Research on Green and Low-Carbon Development of Resource-Based Cities Supported by Smart City Construction

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Abstract.

China has been committed to ecological civilization construction and has proposed "dual carbon" goals, demonstrating a strong emphasis on environmental protection and energy conservation. The continuous development and supply of resources have resulted in high carbon emissions in resource-based cities, which serve as key strategic bases for energy resource security, thereby restricting their sustainable development and hindering the realization of high-quality urban economic development goals. Achieving the "dual carbon" targets faces significant challenges.

Smart city construction, leveraging big data, artificial intelligence, and cloud computing, represents an important approach to new urbanization aimed at building efficient and energy-saving cities. This study analyzes panel data from Chinese cities and uses a multi-period difference-in-differences (DID) approach to examine how smart city development affects carbon emissions in resource-dependent cities and the research findings are as follows: (1) The development of smart cities notably lowers carbon emission intensity in the pilot regions. (2) The impact on carbon reduction becomes clear in the third year following policy implementation and shows long-term sustainability.

This research offers valuable insights and experiences for the green and low-carbon transformation of resource-dependent cities through smart city development. Policy recommendations include encouraging the high-quality and standardized advancement of smart city initiatives.

Keywords: Smart City; Resource-Based City; Carbon Emissions; Impact Mechanism

1 Introduction

As society develops and the population increases, the demand for energy has grown significantly, resulting in significant consumption of conventional fossil fuels like oil and coal. This has resulted in severe environmental and energy security issues. In 2020, China has set its "carbon peak" and "carbon neutrality" targets, intending to hit carbon emissions peak before 2030 and attain carbon neutrality by 2060. The docu-

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ment from the 20th National Party Congress emphasized promoting green development and achieving harmony between humans and nature, outlining strategies for ecological protection and sustainable growth[1].

Rapid urbanization and the heavy reliance on fossil energy have led many resource-based cities in China to face resource depletion, entering periods of maturity and decline[2]. The ongoing exploitation of resources has kept carbon emissions high in these strategic energy bases, limiting their sustainable development and hindering the achievement of high-quality urban economic goals. Being the leading global carbon emitter, China's transition to low-carbon development and sustainable practices in resource-based cities is essential for reducing reliance on high-energy, high-emission industries.

While previous studies have examined the effects of smart city initiatives on urban sustainable development, there are still a lack of research on their specific impact on carbon emissions in resource-based cities. Particularly in a country like China, with numerous resource-based cities and significant carbon emission challenges, this research area is especially important. This investigation is designed to bridge this gap by empirically analyzing the effects of smart city development on carbon emissions in resource-based cities and exploring the potential mechanisms involved.

2 Development of Smart City Construction

The pilot initiatives for smart city development are viewed as a novel approach to fostering sustainable economic and social progress, with low-carbon practices as a fundamental necessity. In December 2012, China's Ministry of Housing and Urban-Rural Development formally initiated the national smart city pilot program to hasten the construction process[3]. In the last ten years, the Chinese government has undertaken extensive initiatives in this field, rolling out three phases of smart city pilot projects. As a result, most cities are now gearing up for the advancement of smart city development.

As a new model of urbanization with Chinese characteristics, smart city construction is vital for tackling high carbon emissions in China. With the dual carbon targets emphasized in national policy, it is essential to carry out extensive studies on the impact of smart city development on carbon emissions in resource-based cities[4].

3 The Impact of Smart City Development on the Green and Low-Carbon Development of Resource-Based Cities

3.1 The Impact of Smart City Development on Technological Innovation

Additionally, smart city development promotes cross-sector resource sharing, accelerates information exchange and dissemination, fosters collaboration between innovation entities, reduces information asymmetry, lowers innovation costs, and conserves valuable innovation resources[5]. As a result, it spurs the creation of green technologies and encourages the application of energy-saving and environmental protection technologies within industries.

While fostering the rapid growth of high-tech industries, smart city development also leads to the agglomeration of industries, capital, and talent, creating a surge in innovation and providing China with a critical opportunity to harness the third technological revolution. This progress contributes to raising the innovation levels and overall competitiveness of cities. Therefore, urban innovation capacity has become one of the key metrics for assessing the efficacy of smart city development.

Based on the selected indicator of patent grants to evaluate urban innovation capacity, the trend chart illustrating patent grants in smart city pilot cities versus non-pilot cities from 2012 to 2022 indicates that both categories of cities have seen an upward trend in patent grants. Specifically, after 2012, the number of patent grants in non-pilot cities increased from an average of 1,242 to 3,571, while in pilot cities, it increased from an average of 3,974 to 8,956. This demonstrates that the growth rate of patent grants in pilot cities was considerably higher compared to those in non-experimental cities, leading to an expanding gap between the two.

In summary, smart city construction has greatly enhanced the innovation capabilities of pilot cities. By encouraging the growth of high-tech industries and cultivating a supportive environment for innovation, it provides these cities with greater opportunities for future development and improved competitiveness.

3.2 The Mechanism of Smart City Development in Promoting Green and Low-Carbon Development

Analyzing the impact mechanism of city development in resource-based cities from a technological innovation perspective requires a multi-dimensional approach. This exploration can uncover various elements that affect the connection between smart city initiatives and carbon emissions[6]. Resource-based cities often face severe carbon emission issues due to their economic structure and industrial characteristics[7]. The application of digital technology in smart city construction can provide breakthrough solutions for resource-based cities to achieve their carbon reduction goals, which can be elaborated upon in the following aspects.

1. Utilization of Technological Innovation in the Energy Sector of Resource-Based Cities: Technological innovation can significantly improve the energy system and boost energy efficiency, leading towards a decrease in carbon emissions.

2.Role of Technological Innovation for Traditional Enterprises in Resource-Based Cities: Technological innovation can optimize production models and encourage the exploration and invention in green energy, effectively reducing carbon emissions.

3. Technological Advancement as a Catalyst for Improvement the Industrial Structure of Resource-Based Cities: Technological innovation acts as an essential catalyst for resource-based cities to transition their industrial structures toward higher value-added sectors.

Building on the previous analysis, this study puts forward the research hypothesis that smart city pilot initiatives can lower carbon emissions in resource-based cities by leveraging technological innovation.

4 Model Construction

The rollout of smart city pilot policies could be considered a policy-induced external disturbance. Given that the execution occurred in phases a difference-in-differences (DID) is employed to assess the effects of the policy. The DID approach is particularly suitable for this study due to the following reasons: 1. Policy Implementation Timing: The smart city pilot policies were implemented in stages in different cities, resulting in a natural experiment. In this scenario, some cities acted as the treatment group (those that adopted the smart city policies), while others served as the control group (those that did not).2. Parallel Trends Assumption: The DID method is grounded in the assumption that, without the intervention, the treatment and control groups would have exhibited similar trends over time. Given the similar initial conditions and trajectories of carbon emissions in both groups before the policy implementation, this assumption is deemed reasonable. 3. Dynamic Policy Effects: The multi-period DID model enables us to analyze the dynamic impacts of smart city policies over time, which is essential for comprehending the lag between policy implementation and its effect on carbon emissions and the formula is as follows:

$$lncarbon_{ti} = \partial_0 + \partial_1 smart_{ti} + \gamma Control_{it} + \mu_i + \lambda_t + \varepsilon_{it} \tag{1}$$

Here, i and t denote cities and years, while "carbon" refers to urban carbon emissions, which are log-transformed to ln(carbon); smart denotes smart city development. assessed through the execution of smart city pilot policies. $\partial 1$ indicates the net effect of smart city development on urban carbon emissions, which serves as the primary coefficient of interest in the study. Should smart city development prove to significantly diminish urban carbon emissions, we would anticipate $\partial 1$ to show a notable negative value. Should $\partial 1$ be insignificant or exhibit a significantly positive value, it would indicate that smart city development does not contribute to a reduction in urban carbon emissions, control signifies the group of variables included to adjust for the impact of multiple factors on city carbon emissions. The term μi denotes fixed effects specific to cities, while λt indicates fixed effects pertaining to years, and ϵ represents the chance error component.

4.1 Variable Selection and Data Sources

Dependent Variable: In this study, carbon emissions (carbon) are defined as the dependent variable, calculated as the logarithm of the ratio of urban carbon emissions to gross domestic product (GDP). Based on data from China's Urban Statistical Yearbook and relevant accounting methodologies, the specific formula for measurement is presented as follows:

$$carbon = Cu + Cp + Ct = \mu \mathrm{Eu} + \upsilon \mathrm{Ep} + \Gamma(\eta \times \mathrm{Et}) \tag{2}$$

In this context, carbon represents urban carbon emissions; Cu, Cp, Ct denote carbon emissions resulting from the consumption of urban natural gas, liquefied petroleum gas, and overall electricity use in society, respectively; Eu, Ep, Et represent the historical data on the consumption of natural gas and liquefied petroleum gas, and total social electricity in cities, respectively. As coal accounts for nearly 60% of China's electricity generation and plays a significant role in the country's energy framework, coal-fired power generation is the leading contributor to carbon emissions. Thus, coal-fired power generation serves as an indicator for measuring the level of carbon dioxide emissions. η denotes the percentage of coal-fired power generation within the overall electricity generation. Given the relatively minor variations in the share of coal-fired power generation among different cities in China, data on coal power ratios from the annual "China Electric Power Yearbook" serve as a standard reference for uniformly assessing the coal power ratio at the city level. μ, ν, Γ indicate the emission factors for natural gas greenhouse gases, liquefied petroleum gas, and coal power plant generation, with respective values of 2.162 kg/m^3, 3.1013 kg/m^3, and 1.3022 kg/(kW•h).

Key Independent Variable: Smart city development (smart) serves as the primary explanatory variable in this study. It represents the interaction term involving indicator variable for smart city pilot areas (du_i) and the virtual variable indicating the time of smart city pilot approval (dt_{it}). The value assignment rule for du_i is as follows: if city i is identified as a smart city pilot (treatment group), then du_i is set to 1; if city i is not recognized as a smart city pilot, then du_i will be set to 0. The value assignment rule for dt_{it} is: if city i is recognized as a smart city pilot in the year it receives approval and in subsequent years, dt_{it} will be set to 1; otherwise, dt_{it} will be set to 0.

Ultimately, through reviewing relevant literature and after selection, the analysis revealed a total of 126 resource-based cities, of which 52 have been approved as smart city pilots and 74 are non-smart city pilots. In other words, this research consists of 52 cities classified as the experimental group and 74 cities in the control group.

The control variables selected in this study include:

1.Economic Development Level (lnpgdp): This is measured as logarithmic transformation of GDP per capita. 2.Consumption Level: This is evaluated using the ratio of total retail sales of consumer goods to gross domestic product (GDP). 3.Population Density: This is calculated as the ratio of the ratio of population to area in the prefecture-level city of its administrative region. 4.Urban Greening Area: This is expressed as the natural logarithm of the urban green space area within built-up zones. 5.Fiscal Dependence: This is reflected by the ratio of local general public budget revenue to gross domestic product (GDP).

The information for the control variables is derived from the "China Urban Statistical Yearbook," covering the period from 2007 to 2020.

4.2 Statistical Summary of Variables

Table 1 is a statistical summary table that provides descriptive statistical information for the variables. It is compiled based on the content of the previous chapter to display key characteristics of the data, including sample size, mean, standard deviation.

Table 1. Statistical Summary of Variables

Variable Names	Sample Size	Overall Sample Mean	Standard Deviation	Sample Size	Control Group Mean	Standard Deviation	Sample Size	Treatment Group Mean	Standard Deviation
lncarbon	1890	4.0580	0.5793	1125	-4.0357	0.5656	780	-4.0905	0.5983
lnpgdp	1890	1.1733	0.7069	1125	1.0777	0.6637	780	1.3130	0.7414
Consumpt	1890	0.3719	0.1088	1125	0.3738	0.1138	780	0.3691	0.1004
Density	1890	0.0419	0.0354	1125	0.0388	0.0324	780	0.0464	0.0354
Greening	1890	7.8370	0.9557	1125	7.6656	0.8368	780	8.0873	1.0546
Fiscal	1890	0.0598	0.0339	1125	0.0566	0.0357	780	0.0644	0.0378

4.3 Baseline Regression

Table 2 outlines the regression findings derived from the baseline model (1), which accounts for fixed effects related to both years and cities. In the first column of Table 2, no supplementary control variables incorporated (2) to (6) sequentially introduce control variables. From Table 2, it is evident that independent of the presence of control variables, the calculated coefficient for smart is negative and is statistically significant at the 1% level. Using column (6), which includes all control variables, as the basis for final analysis, it is evident that the impact of smart city development on carbon emissions has passed the 1% significance test, with a coefficient value of -0.0431.

From an economic perspective, this implies that, compared to non-pilot cities, the implementation of smart city development has led to an average decrease of 4.31% in carbon emission intensity growth rates in pilot cities. In other words, the implementation of smart city pilot policies contributes to reducing urban carbon emissions, yielding carbon reduction effects and promoting improvements in the local ecological environment. Therefore, enhancing smart city development can provide new insights for China to achieve its dual carbon goals.

Regarding control variables, in terms of carbon emission control, the level of economic development (lnpgdp) shows a negative effect that passes the 1% significance test. China's economic achievements in recent years have made it the world's second-largest economy, providing a solid material foundation for effectively controlling carbon emissions. Meanwhile, China might have already passed the turning point of the Environmental KC and entered the declining phase curve, indicating that sustained economic development is key to addressing issues such as carbon emissions.

Table 2. Benchmark Regression Analysis Results

	1	2	3	4	5	6
smart	-0.0691***	-0.0498***	-0.0427***	-0.0427***	-0.0427***	-0.0432***
	(-7.0409)	(-6.5190)	(-5.7136)	(-5.7128)	(-5.7103)	(-5.7543)
lnpgdp		-0.5081***	-0.4557***	-0.4557***	-0.4557***	-0.4545***

		(-44.8437)	(-38.4002)	(-38.3660)	(-37.8243)	(-37.6614)
comsump			0.4993***	0.4993***	0.4993***	0.5061***
			(12.2140)	(12.2053)	(12.1756)	(12.3041)
density				-0.0115	-0.0113	-0.0219
				(-0.0579)	(-0.0569)	(-0.1099)
green					-0.0002	0.0001
					(-0.0194)	(0.0158)
fiscal						0.2002*
						(1.8123)
_cons	-3.4953***	-3.3502***	-3.5282***	-3.5269***	-3.5257***	-3.5411***
	(-366.0600)	(-414.3300)	(-213.1100)	(-194.4900)	(-56.4883)	(-56.2853)
Year	√	√	√	√	√	√
City	√	√	√	√	√	√
Observations	3285	3285	3285	3285	3285	3285
R-squared	0.8319	0.8987	0.9034	0.9034	0.9034	0.9035

The significant positive coefficient for consumption (consump) indicates that the increase in consumption levels exacerbates carbon emissions, reflecting that the current consumption patterns have not fully integrated green concepts, resulting in waste and unreasonable consumption. The effect of population density (density) on carbon emissions is not significant, as its impact may be long-term and dynamic. The regression coefficient for urban greening area (green) is not significant, suggesting that current investment in greening is insufficient to produce significant environmental benefits, and further investment in greening is needed. The significant positive coefficient for fiscal dependence (fiscal) implies that smart city development may have increased urban carbon emissions, reflecting that government intervention may distort market mechanisms, leading to resource waste and hindering the carbon reduction process.

5 Conclusion

This paper investigates whether the construction of smart cities demonstrates a decrease in carbon impact in cities reliant on resources. First, it theoretically analyzes the pathways by which the development of smart cities affects carbon emissions. Utilizing panel data from Chinese cities covering 2006 to 2020, with urban carbon emissions as the dependent variable and smart city construction as the main independent factor, it includes urban economic development level, consumption level, population density, urban greening level, and fiscal dependence as control variables. A multi-period difference-in-differences (DID) model is employed to assess the carbon reduction effect of smart city construction and analyze its impact on carbon reduction in cities with diverse characteristics. The key findings are as follows:

The empirical findings suggest that smart city development significantly suppresses urban carbon emissions. By comparing data from pilot and non-pilot areas, it is found that smart city development resulted in a reduction of approximately 4.31% in the carbon emission intensity growth rate in pilot areas compared to non-pilot areas. This result suggests that the new type of urbanization represented by the development of smart cities plays a crucial role in advancing carbon reduction efforts.

The suppressive impact of smart city development on carbon emissions takes time to manifest. In the early stages of policy implementation, this effect is not immediately apparent, typically becoming noticeable in the third year of policy implementation and gradually strengthening in subsequent years. This indicates that smart city construction requires ongoing efforts and time accumulation and cannot be rushed for immediate results.

However, this research has a few constraints. Initially, owing to data availability, the analysis is limited to cities in China, which may restrict the generalizability of the findings. Second, although we controlled for several variables that could affect carbon emissions, there may still be confounding factors that are not fully captured. Additionally, the study primarily focuses concerning the explicit effect of smart city development on carbon emissions, with insufficient exploration of its potential indirect effects and long-term impacts.

Despite these limitations, the significance of this study should not be overlooked. Firstly, it provides a new perspective on understanding the function of smart city construction in fostering green and low-carbon transformation of resource-based cities. Secondly, the results are crucial for formulating and implementing effective policy measures to reduce carbon emissions in resource-based cities. Lastly, as the global emphasis on sustainable development and climate change response increases, the findings of this study are also relevant for other countries and regions aiming to achieve carbon reduction goals during the advancement of smart city initiatives development.

Subsequent research may delve deeper into the indirect effects and long-term impacts, as well as the effectiveness of implementing smart city development in different varieties and scales of urban areas. Additionally, more social, economic, and environmental factors can be considered in the analysis framework to more comprehensively assess the impacts impact of smart city construction.

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