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Low-Carbon City Building and Green Development: New Evidence from Quasi Natural Experiments from 277 Cities in China

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Abstract: As a high-quality and sustainable growth model, green development has different economic, ecological, and social dimensions and is strategically important for the realization of modern city construction and the sustainable development of human society. The low-carbon city pilot policy (LCCP) is an innovative initiative for promoting green urban development and building a harmonious society in China. Based on balanced panel data from 277 prefecture-level cities from 2007 to 2020, this paper measures the level of urban green development in terms of three dimensions: green economic growth, ecological welfare enhancement, and social welfare increase. This paper also adopts a multi-period difference-in-differences (DID) method for investigating the impact of LCCP on green development with the panel dataset. The results of the study show that: (1) LCCP is generally beneficial to urban green development, and the results still hold after a series of robustness check analyses. (2) The results of the mechanism analysis show that the construction of low-carbon cities has improved the level of green technology innovation, thereby promoting the level of regional green development. Environmental regulation has a masking effect between low-carbon city construction and green development in this study. When environmental regulation is controlled for, the coefficient of the effect of LCCP on green development increases, reflecting that environmental regulation also plays an important role between the two. (3) According to the geographical location, whether it is a resource-based city, and the city cluster, we found that the low-carbon city pilot policy has a significant positive role in promoting green development in the central region, non-resource-based cities, and the Jing-Jin-Ji, but not in the eastern region, the western region, the Yangtze River Delta and Pearl River Delta. We also found that in resource-based cities, this effect presents a significant negative relationship. The above findings enrich the literature on low-carbon city pilot policies and green development and provide Empirical evidence for relevant countries and regions to carry out low-carbon city pilots.

Keywords: low-carbon city pilot policy; green development; multi-period difference-in-differences (DID); mediating effects; suppression effects

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1. Introduction

A good natural resource environment is the fundamental driver of sustainable urban development [1]. Going green is not only an inevitable choice for economic development, social prosperity and environmental well-being but has also been a central demand of many global policies in recent years [2]. Since China's reform and opening up, the crude black economic growth model has led to serious environmental pollution problems. The green development path is not only a traction for China to move towards an ecologically civilized society, but also an important grasp for transforming the economic growth model [3]. However, with the emergence of various environmental problems such as greenhouse gas emissions, increasing weather extremes, and decreasing biodiversity, the search for and implementation of a green development path has become a very urgent issue nowadays.

Based on this, different scholars have given their answers based on different perspectives, such as clarifying green development goals [4], upgrading science and technology finance [5], promoting smart city pilots [6], and building low-carbon cities [7]. However, as the world's largest emitter of greenhouse gases, China has incorporated carbon reduction into its national medium- and long-term development plans [8]. As a result, low-carbon emission reductions will have a more significant impact on green development. To address climate issues and accelerate economic transformation, China's National Development and Reform Commission (NDRC) launched a pilot low-carbon city construction program in 2010 and has been gradually promoting the program since 2012 and 2017. One of the main objectives of the pilot project is to transform economic growth, control the greenhouse gas emissions of urban and rural residents, improve and protect people's livelihoods, and promote green development in the quest for a new type of urbanization [9]. In addition, green technological innovation and environmental regulation are also fundamental drivers of green development [10,11]. The policy tools in the pilot policy for the low-carbon cities, such as research and development subsidies, tax incentives, and financial support, will directly stimulate the vitality of green technology innovation in cities. Meanwhile, as an environmental protection policy, the construction of low-carbon cities will also increase the intensity of environmental regulations. Therefore, green technology innovation and environmental regulation also appear to be key concepts in understanding the relationship between low-carbon city construction and green development.

The rest of the paper is structured as follows. Section 2 introduces the related literature review. Section 3 introduces the main background of low-carbon city construction and proposes the assumptions of the paper. Section 4 introduces the methods and data. Section 5 indicates the temporal and spatial evolution trend of the green development level of prefecture-level cities in China and explores the causal relationship between low-carbon city construction and green development. Section 6 examines the level of green innovation technology and the mechanism of environmental regulation, as well as whether there is heterogeneity due to several factors. Section 7 provides a summary of the entire text.

2. Literature Review

2.1. Definition of the Concept of Green Development

The above raises three important questions for the study of this paper. First, what is the scope of the concept of green development, and how does one go about evaluating it? To begin the study of green development, a precise definition of green development is needed. As a high-quality development model, green development places more emphasis on decoupling resource consumption, pollution emissions, and economic growth while taking efficiency and equity into account through rational allocation of resources, remedying factor shortcomings, and improving policy and institutional construction to ultimately achieve the harmonious and orderly development of the economic system, social system, natural system [12–14]. In short, the main purpose of green development is to find a balance among the economy, ecology and society, and with the deepening of theoretical research, some scholars have been discussing the issues of coordination [15], sustainability [16], and social equity [17]. In the meantime, the number of studies on the impact mechanism and efficiency assessment of green development has been increasing with the advancement of practical exploration and pilot projects. Zhou et al. [18] used the super efficiency EBM method to measure the level of green development of the marine economy in 11 coastal provinces and cities in China; Li et al. [19] used the spatial Durbin model to study the impact of the agglomeration of productive service industries on the level of green development in the Yangtze River Economic Zone of China; Ge et al. [20] explored the relationship between economic growth targets and green development based on panel data from 285 prefecture-level cities in China. These studies provide support for the construction of a green development indicator system in this paper.

2.2. Relationship between Low-Carbon City Construction and Green Development

Second, does low-carbon city construction necessarily promote green urban development? Most research articles on low-carbon cities focus on their role in improving environmental quality and controlling greenhouse gas emissions [21,22]. In the case of China, Cheng et al. [23] used the DID model to check out the role of low-carbon city construction on economic green growth. Qiu et al. [24] used green total factor productivity as a proxy for green development; the study found the positive effect of low-carbon city construction on green development and examined the transmission mechanisms of industrial structure, technological innovation, and energy consumption. Zheng et al. [25] tested the mechanism of influence between low-carbon city construction and industrial structure. Lan et al. [26] found that different urban functional forms play an important role in the construction of low-carbon cities. In general, most studies support the role of low-carbon city construction in promoting green development.

2.3. Mechanisms of Influence between Low-Carbon City Construction and Green Development

Thirdly, how can low-carbon city construction achieve green urban development? Most studies exploring this issue have focused on the themes of economic development and environmental protection. Du et al. [27] proposed that pilot construction can improve the efficiency of carbon emissions and optimize the structure of carbon emissions. Wen et al. [28] confirmed that LCCP can improve the efficiency of carbon emissions by 6.6 percentage points. Other studies have also shown that low-carbon cities have a driving effect on overall urban technological innovation [29,30]. In addition, the government, as a policy maker and public opinion implementer, has played an important leading role in the pilot's construction [31]. As a result, many scholars have focused on the mechanisms of environmental regulation in this context. Zhou et al. [32] found that environmental regulations have a binding effect on energy savings and emission reduction by enterprises. In general, although low-carbon city construction can promote green urban development through energy saving and emission reduction, plantation, optimization of industrial structure, and support for environmentally friendly enterprises, we note that technological innovation and environmental regulation are still in doubt in mechanistic studies.

In technological innovation, Zhou et al. [33] found that the LCCP significantly inhibited urban technological innovation, and technological innovation is not necessarily beneficial to the environment but may also increase greenhouse gas emissions, disguising the "pollution paradise hypothesis" and ultimately hindering green development [34]. In contrast, environmentally friendly technological innovations would be more suitable for green urban development. Green technology innovations are those that have a positive or less negative impact on the environment and are generally related to energy conservation and emission reduction, urban environmental management, and environmentally sound waste treatment [35]. Danish et al. [36] argue that encouraging the diffusion of environmental technologies will contribute to more stable policies. Furthermore, green technology innovations hold more promise for achieving green development and leading to innovation-driven economic growth models [37]. However, little literature has explored the causal relationship between green technology innovation and both, and we still need to confirm this mechanism through a rigorous proof process.

In terms of environmental regulation, the relationship between environmental regulation and green development is not yet clear, and there are different views in the academic community on the relationship between the two. Song et al. [38] suggest that there is an "inverted U-shaped" relationship between environmental regulation and green economic growth. Ye et al. [39] examined the role of environmental regulation on the green development of the marine economy through the GMM method and found that there is a lagged effect in the promotion of environmental regulation. In addition, Lv et al. [40] found that environmental regulation has a negative moderating effect between financial efficiency and green innovation. Tian et al. [41]'s empirical research on China's environmental regulation policy found that environmental regulations hinder economic development and do not improve green development efficiency. Taken together, there is heterogeneity in the mechanical effects of different types of environmental regulations, with different impact mechanisms for directive control, encouraging public participation, and economic incentives [42]. Thus, there is still a lack of discussion on how environmental regulation affects both.

From the literature review, it appears that green technology innovation and environmental regulation are not only part of green development efficiency but also potential tools for low-carbon city construction to influence green development [43–45]. According to the theory of directed technological progress, green technological innovation is a fundamental force in promoting green productivity progress, supporting resource- and environment-friendly industries, and developing green products [46]. At the same time, LCCP acts as a top-down signaling system, with a strong and structured vertical link between the central and local governments [47]. However, as to whether environmental regulation is conducive to green development, the "innovation compensation" school of thought may argue that environmental regulation can force traditional polluters to transform, promote technological innovation, compensate for the costs of regulation, and achieve regional green development [48]. The "cost barrier" school of thought may argue that environmental regulation will impose new constraints on business development, interfere with market flexibility, and ultimately inhibit regional economic development [49]. The relationship between environmental regulation and green development is therefore complex, and more rigorous empirical data and empirical studies are needed to demonstrate the causal relationship between the two.

China's low-carbon city pilot policy (LCCP) provides a valuable opportunity to demonstrate these relationships. In the framework of such a quasi-natural experiment, the multi-period Difference-in-Differences (DID) model was used to examine the effects of low-carbon city construction using data from 2007–2020 for prefecture-level cities in China. The non-pilot cities were used as the reference group, and the pilot cities were used as the experimental group to assess the effect of the LCCP by observing the changes in the two groups before and after the policy treatment and to test the causal relationship between low-carbon city construction and green development. Afterward, the validity of the core findings was tested by the parallel trend test, PSM-DID method, deletion of special samples, placebo test, and Bacon decomposition. On this basis, green technological innovation and environmental regulation are used as mechanism variables, and a mediating effect model is applied to test whether low-carbon city construction can achieve green development by raising the level of green innovation and implementing environmental regulation tools. Finally, considering the heterogeneity among different cities, we studied the heterogeneous influence of different city characteristics through three aspects: geographical location, urban agglomeration, and resource endowment.

2.4. Research Gaps and Possible Marginal Contributions

Based on the above three issues, we found that there are still research gaps in previous studies: first, there is little literature that considers the different connotations of green development in research, and most studies view green development more as a coordinated relationship between economic growth and environmental protection without paying attention to the social value of green development. Secondly, due to the lack of a unified paradigm for defining green development, previous studies have mostly used a single alternative indicator to measure it. It remains to be explored whether low-carbon city construction still has a positive effect on more comprehensive green development. Moreover, existing literature has mostly studied specific impact mechanisms at the provincial level, which makes it difficult to provide an exemplary experience for other cities. Thirdly, the relationship between technological innovation and environmental regulation remains questionable. Based on this, This paper adds to the existing research in three aspects. First, based on the theoretical connotation of green development, this paper attempts to construct a three-dimensional framework of economic, social, and ecological development, to provide a more comprehensive definition of the quality and efficiency of green development, thereby enriching the theoretical connotation and providing practical value. Secondly, this paper uses a panel of 277 prefecture-level cities in China as a sample to anchor the priorities and weaknesses of similar pilot policies for other cities and indeed for other developing countries. Thirdly, this paper uses green technology innovation and directive environmental regulation instruments as mechanism variables to explore the mechanism of their influence on pilot policies and green development, fill the research gap, and provide a reference for further policy improvement.

3. Mechanism Analysis

3.1. Policy Background

Since the 21st century, the concept of low-carbon cities has gradually become popular internationally as the seriousness of the climate problem has been agreed upon. In 2003, the UK first put forward the concept of a “low-carbon city”, which aims to achieve a higher quality of life while reducing energy consumption and pollution. In 2005, the United Nations’ Kyoto Protocol for the first time legally required countries to curb their greenhouse gas emissions. In 2007, Japan introduced the concept of “low-carbon society”, which includes ecological protection as an important indicator of social development.

Following the global wave, China’s National Development and Reform Commission issued the Notice on the Piloting of Low-Carbon Provinces, Regions, and Low-Carbon Cities in 2010, a document that marked the beginning of China’s low-carbon city policy. The Notice on the Second Batch of National Piloting of Low-Carbon Provinces, Regions, and Low-Carbon Cities, published in 2012, further advanced the piloting process, clarified the deployment of tasks, and explored different types. In 2017, in line with China’s work program to control greenhouse gas emissions, the Notice on the Piloting of low-carbon Communities was published to explore a new type of urbanization path and accelerate the construction of low-carbon communities.

The objectives of the LCCP vary by region and specific policies. In terms of China’s national policy, the goal is to promote low-carbon economic and social development, reduce energy consumption, and find a low-carbon, green, and sustainable development path. Since the launch of the pilot, a total of 80 cities as well as one region are currently included.

3.2. Interrelationships between Economic-Social-Ecological Systems

As we have mentioned in the literature review, green development is a sustainable development model featuring economy, ecology, and society, which not only requires the coordinated development of the three but also has dimensional differences in goals. The economic system seeks green, efficient, high-quality, and clean production methods, with a view to eventually achieving a “decoupling” between economic growth and resource consumption. Ecosystems emphasize reducing environmental pollution and providing environments and services that increase human well-being. The social system seeks to increase human welfare, change the people’s concept of production and life, reduce the unfair distribution of income, improve and protect the people’s livelihood, and benefit the people’s livelihood with the fruits of green development.

The coordinated symbiosis of the three systems will develop to achieve true “green prosperity”. This coordinated symbiosis is now linked to all three and mainly includes three aspects: first, on the basis of green economic development and social welfare increases, if we make full use of funds and technology, continue to protect and improve the ecological environment, and increase the ecological supply, we can realize the coordinated symbiosis between economy, society, and ecology [50]; second, while achieving green economic development and enhancing ecological welfare, if resources can be continuously saved, public service input can be increased, and the concept of green social development can be implemented, the coordination between economy, ecology, and society can be realized [51]; third, while increasing social welfare and improving ecological well-being, if we can not only provide a high-quality living environment but also better meet people’s material and cultural needs, create a highland of technology and talents, so as to attract high-quality elements to flow in, and promote the green development of regional economies, we can realize the coordination between society, ecology and economy [52]. Economic, social, and ecological systems interact and coordinate with each other to achieve a virtuous cycle of development for the three and promote the substantive realization of green development.

3.3. Mechanism Analysis and Hypothesis

We construct a conceptual framework as shown in Figure 1. As mentioned earlier, we measure green development through three dimensions: green economic growth, ecological welfare enhancement, and social welfare increase, and focus on exploring the mechanisms of environmental regulation and green technological innovation in between. In this section, therefore, we formalize these hypotheses through theoretical analysis and literature research.

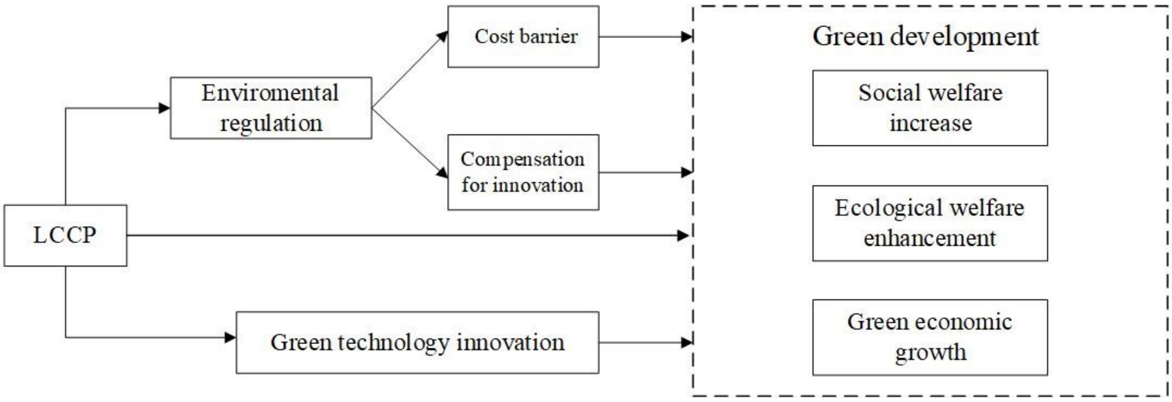

Figure 1. Conceptual framework.

LCCP as a pilot type of policy to actively respond to environmental problems and climate crisis puts forward three specific requirements: one is to further harmonize the relationship between resources and environment, economic development and improving people's lives, and through policy and institutional construction, to form a new pattern of green and low-carbon development and steadily create a new situation of ecological civilization construction [53]; the second is to establish a low-carbon industrial system characterized by resource-friendly and environment-friendly industries, adjust the industrial structure, and vigorously support green strategic emerging industries and modern service industries; the third is to lay out the overall economic and social development, guide residents to live a green and low-carbon life, improve and protect people's livelihoods, and explore a new low-carbon urbanization path [54]. To this end, the pilot cities have formulated fiscal and monetary policies and industrial support policies that are conducive to green urban development, which will not only help to attract high-tech, specialized production factors, and human capital to the cities but also help to guide the construction of low-carbon social infrastructure and improve people's livelihoods.

At the same time, as an important environmental policy in the field of ecological civilization, it will also encourage the adjustment of urban industrialization, the supply of quality ecological products, the provision of green public space, etc. Its effectiveness will be enhanced, while other cities will also approach the pilot cities in terms of policy, technology, and industrial. Accordingly, this study proposes the following hypothesis.

Hypothesis 1 (H1). *LCCP is conducive to leading the green development of cities.*

The use of command-and-control environmental regulation tools has been widely used in China, and LCCP will further emphasize the use of environmental regulation tools. Taking into account the mainstream views of the academic community, this study will explain the mechanism of environmental regulation on green development from the perspectives of "cost barrier" and "compensation for innovation". From the perspective of the "cost barrier", the direct impact of environmental regulation is to increase the "cost of compliance" of enterprises in the short term and to squeeze the profit margin of enterprises in the long term, leading to unhealthy competition [55]. In addition, controls on raw materials can also affect the expansion of firms' production; for example, controls on coal and oil can affect the production and sales of downstream firms. From the perspective of "compensation for innovation", environmental regulation will have a positive impact on green development by reducing carbon emissions, increasing R&D and the demand for clean energy, and thus improving environmental quality [56]. At the same time, the regulatory approach of policy compensation with additional incentives does not necessarily increase the burden on firms either [57]. Thus, the mechanisms of environmental regulation on green development may either facilitate or inhibit it, with the former exhibiting a mediating effect and the latter a "suppression effect". The "suppression effect" is also a phenomenon that exists in mechanism analysis, where the direct and indirect effects have opposite signs and the total effect is masked [58]. Accordingly, this study proposes the following two hypotheses.

Hypothesis 2a (H2a). *There is a mediating effect of environmental regulation between LCCP and green development.*

Hypothesis 2b (H2b). *Environmental regulation has a suppression effect between LCCP and green development.*

Although the mechanism of the role of environmental regulation between LCCP and green development remains divergent, most of the existing literature supports the positive effect of green technology innovation on green development. Low-carbon city construction will encourage low-carbon technology research and development, forcing firms to shift to environmentally friendly production methods, which in turn will promote green economic growth [24]. From the demand side, the construction of low-carbon cities will release demand signals for "low-carbon emission reduction solutions" to the market, which in turn will create a huge market demand for green technology innovation by enterprises and stimulate innovation [59]. From the supply side, the construction of low-carbon cities will attract more high-quality talent, technology, capital, and other innovation factors through policy incentives, improve the efficiency of green development, and accelerate the construction of infrastructure, while market players will be more willing to invest in technologies that go beyond traditional concepts and have certain prospects as development costs decrease [60]. Accordingly, this study proposes the following hypothesis.

Hypothesis 3 (H3). *Green technology innovation produces a positive mediating effect between low-carbon city construction and green development.*

In addition, the pilot role of low-carbon city construction is also likely to be affected by some individual city characteristics, such as resource endowment and geographical location. On the one hand, the economic development level of eastern China is relatively high, but the industrial system is often mature. It is still doubtful whether the construction of low-carbon cities fits with the local industrial advantages. Meanwhile, the eastern region also faces serious "social problems". Some of the "big city diseases" may also crowd out low-carbon city construction. For example, some of China's large cities, such as Beijing, Shanghai, and Shenzhen, are suffering from "big cities problems" such as overcrowding, environmental degradation, and waste of resources, forcing them into a high-energy, high-emissions mode of industrial development, which is difficult to change while urban infrastructure has a long life cycle, also known as "high carbon lock-in" [61].

On the other hand, the central and western regions tend to be more backward in terms of infrastructure, but there is clear scope for industrial development and less costly industrial restructuring and optimization, so there may be a "starting advantage" in building low-carbon cities. Secondly, differences in resource endowments may also have different impacts. The existence of the "resource curse" potentially hinders the green development of cities, while non-resource-based cities may also be able to "Overtake on a corner" by developing high-tech industries. Based on these differences, this paper proposes the following hypothesis:

Hypothesis 4 (H4). *Different geographical locations, resource endowments, and urban clusters can lead to heterogeneous results on the impact of low-carbon city building on urban green development.*

4. Methodology and Data

4.1. Model Established

4.1.1. Multi-Period Difference-in-Differences Method

The core of the difference-in-difference (DID) method, a common method used in empirical research to assess the effects of policies, is that it eliminates the effect of changes in endogenous factors on the explanatory variables by differencing twice, i.e., it looks at the change before and after the policy for individuals affected by the policy and for individuals not affected by the policy, and the difference between the two changes is the effect of the policy intervention on individuals [62]. Since 2010, the National Development and Reform Commission (NDRC) of China has been launching pilot projects for low-carbon cities, and so far, three batches of cities have been piloted. Based on this, this paper treats the three low-carbon city pilot constructions as a quasi-natural experiment and applies the multi-period DID method to study the impact of low-carbon city construction on urban green development. Since some pilot cities are repeated in the three pilots, we define the policy treatment time of the existence of a duplicate pilot city as the earliest time when the city conducts the pilot, and if all the cities in a province are approved as low-carbon pilot areas, the province All cities are considered for low-carbon city pilot work. The pilot cities are considered the experimental group, while other non-low-carbon pilot cities are regarded as the control group. In terms of sample selection, the four municipalities directly under the central government and some regions with missing data were removed from the paper, resulting in 118 experimental groups and 159 control groups.

Based on the above analysis, this paper constructs a multi-period double difference model with two-way city and time-fixed effects, with the model set as follows:

$$Gdevelopment_{it} = c_0 + c_1 LCCP_{it} + \sum_{2}^{k} c_k X_{kit} + \mu_i + \tau_t + \varepsilon_{it}, \tag{1}$$

In Formula (1), $Gdevelopment_{it}$ represents the green development index of the city; $LCCP_{it}$ is the dummy variable responding to the pilot construction, which is the core explanatory variable of this paper. If city i carries out low-carbon city pilot construction in year t, then $LCCP_{it}$ is equal to 1, otherwise it is equal to 0; X_{kit} represents the control variable sets; μ_i and τ_t represent the city fixed effects and time fixed effects, respectively; ε_{it} represents the random disturbance terms.

4.1.2. A Mechanistic Model of the Role of Environmental Regulation and Green Technology Innovation

As we proposed in H2a, H2b, and H3, we argue that environmental regulation and green technology innovation are important channels through which low-carbon city construction affects green development. Based on this, this paper attempts to test these hypotheses using a mediating effects model, as follows:

$$M_{it} = a_0 + a_1 LCCP_{it} + \sum_{2}^{k} a_k X_{kit} + \mu_i + \tau_t + \varepsilon_{it}, \tag{2}$$

$$Gdevelopment_{it} = b_0 + b_1 LCCP_{it} + b_2 M_{it} + \sum_{3}^{k} b_k X_{kit} + \mu_i + \tau_t + \varepsilon_{it}, \tag{3}$$

In Formulas (2) and (3), $Ginov_{it}$ and ER_{it} as mediating variables between green technology innovation and environmental regulation, respectively. The former represents the level of green technology innovation in city i in year t, and the latter represents the strength of environmental regulation in city i in year t. The meanings of the other variables are consistent with the baseline model settings. Equation (1) estimates the total effect of low-carbon city construction on green development c_1; Equation (2) estimates the configurational effect of low-carbon city construction on the mediating variables a_1; Equation (3) estimates the direct and indirect effects of low-carbon city construction on green development b_1 and indirect effects b_2c_1[63]. Given that the Sobel test requires the assumption that the key parameters are normally distributed, it is difficult to satisfy this assumption in practice. Based on this, this paper uses the bootstrap method to assist in testing the mechanism effect [64]. When the confidence interval of the bootstrap method does not contain 0, it indicates that the mechanism effect is not equal to 0.

4.2. Variables

4.2.1. Explained Variable: Green Development

The explanatory variable studied in this paper is the Green Development Indicator ($Gdevelopment$).

Drawing on the work of other scholars [63,65–68], we construct a three-dimensional evaluation framework of economy, society, and ecology and use three secondary indicators of economic green growth (ED), ecological welfare enhancement (GD), and social welfare increase (SD) to comprehensively evaluate the level of green development in cities. In this paper, we construct the indicator system as shown in Table 1.

Table 1. Urban Green Development Indicator System.

Tier 1 Indicators	Secondary Indicators	Specific Indicator Measurements	Indicator Attributes
Economic green growth (*ED*)	Economic growth rate (*ED1*)	Regional GDP growth rate	+
	Structure of Economic Growth (*ED2*)	Industrial structure	+
	Cost of Economic Growth (*ED3*)	Energy consumption per unit of GDP	−
	Economic Growth Drivers (*ED4*)	Intensity of financial science and technology support	+
Ecological welfare enhancement (*GD*)	Eco-safety (*GD1*)	Environmental Pollution Index	−
	Ecological Construction (*GD2*)	Calculated through entropy method	+
Social welfare increase (*SD*)	Income distribution equity achieved (*SD1*)	Calculated by Theil index	−
	Infrastructure Development (*SD2*)	Calculated through entropy method	+
	Level of social security (*SD3*)	Social security and employment expenditure/general budget expenditure	+

Source: Author. Note: + Positive indicator, − Negative indicator.

The measurement of economic green growth indicators (ED) is further deconstructed in this paper from four aspects: economic growth rate, economic growth structure, economic growth cost, and economic growth drivers: economic growth rate is measured by the regional GDP growth rate ($ED1$), which can better reflect the level of economic development of a region [69]; the economic growth structure indicator is measured by the industrial structure indicator ($ED2$), i.e., the ratio of the value-added of the tertiary sector to the value-added of the secondary sector, taking into account the fact that economic growth is driven more by the contribution of environmentally friendly industries [70]. An important task of green development is to promote economic growth with a high degree of "decoupling" from energy consumption, which is measured by the energy consumption per unit of GDP indicator ($ED3$), i.e., the ratio of regional gross domestic product (RMB 10,000 yuan) to regional energy consumption (million tons of standard coal) [71]. However, due to the lack of energy data in China's prefecture-level cities, considering the main aspects of energy consumption, we obtained alternative energy consumption indicators through the conversion of electricity consumption, natural gas, and liquefied petroleum gas in the whole society. In addition, technological innovation, the development of new industries, and attracting green investment are also fundamental forces for green economic development, which is measured by the fiscal support intensity ($ED4$), i.e., the ratio of local government fiscal expenditure on science and technology to local government fiscal expenditure [72].

The measurement of the ecological welfare enhancement (GD) indicator is measured in this paper in terms of both ecological governance and ecological construction, with environmental justice and pollution control being aspects of urban planning and development that cannot be ignored [73]. In this paper, the environmental pollution index ($GD1$) is used to measure this level, which is obtained by assigning an entropy value to three types of pollution data: industrial wastewater emissions, industrial smoke emissions, and industrial sulfur dioxide emissions. In addition, as an important carrier of green development, the city should establish a high-quality sustainable development model for landscaping to meet the diverse needs of the people and contribute to the green and high-quality development of the city [74]. This paper is an attempt to establish a sustainable model of urban greening in built-up areas. In this paper, ecological governance ($GD2$) is calculated by assigning an entropy value to the greening coverage of built-up areas, the number of parks, and the parking area.

This paper deconstructs the measurement of social welfare increase (SD) indicators from three aspects: income distribution equity ($SD1$), infrastructure development ($SD2$), and social security level ($SD3$).

First of all, for the calculation of income distribution equity indicators, previous scholars mostly used the Gini coefficient indicator to measure the income distribution gap, but this method cannot reflect the proportion of urban and rural populations; therefore, this paper uses the Thiel index to measure this indicator; the specific formula is as follows:

$$tl_{i,t} = \sum_{j=1}^{2} \left[\frac{p_{ij,t}}{p_{i,t}}\right] \ln\left[\frac{p_{ij,t}}{p_{i,t}} / \frac{z_{ij,t}}{z_{i,t}}\right], \quad (4)$$

where $tl_{i,t}$ represents the Thiel index, $j = 1, 2$ represents urban and rural areas, respectively. z_{ij} denotes the number of people in urban ($j = 1$) or rural ($j = 2$) areas of the region i. z_i denotes the total number of people in area i, and p_{ij} denotes the total income (expressed as the product of the corresponding population and per capita income) in urban ($j = 1$) or rural ($j = 2$) areas of region i. p_i denotes the total income in area i.

In addition, the manifestation of complex urban functions relies more on the centralized supply of infrastructure and public services. A high-quality infrastructure system not only helps to improve the urban and rural living environments but also provides a basic platform for green development. The rapid urbanization process and stable policy level have a significant impact on green development, among which the degree of improvement of public service facilities is an extremely important influencing factor [75–77]. Therefore, considering the three important aspects of transportation, healthcare, and education, this article includes three sub indicators: per capita road area, number of ordinary higher education institutions, and number of beds in hospitals and health centers in the evaluation system. Calculate the level of infrastructure construction ($SD2$) through the entropy method.

Finally, social security is directly related to the well-being of the population and is a "shock absorber" for the stable functioning of the market economy, which can effectively improve people's livelihoods and accelerate the transformation of their green production and lifestyle [78]. Therefore, this paper incorporates the extent of social security into the social welfare increase indicator system, which is measured by the share of social security and employment expenditure in general budget expenditure.

Based on the description of the above indicators, this paper uses the entropy method to measure the level of urban green development and processes the standardized data. The specific steps are as follows.

Firstly, in order to eliminate the impact of dimensionality and order of magnitude, the positive and negative indicator data are standardized. A positive indicator indicates that the larger the indicator value, the higher the level of urban green development. Negative indicators indicate that the smaller the indicator value, the higher the level of urban green development. At the same time, in order to prevent $z_{ij} = 0$, the standardization method for moving the overall indicator backwards by 0.00001. The standardization method is as follows.

Positive indicator:

$$Z_{ij}^{+} = \frac{x_{ij} - \min\left(x_{1j}, x_{2j}, \cdots, x_{nj}\right)}{\max\left(x_{1j}, x_{2j}, \cdots, x_{nj}\right) - \min\left(x_{1j}, x_{2j}, \cdots, x_{nj}\right)} + 0.00001 \tag{5}$$

Negative indicator:

$$Z_{ij}^{-} = \frac{\max\left(x_{1j}, x_{2j}, \cdots, x_{nj}\right) - x_{ij}}{\max\left(x_{1j}, x_{2j}, \cdots, x_{nj}\right) - \min\left(x_{1j}, x_{2j}, \cdots, x_{nj}\right)} + 0.00001 \tag{6}$$

Among them, x_{ij} represents the data of the original secondary indicators, i represents the city, and j represents the secondary indicators, z_{ij}^{+},z_{ij}^{-} represents the standardized data, where n represents the number of samples and m represents the number of indicators.

Calculate the proportion of the ith sample to the jth indicator:

$$P_{ij} = \frac{x_{ij}}{\sum_{i=1}^{n} x_{ij}} \cdots \tag{7}$$

Calculate the entropy value of the jth indicator:

$$E_j = -k \sum_{i=1}^{n} P_{ij} \ln\left(P_{ij}\right) \tag{8}$$

among them,

$$k = -\frac{1}{\ln(n)} > 0 \tag{9}$$

Calculate information entropy redundancy:

$$d_j = 1 - E_j, j = 1, 2, \ldots, m \tag{10}$$

Calculate the weight of each indicator:

$$W_j = \frac{d_j}{\sum_{j=1}^{m}\left(d_j\right)} \tag{11}$$

Calculate Composite Index:

$$W_j = \frac{d_j}{\sum_{j=1}^{m}\left(d_j\right)} S_i = \sum_{j=1}^{m} W_j x'_{ij}, i = 1, 2, 3 \ldots, n \tag{12}$$

among them, x'_{ij} is the data after standardization.

Composite index S_i is the sum of the weights of all indicators in a certain city multiplied by the standardized values of the corresponding indicators in order to obtain the comprehensive score of the green development level of each city. The comprehensive index range of urban green development is 0–1, and the higher the score, the higher the level of urban green development; The smaller the score, the lower the level of green development in the city.

The indicator system and attributes selected for the entropy method are shown in Table 1.

4.2.2. Core Explanatory Variables

The core explanatory variable in this study is the dummy policies for low-carbon city pilot policy (LCCP), which is the cross-product of the pilot policy and the pilot time. If city i carries out low-carbon city pilot construction in year t, then $LCCP_{it}$ is equal to 1, otherwise it is equal to 0. And the coefficient is c_1, which represents the degree of impact of the pilot construction on green development, which is the main result of interest in this paper. A positive coefficient represents a positive contribution, while a negative coefficient represents a negative inhibitory effect.

4.2.3. Control Variables

Considering that other factors may also have a potential impact on urban green development, cf. Beck et al. [79] study, the following control variables were selected:

(1) population density ($density$), measured by the number of people registered per unit of administrative area; higher population density may inhibit green development by increasing energy consumption and environmental pollution, but higher levels of population density also mean more human capital, which may also provide more dynamism for green development.

(2) Fixed asset investment ratio (fix), measured by the amount of completed fixed asset investment in urban municipal utility construction as a percentage of regional GDP. Higher levels of fixed asset investment can boost the current economy and improve people's livelihoods, while at the same time creating future supply capacity and providing the driving force for future economic growth.

(3) The level of industrialization (ind), measured by the value added of the secondary sector as a percentage of regional GDP, the environmental pollution and resource consumption generated by the industrial development process remain important factors inhibiting the increase in the level of green development.

(4) The size of local governments (gov), measured as a percentage of regional GDP, is a measure of the general budget expenditure of local governments. The "visible hand" can implement green development strategies more efficiently and improve the production methods of enterprises, but the government may also neglect environmental governance under the economic championship, squeezing market flexibility and plunging the industry into "profit-seeking competition".

(5) Fiscal decentralization (fid), measured as the ratio of general local budget revenues to general local budget expenditures, higher independent fiscal authority means higher inclusiveness for local governments, which can more strongly support sustainable growth and increase renewable energy consumption [80].

(6) Financial development (fdp), measured by the loan balance of financial institutions as a share of GDP, can influence the efficiency of green development, and there is heterogeneity in financial development across zones [81].

Of these variables, we logged population density and used lndensity for subsequent empirical manipulations.

4.2.4. Mediating Variables

To measure the level of green technology innovation in cities, this paper uses the number of green inventions applied for in the year ($Ginov_1$) and the number of green utility models applied in the same year ($Ginov_2$), and the level of green innovation in cities is obtained by logarithmic processing, taking into account the existence of zero values and performing the sum plus one, i.e:

$$Ginov = ln(Ginov_1 + Ginov_2 + 1), \tag{13}$$

In this study, the pilot policies are more often signaled through reports, work plans, and approvals, and the work reports of the governments at all levels are the basis for the demands and consensus of all sectors of society and play a decisive role in guiding the implementation of the pilot projects. Therefore, this paper focuses on the important mechanism of command-and-control environmental regulation in the relationship between pilot policies and green development. Refer to the work of other scholars [82,83]. The paper also constructs 27 environmental vocabularies on the importance of environmental governance by local governments in four aspects: "environmental protection objectives", "environmental factors", "environmental pollution" and "environmental protection measures", as shown in Table 2. The ratio of the number of words appearing in the report to the frequency of words in the reports of the prefecture-level municipal governments was finally measured.

Table 2. Selected environmental vocabulary.

Environmental Protection Dimension	Select a Word	Number
Objectives	Environmental protection, environmental protection, green, clean, blue sky, green water, green hills	8
Environmental factors	Ecology, air, climate	3
Environmental pollution	pollution, sulfur dioxide, chemical oxygen demand, haze, particulate matter, carbon dioxide, energy consumption, loose coal, coal burning, emissions, emissions theft, tailpipe	12
Measures	Energy saving, emission reduction, desulphurization, denitrification	4

Source: [83].

4.3. Data Sources and Descriptive Analysis

The data on green development indicators in this study are mainly sourced from the National Bureau of Statistics, China Statistical Yearbook, China City Statistical Yearbook, China Energy Statistical Yearbook and China's economic and social Big data research platform, with some missing data being filled in by consulting the statistical yearbooks of individual cities. Data on urban landscaping was obtained from the CSMAR database. For the measurement of green technology innovation level indicators, patent application data is obtained from the State Intellectual Property Office, and green patents are identified by their green patent classification numbers, which are obtained from WIPO green patent application data. Data relating to environmental regulation is obtained from local government work reports. In addition, some missing values in the sample are filled by linear interpolation. The descriptive statistical analysis of all variables is shown in Table 3.

Table 3. Descriptive statistical analysis of the main variables.

Variable	Mean	SD	Min	Max	N
low-carbon City Pilot Policy	0.237	0.4253	0.000	1.000	3878
City Green Development Index	0.078	0.0691	0.020	0.631	3878
Population density	424.432	325.385	4.824	2927.291	3878
Level of industrialization	0.405	0.1229	0.028	0.887	3878
Local government size	0.192	0.1296	0.043	2.349	3878
Financial decentralization	0.458	0.227	0.046	1.541	3878
Fixed asset investment ratio	0.83	2.2473	0.062	82.066	3878
Financial Development	0.928	0.6075	0.075	9.622	3878
Level of green technology innovation	4.719	1.7564	0.693	10.275	3878
Environmental regulation intensity	0.020	0.020	0.000	0.124	3878

Source:Author, produced by Stata 17.0, data sources can be found in Section 4.3. Note: Mean Average Value, SD Standard Deviation, Min Minimum Value, Max Maximum Value, N Number of Samples.

5. Empirical Results and Discussion

5.1. Assessment of Green Development Level

The entropy method was used to calculate the above indicator system, and the results are shown in Figure 2. Vertically, the level of green development in Chinese cities has significantly improved, and it mostly spreads from the central and coastal areas to the surrounding and inland areas. By observing changes, we can also discover that some cities with higher green levels have shown faster growth potential in their surrounding areas. Horizontally, the areas with high levels of green development are mainly in the central and coastal regions, while the development in the western and eastern regions is relatively slow.

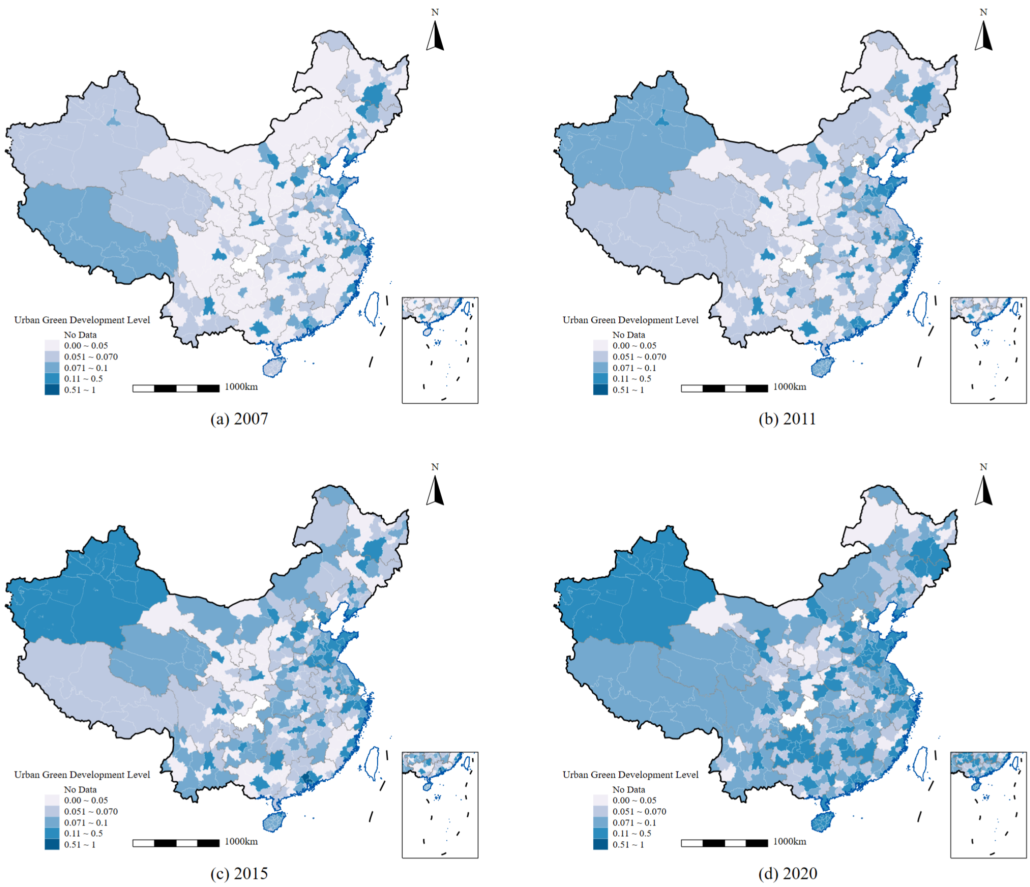

Figure 2. Spatial distribution of urban green development level in prefecture-level cities in China. Source: Author, produced by Stata 17.0, data sources can be found in Section 4.3.

5.2. Pearson Correlation Coefficient Results

Firstly, we calculate the Pearson correlation coefficient for the main variables used in this article and draw a correlation coefficient matrix diagram. The results are shown in Table 4.

5.3. Benchmark Regression Results

This paper uses a multi-period DID model to test the effect of LCCP on urban green development. Table 5 presents the baseline regression results, with heteroskedasticity robust standard errors for all models: Column (1) shows the regression results without the inclusion of control variables while controlling only for city fixed effects, with the regression coefficients significant at the 1% level; column (2) indicates the regression results controlling for both city and time two-way fixed effects without the inclusion of control variables, with the regression coefficients still passing the significance test at the 1% level, but the coefficients Columns (3) and (4) add the above control variables to the first two columns, respectively, and the regression coefficients are still significantly positive at the 1% level. Overall, the preliminary regression results demonstrate that low-carbon city pilot construction is beneficial to urban green development, and hypothesis H1 is supported.

Table 4. Pearson correlation coefficient results between the main variables.

	LCCP	Gdevelopment	ldensity	ind	gov	fid	fix	fdp
LCCP	1							
Gdevelopment	0.242 ***	1						
ldensity	0.061 ***	0.355 ***	1					
ind	−0.125 ***	−0.147 ***	0.174 ***	1				
gov	0.018 ***	−0.210 ***	−0.420 ***	−0.459 ***	1			
fid	0.078 ***	0.520 ***	0.423 ***	0.385***	−0.538 ***	1		
fix	−0.015 ***	−0.014 ***	−0.063 ***	−0.076 ***	0.055 ***	−0.058 ***	1	
fdp	0.227 ***	0.448 ***	0.019 ***	−0.379 ***	0.162 ***	0.198 ***	0.025 ***	1

Note: *** represent the 1 % statistical levels. The specific meanings of variables are shown in Section 4.2. Source: Author, produced by Stata 17.0, data sources can be found in Section 4.3.

Table 5. Benchmark regression results.

	(1) Gdevelopment	(2) Gdevelopment	(3) Gdevelopment	(4) Gdevelopment
LCCP	0.0253 *** (24.35)	0.0061 *** (6.01)	0.0153 *** (15.02)	0.0056 *** (5.77)
ldensity			0.0329 *** (4.65)	0.0219 *** (3.71)
fix			0.0001 (1.21)	−0.0001 *** (−2.99)
ind			−0.0865 *** (−13.91)	−0.0419 *** (−7.81)
gov			0.0098 * (1.96)	−0.0157 *** (−3.13)
fid			−0.0044 (−1.18)	−0.0005 (−0.14)
fdp			0.0089 *** (4.63)	0.0023 ** (2.37)
_cons	0.0722 *** (200.30)	0.0768 *** (238.47)	−0.0865 ** (−2.12)	−0.0301 (−0.88)
Time fixed effects	No	YES	No	YES
City fixed effects	YES	YES	YES	YES
Observations	3878	3878	3878	3878
R-squared	0.9472	0.9665	0.9611	0.9683
F-test	592.905	36.104	194.335	16.414

Note: *, **, and *** represent the 10 %, 5 %, and 1 % statistical levels, respectively. The specific meanings of variables are shown in Section 4.2. Regression Equation: (1) $Gdevelopment_{it} = c_0 + c_1 LCCP_{it} + +\mu_i + \varepsilon_{it}$. (2) $Gdevelopment_{it} = c_0 + c_1 LCCP_{it} + \mu_i + \tau_t + \varepsilon_{it}$. (3) $Gdevelopment_{it} = c_0 + c_1 LCCP_{it} + \sum_{2}^{k} c_k X_{kit} + \mu_i + \varepsilon_{it}$. (4) $Gdevelopment_{it} = c_0 + c_1 LCCP_{it} + \sum_{2}^{k} c_k X_{kit} + \mu_i + \tau_t + \varepsilon_{it}$. Source: Author, produced by Stata 17.0, data sources can be found in Section 4.3.

Secondly, the regression results of the control variables show that population density plays a positive role in promoting green development in cities. The possible reason is that higher population density will raise the level of local human capital, which in turn will promote green development in cities. This is consistent with the reality that green development in cities is driven more by the contribution of high-tech industries and low-carbon environment-friendly enterprises, while high industrialization levels can create serious ecological problems and squeeze the survival space of other industries. The estimated coefficient of local government size shows that high local government size inhibits urban green development to a certain extent, suggesting that too much government intervention leads to a loss of a certain degree of freedom in the market, with companies having to adjust their development strategies to "fit" policy demands and lose their autonomy and flexibility in technological innovation.

5.4. Robustness Test

5.4.1. Parallel Trend Test

The parallel trend test is a prerequisite for the significance of the regression results of the double difference method. Therefore, to further examine the reliability of the baseline regression results, a parallel trend test is required. The baseline period is set as the base period of this paper's study, i.e., 2007. The results are shown in Figure 3.

From the results of the parallel trend test, the regression coefficients for each period before the implementation of the pilot policy were not significant, indicating that there was no significant difference between the experimental and control groups before the pilot and that the assumptions of the parallel trend test were met.

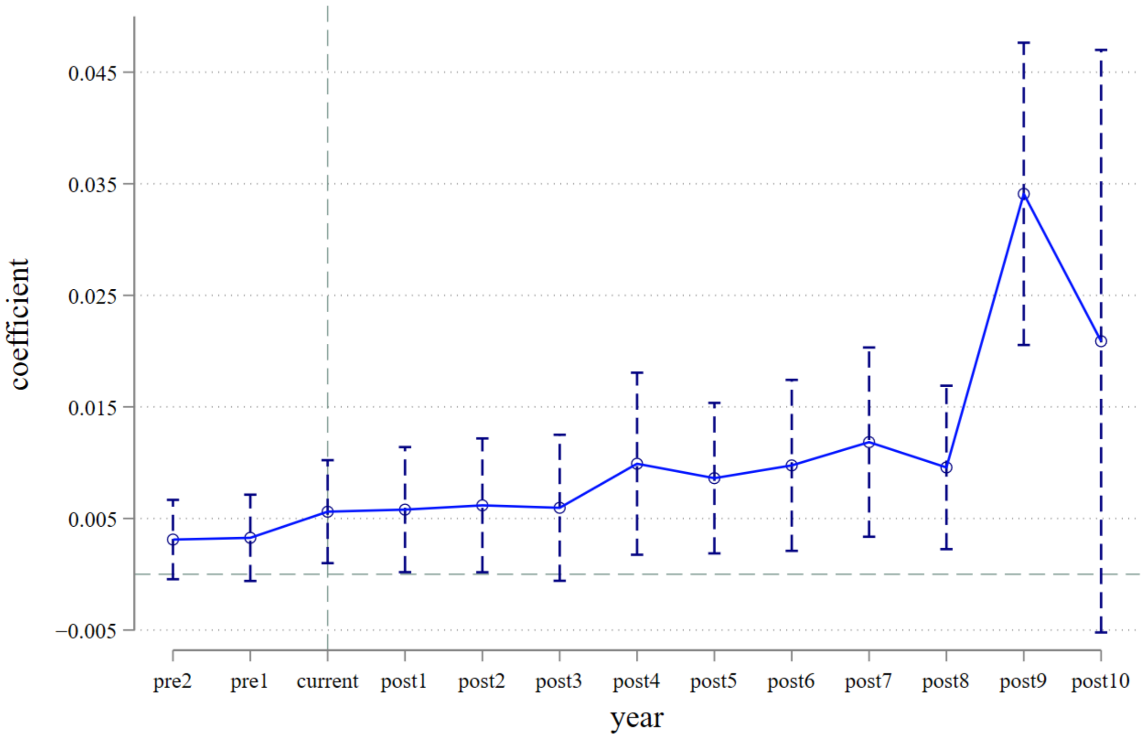

Figure 3. Parallel trend test. Source: Author, produced by Stata 17.0, data sources can be found in Section 4.3.

5.4.2. PSM-DID Test

The PSM-DID method was used to re-estimate Equation (1) using a 1:1 nearest neighbor with the put-back matching method, and the final score was calculated using a logit model. After matching, the standardized deviation was less than 10%, and the regression results of the propensity score matching followed by the DID method are shown in Table 6. The coefficients of LCCP were 0.0254, 0.0062, 0.0146, and 0.0055, all significant at the 1% level, which are consistent with the previous benchmark regression results. The above results indicate the robustness of the estimated result that low-carbon city construction is beneficial to urban green development.

Table 6. PSM-DID regression results.

	(1) Gdevelopment	(2) Gdevelopment	(3) Gdevelopment	(4) Gdevelopment
LCCP	0.0254 ***	0.0062 ***	0.0146 ***	0.0055 ***
	(24.25)	(6.05)	(14.99)	(5.71)
_cons	0.0723 ***	0.0769 ***	−0.0870 **	−0.0318
	(199.05)	(236.77)	(−2.12)	(−0.92)
Control variables	NO	NO	YES	YES
Time fixed effects	NO	YES	NO	YES
City fixed effects	YES	YES	YES	YES
Observations	3855	3855	3855	3855
R-squared	0.9474	0.9665	0.9620	0.9684
F-test	588.082	36.645	191.592	17.034

Note: **, and *** represent the 5 %, and 1 % statistical levels, respectively. The specific meanings of variables are shown in Section 4.2. Regression Equation: (1) $Gdevelopment_{it} = c_0 + c_1 LCCP_{it} + + \mu_i + \varepsilon_{it}$. (2) $Gdevelopment_{it} = c_0 + c_1 LCCP_{it} + \mu_i + \tau_t + \varepsilon_{it}$. (3) $Gdevelopment_{it} = c_0 + c_1 LCCP_{it} + \sum_{2}^{k} c_k X_{kit} + \mu_i + \varepsilon_{it}$. (4) $Gdevelopment_{it} = c_0 + c_1 LCCP_{it} + \sum_{2}^{k} c_k X_{kit} + \mu_i + \tau_t + \varepsilon_{it}$. Source: Author, produced by Stata 17.0, data sources can be found in Section 4.3.

5.4.3. Delete Special Samples

As the data used in this paper is a panel of prefecture-level cities from 2007 to 2020, the policy effects of some of the cities that started piloting in 2017 are often difficult to see in the short term. Therefore, this paper excludes cities that started piloting in 2017 and re-runs the regression estimation in order to test whether the above regression results are still robust. The regression results are shown in Table 7. It can be found that the estimated coefficient of LCCP is still significantly positive; therefore, after removing these particular samples, the impact of low-carbon city construction on urban green development is consistent with the baseline regression results above, further confirming the robustness of the core findings of this paper.

Table 7. Regression results with special samples removed.

	(1) Gdevelopment	(2) Gdevelopment
LCCP	0.0075 ***	0.0067 ***
	(6.31)	(6.18)
_cons	0.0736 ***	−0.0414
	(201.93)	(−1.10)
Control variables	NO	YES
Time fixed effects	YES	YES
City fixed effects	YES	YES
Observations	3463	3463
R-squared	0.9653	0.9680
F-test	39.806	15.334

Note: *** represent the 1 % statistical levels. The specific meanings of variables are shown in Section 4.2. Regression Equation: (1) $Gdevelopment_{it} = c_0 + c_1 LCCP_{it} + \mu_i + \tau_t + \varepsilon_{it}$. (2) $Gdevelopment_{it} = c_0 + c_1 LCCP_{it} + \sum_{2}^{k} c_k X_{kit} + \mu_i + \tau_t + \varepsilon_{it}$. Source: Author, produced by Stata 17.0, data sources can be found in Section 4.3.

5.4.4. Placebo Test

In order to exclude the interference of other policy or randomness factors, a placebo test is required. The core idea of the placebo test is to estimate by fictitious treatment groups or fictitious policy treatment times, and if the coefficient estimates associated with the core explanatory variable LCCP remain significant under different fictitious approaches, the results of the original baseline regression may have some bias, i.e., they may be influenced by other policy or randomness factors. If it is not significant, then the original results remain robust, and low-carbon city construction is indeed conducive to leading urban green development. This paper performs a placebo test by means of a fictitious treatment group, storing the estimated coefficients, standard errors, and *p*-values from 500 regression estimates, grouping cities according to their grouping, with one randomly selected year in each group, and finally obtaining its distribution graph. This paper finally presents the distribution plot of the estimated regression coefficients, as shown in Figure 4. The distribution of the coefficients shows that the randomly sampled coefficients are normally distributed with a mean of zero. 500 regressions have coefficient values that all lie to the left of the baseline regression true estimate of 0.0056. This indicates that our estimates are unlikely to have been obtained by chance and are therefore unlikely to have been influenced by other policy or randomness factors, suggesting that low-carbon city building is indeed conducive to leading green development, in line with the previous findings.

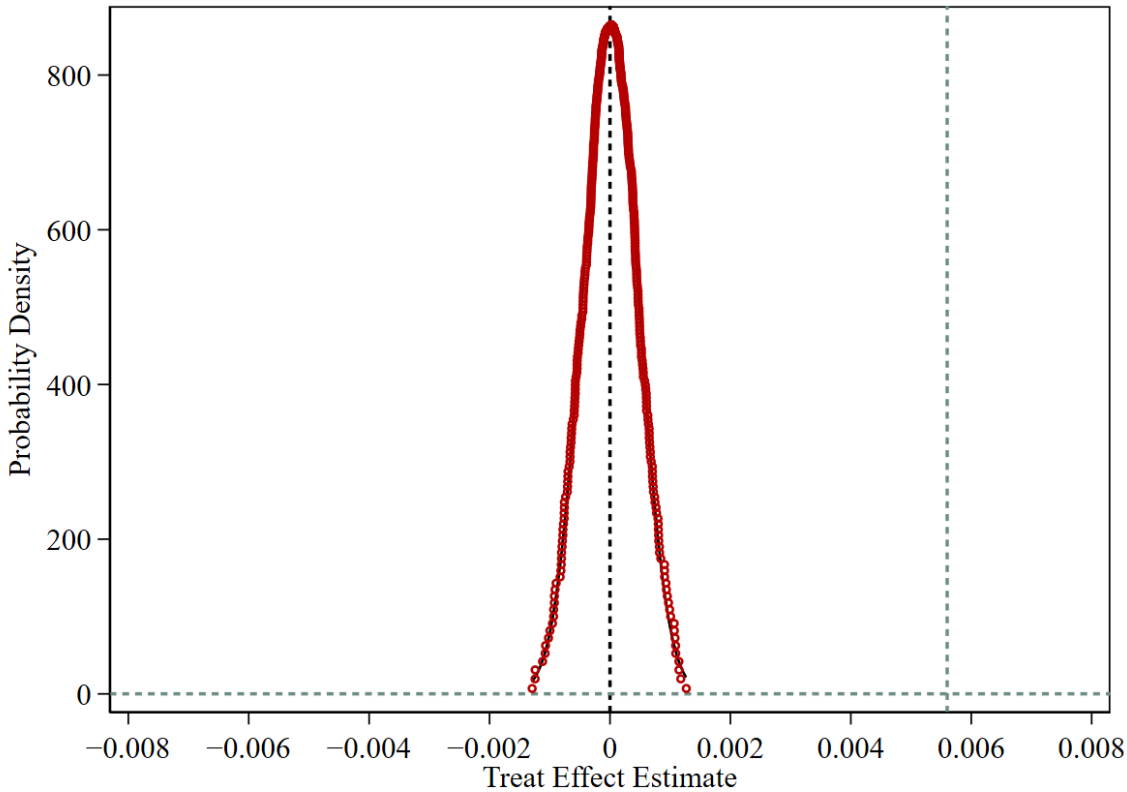

Figure 4. Placebo test. Source: Author, produced by Stata 17.0, data sources can be found in Section 4.3.

5.4.5. Bacon Breakdown

Since the method used in this paper is a multi-period double difference method, Goodman-Bacon [84] suggests that some treatment groups may become control groups at some point in time due to the inconsistency of the time nodes with the onset of policy shocks, thus leading to the estimated coefficients of the final treatment effects being underestimated. This paper employs a Baconian decomposition to diagnose this bias. The results of the Bacon decomposition are reported in Table 8 and Figure 5.

In Table 8, 86.5% of the variation in the LCCP estimates comes from the treated and untreated groups, with the time group (including post-treatment vs. first and first vs. second) having a smaller impact with only 13.4% of the weighting, and the bad control group, post-treatment vs. first, having only 6.4% of the weighting, having a minimal impact on the bias in the LCCP estimates. The results in Figure 5 also show that the time group is mostly around the 0 point and the total estimates and black line are not shifted much, which makes it more intuitive that the LCCP estimates are not biased much.

Table 8. Bacon decomposition results.

Total DID Estimate	**0.006**	
Category	**Weighting**	**Average DID Estimate**
Process first vs. process later	0.070	0.001
Post-processing vs.	0.064	−0.004
Handled vs. Never Handled	0.865	0.007

Source: Author, produced by Stata 17.0, data sources can be found in Section 4.3.

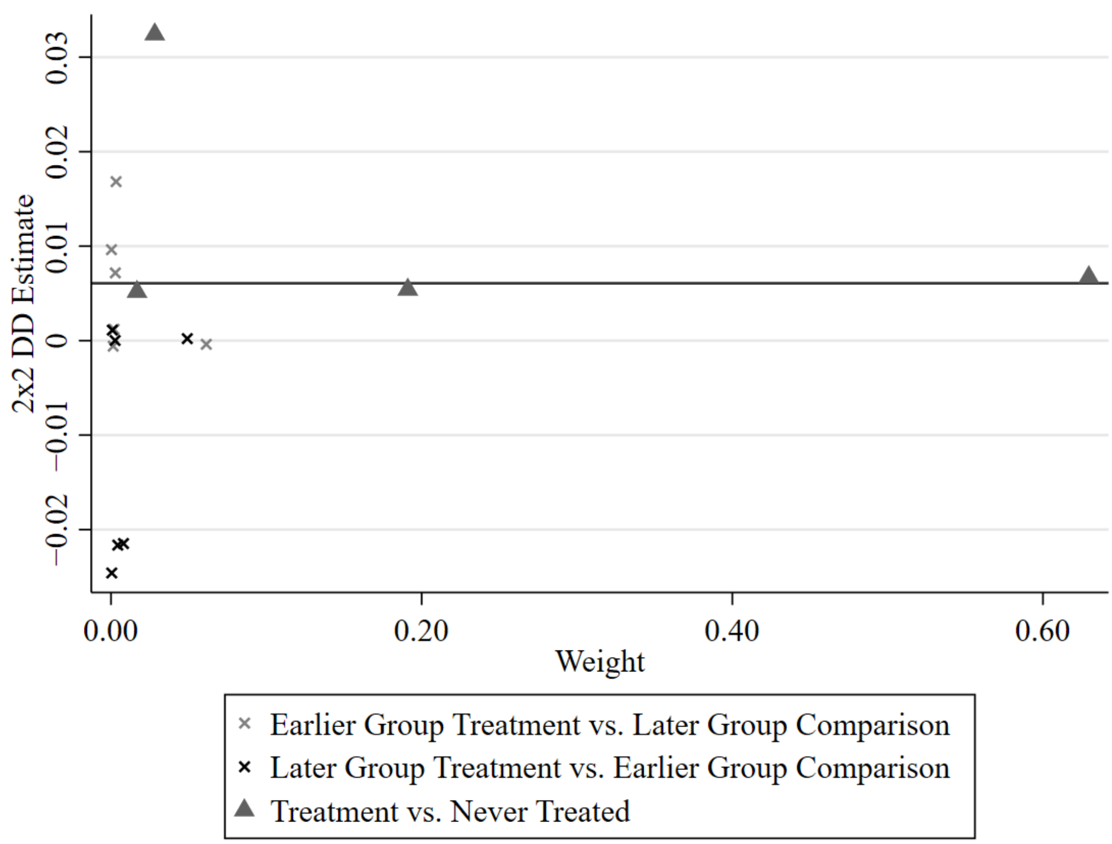

Figure 5. Bacon decomposition. Source: Author, produced by Stata 17.0, data sources can be found in Section 4.3.

6. Mechanism Testing and Heterogeneity Analysis

6.1. Mechanism Testing Results

In order to further test the role of green technology innovation and environmental regulation as mechanisms linking low-carbon cities and green development, this paper is tested through a mediating effects model. The specific regression results are shown in Table 9.

Columns (1) and (2) indicate that the implementation of LCCP will significantly contribute to the level of green technology innovation and hence green development at the 5% level, and hypothesis H3 is supported;

Columns (3) and (4) indicate that the implementation of the LCCP increases the intensity of urban command environmental regulation at the 1% level, and the effect of environmental regulation on green development also passes the significance test at the

1% level. This suggests that environmental regulation does not have a mediating effect between the two but rather a 'suppression effect'.

To further test whether these two effects exist, this paper conducts an auxiliary test using the Bootstrap method. In the auxiliary test for green technology innovation, the 95% confidence interval after bias correction is (0.0120, 0.0159), and the confidence interval interval does not contain 0 and is significant at the 1% level, indicating that green technology innovation does exist as a mediator in low-carbon city construction and green development effects.

Table 9. Mechanism test results

	(1)	(2)	(3)	(4)
	Ginov	**Gdevelopment**	**ER**	**Gdevelopment**
LCCP	0.0604 **	0.0054 ***	0.0058 ***	0.0062 ***
	(1.99)	(5.69)	(9.77)	(6.31)
Ginov		0.0022 ***		
		(5.73)		
ER				−0.1095 ***
				(−4.50)
ldensity	0.1614	0.0215 ***	−0.0015	0.0217 ***
	(1.62)	(3.70)	(−0.67)	(3.73)
fix	0.0006	−0.0001 ***	0.0001	−0.0001 ***
	(0.35)	(−3.10)	(1.60)	(−2.62)
ind	1.0332 ***	−0.0442 ***	0.0080 **	−0.0410 ***
	(4.94)	(−8.08)	(2.54)	(−7.69)
gov	−0.8391 ***	−0.0139 ***	−0.0009	−0.0158 ***
	(−2.70)	(−2.89)	(−0.41)	(−3.16)
fid	0.0403	−0.0006	0.0038 *	−0.0001
	(0.31)	(−0.17)	(1.86)	(−0.02)
fdp	−0.0129	0.0024 **	0.0009 *	0.0024 **
	(-0.41)	(2.42)	(1.69)	(2.42)
_cons	3.5103 ***	−0.0379	0.0219	−0.0277
	(5.90)	(−1.13)	(1.64)	(−0.82)
Time fixed effects	Yes	Yes	Yes	Yes
City fixed effects	Yes	Yes	Yes	Yes
Observations	3878	3878	3878	3878
R-squared	0.9387	0.9685	0.8181	0.9684
F-test	10.098	16.602	16.215	16.233

Note: *, **, and *** represent the 10 %, 5 %, and 1 % tatistical levels, respectively. The specific meanings of variables are shown in Section 4.2. Regression Equation: (1) $Ginov_{it} = a_0 + a_1 LCCP_{it} + \sum_{2}^{k} a_k X_{kit} + \mu_i + \tau_t + \varepsilon_{it}$. (2) $Gdevelopment_{it} = b_0 + b_1 LCCP_{it} + b_2 Ginov_{it} + \sum_{3}^{k} b_k X_{kit} + \mu_i + \tau_t + \varepsilon_{it}$. (3) $ER_{it} = a_0 + a_1 LCCP_{it} + \sum_{2}^{k} a_k X_{kit} + \mu_i + \tau_t + \varepsilon_{it}$. (4) $Gdevelopment_{it} = b_0 + b_1 LCCP_{it} + b_2 ER_{it} + \sum_{3}^{k} b_k X_{kit} + \mu_i + \tau_t + \varepsilon_{it}$. Source: Author, produced by Stata 17.0, data sources can be found in Section 4.3.

The 95% confidence interval after bias correction in the auxiliary test for environmental regulation is (0.0002, 0.0018), with a confidence interval that does not contain 0 and is significant at the 1% level, indicating that there is indeed a suppression effect of environmental regulation in the construction and green development of low-carbon cities.

In previous studies, scholars have tended to focus on the mediating effect but have neglected the existence of suppression and confounding effects in addition to the mediating effect. Mackinnon et al. [58] argue that suppression effects increase the total effect between the independent and dependent variables, i.e., the influence of the independent variable on the dependent variable becomes greater after controlling for suppression effects. In this study, the total effect of low-carbon city construction on green development is 0.0056, which is the result of being "masked" by environmental regulation. This also reflects the important role played by environmental regulation in both cases.

6.2. Heterogeneity Analysis

6.2.1. Heterogeneity Analysis of Different Geographical Locations

China is a vast country with different cities developing different development characteristics, and the impact of LCCP may vary by location. To explore this heterogeneous variation due to geographical location, we further divided the sample cities into three groups—eastern, central and western—and conducted group regressions using cluster standard errors. The regression results are shown in the first three columns of Table 10.

These results suggest that the effect of low-carbon city building is more significant in cities in the central and western regions, but not in the eastern. Thus, we test part of hypothesis H4 that geographical location plays an important role in the effect of low-carbon city construction on green development.

Table 10. Heterogeneity analysis of cities with different geographical locations and resource endowments.

	East	**Central**	**Western**	**Resource-Based Cities**	**Non-Resource-Based Cities**
	Gdevelopment	**Gdevelopment**	**Gdevelopment**	**Gdevelopment**	**Gdevelopment**
LCCP	0.0014	0.0057 ***	0.0065 ***	−0.0038 ***	0.0079 ***
	(0.84)	(3.02)	(3.94)	(−2.94)	(2.99)
_cons	−0.1753	0.0333	0.0048	0.0099	−0.0264
	(−1.23)	(1.53)	(0.13)	(0.33)	(−0.29)
Control variables	YES	YES	YES	YES	YES
Time fixed effects	YES	YES	YES	YES	YES
City fixed effects	YES	YES	YES	YES	YES
N	1330	1386	1162	1554	2324
R-squared	0.9622	0.9798	0.9626	0.9206	0.9706
F-test	3.577	3.934	6.953	7.173	4.648

Note: *** represent the 1 % statistical levels. The specific meanings of variables are shown in Section 4.2. Source: Author, produced by Stata 17.0, data sources can be found in Section 4.3.

The regression results in the first three columns of Table 10 show that in the central region and western region, the effect of low-carbon city pilot construction on urban green development is still significantly positive at the 1% level, achieving a better effect, but in the eastern region, the estimated coefficients, although positive, are not significant and do not show a better effect. On the one hand, the level of green development studied in this paper maps out the different development characteristics of cities under the three-dimensional framework of economy, ecology, and society. On the other hand, the eastern region, as a region with a higher level of economic development, has more opportunities for economic transformation but also often faces more serious "social problems" and bottlenecks in resource constraints, leading to bottlenecks in the promotion of low-carbon city pilots for urban green development.

6.2.2. Heterogeneity Analysis of Different Resource Endowments

Considering the different development patterns of industries among cities and that some cities lead urban development through resource-dependent industries, this paper further grouped the sample of 277 prefecture-level cities into two groups, resource-based cities and non-resource-based cities, according to NDRC [2013] No. 45, and conducted group regressions, with the regression results shown in the last two columns of Table 10. The effect of low-carbon city pilot construction on promoting green development in non-resource-based cities was significantly positive and passed the significance test at the 1% level.

The negative impact on resource-based cities is probably due to the fact that resource-based cities have gradually formed an industrial development system dominated by natural resources, emitting a number of greenhouse gases, lacking innovation drive, and insufficient construction of environment-friendly and resource-friendly industries; the construction of low-carbon cities based on the concept of "low-carbon" will have a certain hindering effect on the green development of cities. The low-carbon city construction based on the concept of "low-carbon" will have a certain hindering effect on the green development of the city. Hypothesis H4 is supported.

6.2.3. Analysis of the Heterogeneity of Different Urban Agglomerations

Finally, this paper selects three major urban agglomerations, namely Beijing-Tianjin-Hebei, the Yangtze River Delta, or the Pearl River Delta, according to the classification criteria of major urban agglomerations in China's national policy documents, and then analyzes the heterogeneous impact of low-carbon city construction on the green development of the three major urban agglomerations. The regression results are shown in Table 11 which shows that the impact of low-carbon city construction on the green development of the PRD and Yangtze River Delta urban agglomerations is not significant. For the Beijing-Tianjin-Hebei city cluster, the impact of low-carbon city construction on green development is also significantly positive, with an estimated coefficient of 0.0253, and passes the significance test at the 1% level. Overall, the impact of low-carbon city construction on green development is most prominent in the Beijing-Tianjin-Hebei urban agglomeration, while the impact on the Pearl River Delta and Yangtze River Delta urban agglomerations is insignificant.

Table 11. Analysis of heterogeneity of different urban agglomerations.

	Beijing, Tianjin and Hebei	**Yangtze River Delta**	**Pearl River Delta**
	Gdevelopment	**Gdevelopment**	**Gdevelopment**
LCCP	0.0253 ***	0.0040	0.0114
	(4.82)	(1.54)	(0.55)
_cons	−0.1631	−0.1334	−0.7853 **
	(−1.10)	(−1.29)	(−2.94)
Control variables	YES	YES	YES
Time fixed effects	YES	YES	YES
City fixed effects	YES	YES	YES
N	154	364	182
R-squared	0.9725	0.9775	0.5855

Note: **, and *** represent the 5 %, and 1 % statistical levels, respectively. The specific meanings of variables are shown in Section 4.2. Source: Author, produced by Stata 17.0, data sources can be found in Section 4.3.

7. Conclusions and Implications

Low-carbon cities are new urban development models that integrate green and low-carbon production methods, harmonious coexistence between people and nature, modern social security and public services, and are directly linked to green development. As we have shown earlier, existing studies have explored the impact of low-carbon city construction and green development under the theoretical linkage between the two and have focused on the institutional role of technological innovation and environmental regulation. However, it sees green development more as an indicator of both economic and ecological aspects, and the role of technological innovation and environmental regulation between the two remains questionable in our view. To address these issues, this paper treats green development as a concept of development with intertwined economic, ecological, andsocial aspects. Based on the collection of data on the pilot construction of low-carbon cities in 277 prefecture-level cities across China from 2007 to 2020, this paper empirically examines the impact of the construction of low-carbon cities on urban green development through a multi-temporal double-difference model.

The paper also examines the role of green technology innovation and directive environmental regulation through mechanism analysis. The main findings and implications of this paper are fourfold.

Firstly, low-carbon city building can significantly contribute to green development, a finding that still holds after parallel trend tests, removal of special samples, PSM-DID tests, placebo tests, and Bacon decomposition diagnostics. Past studies have provided a large number of research bases for the relationship between low-carbon urban construction and green development, such as that low-carbon urban construction can significantly reduce CO_2 concentration [22], favor green economic development [23], and accelerate the change in residents' green living concepts [54]. Some scholars have also supported this relationship based on the perspective of industries, such as the digital industry [7], productive service aggregation industry [85], and financial technology industry [86]. compared with using a single indicator or a single field to cover green development indicators, or focusing on a particular industry to study the relationship. The findings of this paper further support the relationship from an urban perspective based on the more complex connotation of green development. In this sense, we recommend continuing to promote the construction of low-carbon cities, drawing on the experience and focusing on the potential of low-carbon city construction for green economic growth, improving the ecological environment, safeguarding the livelihoods of residents, and promoting social equity. Economically, it is important to encourage the emergence of environment-friendly and resource-friendly industries, and for local governments to abandon the "GDP cult" and develop special policies to support them, thereby developing new models of low-carbon and green economic growth. Ecologically, we need to promote urban landscaping, provide more green public spaces and control environmental pollution and greenhouse gas emissions caused by industry. Socially, we should continue to guide the construction of beautiful villages and new urbanization, increase the accessibility and availability of resources per capita, and improve and protect people's livelihoods.

Secondly, the results of the mechanism analysis suggest that low-carbon city construction can promote green urban development by stimulating green technological innovation in enterprises. While most of the previous studies, as mentioned above, have focused on the role of technological innovation in the relationship between the two and have given both "facilitating" [87] and "inhibiting" [33,34] answers, this paper further clarifies the mechanism of the impact between the two through the mediating variable of green technological innovation. However, although low-carbon city construction can increase the intensity of environmental regulation, it inhibits urban green development, creating a 'suppression effect', and the total effect of low-carbon city construction on green development is effectively amplified after controlling for the variable of environmental regulation. This finding supports the "cost barrier" school of thought, which argues that excessive environmental regulation hinders green development [40,41]. The existence of the suppression effect often leads to different results in the relationship between variables, so the suppression effect cannot be ignored in the process of exploring the mediating effect, and these findings are worth exploring in depth. Based on these findings, we suggest that the construction of low-carbon cities should be complemented by green technological innovation, appropriate environmental regulation policies, and a reduction in the level of intervention in enterprises in order to further exploit the leading role of pilot policies in green development.

Finally, the effect of low-carbon city construction on green development is heterogeneous depending on geographical location, resource endowment and different urban clusters. The policy effect of low-carbon city construction is more obvious in central, non-resource-based cities and the Beijing-Tianjin-Hebei urban agglomeration, indicating that regions with more favorable geographical location and transportation conditions, as well as some space for industrial transformation and development, will have more advantages in building low-carbon cities for urban green development. In addition, the urban development model that relies on resource elements will inhibit the effect of low-carbon city construction on urban green development, and eventually it will be difficult to generate the desired response. Therefore, considering the heterogeneity among cities, low-carbon cities should implement differentiated policy arrangements and different target orientations, and further promote low-carbon cities in central regions and non-resource-based cities, taking advantage of human capital, technology and industry, management mechanisms, etc., focusing on non-conventional challenges, taking on the "tough battles", gnawing on the "hard bones", and guiding green development into the lives of residents, community governance, and industrial construction. The western region should make full use of the pilot experiences of other cities to improve infrastructure conditions and guide green investment. For example, cities in western China with lower levels of infrastructure should first lay out their urban development plans in advance, support environmentally friendly enterprises, and use low-carbon city construction policies to implement catch-up. While the eastern region should focus on the complementary advantages of mature industrial systems, economic development models, and low-carbon city construction.

Although this paper examines the relationship between low-carbon city construction and green development through the DID method, there is still room for further development. On the one hand, the samples studied in this paper are from prefecture-level cities in China. Vertically, we have not considered provincial and county-level samples, and horizontally, this paper on low-carbon city construction and green development in other countries and regions is not deep enough. On the other hand, despite having sizable time series data for the long cross section in this paper, there is still room for further exploration in the use of methods. Therefore, future research can be extended to other countries and regions to conduct multi-scale comparative studies on the same study area and use dynamic panel analysis to establish long-term relationships between indicators.

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Abbreviations

The following abbreviations are used in this manuscript:

LCCP	Low-carbon city pilot policy
NDRC	National Development and Reform Commission
ED	Economic green growth
GD	Ecological welfare enhancement
density	population density
fix	Fixed asset investment ratio
ind	The level of industrialization
DID	Difference-in-Difference Method
gov	The size of local governments
fid	Fiscal decentralization
fdp	Financial development
Ginov	green technology innovation
Ginov1	the number of green inventions applied for in the year
Ginov2	the number of green utility models applied in the same year
ER	environmental regulation
Gdevelopment	City Green Development Index

References

1. Shen, L.; Yang, Y.; Bao, H.D.X.; Du, X.; He, H. Residents' Perceptions on the Urban Resources Environment in Chinese Large Cities. *SSRN Electron. J.* **2023**, *100*, 107080. [CrossRef]
2. Ramzan, M.; Abbasi, K.R.; Salman, A.; Dagar, V.; Alvarado, R.; Kagzi, M.M. Towards the dream of go green: An empirical importance of green innovation and financial depth for environmental neutrality in world's top 10 greenest economies. *Technol. Forecast. Soc. Chang.* **2023**, *189*, 122370. [CrossRef]
3. Xu, G.; Chang, H.P.; Meng, L.; Marma, K.J.S. Green development level, resource utilization, and ecological protection across China from 2006 to 2017: Based on the national standard indicator system. *Environ. Dev.* **2022**, *44*, 100776.
4. Ji, Q.; Li, C.; Jones, P.J. New green theories of urban development in China. *Sustain. Cities Soc.* **2017**, *30*, 248–253. [CrossRef]
5. Tian, Y.; Wang, R.; Liu, L.; Ren, Y. A spatial effect study on financial agglomeration promoting the green development of urban agglomerations. *Sustain. Cities Soc.* **2021**, *70*, 102900. [CrossRef]
6. Cheng, Z.; Wang, L.; Zhang, Y.W. Does smart city policy promote urban green and low-carbon development? *J. Clean. Prod.* **2022**, *379*, 134780. [CrossRef]
7. Wang, Z.; Liang, F.; Li, C.; Xiong, W.; Chen, Y.; Xie, F. Does China's low-carbon city pilot policy promote green development? Evidence from the digital industry. *J. Innov. Knowl.* **2023**, *8*, 100339. [CrossRef]
8. Song, Q.; Qin, M.; Wang, R.; Qi, Y. How does the nested structure affect policy innovation? Empirical research on China's low-carbon pilot cities. *Energy Policy* **2020**, *144*, 111695. [CrossRef]
9. Zhang, H.; Feng, C.; Zhou, X. Going carbon-neutral in China: Does the low-carbon city pilot policy improve carbon emission efficiency? *Sustain. Prod. Consum.* **2022**, *33*, 312–329. [CrossRef]
10. Yadav, A. A review of green and innovative technology for a sustainable environment. *Sustain. Environ.-Clean* **2021**, *1*, 71–83.
11. Zhong, Z.; Chen, Z. Urbanization, green development and residents' happiness: The moderating role of environmental regulation. *Environ. Impact Assess. Rev.* **2022**, *97*, 106900. [CrossRef]
12. D'Amato, D.; Droste, N.; Allen, B.S.; Kettunen, M.; Lähtinen, K.; Korhonen, J.E.; Leskinen, P.; Matthies, B.D.; Toppinen, A. Green, circular, bio economy: A comparative analysis of sustainability avenues. *J. Clean. Prod.* **2017**, *168*, 716–734. [CrossRef]
13. Loiseau, E.; Saikku, L.; Antikainen, R.; Droste, N.; Hansjürgens, B.; Pitkänen, K.; Leskinen, P.; Kuikman, P.J.; Thomsen, M. Green economy and related concepts: An overview. *J. Clean. Prod.* **2016**, *139*, 361–371. [CrossRef]
14. Li, Y.; Chen, Y.; Li, Q. Assessment analysis of green development level based on S-type cloud model of Beijing-Tianjin-Hebei, China. *Renew. Sustain. Energy Rev.* **2020**, *133*, 110245. [CrossRef]
15. Xiao, Y.; Chen, J.; Wang, X.; Lu, X. Regional green development level and its spatial spillover effects: Empirical evidence from Hubei Province, China. *Ecol. Indic.* **2022**, *143*, 109312. [CrossRef]
16. Mondejar, M.E.; Avtar, R.; Diaz, H.L.B.; Dubey, R.K.; Esteban, J.; Gómez-Morales, A.; Hallam, B.J.; Mbungu, N.T.; Okolo, C.C.; Prasad, K.A.; et al. Digitalization to achieve sustainable development goals: Steps towards a Smart Green Planet. *Sci. Total Environ.* **2021**, *794*, 148539. [CrossRef] [PubMed]
17. Chen, H.; Qi, S.; Zhang, J. Towards carbon neutrality with Chinese characteristics: From an integrated perspective of economic growth-equity-environment. *Appl. Energy* **2022**, *324*, 119719. [CrossRef]
18. Zhou, Y.; Li, G.; Zhou, S.; Hu, D.; Zhang, S.; Kong, L. Spatio-temporal differences and convergence analysis of green development efficiency of marine economy in China. *Ocean. Coast. Manag.* **2023**, *238*, 106560. [CrossRef]
19. Li, W.; Zhang, Y.; Yang, C.; feng Gong, W.; Wang, C.; Zhang, R. Does producer services agglomeration improve urban green development performance of the Yangtze River Economic Belt in China? *Ecol. Indic.* **2022**, *145*, 109581. [CrossRef]
20. Ge, T.; Li, C.; Li, J.; Hao, X. Does neighboring green development benefit or suffer from local economic growth targets? Evidence from China. *Econ. Model.* **2022**, *120*, 106149. [CrossRef]
21. Huo, W.; Qi, J.; Yang, T.; Liu, J.; Liu, M.; Zhou, Z. Effects of China's pilot low-carbon city policy on carbon emission reduction: A quasi-natural experiment based on satellite data. *Technol. Forecast. Soc. Chang.* **2022**, *175*, 121422. [CrossRef]
22. Zeng, S.; Jin, G.; Tan, K.; Liu, X. Can low-carbon city construction reduce carbon intensity? Empirical evidence from low-carbon city pilot policy in China. *J. Environ. Manag.* **2023**, *332*, 117363. [CrossRef] [PubMed]
23. Cheng, J.; Yi, J.; Dai, S.; Xiong, Y. Can low-carbon city construction facilitate green growth? Evidence from China's pilot low-carbon city initiative. *J. Clean. Prod.* **2019**, *231*, 1158–1170. [CrossRef]
24. Qiu, S.; Wang, Z.; Liu, S. The policy outcomes of low-carbon city construction on urban green development: Evidence from a quasi-natural experiment conducted in China. *Sustain. Cities Soc.* **2021**, *66*, 102699. [CrossRef]
25. Zheng, J.; Shao, X.; Liu, W.; Kong, J.; Zuo, G. The impact of the pilot program on industrial structure upgrading in low-carbon cities. *J. Clean. Prod.* **2021**, *290*, 125868. [CrossRef]
26. Lan, T.; Shao, G.; Xu, Z.; Tang, L.; Dong, H. Considerable role of urban functional form in low-carbon city development. *J. Clean. Prod.* **2023**, *392*, 136256. [CrossRef]
27. Du, M.; Feng, R.; Chen, Z. Blue sky defense in low-carbon pilot cities: A spatial spillover perspective of carbon emission efficiency. *Sci. Total. Environ.* **2022**, *846*, 157509. [CrossRef]
28. Wen, S.; Jia, Z.; Chen, X. Can low-carbon city pilot policies significantly improve carbon emission efficiency? Empirical evidence from China. *J. Clean. Prod.* **2022**, *346*, 131131. [CrossRef]
29. Pan, A.; Zhang, W.; Shi, X.; Dai, L. Climate policy and low-carbon innovation: Evidence from low-carbon city pilots in China. *Energy Econ.* **2022**, *112*, 106129. [CrossRef]

30. Zou, C.; Huang, Y.; Wu, S.; Hu, S. Does "low-carbon city" accelerate urban innovation? Evidence from China. *Sustain. Cities Soc.* **2022**, *83*, 103954. [CrossRef]
31. Gao, L.; Li, C.; Wang, C.; Zhao, Z. Factors facilitating the development of low-carbon cities: Evidence from China's pilot cities. *Heliyon* **2022**, *8*, e11445. [CrossRef]
32. Zhou, Q.; Cui, X.; Ni, H.; Gong, L. The impact of environmental regulation policy on firms' energy-saving behavior: A quasi-natural experiment based on China's low-carbon pilot city policy. *Resour. Policy* **2022**, *76*, 102538. [CrossRef]
33. Zhou, D.; Yuan, S.L.; Xie, D. Voluntary environmental regulation and urban innovation: Evidence from low-carbon pilot cities program in China. *Technol. Forecast. Soc. Chang.* **2022**, *175*, 121388. [CrossRef]
34. Mehmood, S.; Zaman, K.; Khan, S.; Ali, Z.; ur Rashid Khan, H. The Role of Green Industrial Transformation in Mitigating Carbon Emissions: Exploring the Channels of Technological Innovation and Environmental Regulation. *Energy Built Environ.* 2023, *in press*. [CrossRef]
35. Xu, Y.; Dong, Z.; Wu, Y. The spatiotemporal effects of environmental regulation on green innovation: Evidence from Chinese cities. *Sci. Total Environ.* **2023**, *876*, 162790. [CrossRef]
36. Danish.; Ulucak, R.; Baloch, M.A. An empirical approach to the nexus between natural resources and environmental pollution: Do economic policy and environmental-related technologies make any difference? *Resour. Policy* **2023**, *81*, 103361.
37. Stucki, T.; Woerter, M. Green Inventions: Is Wait-and-see a Reasonable Option? *Energy J.* **2017**, *38*, 43–71. [CrossRef]
38. Song, Y.; Wei, Y.; Zhu, J.; Liu, J.T.; Zhang, M. Environmental regulation and economic growth: A new perspective based on technical level and healthy human capital. *J. Clean. Prod.* **2021**, *318*, 128520. [CrossRef]
39. Ye, F.; Quan, Y.; He, Y.; Lin, X. The impact of government preferences and environmental regulations on green development of China's marine economy. *Environ. Impact Assess. Rev.* **2021**, *87*, 106522. [CrossRef]
40. Lv, C.; Shao, C.; Lee, C. Green technology innovation and financial development: Do environmental regulation and innovation output matter? *Energy Econ.* **2021**, *98*, 105237. [CrossRef]
41. Tian, Z.; Tian, Y.; Chen, Y.; Shao, S. The economic consequences of environmental regulation in China: From a perspective of the environmental protection admonishing talk policy. *Bus. Strategy Environ.* **2020**, *29*, 1723–1733. [CrossRef]
42. Zheng, H.; Zhang, L.; Zhao, X. How does environmental regulation moderate the relationship between foreign direct investment and marine green economy efficiency: An empirical evidence from China's coastal areas. *Ocean. Coast. Manag.* **2022**, *219*, 106077. [CrossRef]
43. Yu, H.Z.; Wang, J.; Hou, J.; Yu, B.; Pan, Y. The effect of economic growth pressure on green technology innovation: Do environmental regulation, government support, and financial development matter? *J. Environ. Manag.* **2023**, *330*, 117172. [CrossRef]
44. Yang, M.; Chen, H.; Long, R.; Sun, Q.; Yang, J. How does government regulation promote green product diffusion in complex network? An evolutionary analysis considering supply side and demand side. *J. Environ. Manag.* **2022**, *318*, 115642. [CrossRef] [PubMed]
45. Guo, M.; Wang, H.; Kuai, Y. Environmental Policy and Green Innovation: Evidence from Heavily Polluting Firms in China. *Financ. Res. Lett.* **2022**, *53*, 103624. [CrossRef]
46. Acemoglu, D.; Akcigit, U.; Hanley, D.; Kerr, W.R. Transition to Clean Technology. *J. Political Econ.* **2014**, *124*, 52 – 104. [CrossRef]
47. Peng, Y.; Bai, X. Experimenting towards a low-carbon city: Policy evolution and nested structure of innovation. *J. Clean. Prod.* **2018**, *174*, 201–212. [CrossRef]
48. Ouyang, X.; Li, Q.; Du, K. How does environmental regulation promote technological innovations in the industrial sector? Evidence from Chinese provincial panel data. *Energy Policy* **2020**, *139*, 111310. [CrossRef]
49. Rubashkina, Y.; Galeotti, M.; Verdolini, E. Environmental Regulation and Competitiveness: Empirical Evidence on the Porter Hypothesis from European Manufacturing Sectors. *SRPN Prod. Issues (Topic)* **2014**, *83*, 288–300. [CrossRef]
50. Wang, J.; Wei, X.; Guo, Y. A three-dimensional evaluation model for regional carrying capacity of ecological environment to social economic development: Model development and a case study in China. *Ecol. Indic.* **2018**, *89*, 348–355. [CrossRef]
51. Wang, D.; Wang, P.; Chen, G.; Liu, Y. Ecological–social–economic system health diagnosis and sustainable design of high-density cities: An urban agglomeration perspective. *Sustain. Cities Soc.* **2022**, *87*, 104177. [CrossRef]
52. Cheng, J.; Zhang, X.; Gao, Q. Analysis of the spatio-temporal changes and driving factors of the marine economic–ecological–social coupling coordination: A case study of 11 coastal regions in China. *Ecol. Indic.* **2023**, *153*, 110392. [CrossRef]
53. Wang, X.; Wang, G.; Chen, T.; Zeng, Z.; Heng, C.K. Low-carbon city and its future research trends: A bibliometric analysis and systematic review. *Sustain. Cities Soc.* **2022**, *2022*, 104381.
54. Zhang, J.; Zheng, T. Can dual pilot policy of innovative city and low-carbon city promote green lifestyle transformation of residents? *J. Clean. Prod.* **2023**, *405*, 136711. [CrossRef]
55. Yang, X.; Yan, J.; Tian, K.; Yu, Z.; Li, R.Y.; Xia, S. Centralization or decentralization? the impact of different distributions of authority on China's environmental regulation. *Technol. Forecast. Soc. Chang.* **2021**, *173*, 121172. [CrossRef]
56. Weiss, J.F.; Stephan, A.; Anisimova, T. Well-designed environmental regulation and firm performance: Swedish evidence on the Porter hypothesis and the effect of regulatory time strategies. *J. Environ. Plan. Manag.* **2019**, *62*, 342 – 363. [CrossRef]
57. Milani, S. The Impact of Environmental Policy Stringency on Industrial R&D Conditional on Pollution Intensity and Relocation Costs. *Environ. Resour. Econ.* **2017**, *68*, 595–620.

58. Mackinnon, D.P.; Krull, J.L.; Lockwood, C.M. Equivalence of the Mediation, Confounding and Suppression Effect. *Prev. Sci.* **2000**, *1*, 173–181. [CrossRef]
59. Jezdovic, I.; Popović, S.; Radenković, M.; Labus, A.; Bogdanović, Z. A crowdsensing platform for real-time monitoring and analysis of noise pollution in smart cities. *Sustain. Comput. Inform. Syst.* **2021**, *31*, 100588. [CrossRef]
60. Wang, J.; Deng, K. Impact and mechanism analysis of smart city policy on urban innovation: Evidence from China. *Econ. Anal. Policy* **2021**, *73*, 574–587. [CrossRef]
61. Zhao, C.; Wang, K.J.; Dong, K. How does innovative city policy break carbon lock-in? A spatial difference-in-differences analysis for China. *Cities* **2023**, *136*, 104249. [CrossRef]
62. Yu, Y.; Zhang, N. low-carbon city pilot and carbon emission efficiency: Quasi-experimental evidence from China. *Energy Econ.* **2021**, *96*, 105125. [CrossRef]
63. Yu, X. An Assessment of the Green Development Efficiency of Industrial Parks in China: Based on Non-Desired Output and Non-Radial DEA Model. *SSRN Electron. J.* **2023**, *66*, 81–88. [CrossRef]
64. Preacher, K.J.; Hayes, A.F. Asymptotic and resampling strategies for assessing and comparing indirect effects in multiple mediator models. *Behav. Res. Methods* **2008**, *40*, 879–891. [CrossRef]
65. Geng, Q.; Wang, Y.; Wang, X. The impact of natural resource endowment and green finance on green economic efficiency in the context of COP26. *Resour. Policy* **2023**, *80*, 103246. [CrossRef]
66. Wang, F.; Wu, M.; Wang, J. Can increasing economic complexity improve China's green development efficiency? *Energy Econ.* **2022**, *117*, 106443. [CrossRef]
67. Wang, L.; Zhou, Z.; Yang, Y.; Wu, J. Green efficiency evaluation and improvement of Chinese ports: A cross-efficiency model. *Transp. Res. Part D-Transp. Environ.* **2020**, *88*, 102590. [CrossRef]
68. Yang, T.; Zhou, K.; Zhang, C. Spatiotemporal patterns and influencing factors of green development efficiency in China's urban agglomerations. *Sustain. Cities Soc.* **2022**, *85*, 104069. [CrossRef]
69. Dong, B.; Ma, X.; Zhang, Z.; Zhang, H.; Chen, R.; Song, Y.; Shen, M.; Xiang, R. Carbon emissions, the industrial structure and economic growth: Evidence from heterogeneous industries in China. *Environ. Pollut.* **2020**, *262*, 114322. [CrossRef]
70. Liang, D.; Lu, H.; Guan, Y.; Feng, L. Drivers for decoupling carbon footprint pressure from economic growth in China's provinces. *Geogr. Sustain.* **2022**, *3*, 258–267. [CrossRef]
71. Xie, P.; Gong, N.; Sun, F.; Li, P.; Pan, X. What factors contribute to the extent of decoupling economic growth and energy carbon emissions in China? *Energy Policy* **2023**, *173*, 113416. [CrossRef]
72. Wang, Z.; Jia, X. Analysis of energy consumption structure on CO_2 emission and economic sustainable growth. *Energy Rep.* **2022**, *8*, 1667–1679. [CrossRef]
73. Venter, Z.S.; Figari, H.; Krange, O.; Vegard, G. Environmental justice in a very green city: Spatial inequality in exposure to urban nature, air pollution and heat in Oslo, Norway. *Sci. Total Environ.* **2022**, *858*, 160193.
74. Pan, Y.; Qiu, L.; Wang, Z.; Zhu, J.; Cheng, M. Unravelling the association between polycentric urban development and landscape sustainability in urbanizing island cities. *Ecol. Indic.* **2022**, *143*, 109348. [CrossRef]
75. Das, R.C.; Chatterjee, T.; Ivaldi, E. Co-movements of income and urbanization through energy use and pollution: An investigation for world's leading polluting countries. *Ecol. Indic.* **2023**, *153*, 110381.
76. Das, R.C.; Chatterjee, T.; Ivaldi, E. Revisiting policy combinations under IS–LM–EE framework introducing capacity utilization. *Qual. Quant.* **2023**, *2023*, 1–30. [CrossRef]
77. Das, R.C.; Ivaldi, E. Is Pollution a Cost to Health? Theoretical and Empirical Inquiry for the World's Leading Polluting Economies. *Int. J. Environ. Res. Public Health* **2021**, *18*, 6624. [CrossRef]
78. Brendler, P. Rising Earnings Inequality and Optimal Income Tax And Social Security Policies. *J. Monet. Econ.* **2022**, *134*, 35–52. [CrossRef]
79. Beck, T.; Levine, R.; Levkov, A. Big Bad Banks? The Winners and Losers from Bank Deregulation in the United States. *Bank. Financ. Inst. J.* **2009**, *65*, 1637–1667. [CrossRef]
80. Sun, Y.; Gao, P.; Razzaq, A. How does fiscal decentralization lead to renewable energy transition and a sustainable environment? Evidence from highly decentralized economies. *Renew. Energy* **2023**, *206*, 1064–1074. [CrossRef]
81. Yang, L.; Ni, M. Is financial development beneficial to improve the efficiency of green development? Evidence from the "Belt and Road" countries. *Energy Econ.* **2021**, *105*, 105734. [CrossRef]
82. Chen, Z.; Kahn, M.E.; Liu, Y.; Wang, Z. The Consequences of Spatially Differentiated Water Pollution Regulation in China. *NBER Work. Pap. Ser.* **2016**, *88*, 468–485.
83. Zhang, J.; Chen, S. Financial Development, Environmental Regulation and Green Economic transformation. *Financ. Res.* **2021**, *47*, 78–93.
84. Goodman-Bacon, A. Difference-in-Differences with Variation in Treatment Timing. *Econom. Mult. Equ. Model. J.* **2018**, *225*, 254–277.
85. Du, M.; Zhang, Y. The impact of producer services agglomeration on green economic development: Evidence from 278 Chinese cities. *Energy Econ.* **2023**, *124*, 106769.

86. Cheng, X.; Yao, D.; Qian, Y.; Wang, B.; Zhang, D. How does fintech influence carbon emissions: Evidence from China's prefecture-level cities. *Int. Rev. Financ. Anal.* **2023**, *87*, 102655.
87. Qu, F.; Xu, L.; He, C. Leverage effect or crowding out effect? Evidence from low-carbon city pilot and energy technology innovation in China. *Sustain. Cities Soc.* **2023**, *91*, 104423.

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