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RESEARCH ARTICLE

The impact of urbanization on CO_2 emissions in China: an empirical study using 1980–2014 provincial data

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Abstract Towns and cities are not only the focus of attention for their consumption of energy and resources; they are also scrutinized closely for their emissions of greenhouse gases. China's urbanization level now exceeds 50%, but there is still much disparity compared with the level of urbanization in developed countries. This study selects China's urban population and carbon emissions data for the years 1980–2014 and discusses the timing and cause effect of urbanization and the corresponding carbon emissions using the Granger causality test and an error correction model (ECM) then uses STIRPAT models to extract six indicators to measure the quality of urbanization, namely, the level of urbanization, area of built-up regions, added value of tertiary industries, disposable income per capita, green areas per capita, and energy intensity. These six indicators represent population agglomeration, the expansion of urban areas, industrial agglomeration, quality of life improvements, ecological conservation, and technological improvements, respectively. The study divides 29 provinces in China into three groups based on the quality of urbanization and analyzes the impacts of the six indicators of urbanization quality on carbon emissions. The findings show that the impacts of different factors on carbon emissions vary substantially among the provinces. Finally, the study uses the findings to give suggestions on how to develop low-carbon urbanization.

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Introduction

Urbanization will be the main source of China's carbon emissions in the future (Song and Xu 2011). The US-China Joint Announcement on Climate Change, which was signed in November 2014, indicates that the level of carbon emissions in China will reach its peak in 2030. China has committed to stop increasing carbon emissions before 2030 and has explicitly stated its intent to reduce its carbon emissions during the period of the 13th Five-Year Plan. Global energy shortages and climate change have made reducing carbon emissions a research focus and political priority.

China's industrial and urbanization construction has entered a stage of rapid development. China's urbanization level was 53.7% in 2013 (China Statistical Yearbook 2014), whereas there was a growth rate of only 1.75% before the reform and opening of the Chinese economy commenced. Meanwhile, energy consumption patterns based on the use of coal also led to the high growth of carbon emissions, and this was exacerbated by population growth, industrial development, and rapid economic growth in the urban districts. Therefore, it is necessary to clarify the relationship between urbanization development and carbon emissions. It is even more important to research the differences and timing characteristics of the urbanization development levels in China in relation to carbon emissions. China has been in a high-industrialization and low-income phase since 2000, in which it has been difficult to change the industrial structure due to the constraints of the economy's transformation, and this has given rise to the first governance problems. It is certain now that human activity is closely related to carbon emissions. China's urbanization process inevitably causes more direct and indirect pollution and also has effects on carbon emissions. Researching the relationship between urbanization and carbon emissions responds actively to the need to develop a low-carbon economy and is a practical initiative.

Research on carbon emissions has concentrated mainly on aspects of the mechanism of carbon emissions, the relationship between carbon emissions and economic growth, and the carbon emissions and energy structure evolution since the 1990s. In recent years, more and more research has been carried out on the effects and mechanisms of urbanization and carbon emissions. In this study, with the urbanization connotation and indicators explained, this study summarizes the relationship between urbanization and carbon emissions from the national, regional, and urbanization levels.

Carbon emissions are the outcome of various factors including urbanization (Xu and Liu 2015; Liu et al. 2015). Many researchers have studied the relationship between urbanization and carbon emissions from the perspective of impact factors. The Kaya identity is one of the main methods used to study the driving factors of greenhouse gases, and the relationship among the economy, energy, population, and environment can be described using a mathematical formula. When studying the driving role of urbanization on carbon emissions, the urbanization factors and urbanization variables are generally included in the Kaya equation (Zhu and Wei 2013; Lin and Liu 2010). Although the driving factors of the Kaya equation can be directly observed, the mechanism is complex, and the effects on greenhouse gas emissions are different; the economic meanings are weak, and there is no clear policy guidance (Yuan and Pan 2013). Scholars have chosen different factors such as population, economic development level, and technology level according to research purposes. All of these factors have been examined from different research perspectives, resulting in different conclusions. In relation to the demographic factors, a growth in population size brings increasing demand for energy, resulting in increased cultivation of forestland and cultivated land (York et al. 2003; Sun and Zhang 2014). In contrast, the increased use of public transport and advanced technologies have inhibited carbon emissions to some extent (Aparna and Saikat 2014; Wang and Wu 2012). In terms of economic development level, which is mainly reflected by the indicators GDP and per capita disposable income, many scholars proposed that the economic development level is linked with enterprise development, which has higher energy consumption requirements, increasing carbon emissions (Wang et al. 2014; Zhao and Chen 2013; Li et al. 2015). Other scholars put forward that investment in science and technology innovation increases when there is economic prosperity, resulting in technologies that reduce industrial production carbonization (Aunan and Wang 2014; Cao et al. 2016). For the technology level, the research conclusion was consistent, namely, when the technical level was improved, which would enhance energy efficiency and reduce carbon emissions (Xu and Zhou 2011).

Other scholars considered that urbanization could contribute to the efficient use of public facilities and public transport and thereby reduce energy consumption and carbon emissions. More and more scholars have conducted detailed research from different perspectives including energy consumption, transportation, house purchases, carbon consumption, and human migration. Satterthwaite (2009) thought that the acceleration of the population urbanization process was the main reason for the increase in carbon emissions. Poumanyvong and Kaneko (2011) showed there were differences in carbon emissions for various countries with diverse urbanization levels due to income gap factors. Guo (2012) considered that carbon emissions were affected by energy consumption, changes in land use patterns, and increase in urban metabolism. They also proposed that China should pay attention to protecting the environment and constructing low-carbon cities. Song and Xu (2011) adopted STIRPAT model to estimate carbon emissions growth of up to 6.2-fold before the reform and opening of the economy; the per capita carbon emission growth rate has averaged 4.4-fold since 2008. Urban carbon emissions are the main element of China's carbon emissions. Wang et al. (2017) considered that population size, per capita disposable income, and carbon intensity have positive effects to carbon emissions across China.

Since Grossman and Krueger put forward the hypothesis of the environmental Cruz Nez curve (EKC curve) in 1991, the research on the relationship between global carbon emissions and urbanization has been an endless stream. Cole (2004) argued that higher urbanization leads to an increase in CO_2 emissions. In order to study the relationship between urbanization and carbon emissions in countries with different economic development levels, Martínez-Zarzos and Maruotti (2011) examined 88 developing countries and found that there was an inverted U-shaped relationship between urbanization and carbon emissions in the high- and low-income countries, although the relationship is not obvious in the low-income countries. Phetke (2010) believed that there was a positive correlation between urbanization and carbon emissions, but Fan (2006) and Sharma (2011) got negative correlation results. Han and Lu (2009) held different viewpoints to those of the above scholars. They analyzed carbon emissions and urbanization data from 165 countries. Their results did not validate the homogeneity of the environmental EKC. These results revealed there were different relationships between economic growth and the environment in different periods, and they did not fit the pattern of a consolidated inverted U-shaped relationship. Zhou (2013) showed that when the urbanization level increases by 1%, carbon emissions will increase by 1.61% in China. Zhang and Zhuang (2015) proposed that China's urbanization was at an important stage of strategic transformation, but it is still unbalanced, uncoordinated, and unsustainable.

When using countries as units to study the relationship between urbanization and carbon emissions, the selection of different datasets or different time periods will affect the results to a certain extent. Studying the relationship in a given country facilitates policy recommendations for energy conservation and emission reduction. However, there are differences in the economic scales, development levels, and technology levels in the same country within different regions and stages of economic development. There have been no systematic studies of panel data on the different levels of economic development within regions. Therefore, the policy recommendations are not suitable for all areas.

Different geographical locations have different effects on urban development, economic growth, and the energy environment. Differences in spatial distribution lead to imbalances in regional carbon emissions. Only Clark (2011) have studied the spatial variation of CO_2 emissions in the eastern, middle, and western regions of China, and their study covered the period from 1997 to 2007. The positive effect of urbanization on the per capita carbon emissions in the eastern regions is lower than that in the non-eastern regions (Lin and Huang 2011; Sun and Zhang 2014; Zhang and Lin 2012; He et al. 2013). The reason for this difference may be the high level of urbanization in the eastern and mid-western regions. The high population densities in these regions may have produced an improvement in the utilization of energy and public facilities, which may have produced a reduction in carbon emissions that more than offsets the increase caused by population growth. It was also found that there was an inverted N-type relationship between urbanization and carbon emissions in the eastern regions, whereas the central regions showed an N-type relationship. The western regions showed an inverted N-type relationship, but it was not statistically significant (Yang and Chen 2013).

The urbanization evolution level is a research area that examines the effect of urbanization in different stages of development on carbon emissions. The energy consumption structure and the residents' lifestyle will change as the stage of urbanization evolves, and the dominant position of the carbon emissions will also be changed. For now, the total amount of carbon emissions in the next period of time will continue to rise with the rapid advance of China's urbanization (Tong and Sun 2010). The early development stage of urbanization does not have obvious impacts on carbon emissions, but changes in the urbanization depth, the development of people's environmental consciousness, the per capita income, and emission reduction efforts can influence carbon emissions in the later urbanization stages. Based on an analysis of rural livestock use and environmental quality, it is thought that establishing higher-level cities will promote the construction of pollution treatment facilities and related mechanisms to reduce carbon emissions (Zhao and Chen 2013).

Research on urbanization and carbon emissions is commonplace both in China and elsewhere. There are a variety of research methods involving multiple perspectives. Most of the studies prove the relationships under review but do not take into account the entire degree of influence or the short-term and long-term effects. Linking urbanization quality to investigate the panel data for each province is rarely involved.

Motivated by the above discussions, the main contributions of this paper can be highlighted as follows:

1. Different from the existing literature in which only traditional urbanization is considered, this paper investigates the connotation of urbanization and examines its impact on carbon emissions.
2. By selecting a few aspects of population, space, industries, technology, and residents' energy consumption, this study discusses the mechanism for generating carbon emissions and analyze the carbon emissions growth binding effect on the development of urbanization.
3. This study selects data from 1980 to 2014 and then considers the long-term and short-term effects and analyzes the impacts of the quality of urbanization factors on carbon emissions in areas with different stages of urbanization.
4. Finally, by using STIRPAT models to analyze the factors influencing carbon emissions from China's regional provinces, some policy recommendations are provided to save energy, reduce emissions, and achieve green development.

Research design

Modeling

Dietz and Rosa, based on the IPAT equation, developed a more scientific STIRPAT model (Dietz and Rosa 1997). The model works in a nonlinear way so it can avoid the heteroscedasticity problem, and an elastic coefficient can also be easily calculated for each variable. The STIRPAT model is extended effectively by adding different variables to observe the influencing factors of urbanization on carbon emissions.

The new urbanization connotation mainly emphasizes population agglomeration, urban regional expansion, and industrial agglomeration and development, as well as the level and quality of life and the construction of an ecological civilization. This study sets the following

STIRPAT model:

$$\ln TC_{it}=\alpha+\beta_1 \ln U_{it}+\beta_2 \ln C_{it}+\beta_3 \ln T_{it}+\beta_4 \ln I_{it}+\beta_5 \ln G_{it} + \beta_5 \ln E_{it}+e_{it} \quad (1)$$

where TC is the country's total carbon emissions, U represents the level of urbanization, C is the built-up areas, T represents the added value of tertiary industries, I represents the disposable income per capita, G represents the green areas per capita, i and t represent the observation of individual and time, respectively, E is the energy intensity which represents technology, and e is the random error term.

Index selection and variable description

There are similar influences and restrictions on urbanization development and carbon emissions. The long-term constant energy structure characteristics of China determine the improvement of the urbanization levels and the increase in carbon emissions. There are interactive mechanisms between them. The urbanization development process is also the process of energy consumption and carbon emissions.

China's urbanization development brings with it a large amount of carbon emissions. First, the consumption of fossil fuel energy exceeds 90%, which leads to huge carbon emissions and much pollution. Second, the speed of urbanization construction in China is accelerating and has the characteristics of extensive form, high investment, high consumption, high pollution emissions, and low energy efficiency. The growth of urbanization enhances the development of the chemical, construction, steel, and other high energy-consuming industries, which inevitably increases carbon emissions. Third, a dual economy and unbalanced regional development are the long-term social economic characteristics in China. China's urban, rural, and regional residents have greatly different income levels, living conditions, and access to important infrastructure. There is also a diverse structure of energy consumption and carbon emission levels in the different stages of urbanization. Fourth, urbanization is not only inseparable from industrial production, but it also has a direct relationship with the influx of rural populations into cities. The consumption habits of rural migrating people have changed with energy consumption growth and the transfer of employment from traditional agriculture to secondary and tertiary industries. In addition, this process requires improvements in the amount of housing, transportation, medical care, education, and other basic facilities, which lead to greater carbon emissions.

Increases in carbon emissions restrict the development of urbanization. First, carbon emissions are often more prominent in densely populated towns and cities. These towns and cities are usually the hardest hit by bad air quality. The emergence of air pollution has not only brought serious harm to people's health but also brought great losses in the production and economic health of the affected towns and cities. The number of premature deaths in China due to air pollution had reached 514,000 by 2010 (China Environmental Yearbook 2011). Second, polluted environments lead to more people choosing to emigrate, causing a brain drain. Some people would rather choose to live in a low-income place than a place with environmental pollution. Productivity and attendance levels are also greatly reduced in these high-pollution locations. This causes direct and indirect losses and hinders the development of urbanization.

It is obvious that the outlook for towns and cities with urban carbon emission problems is quite grim. China has made commitments to stop increasing carbon emissions above its Kyoto Protocol levels by 2030. The development of urbanization inevitably cannot continue without carbon emission controls. These controls need to place higher requirements on low-energy consumption and low emissions. This is the key problem of urbanization and sustainable development and needs to be solved.

On the basis of the above analysis, this study selected the following six indicators to measure the quality of urbanization, namely, the level of urbanization, area of built-up regions, added value of tertiary industries, disposable income per capita, green areas per capita, and energy intensity. These indicators represent population agglomeration, the expansion of urban areas, industrial agglomeration, quality of life improvements, ecological conservation, and technological improvements, respectively.

The population proportion index method is a statistical method that is accepted by China's current government and by scholars generally. This study uses the population proportion index method to calculate the urbanization level in China, as follows:

$$U=\frac{P_c}{N}{*}100\% \quad (2)$$

U represents the urbanization level, P_c represents the total urban population in China at the end of the year, and N is the total population of China at the end of the year.

The level of urbanization reflects the level of urban population agglomeration, while the index of built-up areas is used to reflect the expanding situation and spatial structure of the urban areas.

The proportion of the added value of tertiary industries can better reflect the market, commercial development, and urban service function development, which can reflect industrial agglomeration and development level in the process of urbanization.

The income level of urban residents is described by their disposable income per capita. This index can reflect the environmental pressure brought by economic development and family income improvement.

The green areas per capita indicates the degree of greening and the condition of ecological civilization construction. This index can effectively reflect the impact of carbon emissions caused by ecological environment construction.

Energy intensity is related to technological improvements, and is an important index for evaluating energy efficiency. The lower the per unit GDP energy consumption is, the higher the energy efficiency. Energy intensity decreases gradually along with economic development and technological progress, but with the energy conservation and emissions reduction space narrowing, reducing energy intensity will be more and more difficult.

The carbon emissions calculation model is as follows (3):

$$TC = \sum_{i=1}^{n} TC_i = \sum_{i=1}^{n} E_i{}^{*} c \tag{3}$$

TC is the total carbon emissions of the country caused by fossil fuels, E_i represents the i kind of consumption (million tons of standard coal) of fossil fuels (coal, oil, natural gas), and C is the carbon emissions coefficient; the carbon emissions coefficients of coal, oil, and natural gas were previously calculated using the specific method of IPCC. This study draws lessons from the carbon emissions coefficient table (Cai 2009), which is shown in Table 1.

In order to investigate the impact of the urbanization depth degree on regional carbon emissions in areas with different stages of urbanization, this study examined the data of 29 Chinese provinces for the years 1980–2014. Due to missing data, Xinjiang and Tibet were excluded. The urbanization of high-quality provinces is identified according to the quality of urbanization. Provinces with an urbanization quality of more than 60% were higher than the national average and defined as high-quality provinces; provinces with an urbanization quality of less than 60% were lower than the national average and defined as low-quality provinces (Wang and Qin 2015). The provinces were divided into three groups in each region according to this threshold. The quality of urbanization was higher in the provinces of Beijing, Tianjin, and Shanghai. The quality of urbanization was at a medium level in the provinces of Guangdong, Fujian, Jiangsu, Zhejiang, Heilongjiang, Jilin, Liaoning, Shandong, and Inner Mongolia. The quality of urbanization was lower in the provinces of Qinghai, Ningxia, Gansu, Shaanxi, Sichuan, Guizhou, Yunnan, Hainan, Chongqing, Hebei, Shanxi, Anhui, Jiangxi, Hubei, Hunan, and Guangxi. The energy consumption data in this study are from the Chinese Energy Statistics Yearbook; the urbanization data are from the China Population and Employment Statistics Yearbook and the National Bureau of Statistics website. The carbon emission coefficient is calculated according to the National Energy Research Institute, the State Planning Commission, and the IPCC bulletin data.

Results

Causality between urbanization and carbon emissions

The interactive relationship between the urbanization and carbon emissions was examined. In order to avoid the influence of heteroscedasticity, the time series data of urbanization and carbon emissions needed logarithmic processing at first. In order to ensure the effectiveness and significance of the statistics, the data needed to be examined using the stability test at the same time, mainly through the unit root test method. The logarithm of urbanization and carbon emissions in this study install LU and LTC. Because the two columns' data are both a constant term and trend difference, this study chose a lag period of 2 years and conducted the unit root test. The research found that LU and LTC were not stable time series, so the first order was conducted differently and the test results pass through. The specific results are shown in Table 2.

Table 2 shows that two variables are the first-order integration, so the two variables may have long-term stable equilibrium relationships; cointegration was judged by testing. Engle-Granger is used to get the cointegration equation and find the influence relationship between the urbanization and carbon emissions, then the test is performed.

Engle-Granger is also known as the two-step test method. The cointegration equation is obtained after testing:

$$\begin{aligned} LT\,\hat{C} &= 7.2534 + 1.78233 L\,\hat{U} \\ &\quad (34.2345)\quad (33.7256) \end{aligned} \tag{4}$$

At the 5% significance level, the variables of the regression equation are significant, and there is a cointegration relationship between the two; it shows that the level of carbon emissions increases by 1.78% when the level of urbanization increases by 1%, and there is a visible long-term relationship between the two. When this study continue to conduct the AEG test on the residuals, the t statistic value is − 2.765401, less than the 5% level of the t statistic value, which is − 1.932044, thus rejecting the null hypothesis of a

Table 1 The proportion of total energy consumption that is from coal, oil, and natural gas and their carbon emissions' coefficients

Emission source	Coal	Oil	Natural gas
The proportion of energy consumption (%)	72.4	18.96	2.61
Carbon emissions' coefficients	0.7559	0.5857	0.4483

Table 2 The unit root test results table

Variable	*T* statistic	Threshold	Prob.
LU	− 2.145647	− 3.456754	0.2887
LTC	− 2.745671	− 3.267897	0.1808
dLU	− 5.230981	− 1.876576	0.0000
dLTC	− 10.12654	− 1.923473	0.0000

cointegration relationship existing between LTC and LU from 1980 to 2014 as a first-order cointegration. There is a long-term stable equilibrium relationship between urbanization level and carbon emissions.

Whether there is causality between the LTC_t and LU_t variables can be determined by the Glenn Jaffe causality test (Granger causality test) based on a vector autoregressive model. The results are shown in Table 3.

As can be seen from Table 3, urbanization causes carbon emissions, but carbon emissions do not cause urbanization in the lag period of 2 to 5 units, as determined using the Granger causality test. The development of urbanization has led to carbon emissions, but the increase in carbon emissions is not the important factor hindering the development of urbanization. With the rapid development of urbanization and the increase in carbon emissions, in the new normal economic operation mode urbanization development must pay close attention to the transformation. It is also necessary to stick to the policy of high quality and low emissions to guarantee a path to sustainable urbanization.

It has been shown that there is a long-term cointegration relationship between urbanization and carbon emissions. In order to better meet the actual economic situation, there is a need to use an error correction model to study the short-term dynamic relationship between urbanization and carbon emissions.

According to formula (4), R^2 is equal to 0.983 and DW is equal to 0.214 in the long-term regression equation of the urbanization level and carbon emissions, and the fitting is better, but the DW value is relatively low. It can be seen from the DW test critical table that, given a σ value of 0.05 σ , the critical value of DW is d_L=1.32 and d_U=1.58; because D. W. = 0.214 < d_L, the error term μ_t has positive autocorrelation and the positive autocorrelation is high. The error term μ_t has positive autocorrelation and the positive correlation is high. After the elimination of the difference method, $d_u < D.\ W. =$ 1.6232 < 2.42, the error term μ_t eliminates its autocorrelation, making EMC_t equal μ_t. The error correction model is composed of LTC, two differential variables DDLTC and DDLU of LU, the unbalanced error term ECM_{t-1}, and the random error term ε_t. The model is estimated by the OLS method and formula (5) is obtained.

$$\begin{array}{l} ddLTC = 0.002 - 0.154ECM_{t1} - 0.223ddLU \\ \quad (0.175)\ (-2.765) \qquad (-1.337) \end{array} \tag{5}$$

Regional differences in urbanization and carbon emissions in China

In order to investigate the influencing factors of urbanization, it is necessary to examine heterogeneity in the provincial panel data of China. To do this, the panel data form should be determined firstly. In this study, the *F* test and Hausman test are used to determine whether the panel data model is a fixed effects model or a random effects model. The test results are shown in Table 4.

Table 5 shows that if the national sample urbanization rate increases by 1%, the corresponding carbon emissions will increase by 0.633%. The development of urbanization is one of the most important factors affecting carbon emissions, and this conclusion is consistent with the overall conclusion. In terms of area, it can be clearly seen that the high-quality urbanization areas have smaller effects on carbon emissions and the low-quality urbanization areas have greater effects on carbon emissions. According to Table 5, the effect on carbon emissions for the high-quality urbanization areas is 0.476% and the influence on carbon emissions for the low-quality urbanization areas is up to 0.887%. The results prove that the construction of new urbanization in China have positive effects on constraining carbon emissions, and the improvements in urbanization quality can effectively change the local economic growth mode and the optimization and upgrading of the industrial structure. It can also promote a change in the residents' opinions and strengthen the consciousness of environmental protection, and be conducive in actively adopting advanced new energy technology.

Urbanization in built-up areas affects carbon emissions. The above results show that when the urbanization rate increases by 1% in three different types of areas, the carbon emissions increase by 0.335, 0.242, and 0.124%, respectively, in those areas. It can be seen that urbanized built-up areas are

Table 3 Causality test of urbanization and carbon emissions

Lag period	*F* statistic	Prob.	Conclusion
2	5.58333	0.0081	*LnU* is the Granger reason of *lnTC*
	0.63375	0.5729	*LnU* is not the Granger reason of *lnTC*
3	4.0754	0.0034	*LnU* is the Granger reason of *lnTC*
	0.25467	0.7546	*LnU* is not the Granger reason of *lnTC*
4	3.07654	0.0122	*LnU* is the Granger reason of *lnTC*
	0.52222	0.7547	*LnU* is not the Granger reason of *lnTC*
5	2.55678	0.0322	*LnU* is the Granger reason of *lnTC*
	0.22134	0.8764	*LnU* is not the Granger reason of *lnTC*

Table 4 Panel data model form and test results

Samples	*F* test results			Hausman test results		
	F value	Critical value	Test results	Chi-sq. value	*P* value	Test results
All samples	399.01	2.22	Variable intercept model	− 43.22	0	Fixed effects model
Higher quality of urbanization	277.72	2.43	Variable intercept model	27.4	0	Fixed effects model
Medium quality of urbanization	132.56	2.32	Variable intercept model	397.28	0	Fixed effects model
Lower quality of urbanization	576.27	2.16	Variable intercept model	−54.32	0	Fixed effects model

After testing the data, the panel data model is a fixed effects model. In order to eliminate the heteroscedasticity, it estimates FGLS for the samples. The regression results are in Table 5, which shows that R^2 in the panel data model has a better goodness of fit.

more concentrated, and the contribution rate for carbon emissions is higher. Since China's reform and opening of the economy, the development and agglomeration of the cities have been dependent on the development of the construction, transportation, and real estate industries, and the development of these industries has stimulated economic growth. This inevitably leads to industrial pollution and growing carbon emissions. The conclusion is that the expansion of urban areas and spatial expansion have a proportional relationship with carbon emissions.

The added value of the tertiary industries affects carbon emissions. Tertiary industries are the focus of regional development; their development can effectively reduce the carbon emission levels. The index contribution rate is only 0.126% for high-quality regional urbanization, and the index contribution rate reaches 0.423% for low-quality regional urbanization. Compared with the industry sector, the development of tertiary industries can effectively prevent the increase of carbon emissions and absorb carbon emissions to some degree. It also reflects the importance of the optimization of the industrial structure in China.

The disposable income per capita also affects carbon emissions. The key factors affecting carbon emissions must take into account the residents' consumption and lifestyle. The residents' income is an important determinant. In high-quality areas, the residents have a strong awareness of environmental protection and the benefits of reducing carbon emissions. They have begun to pursue a "low energy consumption and low emission" lifestyle. In medium-quality areas, the residents have higher requirements for their own consumption habits, their travel mode, and their use of household appliances. Their awareness of the benefits of low-carbon emissions is lower than it is for the residents of high-quality areas, but their income is higher than the income of residents in low-quality urbanization areas and the contribution to carbon emissions reaches 0.922% in these areas. These

Table 5 Panel data model estimation results

Factors	Full sample coefficient	Higher quality of urbanization coefficient	Medium quality of urbanization coefficient	Lower quality of urbanization coefficient
ln*U*	0.633***	0.476***	0.487***	0.887***
	(30.22)	(3.33)	(18.23)	(23.34)
ln*C*	0.122***	0.335***	0.242***	0.124***
	(7.38)	(4.23)	(9.76)	(6.34)
ln*T*	0.125***	0.126***	0.332***	0.423***
	(7.43)	(9.24)	(15.42)	(17.42)
ln*I*	0.722***	0.865***	0.922***	0.856***
	(15.43)	(8.43)	(21.34)	(22.22)
ln*G*	0.075*** (1.43)	− 0.042** (− 2.23)	0.087*** (4.32)	0.054* (1.76)
ln*E*	0.613*** (15.22)	0.429*** (4.28)	0.823*** (15.11)	0.856** (19.27)
Adj. R^2	0.765	0.991	0.982	0.923
DW value	2	2	2	2
F value	334.7	522.01	382.34	612.44

Standard errors in parentheses. The value in the bracket is *t* *Significance at the 10% level; **significance at the 5% level; ***significance at the 1% level

The figures in brackets are probability values areas should focus on strengthening the transformation of the economic structure and improving the residents' environmental awareness. The residents living in lower-income areas have a lower quality of urbanization, so their consumption is mainly related to the education of their children and clothing purchases. Compared with the previous two groups, this group has little influence on carbon emissions.

The green areas per capita affects carbon emissions. The results show that it is not obvious that the green areas per capita affect carbon emissions under the 5% level. An increase in the green areas in urban areas with high quality can effectively inhibit carbon emissions, but the opposite is the case for the other two regional groups. This indicates that an increase in green areas per capita may lead to a modest increase in carbon emissions, but the management cost used in urban greening to achieve this is greater than the effect on the inhibition of carbon emissions.

Energy intensity is another major factor affecting carbon emissions except indicators including urbanization and disposable income per capita. For all of China, if energy intensity increases by 1%, carbon emissions will increase by 0.613%. There are different levels of urbanization across regions; the lower the level of urbanization in a region, the greater the region's dependence on energy in economic development. While new technologies can improve energy efficiency, these technologies have not been able to mitigate carbon emissions, which are closely related to China's energy consumption structure.

Conclusions and suggestions

In this study, the relationship between urbanization and carbon emissions is analyzed in China using time series data. First, the relationship between the two is verified in terms of the short-term and long-term effects using Granger causality and an error correction model. There is a long-term cointegration relationship between the two; urbanization causes carbon emissions, but carbon emissions do not cause urbanization. In the short term, if the current urbanization increases by 1%, it causes a relative change in carbon emissions of 1.78%, and if pre-urbanization increases by 1%, it causes a relative reduction of carbon emissions of 0.154%. Second, to analyze the impacts on carbon emissions, a STIRPAT model is used and six indicators were used to measure the quality of urbanization, including the urbanization level, area of built-up regions, added value of tertiary industries, disposable income per capita, green areas per capita, and energy intensity. These indicators represent the population agglomeration of urbanization construction, urban regional prolongation, industrial agglomeration, quality of life, ecological construction, and technological improvements. The research shows that the disposable income per capita and urbanization level are the main causes of carbon emissions. The degree of urbanization development is different; there are huge differences in different factors across diverse regions. Therefore, as China's urbanization progresses, it is key to prioritize reducing carbon emissions improving energy efficiency. Otherwise, the development of urbanization is bound to be slowed or even inhibited by the deterioration of the environment. The process of constructing low-carbon cities and abandoning high-carbon emissions, not only in terms of urbanization but also in other areas of development, requires policymakers to pay attention to controlling carbon emissions from the outset rather than waiting until pollution has set in before taking action. As a consequence of the above conclusions, this study puts forward the following suggestions.

The traditional energy structure of China has determined that fossil fuels are still used in the development of urbanization for the time being, and these fuels have high carbon emissions. Compared with other countries, China's fossil fuel consumption is particularly prominent, and its dependence on such fuels needs to be reduced. The government should provide guidelines to town residents for improving the energy consumption structure, and strive to increase the usage of hot gas, natural gas, and other clean energy utilization energy instead of fuels with high carbon emissions, such as coal.

To strengthen government regulation and guidance, the industrial structure should be optimized, and tertiary industry development should be promoted. Many departments focus on reducing industrial energy consumption and improving industrial energy efficiency, leading to the publication of relevant policies and regulations. The supervision of these regulations is then strengthened.

To further improve the overall planning of low-carbon urban development and to formulate a detailed roadmap for this, a low-carbon development mode should be promoted for urban areas nationwide by increasing financial input and policy support, strengthening institutional innovation, developing the resources, recycling, promoting ecological towns and cities, and looking for experienced managers and advanced management methods to operate good towns and cities. New pathways for low-carbon urbanization should be explored for industry, construction, transportation, energy efficiency, planning, operations, and management.

Technology is the key to change the pattern of China's energy development. Increasing science and technology innovation research will foster new energy industries and promote change. Traditional fuels, such as coal, will not be able to compete with new clean energies. The existing coal industry must proceed and extend the industrial chain from the perspective of welfare, then improve the coal product added value and provide more high-quality green energy.

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References

Aparna D, Saikat KP (2014) CO_2 emissions from household consumption in India between 1993–1994 and 2006–2007: a decomposition analysis. Energy Econ 41(1):90–105

Aunan K, Wang S (2014) Internal migration and urbanization in China: impacts on population exposure to household air pollution (2000–2010). Sci Total Environ 481(1):486–495

Cole M (2004) Trade, the pollution haven hypothesis and the environmental Kuznets curve: examining the linkages. Ecological Economics 48(1):71–81

Clark S (2011) Carbon inequality at the sub-national scale: a case study of provincial-level inequality in CO_2 emissions in China 1997-2007. Energy Policy 9:5420–5428

Cai BF (2009) Study on urban greenhouse gas inventory. Beijing: Chemical Industry Press 4:55–60

Cao Z, Wei J, Chen HB (2016) CO2 emissions and urbanization correlation in China based on threshold analysis. Ecological Indicators 61(2):193–201

Dietz T, Rosa EA (1997) Effects of population and affluence on CO_2 emissions. Proceedings National Academy Sci 94(1):175–179

Guo X (2012) Causal analysis of carbon emissions and urbanization in China. Theoretical Res 10:67–68

Han YJ, Lu C (2009) The relationship between economic growth and environment: An Empirical Study Based on Cruz Nez curve of CO2 environment. Economic Theory and Economic Management 3:5-11

He L, Xu J, Xu YX, Li HX (2013) Empirical study on the relationship between China's natural gas consumption demand and gas transmission network. Inquiry Into Economic Issues 4:70–73

Li JB, Hang XJ, Wu CY (2015) Analysis of spatial heterogeneity impact factors on carbon emissions in China. Economic Geography 35(11): 21–28

Lin BQ, Liu XY (2010) Periodical carbon emissions in China's urbanization: influencing factors and mitigation strategies. Economic Res J 8:435–446

Lin BQ, Huang GX (2011) Evolution trend of China's regional carbon eaemissions under the gradient development pattern from the spatial analysis perspective. J Financ Res 12:35–46

Liu XY, Wang YF, Song QJ (2015) Study on carbon emissions sources in China's urbanization process. China population, Res Environ 25(1): 61–66

Martínez-Zarzos I, Maruotti A (2011) The impact of urbanization on CO_2 emissions: evidence from developing countries. Ecol Econ 70(7): 544–557

Poumanyvong P, Kaneko S (2011) Does urbanization lead to less energy use and lower CO_2 emissions? A cross-country analysis. Ecological Economics 70:434–444

Satterthwaite D (2009) Implications of population growth and urbanization for climate change. Environ Urban 2:545–567

Song DY, Xu A (2011) Regional differences and influencing factors of urban carbon emissions in China. China Population Res Environ 21(11):324–339

Sun X, Zhang KM (2014) The empirical analysis on influence factors of carbon emission intensity in China. Statistical Res 31(2):61–67

Tong XH, Sun M (2010) Countermeasures of the development of low carbon economy during the urbanization process. J Popul 6:60–63

Wang GX, Wu JK (2012) Study on the impact of urban scale and spatial structure on CO_2 emission. Urban Development Studies 19(3):89–95

Wang X, Qin M (2015) Empirical study on influencing factors of carbon emissions under different urbanization quality based on provincial panel data. J Lanzhou Univ 7:60–66

Wang SJ, Fang CL, Ma HT (2014) Spatial differences and multi-mechanism of carbon footprint based on GWR model in provincial China. J Geogr Sci 24(4):612–630

Wang F, Qiu YH, Liu J, Wu CX (2017) A study on the influencing factors of carbon emissions from the perspective of multi-dimensional urbanization based on the spatial dubin panel model of china provinces. China Popul Resour Environ 27(9):152–161

Xu B, Liu BQ (2015) How industrialization and urbanization process impacts on CO_2 emissions in China: evidence from nonparametric additive regression models. Energy Economics 48(3):188–202

Xu Y, Zhou SF (2011) An empirical study on urbanization and CO_2 emission. Resources and Environment in the Yangtze Basin 20(11):1304–1309

Yang XJ, Chen H (2013) Effects of urbanization on carbon dioxide emissions in china: an empirical analysis based on provincial panel data. J China University Geosciences(Social Sci Edition) 1:200–218

York R, Eugene A, Rosa EA, Dietz T (2003) Bridging environmental science with environmental policy: plasticity of population, affluence, and technology. Soc Sci Q 83(1):21–27

Yuan L, Pan JH (2013) The decomposition of carbon emission driving factors of Kaya identity and its limitations. Adv Clim Chang Res 3: 210–215

Zhang CG, Lin Y (2012) Panel estimation lead to less energy use and lower CO_2 emissions,a cross-country analysis. Ecol Econ 49(1): 488–498

Zhang XM, Zhuang GY (2015) Research progress of inter-provincial carbon emission differences in China. China Popul Resour Environ 2:135–143

Zhao H, Chen YMYM (2013) Study on the relationship between urbanization and carbon emission reduction in china. Social Sci China 3: 184–192

Zhou K (2013) An empirical study on the relationship between urbanization and carbon emissions in china. China Popul Resour Environ 4: 41–48

Zhu Q, Wei TY (2013) Impacts of urbanization on carbon emissions from perspective of residential consumption. China Popul Resour Environ 11:21–29