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The impact of green urbanization on carbon emissions: The case of new urbanization in China

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Urbanization in developing countries has brought economic growth and industrial development, but at the same time, it has also brought environmental problems, especially increased carbon emissions. Recently, China has promoted a new type of urbanization with the common goal of economic growth and green development, which provides a reference for the sustainable development of urbanization in developing countries. The study focuses on microscopic impact of this new urbanization on carbon emissions, which has received little attention previously. This study takes China as an example, constructs a quasi-natural experiment based on the first batch of new urbanization pilot areas in China, selects panel data of 164 prefecture-level cities from 2010–2019, applies the double difference method (DID) to identify the emission reduction effects of pilot policy on carbon emission (carbon emission intensity and per capita carbon emission), the mechanism of action model is constructed for further analysis, and various robustness tests are conducted. The results show that the new urbanization pilot policy can effectively diminish carbon emissions, and the sensitivity of pilot policy to per capita carbon emissions is greater than the intensity of carbon emissions, and the emission reduction effect of pilot policy of new urbanization tends to be enhanced with the implementation of pilot policy. With the improvement of infrastructure, the upgrading of advanced industrial structure, and the strengthening of environmental regulation, the inhibitory effect of new urbanization construction on carbon emissions tends to be enhanced. Various robustness tests show that green urbanization can effectively lessen carbon emissions, and under the constraint of economic growth rate target, if the government still gives priority to economic development, it is not conducive to the development of green urbanization. Therefore, the green urbanization process needs to be accelerated, infrastructure construction is linked, strict and appropriate environmental controls are adopted, the industrial layout is customized and the advanced industrial structure is promoted.

KEYWORDS
new urbanization pilot policy, carbon emissions, green urbanization, DID, China

1 Introduction

Urbanization in developing countries has brought economic growth and industrial development, but has also generated environmental problems (especially CO_2 emissions), as exemplified by China. China's long-term static energy structure determines that the increase of urbanization level is along with the increase of carbon emissions (Yang and Chen, 2013). Accompanied by the concentration of a large number population from countryside to cities, expansion of spatial scale, increase of residents' consumption income, and increase of infrastructure construction, urbanization inevitably requires a large amount of energy consumption, especially in countries with an energy composition based on fossil energy, and generates more carbon emissions (Wang, 2017). In recent years, China has been actively looking for a sustainable development path which inter-coordinate with urbanization and environment. In 2014, the Chinese government issued the "National New Type Urbanization Plan (2014–2020)", which proposed new requirements to improve the quality of urbanization development in all aspects, to implement the "new urbanization". The new urbanization proposed in the Plan is to adhere to the people-oriented, new industrialization as the driving force, the principle of coordination, promote urban modernization, urban clustering, urban ecology, urbanization of rural areas, comprehensively improve the quality and level of urbanization, take the scientific development, intensive and efficient, functional, environmentally friendly, social harmony, distinctive personality, urban and rural areas as an integrated, small, medium and large cities and small towns coordinated development of urbanization construction path. The new urbanization focuses more on the harmonious development of people, economy and environment, which helps to reduce emissions and mitigate global climate change. New urbanization is a green urbanization that realizes the harmonious development of human and nature, is an inheritance of the Marxist theory of comprehensive development (Xiong and Xu, 2018), and provides a template for other countries, especially developing countries, to learn from for sustainable urbanization. However, the impact of new urbanization on the environment is complex. First, one of the core objectives of urbanization is economic growth and improvement of people's living standards. Otherwise, impoverished urbanization is meaningless. However, the expansion of economic scale will tend to increase carbon emissions. Second, urbanization with green objectives will promote the improvement of human capital, industrial structure upgrading and technological progress, which will tend to reduce carbon emissions (Romero, 2007). Therefore, it is significant to clarify the following questions: (1) Can the pilot policy of new urbanization contribute to carbon emission reduction? (2) How does the new urbanization, as green urbanization, affect carbon emissions? (3) How does the new urbanization policy achieve carbon emission reduction?

There has been a long history of research on green urbanization. Howard (1946) proposed the concept of "idyllic cities", which was the beginning of modern green urbanization theory. After the 1990s, the application of "green development" flourished, and the construction of green urbanization gradually deepened from only green planning to green production, green culture, green life and other fields. Dominski (1992) proposed that urban development should follow the "3R" principle, including reduce, reuse and recycle urban development model. Fay et al. (2014) pointed out green urbanization was a sustainable model of urban development. Shi et al. (2020) considered new urbanization generally referred to a new-type urbanization mode that integrated green development into urban development, solved a series of practical problems in the process of urbanization and achieved the optimization of urban economic development and the ecological carrying capacity and resource supply. Gu et al. (2018) considered that new urbanization was a people-oriented, high-quality urbanization led by the concept of green development, the pursuit of comprehensive and coordinated, green and low-carbon, dynamic and balanced, economically efficient urban development, more attention to the harmonious coexistence of human and nature, economic, social and ecological coordination and compatibility.

Currently, more scholars have studied the relationship between urbanization and carbon emissions, and less attention has been paid to the impact of green urbanization on carbon emissions. Although some scholars have proposed green low-carbon technology as a powerful tool to promote green urbanization and achieve carbon emission reduction based on theoretical level, but there is a lack of empirical test (Santos et al., 2013; Ceder, 2015). (Rehman and Rehman. 2022) identified energy use and urbanization as major factors in the growth of carbon emissions in China and Pakistan. Zhou et al. (2019) took the Yangtze River Delta as an example, explored the impact of urbanization on carbon emissions and concluded that the impact of urbanization on carbon emissions was more complex and was the result of a combination of factors, but with the acceleration of the green urbanization process, it would help reduce carbon emissions. Abdallh and Abugamos, (2017) explored the relationship between urbanization and carbon emissions using panel data for the MENA countries, concluding that there was no inverted U-shaped relationship between urbanization and carbon emissions, that per capita carbon emissions declined as urbanization increases, and that energy use and economic growth were the main factors for carbon emissions. Al-mulali et al. (2012)argued that in most high-income countries, there was a long-term positive effect of urbanization and carbon emissions; in low-income countries, there was no relationship. In the empirical study of the impact of new urbanization on carbon emissions, the focus is on the coupling relationship between new urbanization and carbon emissions, and the analysis of the impact mechanism of new urbanization on carbon emissions. Song and Lv, (2017) explored the coupling relationship between carbon emissions and new urbanization, found that the overall coordination of the two couplings was not high. Xue, (2018) empirically studied the impact new urbanization on ecological environment quality, concluded that new urbanization was a key factor affecting ecological environment. In the above-mentioned studies, the evaluation index system is constructed to measure the level of new urbanization, which is analyzed the impact on the environment. While the literatures on new urbanization as a policy and its impact on carbon emissions are relatively little. In China, among the studies on the impact of green urbanization on carbon emissions, taking new-type urbanization as an example, most scholars construct an evaluation index system to measure the level of new urbanization and analyze the effect of the level of new urbanization on carbon emissions, while there is relatively little literature that considers new urbanization as a policy and explores the impacts of this policy on carbon emissions.

Many scholars have investigated the impact of environmental regulation policies on carbon emissions. Generally speaking, the government intends to improve environmental quality by strengthening environmental regulation, which is expected to have positive emission reduction effects on carbon emissions, such as carbon trading policies and low-carbon pilot policies. Li Wang, (2021) argued that carbon trading pilot policies were not only effective in reducing local carbon emissions, but also have a dampening effect on the neighboring regions. Lin and Huang, (2022) analyzed whether the reduction of carbon emissions in China's carbon trading policy was caused by market mechanisms or the government regulation, found that carbon trading policies reduced carbon emissions mainly caused by government intervention. Zhang et al. (2020) indicated that the emission trading policy adopted in pilot regions had reduced carbon emission by approximately 16.2% and such effect was particularly prominent in eastern areas of China where the economy was more developed. Zhang et al. (2022) used a dataset of 285 cities in China spanning 2003–2018, examined the impact of the low-carbon city pilot (LCCP) policy on CEE, DID estimated document that the LCCP policy resulted in a 2.04% increase in CEE in pilot cities relative to non-pilot cities after the policy implementation. Pan et al. (2022) took the power industry as an example to study the low-carbon policy of China's energy industry, the social impact of low-carbon policy on carbon reduction effect was obtained. From the above analysis, it can be found that existing studies mostly explore the impact of carbon policies on carbon emissions, while ignoring the impact of green urbanization policies on carbon emissions.

In studies that consider new urbanization as a policy, the impact of the policy on economic development and environmental pollution are mostly explored. Based on Chinese municipal panel data, Guo and Zhang (2018) examined the impact of the pilot policy of new urbanization on the quality of economic development, and found that the policy could improve the quality of regional development. Jiang and Yang, (2020) analyzed the impact of new urbanization on economy productivity using the DID, found that new urbanization significantly contributed to high-quality urban economic growth. Chen et al. (2020) used the DID to assess the impact of the new urbanization on the regional ecological environment, showed that the new urbanization significantly improved the environment. A summary of the literature reveals that there is a lack of literature that considers new urbanization construction as a policy and explores its impact on carbon emissions. In particular, developing countries such as China and India are accelerating the urbanization process, which lead to the increase of carbon emissions, making them the main source of carbon emissions, and how to reduce carbon emissions in the urbanization process is a key concern for the government.

Taking China as an example, this study constructs a quasi-natural experiment based on the first batch of new urbanization pilot areas, and uses the DID to identify the emission reduction effects of new urbanization policies, builds an interaction mechanism model to empirically test the effect mechanism of new urbanization policies to achieve carbon emission reduction. Compared with the previous literature, the main contributions of the study are following: the study considers the construction of new urbanization as a proposed natural experiment from two perspectives of carbon emission intensity and per capita carbon emission, and adopts the DID method to explore the direct policy impact of green urbanization pilot policies on carbon emissions. The study selects the expected government economic growth rate target as an instrumental variable, compares and analyzes the impact of the new urbanization pilot policies on carbon emissions under the influence of the instrumental variable. In the context of the new urbanization strategy, the impact of infrastructure construction on carbon emissions cannot be ignored. Theoretically, the effect of the new urbanization on carbon emissions is analyzed through infrastructure construction, advanced industrial structure and environmental regulation, which are tested empirically.

The rest of the paper is organized as the second section contains theoretical mechanism and hypothesis, Section 3 contains methodology, Section 4 is results and discussion, Section 5 presents robustness test, Section 6 concerns conclusion.

2 Theoretical mechanism and hypothesis

The plan pointed out that "the concept of ecological civilization will be fully integrated into the urbanization process, focusing on green development, circular development and low-carbon development, and to promote the formation of green and low-carbon production and lifestyle, and urban construction and operation mode". "Ecological civilization, green and low-carbon" is one of the basic principles and goals of new urbanization construction. The new urbanization construction and its carbon emission problems are long-standing, and the direction of the impact on carbon emissions is unclear. On the one hand, the new urbanization leads to a large amount of carbon emissions. New urbanization construction needs much energy to support. However, Chinese energy structure is still dominated by fossil energy, which will certainly generate massive carbon emissions. The new urbanization construction requires sufficient infrastructure construction, which will drive the development of upstream and downstream energy-consuming industries such as iron and steel, cement, chemical industry and electric power, and generate substantial carbon emissions. The essence of new urbanization is the transfer of numerous rural people to cities. The expansion of urban population scale will certainly increase the demand for land, squeeze out arable land and forest land, and reduce the source of carbon sink. The concentration of rural population in urban areas is accompanied by the improvement of income level and the change of production and lifestyle. The new population generates more carbon emissions than the stock population. The reduction size of urban family and the increase number of family lead to an increase of energy consumption. With the gradual aging of society, the carbon emissions generated by the aging population in cities are obviously higher than those in rural areas (Li, 2015). On the other hand, the new urbanization may be beneficial to reduce carbon emissions. New urbanization construction is conducive to improving the level of human capital, promoting technological progress, improving energy use efficiency, which contribute to the reduction of carbon emissions. The new urbanization promotes the optimization and upgrading of industrial structure, increases the proportion of green industries, promotes the development of the scale of the tertiary industry, and leads to a shift in its energy approach to the direction of intensification, which contributes to the decline of carbon emissions. The new urbanization has improved the construction of infrastructure and public facilities, and curbed carbon emissions by sharing facilities. The new urbanization raised the income level of residents, increases the public's demand for environmental quality, and forces the government to strengthen environmental regulations. Many environmental control policies implemented by the government can restrain carbon emissions from the perspective of enterprises and individuals.

It is formulated as hypothesis 1: the new urbanization has a notable impact on carbon emissions, but the direction is uncertain.

The Plan clearly proposes to promote the development of regional infrastructure and the public service facilities, enhance the supporting and guiding role of infrastructure development on urbanization patterns. It is necessary to strengthen infrastructure networks to promote urbanization, forming a coordinated urban pattern. Accelerating urban infrastructure construction has an irreplaceable role in promoting the healthy development of new urbanization (Zhong, 2018). Therefore, the new urbanization requires adequate infrastructure construction, especially the large-scale construction of transportation, which certainly consumes massive fossil energy and generates considerable carbon emissions. But the improvement of infrastructure contributes to lower carbon emissions (Guo et al., 2021). Infrastructure construction is favorable to the introduction of advanced production technology and energy-saving technology to inhibit the increase of carbon emissions. As a quasi-public good, infrastructure construction can promote high-quality development of new urbanization through its positive externalities, enhance regional accessibility, lower transaction, search and transfer costs, improve public services, promote the development of tertiary industry. Infrastructure construction is advantageous to promote population clustering and industrial agglomeration, forming a scale effect, which is useful to cut carbon emissions under the macro regulation of the government. Therefore, the new urbanization has immense potential to improve carbon emissions through infrastructure development.

Therefore, hypothesis 2: the new urbanization curbs carbon emissions through infrastructure development.

The Plan clearly stated that the strictest environmental regulation system would be implemented and environmental enforcement would be increased. Environmental regulation involves the government imposing appropriate incentives and constraints on market players in order to achieve energy saving and emission reduction as well as to improve the ecological environment. Carbon emissions are public goods with externalities, which are difficult to achieve emission reduction targets only through voluntary actions of enterprises and individuals (Ren and Fu, 2019). Therefore, the government must control by means of regulation, and whether environmental problems can be effectively solved is inextricably linked to the effectiveness of environmental regulation policies introduced by the government. The new urbanization demands rigorous and appropriate environmental regulation to achieve the low-carbon city construction. The government can employ market-incentive-based environmental regulations such as taxes to increase the costs of fossil energy producers and users to suppress the demand for fossil energy (Xu et al., 2015), or encourage the utilization of clean energy by giving clean energy subsidies. The government can mandate the share of enterprises' emissions through environmental regulatory instruments to force them to innovate technologically or introduce advanced energy-saving and emission-reducing technologies to lessen carbon emissions. In the context of new urbanization, the government attaches more importance to ecological environmental protection, increasing the investment in environmental prevention. It also actively encourages enterprises to implement environmental technology innovation, which can solve the problem of insufficient funds for enterprise innovation and helps to obtain the "innovation compensation effect", which can effectively limit carbon emissions.

Hence, hypothesis 3: the new urbanization suppresses carbon emissions through environmental regulation.

The Plan proposed to transform and upgrade traditional industries, eliminate backward production capacity, expand strategic emerging industries, promote the development of productive service industries, and guide the agglomeration of productive service industries. The Plan pointed out that industrial structure upgrading is an important project and motivation for new urbanization construction. The advanced industrial structure indicates the development process of industrial structure from low level to high level. In terms of quantity, the proportion of primary industry decreases, the share of secondary and tertiary industries increases, and the latter dominates, reflecting the characteristics of "economic service". The quality of the traditional industry is expressed in the continuous upgrading and innovation of production technology or the improvement of product technology level (Han et al., 2016). The advanced industrial structure reduces carbon emission mainly through three routes: ① Eliminate the old production mode. The advanced industrial structure is accompanied by the change of production mode, the industrial structure from high fossil energy consumption industries to low fossil energy consumption industries, "economic service" will adjust the current energy consumption structure, which is sure to limit the total fossil energy consumption and reduce carbon emissions; ② Promote technological progress. The advanced industrial structure promotes the progress of energy saving and emission reduction technology, which makes energy consumption diminish with the improvement of overall supporting facilities, and promotes the rapid development of new energy and renewable energy, which can effectively decrease carbon emissions; ③ the development of new industries. New industrial sectors with high value-added and low energy consumption will gradually occupy the dominant position in the market and the phenomenon of "good money drives out bad money" (Zhou and Luo, 2021).

Accordingly, Hypothesis 4: The new urbanization can be realized through advanced industrial structure to effectively mitigate carbon emissions.

3 Methodology

3.1 Sample selection and data description

In December of 2014, the first batch of new urbanization pilot cities and their implementation plans were jointly announced by the China Development and Reform Commission and other ministries. The first batch of new urbanization pilot cities involved 62 cities, which constitutes the terms for constructing a quasi-natural experiment in the study, and provides support for assessing the impact of new urbanization pilot cities on carbon emissions using the DID, spanning the period 2010–2019. To completely separate the later pilot policy effects from the 2014, thus ensuring that 2014 is treated as the only policy shock point for identification, the additional pilot samples of 2015 and 2016 are excluded. Considering that the study sample is prefecture-level cities, the four municipalities are excluded from the total sample, and to avoid bias in the sample grouping due to the level city where the district or county city entered the list, the sample of prefecture-level cities where the district or county is located is excluded. The prefecture-level cities with more serious missing data, including Taiwan, Hong Kong and Macao, were eliminated. Finally, 59 prefecture-level cities were obtained as the experimental group and 105 cities as the control group (Specifically, refer to Exhibit 1).

The data of prefecture-level cities used are from the China City Statistical Yearbook. The data of green patent authorizations are drawn from the China Research Data Service Platform. Infrastructure construction indicators, based on the fixed asset investment price index, GDP per capita, based on the GDP per capita price index, deflated by 2010 as the base period.

3.2 Double difference method

According to the theoretical analysis of Sun and Yan, (2019), DID is adopted for regression, and the specific model is established as shown in Eq. 1.

$$Y_{it} = \beta_0 + \beta_1 DID + \sum \gamma_j Controls_{it} + \mu_i + \nu_t + \varepsilon_1 \tag{1}$$

Y_{it} represents the dependent variable, DID is the core explanatory variables, which is the interaction term between treated and t. The treated is the sample selection identification variable of the pilot policy implementation. *Treated* = 0 means that the sample city enters the control group without receiving the pilot policy of the trial, *treated* = 1 indicates that the sample city is the pilot area. T is the time identification variable for pilot policy implementation. Since the first batch of new urbanization pilot areas was announced in December of 2014, 2015 is considered as the policy shock time. $T = 0$ stands for year < 2015, the pilot policy has not been applied before 2015. $T = 1$ indicates year ≥ 2015, the pilot policy has been imposed in and after 2015. Controls means control variables, u_i refers to individual fixed effects, v_t denotes time fixed effects, and ε_1 is the disturbance term.

3.3 Variable selection and data descriptive statistics

The carbon emission data refers to the study of Wu and Guo, (2016), electricity, gas and LPG are summed to obtain

TABLE 1 Variable selection and explanation.

Variable type	Variable name	State	Calculation methodology
Dependent variable	Carbon Intensity	CI	Total carbon emissions/real GDP
	Carbon Emissions Per Capita	CP	Total carbon emissions/average population
Independent variable	New Urbanization Pilot Policy	DID	Treated × t
Adjusting variables	Infrastructure Construction	IC	Productive capital stock
	Advanced Industrial Structure	IS	The calculation can be observed in Eq. 3
	Environmental Regulation	ER	Frequency of carbon emission-related terms
Control variable	Total Population at year-end	TP	Year-end total population of prefecture-level cities
	Energy Consumption	EC	Total energy consumption
	Economic Development	ED	Real GDP per capita
	Technological Advances	TA	Number of green utility patents in the year
	Foreign Direct Investment	FDI	Foreign Direct Investment/GDP

the carbon emission for each city. Infrastructure drawing on the measurement method of Xue (2018), the perpetual inventory method is adopted to measure the productive capital stock of each city from 2010–2019. Environmental regulation takes into account the study by Chen and Chen, (2018), who counts the number of occurrences of words related to carbon emissions and calculates their proportion of the total word frequency of the full government report. The words relevant to carbon emissions include energy consumption, emission reduction, ecology, and carbon dioxide. The selection of control variables is based on existing studies (Jia et al., 2021), and variables with high correlation with carbon emissions are selected. The specific indicators are selected as shown in Table 1, and the descriptive statistics of indicators are listed in Exhibit 2. The Exhibit 2 shows the statistical values of every variable after taking logarithms, the study sample is the panel data of 164 prefecture-level cities in 2010–2019. The data of each indicator changes relatively smoothly, all passed the panel unit root (fisher) test. The variance inflation factor (VIF) is adopted to test for multicollinearity, the VIF values are below 4, suggesting that there is no multicollinearity between indicators.

The index of advanced industrial structure follows the research of Yuan and Zhu, (2018), and the formula is provided in Eq. 2.

$$IS_{it} = \sum_{m=1}^{3} y_{i,m,t} \times m\,(m = 1, 2, 3) \tag{2}$$

$y_{i,m,t}$ stands for the proportion of the m industry in i region at t year to the GDP. The index reflects the evolution of the proportional relationship of the three major industries in China from the dominant region of the primary industry to the leading position of the secondary and tertiary industries gradually.

4 Results and discussion

4.1 Baseline regression results

Hypothesis 1 is tested using a double fixed effects model, and the regression results are presented in Table 2. The regression coefficient of the new urbanization pilot policy on carbon emission intensity is −0.0339. And the coefficient of the pilot policy on carbon emission per capita is −0.0540, both of which pass the 1% significance level test, indicating that the new urbanization policy has a remarkable carbon emission reduction effect and is more sensitive to per capita carbon emissions than carbon emission intensity. The reasons for the conclusion: the new urbanization construction reduces total carbon emissions, stimulates economic development and urban population agglomeration, and population clustering is instrumental in reducing carbon emissions (Zhang et al., 2021).

4.2 Dynamic effect test result

After a policy is implemented, it may gradually weaken or strengthen over time. Therefore, the study of policy effects should not only focus on the current situation, but also on the sustainability of policy implementation afterwards. We construct a dynamic effect model as shown in Eq. 3 to test the dynamic changes of new urbanization policy on carbon emissions by setting the policy time before and after the year 2015 (Jiang and Yang., 2020). The equation is as follow:

$$Y_{it} = \alpha_0 + \sum_{t=2010}^{2019} \alpha_t treat \times T_t + \varepsilon_{it} \tag{3}$$

The list of pilot cities was published in 2015, which is as the base year. α_t is the estimating coefficient of the multiplicative difference term from 2010 to 2019. T_t identifies the time dummy

TABLE 2 Regression results of new urbanization pilot policies on carbon emissions.

Variables	Carbon emission intensity	Carbon emissions per capita
DID	−0.0339*** (0.00)	−0.0540*** (0.00)
Control variables	YES	YES
C	3.534*** (0.00)	5.191*** (0.00)
R^2	0.9665	0.9580

*, **, *** indicate significance at the 10%, 5%, and 1% statistical levels, with *p* values in parentheses.

TABLE 3 Regression results of the mechanism of action test.

Variable	Carbon emissions intensity			Carbon emissions per capita		
DID	−0.0471*** (0.00)	−0.0400*** (0.00)	−0.0432*** (0.00)	−0.0738*** (0.00)	−0.0296** (0.02)	−0.0593*** (0.00)
DID × IC	0.0537*** (0.00)			0.0805*** (0.00)		
DID × IS		0.1797*** (0.00)			0.7132*** (0.00)	
DID × ER			0.1005*** (0.00)			0.0579*** (0.00)
Controls	YES	YES	YES	YES	YES	YES
C	3.5322*** (0.00)	3.5649*** (0.00)	3.5383*** (0.00)	5.1889*** (0.00)	5.0669*** (0.00)	5.1938*** (0.00)
R^2	0.9668	0.9665	0.9667	0.9586	0.9584	0.9581

*, **, *** indicate significance at the 10%, 5%, and 1% statistical levels, with *p* values in parentheses.

variable for each year before and after the policy implementation. Treat represents the policy dummy variable. For example, T_{2014} denotes $T = -1$, T_{2013} indicates $T = -2$, T_{2015} is $T = 0$, T_{2016} means $T = 1$. Other variables are consistent with Eq. 1.

The dynamic effect model examines whether the parallel trend test is satisfied in the event of a change in the policy window by shifting the policy point in time forward and backward, respectively, and the results are shown in Figure 1. The regression coefficients of the pilot policy on dependent variable (carbon intensity or carbon emissions per capita) fluctuate around 0 in 2011–2015, both fail to pass the significance level test. The regression coefficients are significantly negative in 2017–2019. When the dependent variable is carbon emission per capita, the absolute value of the coefficient tends to increase. The findings indicate that the pilot policy has a significant suppression effect on carbon emissions, and the carbon reduction effect tends to be enhanced with the implementation of the green urbanization policy.

4.3 Further discussion

According to the above mechanism of action analysis, the new urbanization affects carbon emissions through infrastructure construction, environmental regulation and advanced industrial structure. In order to test hypotheses 2 to 4, the following regression model is constructed with the reference of Beck et al. (2010).

$$Y_{it} = \alpha_0 + \alpha_1 DID + \alpha_2 DID \times M_{it} + \sum \eta_j Controls_{it} + \mu_i + \nu_t + \varepsilon_2 \tag{4}$$

Where Mit is infrastructure development (*IC*), environmental regulation (*ER*) and industrial structure advanced (*IS*), and other variables are the same as Eq. 1.

We conducted the regression using a double fixed-effects model, and the specific estimation results are shown in Table 3. In Table 3, the interaction terms DID × IC, DID × IS, and DID × ER are always significantly positive, and the suppressive effect of new urbanization on carbon emissions (carbon emission intensity or per capita carbon emission) tends to be enhanced with the improvement of infrastructure construction, advanced industrial structure, and the increase of environmental regulation intensity, which verifies Hypotheses 2–4. The reasons for this conclusion are following: the construction of new urbanization, with the large-scale migration of rural population to cities, will certainly increase the demand for infrastructure, and with the gradual improvement of infrastructure and the government's macro-control of fixed assets, it is conducive to curbing carbon emissions (Li and Cao., 2014). The construction of new urbanization is associated with the vigorous development of new and strategic industries and the expansion of the scale of tertiary industry, which promotes the development of industrial structure toward advanced level. As the residents' demand for

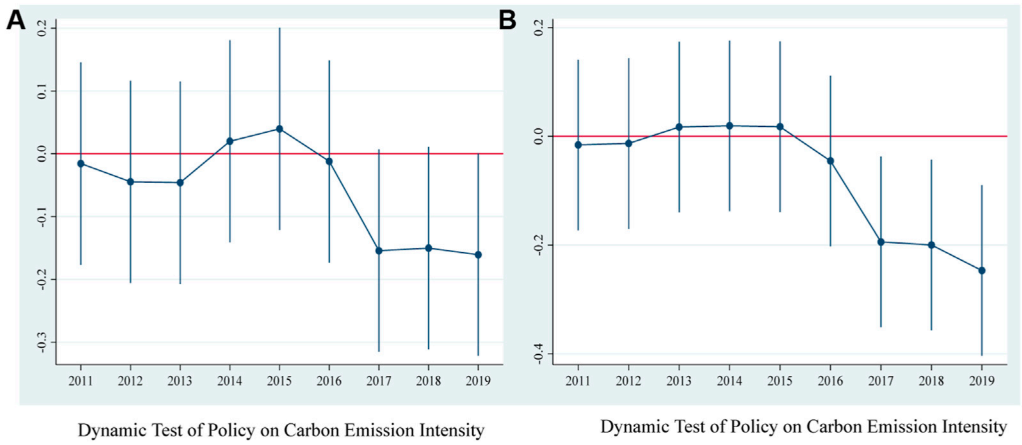

FIGURE 1
Results of dynamic effects test. **(A)** Dynamic Test of Policy on Carbon Emission Intensity. **(B)** Dynamic Test of Policy on Carbon Emission Intensity.

environmental quality improves, the new urbanization strategy puts forward the requirement of strengthening environmental regulation, and this conclusion coincides with the content of the Plan, which verifies the previous theoretical analysis.

5 Robustness test

To guarantee the reliability of the findings, we adopt a series of robustness tests. The placebo test and the elimination of interference from other pilot policies test demonstrate that green urbanization has a considerable inhibitory effect on carbon emissions. This endogeneity test shows that the new urbanization policy has a suppressive effect on carbon emission intensity after considering the influence of instrumental variable, and that under the constraint of economic growth rate target, it is unfavorable to the development of green urbanization if the government still gives priority to economic development.

5.1 Placebo test

The placebo test is required to remove the impact caused by individual and time factors, to ensure that the finding is generated by the new urbanization pilot policy. The placebo test is applied by randomly selecting 59 samples from the overall sample as the experimental group, and assuming that the samples selected are pilot areas, and those not selected are the control group, and 250 “pseudo-policy regressions” are conducted by adopting the method of Shi et al. (2018). Figure 2 shows the results of the placebo test, where the X-axis is the regression coefficient of the “pseudo-policy dummy variable” on carbon emissions, the Y-axis is the p-value, and the dots are the p-values corresponding to the estimated coefficients. In the Figure 2, the dependent variable is either carbon intensity or carbon emissions per capita, p-value overwhelmingly ranges from [0.5,1.0], which does not pass the significance level check. The curve shows the kernel density distribution of the estimated coefficients, which takes values in the range of [−0.1,0.1], with small estimated coefficient values around zero. The finding implies that the effect of pseudo-policy on carbon emissions is not significant, concluding that the estimated result is unlikely to be obtained by chance and thus least likely to be influenced by other factors or omitted variables. The placebo test result illustrates that green urbanization still has a pronounced carbon reduction effect after excluding the influence of individual and time factors.

5.2 Eliminate other pilot policy interference tests

China has launched a variety of environmental regulatory policies to abate carbon emissions. Two environmental policies are mainly selected for analysis. One is low-carbon city pilot policy, which were carried out in 2010 and 2012 respectively. The low-carbon city pilot policy was introduced to mitigate carbon emissions (She et al., 2020). We exclude the 2010 low-carbon pilot cities and some regions with more serious data deficiencies, reserve the 2012 low-carbon pilot cities and classify them as the experimental group, with the unimplemented cities as the control group. However, the second batch of low-carbon city pilot list was promulgated in December 2012, therefore, 2013 is considered as the policy implementation year. The other is the carbon trading pilot policy, which began work in 2013 and has been proven to have dramatic carbon reduction effects (Li and

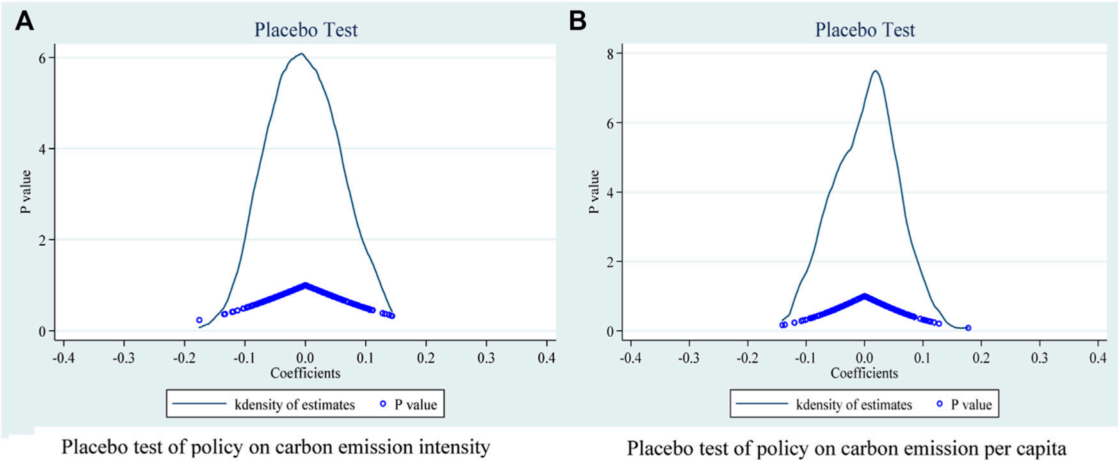

FIGURE 2
The results of the placebo test. **(A)** Placebo test of policy on carbon emission intensity. **(B)** Placebo test of policy on carbon emission per capita.

Lin., 2020). In order to accurately identify the influence of green urbanization on carbon emissions, the interference of low-carbon city pilot policy and carbon trading pilot policy is exclude. Taking reference from Cao (2020), Eq. 5 is constructed on the basis of Eq. 1.

$$Y_{it} = \eta_0 + \eta_1 DID + \eta_2 DID_1 + \eta_3 DID_2 + \sum \eta_i Controls_{it} + \mu_i + \nu_t + \varepsilon_3 \tag{5}$$

Where DID is the green urbanization policy dummy variable. DID_1 is the low-carbon city pilot policy dummy variable, and DID_2 is the carbon trading policy dummy variable. If i city is a pilot region for implementing low carbon in t year, $DID_1 = 1$, otherwise $DID_1 = 0$. If j city is a pilot region for implementing carbon trading in t year, $DID_2 = 1$, otherwise $DID_2 = 0$. The control variables are the same as Eq. 1.

The regression results obtained according to Eq. 5 are presented in Table 4. In Table 4, when the dependent variable is carbon emission intensity, the negative impact of low-carbon city pilot policy is the largest, followed by carbon trading pilot policy, and the degree of negative effect of the new urbanization pilot policy is relatively feeble. When the dependent variable is per capita carbon emissions, the inhibitory effect of carbon trading pilot policy is the most prominent, and the new urbanization pilot policy is next. After exclusion of low-carbon pilot policy and carbon trading pilot policy, the inhibitory effects of the new urbanization on carbon emissions (carbon intensity or per capita carbon emissions) are both effective, implying that the new urbanization pilot policy can effectively reduce carbon emissions. Eliminating other pilot policy interference test results show that green urbanization has a powerful carbon abatement function.

5.3 Endogeneity test

The peripheral city model and the instrumental variable model are used to overcome the estimation bias caused by the endogeneity problem. The identification of the new urbanization pilot cities is not a completely random even. For example, the national strategic planning prefers to select regional central cities with relatively more developed economic level, superior ecological resources and environment, and leading demonstration role to implement pilot policy. In general, the governments of regional center cities pay attention to environmental protection and have stricter control of carbon emission, thus leading to reverse causality. In view of this, regional central cities (provincial and sub-provincial cities) are excluded and fixed-effects model is applied for regulation in order to alleviate the endogeneity problem brought by the reverse factor. The specific regression results are shown in Table 5 (1) and column (2). The level of negative effect of the new urbanization on carbon emissions (carbon emission intensity or per capita carbon emission) decreases to a larger extent compared with the baseline regression, reflecting that the selection of pilot areas for new urbanization is a non-random event, and the suppression effect on carbon emissions is more significant after the implementation of the new urbanization in peripheral cities compared with regional central cities. The regression coefficient of the pilot policy is obviously negative, indicating that after overcoming the reverse causality, the new urbanization can effectively suppress carbon emissions.

The empirical study may omit some certain difficult-to-measure factors that simultaneously affect the level of carbon emissions, leading to the problem of endogeneity of the core explanatory variable. Therefore, the instrumental variable model is employed to estimate the regression for model (1). According

TABLE 4 Regression results excluding other pilot policies.

Variables	Carbon emission intensity	Carbon emissions per capita
DID	−0.0422*** (0.00)	−0.0566*** (0.00)
DID1	−0.0631*** (0.00)	−0.0463** (0.00)
DID2	−0.0528*** (0.00)	−0.0832*** (0.00)
Control variables	YES	YES
C	3.5336	5.0618
R^2	0.9669	0.9587

*, **, *** indicate significance at the 10%, 5%, and 1% statistical levels, with *p* values in parentheses.

TABLE 5 Endogenous problem processing results.

Models	Peripheral city Model (Carbon emission)		Instrumental variable model (Carbon emission)	
Variables	Intensity	per capita	Intensity	per capita
DID	−0.0266*** (0.01)	−0.0369*** (0.00)	−0.2818*** (0.00)	0.1413** (0.02)
Control variables	YES	YES	YES	YES
C	3.5753*** (0.00)	5.5838*** (0.00)	3.0610*** (0.00)	5.7849*** (0.00)
R2	0.9687	0.9624	0.9540	0.9494

*, **, *** indicate significance at the 10%, 5%, and 1% statistical levels, with *p* values in parentheses.

to Goldsmith et al. (2022), considering that the expected economic growth rate target is government expectation of economic growth, which influences the construction of the new urbanization, and the target is a value set by the government based on historical economic development, without considering carbon emissions, so there is no direct connection with carbon emissions. However, the expected economic growth target influences the construction of new urbanization and determines the layout of new urbanization industries, which in turn has an impact on carbon emissions. Therefore, we choose the expected economic growth rate target as an instrumental variable and use two-stage least squares (2SLS) to test for endogeneity, the results of which are shown in columns (3) and (4) of Table 5. In the first stage of the 2SLS model, the correlation coefficient of the instrumental variable on the pilot policy is −0.2289, which passes the 1% significance level test, proving that the instrumental variable has a strong correlation with the new urbanization pilot policy, but the higher the expected target of economic growth rate is, the more unfavorable it is to the construction of new urbanization. Hausman test at the 1% level concludes that there is an endogenous variable of the explanatory variable, and the minimum eigenvalue statistic amount of 53.25 is much greater than 10, there is no weak instrumental variable, and the instrumental variable has strong explanatory power. The regression coefficient of the new urbanization pilot policy on carbon emissions intensity is −0.2818, which is significantly higher compared with the baseline regression. Under the constraint of the expected target of economic growth rate, the governments pay more attention to economic development, which inevitably consumes a lot of energy and produces more carbon emissions, but the enhancement effect of economic growth is more significant, which leads to the decrease of carbon emission intensity instead. The regression results of the pilot policy on carbon emissions per capita support the conclusion. This endogeneity test shows that the new urbanization has a suppressive effect on carbon emission intensity after considering the influence of instrumental variable, and that under the constraint of economic growth rate target, it is unfavorable to the development of green urbanization if the government still gives priority to economic development.

6 Conclusion

Urbanization in developing countries has brought economic growth and industrial development, it also leads to environmental problems, especially increases carbon emissions. China's promotion of the new urbanization with the common goal of economic growth and green development provides a reference for the sustainable development of urbanization in developing countries. In this study, a quasi-natural experiment is constructed based on the first batch of new urbanization pilot areas in China, and the effect of new urbanization pilot policy on carbon emission reduction is identified using DID, the mechanism of action model is constructed for further analysis, and various robustness tests are conducted. The results show that the new urbanization pilot policy can effectively diminish carbon emissions, and the sensitivity of pilot policy to per capita carbon emissions is greater than the intensity of carbon emissions, and the emission reduction effect of pilot policy of new urbanization tends to be enhanced with the implementation of pilot policy. With the improvement of infrastructure, the upgrading of advanced industrial structure, and the strengthening of environmental regulation, the inhibitory effect of new urbanization construction on carbon emissions tends to be enhanced. Various robustness tests show that new urbanization can effectively lessen carbon emissions, and under the constraint of economic growth rate target, if the government still gives priority to economic development, it is not conducive to the development of green urbanization.

According to the above analysis, developing countries still need to make efforts in the following aspects to reduce carbon emissions and improve the quality of green urbanization. We put forward the following recommendations: (1) Accelerate the process of green urbanization and promote the concept of low-carbon urban development. Through the establishment of exhibition boards, the distribution of publicity manuals and other ways to the public and enterprises to focus on the promotion of green low-carbon, energy saving and consumption and others. Advocate people to travel green and practice low-carbon life. Combined with online methods to popularize energy-saving, low-carbon knowledge to the public. Encourage the posting of slogans such as “Save Food, Stop Wasting” in all restaurants to remind everyone to practice conservation. Turn off all kinds of power after work. Recycling office supplies, gradually implementing paperless office and using energy-saving appliances. (2) Continue to advance the construction of infrastructure to reduce carbon emissions in each construction process. In the design phase, consider that proper insulation, natural lighting and shading can reduce the demand for energy use later. Understand the materials specified in the building and their sources, measure the energy and carbon used in their extraction, production and transportation, and select the path with the lowest energy use. In the construction phase, consider the impact of heavy machinery, material transportation and waste generation, and dispose of them properly to increase the product life. Select sustainable materials, such as sustainable wood panels, integrated photovoltaic facades (BIPV), thermally efficient enclosures, and LED lighting. (3) Adopt strict and appropriate environmental regulations. Promote green development through economic and social regulations and increase the cost of violation. Design effective incentive mechanisms, internalize external costs and benefits through economic policy tools such as taxes, prices, financial subsidies, green credits and emission trading, so that market mechanisms can play a positive incentive role and guide market players to green production and consumption. (4) Adapt the layout of industries to local conditions and promote the advanced industrial structure. According to the current development situation of each region for the layout of industries, for example, regions with talent advantages can encourage the development of science and technology, strategic and emerging industries, promote the development of high-tech industries, and refine the professional division of labor. Regions with ecological advantages and resource advantages, vigorously develop tourism and big health industries; regions with population and arable land advantages, introduce labor-intensive industries, such as garment manufacturing, light industry, food processing industry. In addition, we should give certain environmental subsidies to encourage the purchase of energy-saving and emission-reducing equipment and processes.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding author.

Author contributions

First draft writing: YL; Review writing: KG.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher’s note

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APPENDIX

TABLE A1 Pilot and non-pilot areas of new urbanization prefecture-level cities in China.

Pilot cities (59 prefecture-level)	Non-pilot cities (105 prefecture-level)
Shijiazhuang, Ningbo, Dalian, Putian, Changchun, Yingtan, Qingdao, Jilin, Nanjing, Yangzhou, Suzhou, Shaoxing, Harbin, Xuzhou, Qiqihar, Zhenjiang, Mudanjiang, Wuxi, Hefei, Wuhu, Changzhou, Huangshan, Nantong, Suzhou, Lianyungang, Bozhou, Huai'an, Xuancheng, Weihai, Yancheng, Huainan, Taizhou, Huaibei, Suqian, Wuhan, Guangzhou, Bengbu, Changsha, Dezhou, Ma'anshan, Luoyang, Shenzhen, Tongling, Anshun, Anqing, Luzhou, Chuzhou, Qujing, Jinchang, Fuyang, Xiaogan, Zhuzhou, Lu'an, Liuzhou, Dongguan, Chizhou, Huizhou, Laibin, Guyuan	Chengde, Songyuan, Jinzhou, Cangzhou, Yuncheng, Fuxin, Langfang, Liaoyuan, Changye, Hengshui, Taiyuan, Yangquan, Shuozhou, Zhangjiajie, Shanwei, Xinzhou, Baicheng, Wuzhou, Wuhai, Shantou, Loudi, Qingyuan, Ulanqab, Yuxi, Beihai, Fushun, Yiyang, Baoji, Dandong, Jiayuguan, Yingkou, Heyuan, Pu'er, Liaoyang, Pingliang, Ziyang, Panjin, Hanzhong, Guang'an, Tieling, Ankang, Chaoyang, Huludao, Jixi, Hegang, Shuangyashan, Daqing, Lanzhou, Qitaihe, Hangzhou, Wenzhou, Jiaxing, Zhoushan, Lishui, Zhaotong, Xiamen, Jingdezhen, Xinyu, Shangrao, Zaozhuang, Dongying, Taian, Rizhao, Tongchuan, Liaocheng, Binzhou, Pingdingshan, Anyang, Jiaozuo, Luohe, Sanmenxia, Nanyang, Shangqiu, Xinyang, Zhoukou, Zhumadian, Shiyan, Ezhou, Huanggang, Xianning, Hengyang, Shaoyang, Weiwu, Yueyang, Zhuhai, Jiangmen, Zhanjiang, Meizhou, Zhongshan, Nanning, Fangchenggang, Guigang, Hezhou, Hechi, Chongzuo, Panzhihua, Deyang, Guangyuan, Neijiang, Leshan, Yibin, Ya'an, Kunming, Urumqi

TABLE A2 Data descriptiveness and multi-collinearity test.

Variable	Obs	Mean	Std. Dev.	Min	Max	VIF
CI	1,640	2.81	1.17	−0.40	6.98	
CP	1,640	4.19	0.81	1.55	7.56	
DID	1,640	0.18	0.38	0.00	1.00	1.23
IC	1,640	4.79	0.53	2.97	6.27	
IS	1,640	2.49	0.81	−0.34	5.88	
ER	1,640	5.05	0.31	3.14	5.86	
TP	1,640	5.84	0.69	3.01	7.14	1.45
EC	1,640	4.66	1.13	1.29	8.04	3.06
ED	1,640	5.58	0.58	4.15	8.14	2.21
TA	1,640	4.26	1.67	0.01	9.13	3.77
FDI	1,640	4.67	1.42	−2.10	10.32	1.16