'Neill and Chen (2002) took the attitude that population aging would speed up the family miniaturization and lead to more energy consumption and CO_2 emissions. In contrast, some other scholars studied the effect of aging of the American population on its future CO_2 emissions, reporting that population aging could restrain the long-term CO_2 emissions (Michael

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et al., 2008). Hassan and Salim (2015) examined the effects of population aging on CO_2 emissions in 25 high-income OECD (Organization for Economic Co-operation and Development) countries and demonstrated that a one percent increase in the share of aged population would reduce per capita CO_2 emission by 1.55 percent in the long run.

In China, great changes have been taking place in demographic structure since the one-child policy was implemented in 1979. For example, Chinese dependency ratio (which compares the number of people under the age of 15 and over the age of 64 with those aged 15 to 64) declined from 62.6% in 1982 to 34.2% in 2010. Due to the low dependency ratio and a large laboring population, China's economy developed rapidly during that period. However, in 2000 population over 60 years of age accounted for 10.2% of the total population in China while over 65 years of age accounted for 6.96%, which meant China's entry into an aging society. Moreover, by 2014 Chinese dependency ratio to the total population went up to 36.2%. Meanwhile, the proportion of population over 60 years old rose to 15.5% and that of population over 65 years old rose to 10.06%. Compared with China, the ratio of people over 60 in France just increased from 7% to 14% within 150 years, 85 years in Switzerland, and 60 years in the United States. In the past, population growth is the main driving force of economic development, but now, an increasing population has imposed great pressure on the environment.

With great changes in Chinese demographic structure, China's industrial structure has undergone great changes (Chang, 2015). China divides its industries into three classes: the primary industry includes agriculture; the secondary industry includes industry and construction; while the others such as service industry belong to the tertiary industry. In short, industrial structure represents the proportion of the three industries. From 1978 to 2014, China's primary industry ratio to GDP dropped rapidly from 27.9% to 9.2% while secondary industry shared around 45%; at the same time the tertiary industry proportion was rising constantly, starting to surpass the secondary industry proportion in 2013 and reaching 48.1% in 2014. There were scholars who put forward for the first time that the government could control CO_2 emissions through updating industrial structure to achieve the coordinated development of the environment and industry (Tu, 2008; Cai et al., 2008). Thereafter, Zhang's (2010) paper further analyzed the relationship between industrial structure and CO_2 emissions, implying that the secondary industry's CO_2 emissions intensity was much higher than the other two and the high proportion of the secondary industry increased China's CO_2 emissions in 1987–2007. Moreover, the result showed the construction sector of China emitted the most consumption emissions (Chen et al., 2016). Consequently, the key to CO_2 emissions reductions in the future is lowering energy intensity and adjusting industrial structure (Liu and Fu, 2011; Guo, 2012).

To sum up, the previous studies related to CO_2 emissions are primarily concentrated on the economic field. Firstly, there are few studies that pay attention to the impact of other population-related factors except population size on CO_2 emissions. Simultaneously, the literature reports on the effect of population aging on CO_2 emissions are sometimes controversial. Besides, empirical research on the impact of industrial structure on carbon emissions is not sufficient. Lastly, the conflict among population, economical development, and the environment is increasingly acute with the acceleration of population aging and industrialization in most countries, especially in China. Considering that population aging and industrial structure creates serious challenges to the environment, it is surprising that there is hardly any comprehensive study linking the two issues. Therefore, it is necessary to examine the impact of population aging and industrial structure on CO_2 emissions as well as enact correspondingly environmental policies in China.

This study presents three new aspects with respect to the literature reports. Firstly, as far as we know, this is the first study that combines the role of population aging on CO_2 emissions along with industrial structure. Secondly, based on the STIRPAT (Stochastic Impacts by Regression on Population, Affluence, and Technology) model (Dietz and Rosa, 1994), for instance, Rafiq et al. (2016) analyzed the impact of urbanization and trade openness on emissions and energy intensity in twenty-two increasingly urbanized emerging economies. This study is the first to extend the model by choosing population aging as the demographic variable and adding a new variable of industrial structure. This study attempts to offer evidence on two factors in increasing CO_2 emissions. Finally, the other main contribution of this study is to predict the CO_2 emissions trend till 2030 in China by both the scenario analysis and Grey System model (Deng, 1982). The study applies the extended STIRPAT model to investigate the impact of population aging and industrial structure on CO_2 emissions in China and made predictions of future CO_2 emission trend, providing a theoretical basis for realizing the targets of China's CO_2 emission reductions.

The rest of this study is organized as follows. Section 2 introduces the methodology and data sources. Section 3 presents estimation methods and analysis of results, followed by conclusions and policy suggestions in Section 4.

2. Methodology and data

2.1. Extended STIRPAT model

The theoretical framework for this study rests upon the highly popular conceptual framework, namely the STIRPAT model. However, in view of the indirect or direct impact of demographic and industrial structure on CO_2 emissions in China, this study considers population aging as the demographic variable and introduces industrial structure into the analysis framework as follows:

$$\ln I = \alpha + \beta_1 \ln P + \beta_2 \ln A + \beta_3 \ln T + \beta_4 \ln S + \varepsilon \quad (1)$$

where I stands for CO_2 emissions; P represents the degree of population aging defined as population over 60 years of age ratio to total population; A is per-capita GDP (Gross Domestic Product); T denotes the technology level represented by energy intensity, defined as the amount of energy consumed for every unit of economic output, while S stands for industrial structure by the ratio of output of tertiary industry to GDP. ε is an error term and α is a constant. β_1, $\beta_2 l$, β_3, β_4 correspond to the coefficient of each driving factor.

2.2. Grey system model

The concept of Grey System was put forward by Chinese professor Julong Deng in 1982 for the first time. In the next year, Deng built the Grey System theory which was a new method for researching uncertain problems lacking data and information (Deng, 1983). The Grey System takes an uncertain system without adequate data and information, which means part of the information is known and the other part is unknown, as the research object, and extracts valuable information by generating and developing the known part. Therefore, an accurate description and an effective monitoring of system run-time behaviors and evolution rules can be achieved. The Grey Model (GM) is an important part of Grey System theories. Nowadays many scholars have been able to make a prediction in their research fields and achieve a lot of valuable results through this forecasting model (Wang et al., 2017a,b; Ma and Liu, 2017; Li et al., 2016; Yuan et al., 2016; Yu et al., 2015).

This study used GM (1, 1) and data of China's total CO_2 emissions in 1990–2014 to forecast China's CO_2 emissions in 2015–2030 through the Matlab software. The first 1 in GM (1,1) means that there is only one variable while the next 1 means that the model is constructed by the first order Grey differential equation. In summary, the model derives a new regular data sequence by accumulating the initial data firstly, and then establishes a differential equation so as to work out predictions, as described in *The Primary Methods of Grey System Theory* (Deng, 1987).

First, a primitive sequence is given: