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Urbanisation, energy consumption, and carbon dioxide emissions in China: A panel data analysis of China's provinces

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HIGHLIGHTS

- Urbanisation, energy consumption, and CO_2 emissions relationship is investigated.
- We present a panel model and a reduction potential analysis for China's provinces.
- Emissions of provinces in east region are much higher than that in central and west regions.
- The three variables are found to have a positive bi-directional long run relationship.
- Whilst China's CO_2 emissions will increase up to 2020, the potential for reductions is great.

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ABSTRACT

Global warming resulting from rapid economic growth across the world has become a worldwide threat. The coordination of development of urbanisation, energy consumption, and carbon dioxide (CO_2) emissions therefore forms an important issue; it has attracted considerable attention from both governments and researchers in recent years. This study investigated the relationship between urbanisation, energy consumption, and CO_2 emissions over the period 1995–2011, using a panel data model, based on the data for 30 Chinese provinces. The potential to reduce CO_2 emissions was also analysed. The results indicated that per capita CO_2 emissions in China were characterised by conspicuous regional imbalances during the period studied; in fact, per capita CO_2 emissions decrease gradually from the eastern coastal region to the central region, and then to the western region. Urbanisation, energy consumption, and CO_2 emissions were found to present a long run bi-directional positive relationship, the significance of which was discovered to vary between provinces as a result of the scale of their respective economies. In addition, a bi-directional causal relationship was found to exist between urbanisation, energy consumption, and CO_2 emissions: specifically, a bi-directional positive causal relationship exists between CO_2 emissions and urbanisation, as well as between energy consumption and CO_2 emissions, and a one way positive causal relationship exists from urbanisation to energy consumption. Scenario simulations further demonstrated that whilst China's per capita and total CO_2 emissions will increase continuously between 2012 and 2020 under all of the three scenarios developed in this study, the potential to achieve reductions is also high. A better understanding of the relationship between urbanisation, energy consumption, and CO_2 emissions will help China to realise the low-carbon economic development.

1. Introduction

China is the largest developing country in the world; its economy has undergone rapid and continuous expansion since the Chinese economic reform in 1978 [1]. Over the past three decades of rapid economic growth, China has witnessed equally fast-paced urban development [2,3], with the country's level of urbanisation rising from 17.9% in 1978 to 51.27% in 2011, an average annual growth rate of 1.02% [4–6]. The equally rapid increases in urban sprawl that have resulted from this phenomenal growth pose tremendous challenges for China through the pressure that they place upon the environment. One such challenge lies in increases in energy demand, which may in fact lies behind China's increasing energy consumption and CO_2 emissions over the last three decades

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[7]. These issues have drawn attention nationwide. Facing greatly increased CO_2 emissions, the Chinese government's 12th Five-Year Plan (2011–2015) called for a 16% reduction in energy intensity (energy consumption per unit of GDP) and for a 17% reduction in carbon intensity (CO_2 emissions per unit of GDP) [8]. The emphasis currently being placed on emission reduction measures in China provides renewed stimulus for investigating the relationships between urbanisation, energy consumption, and CO_2 emissions. An understanding of this relationship would allow us to determine whether urbanisation is indeed a major factor behind the energy consumption and CO_2 emissions witnessed in China's provinces. Furthermore, forecasting future CO_2 emissions under different scenarios based the relationship will have an important reference value for policy makers in assisting their design and implementation of appropriate energy conservation and emission mitigation measures.

In recent years, a large number of researchers have engaged in investigations of the relationship between urbanisation, energy consumption, and CO_2 emissions. Results are, however, inconsistent. On the one hand, studies undertaken by Li et al. [9], O'Neill et al. [10], and Parshall et al. [11] nominated urbanisation as one of the most important factors affecting energy consumption in China, India, and the United States. These results were supported by studies undertaken in relation to developing countries by Jones [12] and Parikh and Shukla [13]; in Canada by Lantz and Feng [14]; in Tunisia by Shahbaz and Lean [15]; and in regional China by Zhang and Lin [16]. On the other hand, Lariviere and Lafrance [17] and Ewing and Rong [18] found a negative relationship between urbanisation and energy consumption. Using the logarithmic mean Divisia index decomposition analysis, Zha et al. [19], found that residential CO_2 emissions declines in response to energy intensity and increases in response to income effects, in both urban and rural China. Similarly, using a decomposition analysis, Paul and Bhattacharya [20] found economic growth has the largest positive effect in CO_2 emissions changes in all the major economic sectors. In addition, while Cole and Neumayer [21] and Liddle and Lung [22] found a positive relationship between urbanisation and CO_2 emissions, Fan et al. [23] located a negative relationship between the two variables in developing countries. Similarly, whilst Martinez-Zarzoso and Maruotti [24] demonstrated an inverted U-shaped relationship between urbanisation and CO_2 emissions, Zhu et al. [25] found little evidence to support that relation – in fact, through their analysis of 20 emerging countries using the semi-parametric panel data model, they identified a non-linear relationship between urbanisation and CO_2 emissions.

Poumanyvong and Kaneko [26] also found that urbanisation increased CO_2 emissions in some developed and developing countries. In particular, their study indicated that urbanisation suppressed increases in energy consumption in low-income countries, while urbanisation promoted increases in energy consumption in high-income countries. However, Sharma [27] found that urbanisation had negative effect on the CO_2 emissions in high income, middle income and low income panels, and the global panel. Taking Tunisia as an example, Shahbaz and Lean [15] discovered a bi-directional causality between finance and energy consumption, finance and industrialisation, and urbanisation and energy consumption. Additionally, Al-mulali et al. [7] found a long run bi-directional causality to exist between urbanisation, energy consumption, and CO_2 emissions in 21 MENA (Middle East and North Africa) countries. A study of 19 selected countries taken by Al-mulali et al. [28] and of the newly industrialised countries taken by Hossain [29] and Karachi by Sajjad et al. [30] all corroborated these results. Additionally, in order to reduce CO_2 emissions, some scholars had begun to study on emission reduction measures in many areas including the improvement of technology level (energy efficiency and CO_2 emission performance) [31–35].

Addressing the relationship between energy-related CO_2 emissions and economic growth in China, Wu et al. [36] identified a one way positive relationship from CO_2 emissions to economic growth – i.e., high CO_2 emissions were found to motivate economic growth, while economic growth was not found to result in significant increases in CO_2 emissions. Dai and Liu [37] found that high energy consumption, high emission levels, and extensive economic growth do not benefit the progression of urbanisation. In an analysis of eight Asia–Pacific countries, Niu et al. [38] found that whilst in developed countries high energy efficiency led to low energy and carbon intensities, the opposite was true in developing countries. In addressing the impact factors of CO_2 emissions, Du et al. [39] found economic development, technological progress, and industry structure to be the most important factors affecting China's CO_2 emissions, while energy consumption structure, trade openness, and urbanisation levels were found to have a negligible impact. In addition, Feng et al. [40] found that technological improvements in China had not been able to fully compensate for the increase in emissions resulting from population growth and increasing wealth, which is in line with results from a number of other studies. However, according to evidence gathered in Beijing city by Wang et al. [41], urbanisation levels, economic levels, and industry proportion positively influenced CO_2 emission levels; conversely, tertiary industry proportion, energy intensity, and R&D output negatively influenced CO_2 emissions. Using the ridge regression method, Zhu and Peng [42] revealed that changes in consumption levels and the population structure should be the major impact factors, rather than changes in population size. Similarly, using an extended STIRPAT model, Wang et al. [43] found that factors such as population, urbanisation, per capita GDP, the industrialisation level and the service level can bring about CO_2 emissions increase. However, technology levels, the energy consumption structure, and the degree of foreign trade, the same study revealed, can decrease CO_2 emissions. In addition, Sun et al. [44] found steel production to be the major factor in increasing CO_2 emissions, and energy consumption to be the largest contributor in decreasing CO_2 emissions.

In the field of CO_2 emissions modelling and forecasting, the existing literature mainly falls into several categories, which can be differentiated in terms of their distinct methodological perspectives [39]. Among them, the index decomposition analysis [40,46,47], bottom-up sector-based analysis [47,49], system optimization [49,51], the input–output analysis [51,53], the computable general equilibrium model [53], and the panel data analysis [54] are the most well-known methods used for forecasting emissions. The majority of previous studies have been based on national time-series data or industrial-level cross-sectional data; only a handful of studies have utilised panel data models [39]. It is widely known that panel data models have several major advantages over conventional cross-sectional or time series data models [55]. Panel data usually give the researcher(s) a larger number of data points. Panel data models allow controlling for individual heterogeneity, as well as identifying effects that cannot be detected in simple time series or cross-section data [39]. A number of previous studies of CO_2 emissions based on cross-sectional panel data models – for instance, Lantz and Feng [14], Maddison [56], Aldy [57], Auffhammer and Carson [58] and Du et al. [39] – have taken advantage of panel data econometric models.

In comparison with the precious studies, our study further obtained the estimated elastic coefficients for each province, while most previous studies and analysis focused on the regional level, not the provincial level. Although some previous studies had conducted the provincial panel data analysis in China, they still focused on the regional analysis. For instance, Zhang and Lin [16] conducted the panel estimation for urbanization, energy consumption and CO_2 emissions using the IPAT model from the perspective