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Scenario analysis of carbon emissions' anti-driving effect on Qingdao's energy structure adjustment with an optimization model, Part I: Carbon emissions peak value prediction

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ABSTRACT:

Taking Qingdao as a case study, an extended STIRPAT model was introduced to determine the relationship between CO_2 emissions and different driving factors (permanent resident population, economic level, technical level, urbanization level, energy consumption structure, service level, and foreign trade degree) based on the SPSS statistical software as well as the relevant data of Qingdao from 1988 to 2014. Combined with the satisfactory fitting results and model verification, it can be found that the STIRPAT model could be applied to the prediction of Qingdao's future CO_2 emissions. To check the impact of different combinations of driving factors on CO_2 emissions, scenario analysis was employed in this study, and Qingdao's CO_2 emissions during the period 2015–2030 and corresponding amount as well as occurrence time of carbon emissions peak values under different scenarios were acquired. Finally, several policy recommendations were put forward to ensure the smooth implementation of Qingdao Low-carbon Development Program (2014–2020). The results could not only provide a theoretical foundation for Qingdao to build the management framework of carbon emissions peak value, set reasonable targets of social-economic development and carbon emissions reduction, but also help decision makers enact appropriate measures of energy conservation and emission reduction.

1. Introduction

As the first-ever universal, legally binding global climate deal aimed at curbing climate change, the Paris Agreement was adopted by 195 countries at the 21st session of the Conference of the Parties (COP21) in December 2015. It set a long-term goal of maintaining the rise in global average temperature to below 2 °C above pre-industrial levels, and strived to limit the increase to 1.5 °C in order to reduce the risk and impact of climate change significantly. To accomplish these, all concerned parties should participate in the global actions, and make great efforts to achieve their own CO_2 emissions at a peak as soon as possible, especially for China, whose emissions account for almost 30% of the total global CO_2 emissions, exceeding the combined emissions of the United States and European Union (Liu et al., 2014).

In fact, in response to global climate change, Chinese government has vowed to cut 40–45% of the carbon intensity per unit of GDP by 2020 compared with the 2005 level at the 2009 Copenhagen Climate summit (Yi et al., 2016). In addition, to fulfill its commitment to the Paris Agreement, China has identified the action objectives by 2030 in its intended nationally determined contributions (INDCs): to increase the share of non-fossil fuels in primary energy consumption to around 20%; to cut its carbon emissions per unit of GDP by 60–65% from the 2005 level; to achieve the peak of carbon emissions around 2030 and making best efforts to peak early. Not only this, in China's 13th Five-Year Plan, ecological civilization construction is an important content, and series of policy recommendations such as optimizing the industrial structure, establishing low-carbon energy system and national carbon emissions trading market as well as developing green buildings and low-carbon transport have been put forward.

In order to realize the target, implement the policy measures and accelerate China's low-carbon economy, the National Development and Reform Commission of China (NDRCC) has launched a national low-carbon province and low-carbon city experimental project. According to its two notices issued in 2010 and 2011, a total

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of 6 provinces (Guangdong, Hubei, Liaoning, Shanxi, Yunnan and Hainan) and 36 cities (Beijing, Shanghai, Tianjin, Chongqing, Qingdao, etc.) were picked as low-carbon pilots, where the relevant government authorities were requested to research and develop a low-carbon development program, and accelerate the establishment of low-carbon industrial system. Moreover, calculating and setting a control target amount of local carbon emissions was another important task for each low-carbon pilot area. In particular, as one of the national pilot low-carbon cities located in the eastern coastal developed districts, Qingdao was required to make its best effort to peak in 2020, and launch the management process of carbon emissions peak value in time. Therefore, predicting the amount and occurrence time of carbon emissions peak value accurately became an urgent issue to be tackled for Qingdao.

Among previous studies, a variety of methods were mainly developed and applied to project the CO_2 emissions related to energy consumption at different temporal and spatial scales. For example, based on the analysis of the dynamic relationships between CO_2 emissions, energy consumption, and real output for Brazil over the period 1980–2007, Pao and Tsai (2011) applied the Grey prediction model (GM) and autoregressive integrated moving average (ARIMA) model to predict the energy consumption and associated CO_2 emissions in Brazil from 2008 to 2013. Chang et al. (2013) advanced a novel quantum harmony search (QHS) algorithm-based discounted mean square forecast error (DMSFE) combination model to predict the CO_2 emissions of the World top-5 CO_2 emitters. Within the framework of STELLA software, an integrated system dynamics model was developed by Feng et al. (2013) to model the energy consumption and CO_2 emission trends for the City of Beijing over 2005–2030. Meng et al. (2014a) proposed a small-sample hybrid model to forecast the CO_2 emissions of China from 1992 to 2011, and compared the results with that from the traditional linear model and GM (grey model) (1, 1). Based on the nighttime light imagery and statistical energy data, a top-down method was adopted by Meng et al. (2014b) to estimate the CO_2 emissions at an urban scale in China. With a combination of areal interpolation method and DMSP/OLS nighttime light data, Wang and Ye (2017) interpolated the provincial CO_2 emissions to prefectural cities for the first time, and tested the EKC hypothesis with this city-level data and spatial econometric modeling. In other words, the majority of the existing studies relative to CO_2 emissions prediction mainly considered the effect of energy consumption and/or economic growth, and usually overlooked other impact factors such as population, urbanization, energy structure, industrial structure, etc., not to mention involving the relevant issues of carbon emissions peak value.

As an increasingly dominant method that could reveal the relationship between the environment pressure (for instance, carbon emissions) and various driving factors of human activities systematically and effectively, the IPAT model attracted more and more attention. On this basis, the STIRPAT (Stochastic Impacts by Regression on Population, Affluence, and Technology) model has been extensively developed and applied by more and more researchers in recent years. For instance, dividing China's 30 provinces into three kinds of regions according to different economic levels, Wang and Zhao (2015) employed an extended STIRPAT model to examine the regional differences of factors on energy-related CO_2 emissions. To shed some light on the impact factors of carbon emissions at the city level, an extended STIRPAT model was developed by Li et al. (2015) to systematically identify the main driving factors of CO_2 emissions in Tianjin during the period 1996–2012. Based on time sequence data over 1958–2010 in Xinjiang, a STIRPAT model was adopted by Huo et al. (2015) to analyze the impact of social and economic development on carbon emissions considering the context of different polices. Taking Ningxia Hui Autonomous Region as an example, Guan et al. (2016) applied a STIRPAT model and random parameters model to assess and quantify the strength of the relationship between CO_2 emissions that are attributed to energy consumption and their major drivers (i.e., population, economy, and technology). An extended STIRPAT model was reconstructed by Lin et al. (2017) to analyze the effects of the driving forces, especially urbanization and real economic development, on CO_2 emissions for non-high income countries, upper and lower middle-income countries. However, most of those studies mainly focused on examining the contribution of different anthropogenic factors (i.e. population urbanization rate, carbon emissions intensity, energy intensity, etc.) to regional CO_2 emissions in order to identify the key factors, and stopped there. That is to say, fewer studies were conducted to further predict the CO_2 emissions in the future, not mention to quantify the regional carbon emissions peak values which could provide data support for the development of local low-carbon economy.

In this study, taking Qingdao as a case study, driving factors such as permanent resident population, economic level, technical level, urbanization level, energy consumption structure, service level and foreign trade degree were taken into consideration and an extended STIRPAT model was introduced to determine the relationship between CO_2 emissions and above driving factors with the aid of software package SPSS. The detailed tasks of this study are: (a) confirming whether the extended STIRPAT model could be used to forecast Qingdao's future CO_2 emissions or not; (b) acquiring the corresponding amount and occurrence time of carbon emissions peak values under different CO_2 emissions scenarios; (c) putting forward several policy recommendations to ensure the smooth implementation of Qingdao Low-carbon Development Program (2014–2020).

2. Study area

As a major coastal city in Eastern China, Qingdao (35°35′-37°09′ N, 119°30′-121°00′ E) is situated in the south of the Shandong Peninsula, adjacent to the Yellow Sea (Zhao et al., 2014), which borders three prefecture-level cities, namely Yantai to the northeast, Rizhao to the southwest, and Weifang to the west (as shown in Fig. 1). It currently has seven districts (Shinan, Shibei, Sifang, Licang, Laoshan, Huangdao, and Chengyang) and four county-level cities (Jiaozhou, Jimo, Pingdu, and Laixi) with a total area of 10,654 square kilometers, 1159 square kilometers of which is the urban area. Located in the north temperate monsoon region, Qingdao is associated with a temperate monsoon climate. Due to the regulation of marine environment and the effect of southeast monsoon, ocean current, and water mass, the urban area has distinctive features of marine climate. It has an annual average temperature of 12.7 °C, a mean annual rainfall of 662.1 mm, and the dominant wind direction is ES with an annual average wind speed of 5.2 m/s.

Administered at the sub-provincial level, Qingdao is undergoing rapid economic growth and a growing population in recent years. For example, the city's GDP in 2014 hit RMB¥ 869.21 billion, with an increase of 8.56% over 2013, which brought GDP per capita to more than RMB¥ 96,524 (QDSY, 2015). The permanent resident population of Qingdao was 9.05 million at the end of 2014, with 4.88 million living in the urban area (QDSB, 2014). All of this eventually led to the fast-growing demand of energy resources in the past few years. For instance, the social total energy consumption during the 11th Five-Year Plan period (2006–2010) was 172.72 million tonnes coal equivalent (Mtce), with an average annual increase of 8.33% (QDDRC, 2011). In addition, according to the prediction of Qingdao's 12th Five-Year Plan (2011–2015), it would reach about 56.06, 246.23 Mtce in 2015 and over the 12th Five-Year Plan period.