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Assessing the impact of population, income and technology on energy consumption and industrial pollutant emissions in China

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HIGHLIGHTS

- We assessed human impact on energy use and three types of industrial pollutant emissions in China.
- Higher population density would decrease energy use and pollutant emissions.
- The impact of economic development on the environment varies across regions.
- Higher industrial energy intensity would lead to higher levels of emissions.
- We did not find evidence of the EKC hypothesis for industrial waste in China.

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ABSTRACT

Elucidating the complex mechanism of the impact of demographic changes, economic growth, and technological advance impacts on energy consumption and pollutant emissions is fundamentally necessary to inform effective strategies on energy saving and emission reduction in China. Here, based on a balanced provincial panel dataset in China over the period 1990–2012, we used an extended STIRPAT model to investigate the effects of human activity on energy consumption and three types of industrial pollutant emissions (exhaust gases, waste water and solid waste) at the national and regional levels and tested the environmental Kuznets curve (EKC) hypothesis. Empirical results show that a higher population density would result in a decrease in energy consumption in China as a whole and in its eastern, central and western regions, but the extent of its effect on the environment depends on the type of pollutants. Higher population density increased wastewater discharge but decreased solid waste production in China and its three regions. The effect of economic development on the environment was heterogeneous across the regions. The proportion of industrial output had a significant and positive influence on energy consumption and pollutant emissions in China and its three regions. Higher industrial energy intensity resulted in higher levels of pollutant emissions. No strong evidence supporting the EKC hypothesis for the three industrial wastes in China was found. Our findings further demonstrated that the impact of population, income and technology on the environment varies at different levels of development. Because of the regional disparities in anthropogenic impact on the environment, formulating specific region-oriented energy saving and emission reduction strategies may provide a more practical and effective approach to achieving sustainable development in China.

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1. Introduction

Over the past three decades, China has been experiencing a rapid economic growth with accelerating industrialisation and urbanisation. The sustained economic growth was largely achieved at the cost of over-consumption of energy resources, which inevitably caused many environmental problems that included air and water pollution, waste disposal, and massive energy demand [1–5]. According to the 2014 Environmental Performance Index (EPI) released by Yale University and Columbia University, China's environmental performance was relatively poor, ranking the 118th out of 178 countries [6]. Several factors have been recognised as the driving forces of such poor environmental

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performance; industrialisation is one primary force. China's State Environmental Protection Administration estimated that industrial pollution accounts for over 70% of the nation's total pollution emissions [7]. Industrial exhaust (or flue) gases,[1] wastewater and solid waste have been long regarded to be the primary issues affecting environmental quality and sustainable development in China [1,8]. The First National Census of Pollution Sources in China, conducted in 2007, showed that the country's total amount of industrial exhaust gas emissions was 6122 million cubic metres (m^3), and the amount of solid waste production and wastewater discharge reached 3.85 and 24 billion tons, respectively [9]. Exacerbating such problems is the fact that many polluting industries are located in densely populated areas, where increased emissions exposure poses a serious threat to human health. The World Bank estimated that the health and non-health cost of air and water pollution in China was approximately 100 billion USD per year [10]. In the process of rapid industrialisation, water pollution has exacerbated the severe water scarcity problems in China. Faced with such increasing challenges, the Chinese government set binding targets in the "Twelfth Five-Year Plan" to reduce the unit GDP energy consumption by 16% and the total discharge of CO_2, SO_2, NO_x and COD by 17%, 8%, 8% and 10% by the end of 2015 (compared with the 2010 levels), respectively.

Rapid urbanisation has occurred along with the accelerating industrialisation. As the most populous country in the world, China has experienced unprecedented urbanisation since economic reforms initiated in 1978. The level of urbanisation in China has increased from 19.4% in 1980 to 54.4% in 2014 and is predicted to reach 61% and 75.8% by 2030 and 2050, respectively [11]. Urbanisation will most likely continue to be one of the main driving forces for China's economic development. As a result, more urban infrastructure will inevitably be required to support the continuously growing urban population, which will potentially lead to greater energy demand, in turn exerting additional pressure on fragile ecosystems [12]. Therefore, researches concerning specific factors that have an impact on energy consumption and pollutant emissions and the extent of their impact have been of great importance because these factors directly influence the formulation of pollutant abatement measures, policies and strategies in China [13].

The complex nexus between human activities and environmental impact has been extensively studied with various methods and results over the past decades. The representative models include the input-out model [14], the IPAT or STIRPAT model [15], the LMDI method [16] and so forth. Among them, the STIRPAT (stochastic impact by regression on population, affluence and technology) model is a well-known method that is widely used to examine the impact factors of energy use or pollutant emissions because the model can be expanded to incorporate additional factors. Demographic changes, economic growth and technological advances are usually acknowledged to be the key factors influencing energy consumption and pollutant emissions, and their impact on pollutant emissions are demonstrated to be heterogeneous across different countries and regions [12,13,17–21]. However, the question as to relationship between different levels of development, technology and population and environmental impact in each country remains to be resolved. Furthermore, the EKC hypothesis has also been introduced into the STIRPAT model in recent years to determine whether there is an inverted U-shaped relationship between per capita income and pollutant emissions [15,22–24]. The mixed results concerning the validation of EKC hypotheses for environmental quality in China have also been obtained. Some studies have found evidence supporting the existence of an EKC for pollutant emissions [22,25,26], whereas inconsistent findings have also been detected [27–29]. Therefore, further validation of the EKC hypothesis in China is imperative. Moreover, regional discrepancies in geographical and biophysical conditions exist in China, and the related environmental issues affected by anthropogenic activities vary across regions as well. Further investigation of the relationship between demographic changes, economic development, technological advances and pollutant emissions in China with consideration of regional differences is also necessary. Thus, the main aim of this study was to examine the impacts of population, income and technology on energy consumption and industrial pollutant emissions in China by national and regional analyses. Specifically, based on a balanced panel dataset of 30 provinces in China over the period 1990–2012, we used an extended STIRPAT model to investigate the factors influencing energy consumption and industrial pollutant emissions accounting for the regional differences, to assess the extent of their impacts on energy consumption and emissions, and to test the EKC hypothesis. These research results would provide theoretical guidance for formulating effective strategies on energy conservation and emission reduction in China.

The remainder of this paper is organized as follows: Section 2 describes the literature review; Section 3 introduces theoretical base and methodology; Section 4 presents the data; Section 5 describes and discusses the main results; and Section 6 offers conclusions and policy implications.

2. Literature review

Past studies on the effects of anthropogenic activities on the environment can be roughly divided into two lines of research. The first strand primarily focuses on the relationships between demographic changes, energy consumption and pollutant emissions at different scales with various methods and results. Among these human factors, demographic changes, including changes in population size, urbanisation, and the size and age composition of households, have implications for the patterns of energy consumption and pollutant emissions [18,21]. The elasticity of population size to CO_2 emissions depended on the type of data and the research methods used [18]. Studies using time-variant data have produced much greater variance in population elasticity estimations [12,28,30,31]; whereas cross-sectional analyses typically have estimated population elasticity near one [15].

The relationships between urbanisation, energy consumption and CO_2 emissions have been studied extensively in recent decades but have generated inconsistent results. Some studies have shown that urbanisation increases energy consumption and produces a higher level of emissions [12,15,31–33]. Using the STIRPAT model, Cole and Neumayer [31] found that urbanisation increases CO_2 emissions. Poumanyvong and Kaneko [12] concluded that urbanisation decreases energy consumption in low-income countries but increases energy use in middle- and high-income countries, and the impact of urbanisation on emissions is positive. Zhang and Lin [32] and Wang et al. [34] also found that urbanisation increases energy consumption and CO_2 emissions in China. Some researchers also identified urbanisation as one of the primary driving forces for the increase in CO_2 emissions in Beijing [28] and Guangdong province [35]. Similar evidence was also obtained in OECD countries [36,37] and European Union countries [38]. Conversely, others argued that urbanisation improves the efficient use of public infrastructures and thus lowers energy use and emissions [17,39]. Studies have indicated that urbanisation had a negative impact on per capita road energy use in OECD countries but

[1] In this study, industrial exhaust gases refer to the pollutant-containing gas emitted into atmosphere in the fuel combustion and production processes mainly as result from industrial process, while the exhaust gases emitted by automobiles are not include and discussed in this study. The "industrial exhaust gases" include a combination of sulphur dioxide, nitrogen oxides, and soot and dust.

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