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Can Green Infrastructure Investment Reduce Urban Carbon Emissions:Empirical Evidence from China

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Abstract: Green infrastructure (GI) plays a pivotal role in contemporary urban infrastructure. Green infrastructure investment (GII) provides a fresh perspective for controlling urban carbon emissions in the context of global climate change. Based on theoretical analysis, we employed panel data from Chinese cities to examine the effects and operating mechanisms of GII on urban carbon emissions. The research reveals that the incremental GII can notably decrease urban carbon emissions, and various robustness tests and endogeneity checks corroborate this finding. However, when considering the cumulative effect, the GII stocks do not appear to influence urban carbon emissions; GII mitigates urban carbon emissions by drawing in pollution control talents, improving the efficiency of household waste treatment, increasing urban green spaces, and heightening public attention to the environment. Relative to cities in the central-western region, northern cities, smaller cities, resource-based cities, smart pilot cities, and cities with a lesser environmental emphasis, GII is more effective in curbing carbon emissions in eastern cities, southern cities, larger cities, non-resource-intensive cities, cities not in the smart pilot initiative, and cities with a stronger environmental focus. This research enhances the understanding of GI's environmental outcomes and the determinants of urban carbon emissions from an investment viewpoint. It also dissects the four operative mechanisms through which GII lowers urban carbon emissions, offering a novel interpretation of GII for the variance in carbon emission levels across cities with diverse traits.

Keywords: global warming; green infrastructure investment; urban carbon emissions; operating mechanism

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1. Introduction

One of the most significant environmental challenges of the 21st century is global warming. The increase in greenhouse gas emissions due to human activities is a significant contributor to rises in temperature, with carbon dioxide as the predominant greenhouse gas. According to statistics, cities, which are centers of global economic activities and energy use, contribute 70% of the world's carbon emissions [1]. Against this backdrop, scholars are increasingly engaging in the consideration and assessment of policies and investments aimed at advancing urban environmental sustainability [2,3]. As infrastructure construction serves as an essential pillar for modern city growth, the escalating global warming issues, combined with the increased challenges of energy consumption, resource wastage, and environmental pollution from conventional infrastructures, have paved the way for the emergence of the green infrastructure (GI) concept. Green infrastructure (GI) pertains to aspects such as green transportation, green buildings, green water utilities, renewable energy facilities, urban green spaces, and ecological corridors [4]. Compared to traditional infrastructures, GI emphasizes harmoniously coexisting with nature and realizing comprehensive advantages for society, economy, and the environment.

Cities in many countries around the globe have extensively implemented green infrastructure (GI) [5]. In 2017, Germany released the Federal Green Infrastructure Conceptual

Plan, which distinctly outlined the foundational objectives and targets for Germany's green infrastructure initiatives [6]. Due to China's swift economic growth and urbanization over the past years, the pressure of carbon emissions in cities is projected to keep rising. To address global warming and associated environmental challenges, in February 2022, four departments led by China's National Development and Reform Commission released their Guidance on Accelerating Urban Environmental Infrastructure Construction. The directive set a target for 2025 to form an environmental infrastructure system that consolidates sewage, garbage, solid waste, hazardous waste, medical waste management, and monitoring and regulatory proficiencies. In pursuit of this objective, the Chinese government has steadily increased its investments in green infrastructure initiatives (GIIs) for urban areas.

Currently, the literature predominantly zeroes in on the conceptual content of GI [7–9], its spatial organization [10], determinants [11], and the interplay with other components [12]. For example, certain studies suggest that GI constitutes an ecological network of green spaces and natural environments [8], representing a multi-faceted, cross-disciplinary notion that spans urban planning, ecology, geography, and economics, among others [12]. Moreover, it is noted that there is a lack of a unified standard in defining and prioritizing GI among academics across various countries, developmental stages, and disciplines [6,13]. Conversely, a segment of the research focuses on evaluating the social, ecological, and economic advantages of GI [14]. For example, research has discovered that GI contributes to improving human health [15], enhancing rainstorm regulation and purification capacities [16], reducing air pollution [17], lowering greenhouse gas emissions [18], and mitigating urban heat islands [19]. However, it is also highlighted in the literature that despite the positive ecosystem services provided by GI, it can result in adverse impacts, like water usage, biological invasions, and the emission of volatile organic pollutants [20–22]. In the realm of GII research, GII is characterized as specific investments for enhancing pollution conditions and creating a favorable ecological environment [23], mainly including the development of urban sewage and waste treatment, centralized heating, gas infrastructure, and urban environmental greening [24]. Furthermore, there are studies suggesting that GII can impact the sustained growth of urban economies [8], with others asserting that GII not only propels economic growth but also boosts employment [25]. Yet, conventional economists argue that GII possesses a "crowding-out effect," impeding urban economic expansion [8,26].

Additionally, a segment of the literature concentrates on exploring the determinants of low-carbon economic development, primarily on the aspects of total carbon emissions [27–29] and carbon emission efficiency [30–33]. For instance, research has investigated the spatial spillover impacts of carbon emission trading programs on the comprehensive carbon emission efficiency in cities [31]. Some studies have focused on the impact of transportation infrastructure on urban carbon emissions, finding that transportation infrastructure has exacerbated carbon emissions in surrounding cities [34]. Pertaining to the studies on GII and low-carbon economic development, we identified some articles, with one asserting that GII aids in diminishing CO2 emissions in Arab nations [5]. Additionally, there have been scholarly investigations into the effectiveness of urban green infrastructure (GI) in mitigating carbon emissions. However, these studies have a limited scope, encompassing only 35 major cities, which poses challenges in accurately gauging the broader impact of green infrastructure investment (GII) on carbon emissions across Chinese cities. Furthermore, this paper places a heightened emphasis on exploring the specific implications of GII, in contrast to the broader concept of GI [35]. In addition, one piece of research employing provincial panel data in China as its sample investigates the correlation between GII and carbon emissions. The authors of this study discovered an inverse U-shaped correlation between GII and carbon emissions. GII affects the area's level of greening and technology via a U-shaped trajectory, which in turn fosters the inverse U-shaped link between GII and carbon emissions, attributed to both greening and technological influences [23]. This paper distinguishes itself from existing literature in three key aspects. Firstly, our investigation focuses on the impact of Green Infrastructure Investment (GII) on carbon intensity, as opposed to the total volume of carbon emissions. Our study's contribution is in its detailed exploration of how GII influences carbon intensity, a metric with profound economic implications. While total carbon emissions serve as a straightforward indicator of environmental impact, carbon intensity elucidates the relationship between the efficiency of economic activities and their environmental repercussions. This approach fosters an integrated consideration of economic efficiency and sustainability, facilitating a more effective equilibrium between environmental conservation and economic growth. Secondly, our research employs data at a more detailed level. In China, urban areas are the epicenters of economic activity and energy consumption. Notably, significant variances exist between cities within the same province. As such, city-level data provide a more accurate reflection of GII's impact on carbon emissions compared to provincial data. Thirdly, our paper delves more intricately into the underlying mechanisms linking GII and carbon emissions. Previous studies have primarily focused on the pathways of green and technological effects, which inadequately clarify the influence of GI on carbon emissions. In contrast, our study introduces more cogent pathways, thereby elucidating why GII can effectively reduce carbon intensity.

To sum up, a substantial number of studies have delved into the merits of GI and scrutinized the interplay between GII and economic ascent. A minimal number of studies have probed the environmental dividends of GII. With the diversity in research samples, viewpoints, and methodologies, there is not a unified finding on GII's influence on carbon discharges, which underlines the need for more in-depth exploration. Therefore, based on the research context and research gaps, this study defines GI from an environmental economics perspective, postulating GI as infrastructures designed to counteract human-induced repercussions, such as climatic alterations, resource depletion, and ecosystem degeneration. These infrastructures adopt a scientific approach in planning, designing, constructing, and operating the natural resources and environment, maintaining persistent surveillance and assessments, and transmuting them into tangible productive entities. The overarching goal is to substantially mitigate the detriments to the natural surroundings, bolster resource efficiency, and foster symbiotic harmony between humankind and nature. Furthermore, by harnessing the panel data of 283 Chinese cities spanning 2006–2019, we delve into the ramifications and operative mechanisms of GII on urban carbon outputs, aspiring to augment the environmental gains of GI viewed through the investment perspective and providing Chinese experience and evidence for the global realization of carbon emission reduction from the perspective of GII.

This study's primary contributions encompass the following: (1) Pertaining to the research sample dimension, cities serve as the pivotal spatial vessels for green infrastructural endeavors. Setting itself apart from extant studies, our investigation zeroes in on China's urban stratum, precisely gauging GII's impact on urban carbon emissions in China and sidestepping the skewed interpretations induced by the prior literature's reliance on provincial-level data. (2) Regarding influential mechanisms grounded in theoretical and empirical scrutiny, our study traverses four areas: magnetizing expertise in pollution control, elevating household refuse processing rates, augmenting urban green cover percentages, and amplifying public environmental awareness and demystifying the quartet of mechanisms through which GII curtails urban carbon discharges. (3) From the perspective of heterogeneity effects, this exploration systematically elucidates the differential ramifications of GII on urban carbon outputs, factoring in city-specific traits and proffering a refreshed interpretation for the disparities observed in urban carbon emission magnitudes through the lens of GII.

2. Theoretical Mechanism

As specific types of GI, green buildings and smart grids have notable benefits in enhancing energy efficiency. For instance, green buildings, with their efficient insulating materials and state-of-the-art energy-saving devices, can notably decrease energy use and carbon emissions. Hence, substantial investments in urban green structures and smart grids will indubitably yield a positive impact in slowing urban carbon emissions [36]. Additionally, GII frequently backs renewable energy endeavors, like solar, wind, and hydro energy, which have the potential to supplant conventional fossil fuels, leading to a decrease in emissions [37]. At the same time, directing funds towards efficient public transport and non-motorized pathways can considerably lessen dependence on personal vehicles, leading to a further decline in transportation-generated carbon emissions. As an economic policy instrument, GII can spur businesses to enhance their focus on developing eco-friendly technologies [38], fostering the innovation and deployment of novel technologies and goods, and ultimately minimizing energy consumption and carbon emissions at the onset of production processes [39].

Hypothesis 1: *Investments in green infrastructure can potentially diminish urban carbon emissions*.

Building and maintaining GI requires individuals with a high degree of expertise. As the gravity of environmental concerns intensifies and GII's prominence rises, the domain of GI continually broadens. This brings about increased positions, better compensations, and heightened societal acknowledgment, undeniably pulling in more professionals adept in pollution management. Additionally, GII can foster collaboration between corporations and academic institutions, offering hands-on experiences for students and researchers, and thereby cultivating and drawing in experts in pollution mitigation.

In urban areas, the dumping and burning of household waste have emerged as primary contributors to carbon emissions. Hence, GII strives to establish efficient centers for managing household waste, with objectives centered around amplifying the efficiency and curbing environmental contamination and carbon discharge during the treatment phase. Delving deeper, GII offers essential financial backing for pioneering household waste management techniques, like bio-decomposition, combustion, landfill practices, and resource recuperation, considerably enhancing the comprehensive treatment proficiency of household refuse. To achieve effective handling of household waste, imparting environmental education and facilitating training to the masses and businesses is of paramount significance. GII can channel funds into pertinent educational and training ventures, in turn elevating the public's environmental consciousness and honing their adeptness in segregating and amassing domestic waste. Furthermore, the public–private collaboration model proves markedly efficacious in enhancing the efficiency of household waste management. Green infrastructure investments can motivate private enterprises to engage in waste treatment endeavors, jointly shouldering risks and reaping the rewards with the public sector, ultimately realizing a sustainable trajectory for household waste management.

Urban parks offer a variety of ecological benefits. First, the photosynthesis process in plants enables them to absorb atmospheric CO_2 effectively, offering a robust foundation for diminishing urban carbon discharges [40]. Moreover, green areas introduce a cooling sensation to urban areas, aiding in the alleviation of the urban heat island phenomenon, and leading to decreased reliance on air conditioning and reduced energy use [19]. Importantly, urban greenery also plays a role in moderating rainwater surges, absorbing contaminants from both air and water, which aids in further curbing regional carbon outputs [41]. GII has offered pivotal funding for the establishment and upkeep of urban parks, encompassing areas such as land purchase, tree planting, park development, and the maintenance of current green spaces. Additionally, GII backs technical advancements and research in urban green space development, like soil enhancement, plant variety selection, refining irrigation systems, and greenery planning and designing, all aimed at cost cutting and elevating the ecological standard of the green areas. To enhance urban green coverage, it is vital to educate both the public and businesses. GII can fund such educational endeavors, boosting environmental understanding among the populace and motivating them to partake in the creation and care of green zones. Additionally, public–private collaboration is seen as a potent method for increasing urban green space ratios. With GII's financial backing, the private sector is lured to join green space projects, enabling a joint approach to risks and benefits and furthering the continual growth of urban greenery.

As the general public becomes more versed and attentive towards environmental issues, they incline towards adopting greener lifestyles, opting for public transit, minimizing energy usage, and championing renewable energies. The heightened environmental consciousness among people can sway governmental policymaking and its execution, nudging businesses towards greener production processes, and subsequently leading to a further dip in urban carbon releases. Projects centered on green infrastructure, such as urban parks and eco-parks, can act as platforms for environmental tutelage, presenting the populace with chances to learn and immerse themselves. Such endeavors enlighten the public about how ecosystems operate, making them cognizant of the repercussions of human actions on the environment, which in turn bolsters their proclivity and measures towards preserving nature. Green construction and urban greenery investments can furnish the public with a serene and salubrious habitat, amplifying their insights and interest in conserving the environment.

Hypothesis 2 : *GII reduces urban carbon discharges by drawing in expertise on pollution management*.

Hypothesis 3: *GII reduces urban carbon discharges by ramping up household waste treatment ratios*.

Hypothesis 4: *GII reduces urban carbon discharges by augmenting urban green zones.*

Hypothesis 5: *GII reduces urban carbon discharges by elevating environmental consciousness among the masses*.

The mechanism path in this paper is shown in Figure 1.

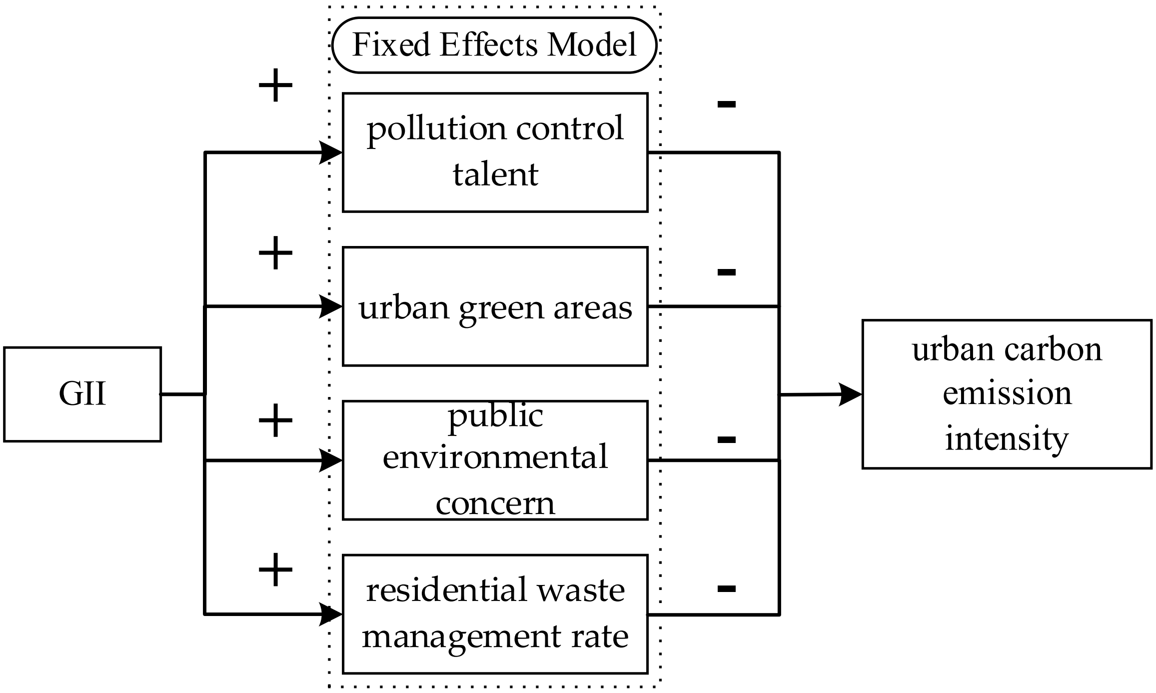

Figure 1. Influence channels of the GII on urban carbon emission intensity.

3. Method

3.1. Research Design

To test Hypothesis 1, we employed a panel fixed-effects model to investigate the influence of GII on city carbon emissions intensity. The model is defined as follows:

$$UCE_{it} = \alpha_0 + \alpha_1 GII_{it} + \varphi X_{it} + \mu_i + v_t + \varepsilon_{it} \quad (1)$$

where UCE denotes a city's carbon emissions intensity, GII_{it} signifies the investment in urban green infrastructure, X is a set of control variables potentially impacting city carbon emissions, α_0 denotes the constant term, α_1 is the coefficient measuring GII's effect on city carbon emissions, φ is the coefficient of the control variable, μ_i indicates individual fixed effects, v_t is the time-fixed effects, and ε_{it} is the error term.

3.2. Variable Selection

3.2.1. Dependent Variable

By drawing on the existing literature [42], for this study, we used the logarithm of urban carbon emission intensity to measure the UCE. Utilizing existing research [38,39], this analysis calculates the aggregate carbon emissions of cities based on underlying data. The encompassed emission sources consist of the consumption of natural gas, liquefied petroleum gas, thermal energy, and electricity. The carbon emission coefficients for the aforementioned three sources are, respectively, 2.1622 $kgCO_2/m^3$, 3.1013 $kgCO_2/m^3$, and 2.53 $kgCO_2/kg$, and the carbon emissions attributable to electricity consumption are ascertained by multiplying the electricity usage with the relevant regional grid emission factor [43].

$$\begin{aligned} UCE_{it} = \ln[& (2.1622 \times \text{natural gas} + 3.1013 \times \text{iquefied petroleum gas} \\ & + 2.53 \times \text{thermal energy} \\ & + \text{regional grid emission factor} \times \text{electricity})/\text{GDP}] \end{aligned} \quad (2)$$

3.2.2. Key Independent Variable

To enhance the measurement of the GII, we approach its calculation from both incremental and existing stock perspectives. Firstly, this research sums up investments in wastewater treatment, sludge disposal from urban drainage investments, urban landscaping investments, and investments in urban appearance and environmental sanitation. The logarithm of the total investment amount is used to measure incremental GII. This measurement has been adopted in the existing literature [8,23]. Secondly, the existing stock of GII is estimated using the perpetual inventory method. The detailed methodology is as follows:

$$GIIS_{it} = GII_{i,t-1}(1-\delta) + GII_{it} \quad (3)$$

where $GIIS_{it}$ is the stock of GII. In this paper, we take the depreciation rate δ to be 9.6% and use the volume of GII in 2000 divided by 10% as the base period capital stock, in accordance with the authoritative practice in the existing literature [44].

3.2.3. Mediating Variables

Since the *China Urban Statistical Yearbook* does not individually record the employment figures in the ecological protection and environmental governance sector, it aggregates the employment data across three industries: water management, ecological protection and environmental governance, and public facilities management. Consequently, we utilized the ratio of total employees in urban water, environmental, and public facilities management sectors to the overall urban employment as a proxy for measuring pollution control talent (PCT). Moreover, for this study, drawing on existing research, we used the green space ratio in built-up urban areas as a metric for urban green areas (GLA) [45], applied the Baidu index search engine to gauge the frequency of "environmental pollution" keyword searches by residents of various prefectural-level cities over the years as an indicator of public environmental concern (CON) [46,47], and measured the residential waste management rate (RBU) using the proportion of city's processed residential waste to its generated amount [48].

3.2.4. Control Variables

Drawing upon existing research [49,50], this research identifies the following nine control variables:

(1) Urbanization (URB). URB typically accompanies an increase in population density and shifts in lifestyles, potentially leading to a rise in energy demand and consequently increased carbon emissions. Urbanization may also lead to enhanced energy efficiency and public transit systems, although this hinges on urban planning and management. This research quantifies URB based on the ratio of the urban population to the total permanent population at the end of the year.

(2) Industrial Structure (INDUSTR). INDUSTR defines the principal economic activities within a city. Heavy industry and manufacturing usually emit more carbon than service or high-tech sectors. Consequently, a transition in industrial structure, like moving from manufacturing to services, could lower carbon emissions. We assessed INDUSTR by the share of the secondary industry's added value in GDP.

(3) Level of Economic Development (AGDP). Cities with advanced economic development often experience greater energy consumption, yet they might also exhibit more efficient energy utilization and stringent environmental regulations, potentially decelerating the increase in carbon emissions. We calculated the AGDP per capita GDP.

(4) Environmental Regulation (ER). Stringent ER can significantly curtail carbon emissions, such as by constraining the growth of high carbon-emitting industries, encouraging renewable energy usage, or instituting carbon taxes and emission trading systems. We quantified ER by the sulfur dioxide elimination rate.

(5) Degree of Openness (OPEN). OPEN could result in the refinement of industrial structures and technological progress, influencing carbon emissions. International trade and foreign direct investment can introduce advanced low-carbon technologies, yet they might also lead to carbon emission relocation. We evaluated OPEN based on the ratio of total imports and exports to GDP.

(6) Government Intervention (GOV). Government policies and intervention measures, like subsidizing renewable energies and curbing the growth of highly polluting sectors, significantly influence urban carbon emissions. We determined GOV based on the ratio of government spending outside of science and education to overall fiscal expenditures.

(7) Urban Technological Advancement (TEC). TEC, especially progress in energy efficiency and clean energy technology, can notably reduce urban carbon emissions. We gauged TEC by the urban total factor productivity.

(8) Level of Wealth (WEALTH). Typically, cities with a higher wealth level might possess more resources to invest in clean energy and efficient technologies, thereby having the potential to reduce carbon emissions. We quantified WEALTH based on the average wage of employees.

(9) Scale of Population (SCALE). The growth in population size usually results in increased energy demand and carbon emissions, particularly in cities where energy efficiency is low and the energy structure is predominantly reliant on fossil fuels. In this research, SCALE was measured based on population density.

Building upon the foundation of controlling for specified variables, our study further integrates fixed effects for both city and year. This integration is pivotal in managing the effects of unobservable variables that are consistent across different cities and over time. By doing so, we effectively mitigate the impact of the omitted variable problem on our estimation outcomes, thereby enhancing the reliability and precision of our results.

3.3. Data Source

This study excluded cities with variations in areas such as regional size, administrative affiliation, and cities with significant data omissions. For example, Chaohu City, Lhasa City, Haidong City, Sansha City, Danzhou City, Bijie City, and Tongren City, finally retaining 283 cities from 2006–2019. Data related to public environmental concern (CON) were obtained by searching the Baidu Index website, and raw data for other variables were sourced from the *China City Statistical Yearbook* (2007–2020), *China Urban Construction Statistical Yearbook* (2007–2020), *China Urban and Rural Construction Statistical Yearbook* (2007–2020), and the EPS data platform (https://www.epsnet.com.cn/index.html accessed on 6 January 2023). Some missing data were supplemented using linear interpolation and regression methods. Descriptive statistics of the variables are shown in Table 1.

Table 1. Descriptive statistics of variables.

Variable	N	Mean	SD	Min	Max	Data Source
UCE	3962	−1.074	0.824	−3.783	4.392	Calculated according to Formula (2)
GII	3962	5.640	1.273	1.364	19.760	China City Statistical Yearbook
GIIS	3962	46.330	18.660	8.072	100.000	Calculated according to Formula (3)
URB	3962	47.790	10.870	10.680	90.970	China Urban Construction Statistical Yearbook
INDUSTR	3962	10.400	0.808	7.922	13.190	China City Statistical Yearbook
AGDP	3962	0.531	0.297	0.000	1.000	China City Statistical Yearbook
ER	3962	0.311	0.750	0.000	24.880	China City Statistical Yearbook
OPEN	3962	0.804	0.044	0.613	0.980	China City Statistical Yearbook
GOV	3962	1.712	0.803	0.185	17.460	China City Statistical Yearbook
TEC	3962	10.580	0.500	8.509	12.060	China City Statistical Yearbook
WEALTH	3962	5.739	0.914	1.609	7.882	China Urban and Rural Construction Statistical Yearbook
PCT	3962	1.836	0.974	0.039	7.888	China Urban Statistical Yearbook
GLA	3962	34.860	6.572	0.970	63.520	China Urban Statistical Yearbook
CON	2511	13.110	13.620	0.000	75.360	Baidu Index search
RBU	3962	34.860	6.572	0.970	63.520	China Urban Statistical Yearbook

4. Result and Discussion

4.1. Benchmark Analysis

The benchmark regression results of the impact of GII on urban carbon emissions are shown in Table 2. In Table 2, it can be observed that regardless of whether control variables and fixed effects are added, the impact coefficient of GII on urban carbon emissions is significantly negative. Taking column (5) as an example, for every 1% increase in GII, urban carbon emissions decrease by an average of approximately 1.11%. This indicates that GII significantly reduces the level of urban carbon emissions, thus validating Hypothesis 1. Column (6) analyzes the impact of the accumulated volume of GII on carbon emissions, revealing that its coefficient is negative but not statistically significant. This suggests that the influence of China's GII on carbon emissions is correlated with the investments made within the same year rather than being cumulative. This finding aligns with the reality in China, where investments, including GII, are predominantly driven by government initiatives. Consequently, the impact of GII is often more pronounced in new investments that align with the government's policy cycles. Additionally, within the unique context of what can be metaphorically described as an "official promotion tournament" in China, local government officials' career advancements are closely linked to their success in pollution control. This scenario fosters a form of competitive environmental governance, or an "environmental tournament". As a result, officials are incentivized to substantially increase GII during their terms, typically not exceeding five years, and aggressively implement pollution control measures, aiming to demonstrate their accomplishments for career progression. The primary goal of this study will be to conduct a thorough analysis of GII from the incremental rise, as the current stock of GII has not affected urban carbon emissions.

Table 2. Empirical results of the benchmark analysis.

Variables	(1)	(2)	(3)	(4)	(5)	(6)
GII	−0.0592 ***	−0.0624 ***	−0.0103 **	−0.0252 ***	−0.0111 **	−0.0019
	(−5.779)	(−6.637)	(−1.969)	(−4.567)	(−2.127)	(−1.621)
URB		0.0180 ***	0.0010		0.0010	0.0010
		(18.340)	(1.346)		(1.381)	(1.358)
INDUSTR		0.0055 ***	−0.0013		−0.0021	−0.0022
		(4.408)	(−1.198)		(−1.495)	(−1.542)
AGDP		0.0673 **	−0.5772 ***		−0.5093 ***	−0.5142 ***
		(2.149)	(−14.757)		(−10.609)	(−10.734)
ER		−0.1229 ***	−0.0447		−0.0406	−0.0376
		(−2.644)	(−1.300)		(−1.142)	(−1.056)
OPEN		−0.0092	−0.0731 ***		−0.0750 ***	−0.0748 ***
		(−0.564)	(−7.711)		(−7.937)	(−7.914)
GOV		2.3016 ***	0.3624 **		0.5815 ***	0.5785 ***
		(8.134)	(2.012)		(2.963)	(2.947)
TEC		0.0981 ***	−0.1542 ***		−0.1532 ***	−0.1534 ***
		(6.522)	(−14.713)		(−14.433)	(−14.450)
WEALTH		−0.7027 ***	0.0213		0.0723	0.0667
		(−18.116)	(0.564)		(1.438)	(1.331)
SCALE		−0.0399 ***	0.0762		0.1121	0.1075
		(−2.828)	(0.611)		(0.898)	(0.861)
_cons	−0.7395 ***	3.1948 ***	4.3632 ***	−0.9316 ***	2.7721 ***	2.9559 ***
	(−12.479)	(7.872)	(6.097)	(−29.609)	(2.827)	(3.023)
Fixed city	NO	NO	YES	YES	YES	YES
Fixed year	NO	NO	NO	YES	YES	YES
N	3962	3962	3962	3962	3962	3962
r2	0.0084	0.2418	0.8891	0.8726	0.8909	0.8908
r2_a	0.0081	0.2398	0.8802	0.8623	0.8818	0.8817
F	33.4025	125.9740	348.2245	20.8580	63.6716	63.4494

Note: Regression coefficients are t-values in parentheses, and **, and *** indicate significance at the 5%, and 1% levels, respectively.

4.2. Robustness Analysis

The authors of this study conducted a robustness check on the benchmark regression results by altering the measurement method of the dependent variable, using clustered standard errors, eliminating specific samples, excluding other environmental policy interferences, and performing endogeneity tests.

(1) Firstly, for this research, we used urban per capita carbon emissions as the proxy indicator for urban carbon emissions. The results of the model regression are shown in the first column of Table 3.

(2) Secondly, for this research, we employed standard errors clustered at the city level, and the model regression results are presented in the second column of Table 3.

(3) Thirdly, some cities in China have higher administrative rankings, which might disturb the empirical results. For this study, we eliminated samples from Beijing, Shanghai, Shenzhen, Chongqing, and sub-provincial cities and ran the benchmark model regression again. The Civilized City Pilot Policy is designed to elevate the cultural and ethical standards of urban residents. It underscores maintaining the cleanliness of urban public spaces, fostering civilized conduct among citizens, and enhancing the quality of public services. While not directly aimed at reducing carbon emissions, this policy indirectly contributes to this goal by nurturing environmental consciousness among citizens and encouraging eco-friendly practices, such as utilizing public transport and minimizing waste production. The Low-Carbon City Pilot Policy is dedicated to advancing low-carbon initiatives within cities, particularly in the realms of energy usage, transportation, building, and industrial activities. This policy facilitates a direct reduction in urban carbon emissions through various initiatives, including the adoption of clean energy sources, enhancement of energy efficiency, promotion of green transportation systems, and the construction of energy-efficient buildings. Cities implementing this policy often establish explicit carbon reduction objectives and implement measures to fulfill these targets. The Energy Conservation and Emission Reduction Fiscal Policy encompasses tax benefits, subsidies, and financial

supports that are directed towards the development and application of technologies and products aimed at energy conservation and emission reduction. These policies are intended to lower the costs of eco-friendly products, thereby incentivizing businesses and consumers to embrace more sustainable technologies and products. For instance, governmental subsidies might support sectors like energy-efficient vehicles and solar energy generation. Such initiatives are instrumental in hastening the adoption of clean energy and energy-saving technologies, effectively diminishing societal carbon emissions. The regression results can be found in the third column of Table 3.

(4) Fourthly, to filter out the influence of other environmental policies related to carbon reduction on the research findings, we integrated the Civilized City Pilot Policy (WEN), Low-Carbon City Pilot Policy (DT), and Energy Conservation and Emission Reduction Fiscal Policy (FS) into the benchmark regression model. The regression results after excluding the environmental policy interferences are shown in the fourth column of Table 3.

(5) Fifthly, for this study, we used the one-period lag of GII as the instrumental variable for GII to test for endogeneity. The results are presented in the fifth column of Table 3. Considering the regression results from the above five robustness analyses, GII still significantly reduces urban carbon emissions, further confirming Hypothesis 1.

Table 3. Robustness test results.

Variables	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**
	Per Capita Carbon Emission	**Clustered Standard Error**	**Exclude Special Sample**	**Exclude Environmental Policy**	**Endogeneity Test**
GII	−0.0111 **	−0.0111 **	−0.0096 *	−0.0107 **	−0.0191 **
	(−2.127)	(−2.204)	(−1.678)	(−2.049)	(−2.034)
DT				0.0068	
				(0.359)	
WEN				−0.0210	
				(−1.047)	
FS				−0.0976 ***	
				(−3.189)	
URB	0.0010	0.0010	0.0005	0.0011	−0.0002
	(1.381)	(0.911)	(0.588)	(1.425)	(−0.204)
INDUSTR	−0.0021	−0.0021	−0.0025	−0.0024 *	−0.0017
	(−1.495)	(−1.179)	(−1.605)	(−1.681)	(−1.148)
AGDP	0.4907 ***	−0.5093 ***	−0.5138 ***	−0.5122 ***	−0.4482 ***
	(10.220)	(−5.966)	(−9.562)	(−10.652)	(−8.755)
ER	−0.0406	−0.0406	−0.0477	−0.0399	−0.0529
	(−1.142)	(−1.172)	(−1.220)	(−1.122)	(−1.356)
OPEN	−0.0750 ***	−0.0750 ***	−0.0779 ***	−0.0757 ***	−0.0713 ***
	(−7.937)	(−7.383)	(−7.684)	(−8.007)	(−4.879)
GOV	0.5815 ***	0.5815 **	0.6949 ***	0.5469 ***	0.3075
	(2.963)	(2.219)	(3.120)	(2.764)	(1.465)
TEC	−0.1532 ***	−0.1532 **	−0.1584 ***	−0.1484 ***	−0.2430 ***
	(−14.433)	(−2.570)	(−12.590)	(−13.825)	(−17.729)
WEALTH	0.0723	0.0723	0.0757	0.0574	0.0212
	(1.438)	(1.172)	(1.408)	(1.136)	(0.372)
SCALE	0.1121	0.1121	0.2203	0.1399	0.1871
	(0.898)	(0.829)	(1.410)	(1.119)	(1.403)
_cons	−6.4383 ***	2.7721 **	2.0287 *	2.8346 ***	
	(−6.566)	(2.193)	(1.825)	(2.891)	
Fixed city	YES	YES	YES	YES	YES
Fixed year	YES	YES	YES	YES	YES
N	3962	3962	3472	3962	3679
r2	0.9487	0.8909	0.8868	0.8912	0.1718
r2_a	0.9444	0.8818	0.8773	0.8820	0.0969
Kleibergen-Paap rk LM statistic					1296.256 ***
					[0.0000]
Cragg–Donald Wald F statistic					1835.516
					{16.38}
F	40.5997	32.1724	52.9209	49.9512	70.1766

Note: In the regression, values inside the parentheses correspond to t or z values. *, **, and *** denote significance at levels of 10%, 5%, and 1%, respectively. Numbers inside [ ] correspond to *p*-values. The figures within { } are the critical values for the Stock–Yogo weak identification test at a 10% significance level. Both the individual and time-fixed effects have been accounted for.

4.3. Analysis of the Operating Mechanism

Referring to the earlier-stated Hypothesis, and drawing from the established literature on panel mediation effect models [51], in this study, we delved deeper into the four mechanisms by which GII_{it} curtails urban carbon emissions. The model was constructed as follows:

$$M_{it} = \alpha_0 + \alpha_1 GII_{it} + \varphi X_{it} + \mu_i + v_t + \varepsilon_{it} \quad (4)$$

where M_{it} stands for the potential mechanism variables of different types, while the interpretations of other variables align with the model (1). Table 4 displays the outcomes of the mechanism examination. Notably, GII has a significantly positive impact on pollution control talent (PCT), residential waste treatment rate (RBU), urban green land (GLA), and public environmental concern (CON). With a 1% surge in GII, PCT, RBU, GLA, and CON will see respective increases of 2.24%, 78.21%, 29.39%, and 15.71%.

Table 4. Results of operating mechanism test.

Variables	(1) PCT	(2) RBU	(3) GLA	(4) CON
GII	0.0224 **	0.7821 ***	0.2939 ***	0.1571 *
	(2.469)	(4.140)	(4.355)	(1.721)
URB	−0.0016	−0.0657 **	0.0105	−0.0523 ***
	(−1.206)	(−2.402)	(1.073)	(−4.109)
INDUSTR	−0.0116 ***	−0.0793	−0.0264	−0.0767 ***
	(−4.742)	(−1.549)	(−1.444)	(−3.207)
AGDP	0.0024	−2.1506	2.3125 ***	2.6495 ***
	(0.029)	(−1.239)	(3.729)	(3.487)
ER	−0.0454	−1.2088	−0.8244 *	−3.5108 ***
	(−0.736)	(−0.940)	(−1.795)	(−3.824)
OPEN	0.0227	0.0848	0.0393	0.6495
	(1.382)	(0.248)	(0.322)	(0.854)
GOV	1.8608 ***	33.7404 ***	6.8641 ***	1.7963
	(5.468)	(4.755)	(2.708)	(0.491)
TEC	0.0859 ***	−0.8718 **	−0.3658 ***	−1.4117 ***
	(4.667)	(−2.272)	(−2.669)	(−5.198)
WEALTH	0.2801 ***	3.6417 **	0.9087	2.6743 ***
	(3.214)	(2.004)	(1.400)	(3.165)
SCALE	−0.9669 ***	−1.4494	3.2674 **	−4.3391 *
	(−4.462)	(−0.321)	(2.025)	(−1.853)
_cons	3.2750 *	63.9436 *	−22.9032 *	−10.8566
	(1.926)	(1.803)	(−1.808)	(−0.610)
Fixed city	YES	YES	YES	YES
Fixed year	YES	YES	YES	YES
N	3962	3962	3962	2511
r2	0.7648	0.4936	0.7135	0.9505
r2_a	0.7452	0.4514	0.6896	0.9439
F	11.2005	6.8357	7.1822	9.1139

Note: Regression coefficients are t-values in parentheses, and *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively. Individual fixed effects and time-fixed effects were controlled.

The recruitment and development of professionals specializing in pollution control is vitally important for urban areas striving to diminish carbon emissions. Such professionals are typically equipped with sophisticated knowledge in environmental science and are instrumental in the development and dissemination of innovative technologies, including clean energy, waste recycling, and pollution control methods. Furthermore, their expertise is invaluable in shaping policy development, enhancing public education, and providing consultation to businesses. This, in turn, cultivates broader societal awareness about environmental protection and fosters the implementation of effective strategies. Thus, the attraction and retention of these experts are pivotal to bolstering a city's capacity for environmental management and achieving enduring goals in carbon emission reduction.

Elevating the efficiency of domestic waste management constitutes a crucial strategy in curbing urban carbon emissions. Enhancing waste segregation, recycling, and repurposing processes can considerably reduce the volume of waste destined for landfill or incineration, thereby curtailing the associated greenhouse gas emissions.

Urban greenery plays a pivotal role in mitigating urban carbon emissions. Through photosynthesis, plants absorb atmospheric carbon dioxide, making the expansion of green spaces a significant contributor to urban carbon sequestration. Additionally, these green areas offer natural recreational spaces that encourage walking and cycling, thereby reducing reliance on and emissions from motor vehicles. As such, strategically augmenting urban greenery not only facilitates direct carbon absorption but also underpins a shift towards eco-friendly lifestyles, contributing to a reduction in carbon emissions indirectly.

Enhancing public awareness of environmental issues is a critical method for reducing urban carbon emissions. Educational and outreach initiatives can elevate citizens' understanding of climate change and the imperative of carbon reduction, motivating them to engage in proactive measures. Public involvement extends beyond personal behavioral changes to influencing policy decisions, such as endorsing green policies and participating in environmental initiatives. Additionally, consumer preferences can sway corporate production choices, nudging the market towards more sustainable products and services. Therefore, fostering public environmental consciousness is an essential element in realizing the objectives of sustainable urban development and carbon emission reduction.

Therefore, GII curtails urban carbon emissions by drawing in pollution control professionals, augmenting the rate of residential waste treatment, expanding urban greenery, and amplifying the public's focus on the environment.

4.4. Analysis of Heterogeneity

China, with its expansive territory, displays imbalances among cities in terms of economic progress, resource allocation, and more. It is essential to objectively evaluate the carbon-reduction effects of GII in cities at present to advance balanced low-carbon urban growth. Hence, this research probes into the diverse emission-reducing impacts of GII from multiple viewpoints.

Regarding city locational heterogeneity, this paper classifies city samples into eastern, central-west, and north-south regions based on their geographical locations to examine if locational variances influence GII's carbon reduction outcomes. Columns (1), (2), (3), and (4) of Table 5 display the examination results. Notably, GII exerts a marked suppressive impact on the carbon emissions of eastern cities. One potential explanation is that eastern cities, given their economic prowess, frequently acquire greater funds and resources to back GII initiatives. This endows these cities with a significant edge in green infrastructure establishment and operation; concurrently, eastern cities tend to possess enhanced policy enforcement and oversight capacities. This indicates that in these cities, GII-related policies and actions could achieve more efficient execution, leading to superior carbon emission containment outcomes. Additionally, the populace of eastern cities frequently demonstrates elevated environmental consciousness and engagement, fostering the deployment and triumph of GII projects. GII notably suppressed carbon emissions in the south while augmenting them in the north. Delving into the cause, at the onset of green progression, GII operates on a minor scale, holding limited transformative capacity for production and pollution management techniques. At this juncture, GII could potentially enhance initial energy utilization efficiency; however, this might induce businesses to utilize greater energy, exhibiting an "energy rebound effect". In this phase, northern cities may be more inclined to this repercussion given their potential heavier reliance on conventional, high-carbon emission production approaches, whereas southern cities might be undergoing a transformation, thereby more effectively mitigating carbon emissions.

Differences in urban scale. Based on 2014's Notification on Adjusting Urban Scale Division Standards, this paper categorizes cities into large and small scales. In Table 5, columns (5) and (6) present the estimated results for city size heterogeneity. It can be observed that GII significantly curbs carbon emissions in larger cities, while it does not have a notable effect on smaller cities, suggesting a more evident carbon-reducing impact of GII on larger cities. A plausible explanation might be that, owing to their extensive size and economic operations, larger cities exert a more pronounced influence on carbon emissions. In larger cities, GII might more readily attain economies of scale, meaning the returns on investment grow as the scale expands. Hence, a GII of equivalent scale might yield a more substantial emission-reducing impact in bigger cities. Additionally, larger cities typically possess a more intricate energy consumption pattern, encompassing a broader range of sectors like industry, transport, and construction. Investments in green infrastructure can be tailored to these sectors, leading to enhanced carbon reduction outcomes. On the other hand, smaller cities might have a relatively straightforward energy consumption layout, making the influence of green infrastructure investments less discernible.

Table 5. Test for urban heterogeneity: Characteristic One.

Variables	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
	Eastern Cities	**Central and Western Cities**	**Northern Cities**	**Southern Cities**	**Large Cities**	**Small Cities**
GII	−0.0188 ***	−0.0032	0.0169 *	−0.0231 ***	−0.0257 ***	0.0033
	(−2.705)	(−0.434)	(1.685)	(−3.971)	(−4.795)	(0.370)
URB	0.0020 **	0.0002	0.0011	0.0021 ***	0.0032 ***	−0.0018
	(2.255)	(0.133)	(0.510)	(2.684)	(4.309)	(−1.370)
INDUSTR	−0.0077 ***	−0.0019	−0.0057 **	0.0011	−0.0019	−0.0018
	(−3.512)	(−0.976)	(−2.147)	(0.654)	(−1.238)	(−0.785)
AGDP	−0.5573 ***	−0.2482 ***	−0.2077 **	−0.5077 ***	−0.5617 ***	−0.4224 ***
	(−8.255)	(−3.418)	(−2.349)	(−8.185)	(−10.854)	(−5.245)
ER	0.0073	−0.0298	−0.0465	−0.0540	−0.1108 ***	0.0074
	(0.141)	(−0.638)	(−0.696)	(−1.342)	(−2.741)	(0.135)
OPEN	0.0430 *	−0.0813 ***	−0.1223 *	−0.0858 ***	0.0016	−0.0796 ***
	(1.945)	(−7.445)	(−1.897)	(−9.910)	(0.092)	(−6.551)
GOV	0.3136	0.0006	−0.6706	0.3699 *	−0.1556	0.7303 **
	(1.113)	(0.002)	(−1.607)	(1.667)	(−0.733)	(2.191)
TEC	−0.0719 ***	−0.2847 ***	−0.2248 ***	−0.1119 ***	−0.0649 ***	−0.3102 ***
	(−5.916)	(−16.049)	(−11.094)	(−9.360)	(−6.654)	(−14.216)
WEALTH	0.4047 ***	−0.1171 *	−0.0203	0.2409 ***	0.1896 ***	−0.0845
	(4.749)	(−1.882)	(−0.266)	(3.501)	(3.462)	(−1.034)
SCALE	0.3600 **	0.0940	0.3779	0.1452	0.0737	0.3233
	(2.048)	(0.530)	(1.632)	(0.985)	(0.539)	(1.527)
_cons	−1.1993	2.6828 **	0.8848	0.5240	2.8293 **	2.4558 *
	(−0.825)	(2.050)	(0.547)	(0.408)	(2.377)	(1.709)
Fixed city	YES	YES	YES	YES	YES	YES
Fixed year	YES	YES	YES	YES	YES	YES
N	1666	2296	1344	2618	1960	2002
r2	0.8723	0.9020	0.8858	0.8827	0.9074	0.8904
r2_a	0.8605	0.8934	0.8748	0.8725	0.8990	0.8805
F	30.1969	44.0661	20.1573	33.7535	34.0529	42.5969

Note: Regression coefficients are t-values in parentheses, and *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively. Individual fixed effects and time-fixed effects were controlled.

Based on the National Sustainable Development Plan for Resource Cities (2013–2020), this research categorizes cities into those that are resource oriented and those that are not. In Table 5, columns (1) and (2) present the estimated outcomes regarding the diversity in city resource endowments. It is evident that GII has notably curtailed carbon emissions in cities that are not resource oriented, yet it has not done so for resource-oriented cities. Delving into the reasons, resource-oriented cities, whose economies are profoundly anchored in resource extraction, might have policy and managerial biases. This could curtail the impact of green infrastructure investments, whereas cities not centered around resources might be more inclined towards green growth in their policies and management. Additionally, resource-centric cities usually have economies centered around resource extraction and processing, activities known for their high carbon footprint. Even with investments in green infrastructure, it is tough to notably curtail these high-emission activities. Conversely, cities not centered around resources have a more varied economic landscape, making it more feasible for GII to pinpoint effective ways to reduce emissions.

The Smart City pilot initiative is centered on leveraging information technology and the Internet of Things to bolster the efficiency of urban management. This endeavor encompasses the deployment of intelligent traffic systems to alleviate congestion, the creation of smart grids for more effective energy distribution, the development of energy-efficient smart buildings, and the enhancement of citizen life through digitized public services. Moreover, a pivotal aspect of the Smart City initiative is its emphasis on data-driven decision-making, which fosters urban planning and operations that are more eco-friendly, efficient, and adaptable, steering urban development towards greater sustainability. Such advancements have potential implications for the efficacy of Green Infrastructure Investment (GII) in reducing carbon emissions. In Table 6, columns (3) and (4) show that GII is more effective in reducing carbon emissions in non-smart pilot cities compared to smart pilot cities. Additionally, GII is more capable of reducing carbon emissions in cities with high environmental awareness compared to those with low environmental awareness. Delving into the reasons, smart pilot cities might have already rolled out a range of environmental policies and management initiatives. In contrast, non-smart pilot cities might have a broader scope for enhancement, and GII in these cities could potentially benefit from stronger policy backing and more effective management. Additionally, non-smart pilot cities might start with higher levels of carbon emissions and inferior energy efficiency, leading to GII potentially having a more pronounced effect in reducing carbon emissions in these cities. In our analysis, we have categorized cities with a level of Public Environmental Concern above the average as “High Attention Cities,” while those falling below this threshold are classified as “Low Attention Cities”. In cities where environmental consciousness is heightened, the populace tends to be more attuned to environmental challenges. As a result, they are more inclined to embrace and endorse the development and investment in green infrastructure. Such proactive public involvement and backing can expedite the rollout and popularization of green initiatives. Furthermore, cities with a pronounced focus on the environment typically boast a robust system for environmental education and training, furnishing GII with the requisite talent and safeguards.

Table 6. Test of city heterogeneity: Characteristic Two.

Variables	**(1)** Resource-Based City	**(2)** Non-Resource-Based City	**(3)** Intelligent Pilot City	**(4)** Non-Intelligent Pilot City	**(5)** High Attention City	**(6)** Low Attention City
GII	0.0006	−0.0208 ***	−0.0099	−0.0182 ***	−0.0097 *	0.0006
	(0.067)	(−3.248)	(−1.022)	(−2.786)	(−1.769)	(0.065)
URB	−0.0019	0.0024 ***	−0.0008	0.0010	0.0026 ***	−0.0041 ***
	(−1.308)	(2.784)	(−0.701)	(1.161)	(3.635)	(−2.684)
INDUSTR	−0.0069 ***	0.0028	0.0017	−0.0025	−0.0080 ***	0.0057 **
	(−3.095)	(1.568)	(0.730)	(−1.459)	(−4.687)	(2.377)
AGDP	−0.1644 **	−0.8478 ***	−0.3375 ***	−0.5109 ***	−0.4772 ***	−0.5101 ***
	(−2.151)	(−13.054)	(−4.639)	(−8.774)	(−7.931)	(−6.309)
ER	0.0004	−0.0970 **	0.0208	−0.0390	0.0096	−0.2675 ***
	(0.007)	(−2.231)	(0.230)	(−0.955)	(0.266)	(−2.729)
OPEN	−0.0758 ***	−0.0183	0.2120 *	−0.0760 ***	−0.0692 ***	0.0156
	(−6.543)	(−1.012)	(1.773)	(−7.662)	(−7.348)	(0.133)
GOV	0.8232 **	0.2833	0.9488 **	0.7118 ***	0.1680	0.9274 **
	(2.518)	(1.164)	(2.274)	(3.128)	(0.845)	(2.337)
TEC	−0.3325 ***	−0.1037 ***	−0.0760 **	−0.1415 ***	−0.0785 ***	−0.3103 ***
	(−12.748)	(−9.243)	(−2.426)	(−12.338)	(−8.222)	(−9.708)
WEALTH	−0.0253	0.0290	−0.1059	0.0857	0.2404 ***	−0.0977
	(−0.276)	(0.492)	(−0.930)	(1.510)	(4.320)	(−1.197)
SCALE	0.6319 ***	−0.3110 **	−0.0850	0.1417	−0.0647	−0.2609
	(2.655)	(−2.092)	(−0.366)	(0.931)	(−0.508)	(−0.907)
_cons	−2.0971	9.1774 ***	3.3556 *	2.4163 **	2.2589 **	6.4230 ***
	(−1.390)	(6.912)	(1.749)	(2.057)	(1.966)	(3.419)
Fixed city	1596	2366	661	3301	2274	1680
Fixed year	0.8956	0.8924	0.9651	0.8880	0.9373	0.9163
N	0.8858	0.8830	0.9579	0.8766	0.9276	0.9020
r2	35.2825	43.8414	7.9797	47.9324	34.6322	29.4050

Note: Regression coefficients are t-values in parentheses, and *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively. Individual fixed effects and time-fixed effects were controlled.

5. Conclusions, Policy Recommendations, Limitations, and Future Research

5.1. Conclusions

GI plays a crucial role in modern urban infrastructure. In the context of global climate change, GII provides a fresh perspective for controlling urban carbon emissions. Utilizing panel data from Chinese cities, the authors of this study investigated the effects and mechanisms of GII on urban carbon emissions. It was found that the incremental GII can notably decrease carbon emissions in Chinese cities. For every 1% increase in GII, the average carbon emission intensity of cities decreases by approximately 1.11%. The results of various robustness tests, including changing the measurement of the dependent variable, adopting clustered standard errors, removing outlier samples, accounting for other environmental policy interferences, and endogeneity checks consistently uphold this finding. Nevertheless, GII does not seem to affect urban carbon emissions when taking into account the cumulative effect of stocks. The key mechanisms by which GII reduces carbon emissions in Chinese cities include attracting experts in pollution management, enhancing household waste processing rates, expanding urban green areas, and elevating public environmental consciousness. Relative to central and western cities, northern cities, smaller cities, resource-rich cities, smart pilot cities, and cities with lower environmental focus, GII has a more pronounced effect in reducing carbon emissions in eastern cities, southern cities, major cities, non-resource cities, cities outside of the smart pilot program, and cities with heightened environmental attention.

5.2. Policy Suggestions

Considering that GII plays a significant role in reducing carbon emissions in Chinese cities, our policy suggestions include the government offering fiscal subsidies, tax incentives, or special funds to motivate businesses and individuals to invest in green infrastructure—this encompasses areas such as green transportation, renewable energy projects, and energy-efficient buildings; clearly defining the proportion and standards of green infrastructure in urban planning; guaranteeing that green elements are thoroughly integrated into new urban development and the renovation of old urban districts; advocating for the adoption of green building materials and technologies, like green roofs, rainwater harvesting systems, solar panels, and ecological urban design, including urban green spaces and wetland restoration; investing in public transport, promoting the use of electric vehicles and bicycles, and constructing additional bike lanes and pedestrian pathways to cut down on urban transport's carbon emissions; enhancing the share of renewable energy sources like solar, wind, and biomass in the urban energy mix, thereby diminishing dependence on fossil fuels.

Considering the potentially limited direct impact of the GII stocks on carbon emissions, it is imperative for relevant organizations to establish regular monitoring and evaluation mechanisms. These mechanisms are crucial to precisely quantify the specific contributions of GII projects in mitigating carbon emissions. The evaluation should encompass not only the direct environmental benefits derived from the project itself but also its broader indirect effects on the surrounding communities and economic activities. Informed by these holistic assessment outcomes, policymakers and practitioners are advised to promptly revise their strategies and practices. Such revisions are essential to amplify the long-term contribution of GII towards achieving carbon emission reduction objectives.

Given that attracting talent in pollution management, improving the residential waste treatment rate, expanding urban green spaces, and elevating public awareness of environmental issues are key mechanisms through which GII reduces carbon emissions in Chinese cities, our policy suggestions include the following: (1) Offering scholarships and research grants to motivate students and researchers to concentrate on environmental science and pollution control; partnering with universities and research institutes to carry out specialized training and research projects in environmental protection and pollution control; offering incentives like tax breaks and housing allowances to environmental experts and technicians. (2) Developing and enhancing waste sorting and treatment facilities and advocating for waste segregation and recycling; applying the "polluter pays" principle for waste treatment charges to incentivize waste reduction and boost recycling rates; organizing public education initiatives to enhance resident awareness about waste segregation and environmental preservation. (3) Allocating adequate space in urban planning for the construction of parks, green belts, and additional green areas; motivating communities and corporations to engage in urban greening initiatives, like rooftop and community gardens; offering financial backing and technical advice to aid cities and communities in executing greening projects. (4) Employing media, social platforms, and public events to spread environmental knowledge and enhance public understanding of environmental concerns; promoting public involvement in environmental conservation activities, like Tree Planting Day and World Environment Day; creating a system for publicizing environmental information, enabling the public to be informed about local environmental conditions and governmental environmental actions.

In light of the observed variances in the efficacy of Green Infrastructure Investment (GII) across different city types for carbon emission reduction, it is imperative that the government adopts tailored strategic approaches. For municipalities in central, western, and northern regions, an increase in financial backing and technical support is recommended, fostering the adoption of locally attuned low-carbon solutions. In smaller and resource-dependent cities, there should be an emphasis on fostering green urban planning initiatives and steering towards a sustainable industrial reorientation. Cities with lower levels of environmental concern necessitate intensified efforts in environmental education and elevating public consciousness, coupled with the establishment of incentive mechanisms to catalyze environmental enhancements. Conversely, in resource-rich and technologically advanced cities, particularly those in eastern and southern regions as well as larger and non-resource-based urban areas, the government should motivate the showcasing of carbon reduction exemplars through groundbreaking green initiatives. Moreover, cities engaged in smart city pilots and those with heightened environmental awareness are encouraged to persist in spearheading low-carbon advancements and disseminating their insights on integrating smart technologies within Green Infrastructure frameworks. Such a diversified policy approach aims to optimize the role of GII in facilitating carbon emission reductions tailored to the unique characteristics and needs of various urban settings.

5.3. Limitations and Future Research Directions

Given the constraints of time and resources, this study's shortcomings and potential future research directions include the following: (1) This research solely employed Chinese data to evaluate the effects and mechanisms of GII on carbon emissions. Future research could utilize global or other developing countries' data to further explore GII's impact on carbon emissions. (2) Owing to restrictions of the urban data, we used the aggregate of investments in urban sewage treatment, sludge disposal, urban landscaping, and urban environmental sanitation to approximate GII. Should future data availability allow, we intend to employ a broader range of indicators to measure and evaluate GII. (3) Furthermore, in future research, we aim to utilize distance–weight matrices and the spatial Durbin model to explore the spatial spillover effects and boundaries of GII's impact on carbon emissions. Concurrently, the decrease in carbon emissions might lead to unintended outcomes. The ecological, climatic, and environmental changes resulting from the reduction of carbon emissions due to GII are also areas for our future research.

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References

1. IEA. *Empowering Cities for a Net Zero Future*; IEA: Paris, France, 2021.
2. Nesticò, A.; Guarini, M.R.; Morano, P.; Sica, F. An economic analysis algorithm for urban forestry projects. *Sustainability* **2019**, *11*, 314. [CrossRef]
3. Nesticò, A.; Maselli, G.; Ghisellini, P.; Ulgiati, S. A Dual Probabilistic Discounting Approach to Assess Economic and Environmental Impacts. *Environ. Resour. Econ.* **2023**, *85*, 239–265. [CrossRef]
4. Hanna, E.; Comín, F.A. Urban green infrastructure and sustainable development: A review. *Sustainability* **2021**, *13*, 11498. [CrossRef]
5. Jayasooriya, V.M.; Ng, A.W.M.; Muthukumaran, S.; Perera, B.J.C. Green infrastructure practices for improvement of urban air quality. *Urban Urban Gree* **2017**, *21*, 34–47. [CrossRef]
6. Hu, T.H.; Chang, J.; Ralf-Uwe, S. Infrastructure Planning in Germany: The Background, Spatial Framework and Implementations. *Urban Plan. Int.* **2021**, *36*, 109–119.
7. Wu, W.; Fu, X. The Concept of Green Infrastructure and Review of Its Research Development. *Urban Plan. Int.* **2009**, *24*, 67–71.
8. Zhou, Y.N.; Yin, H.W. Foreign green infrastructure planning theory and practice. *Urban Dev. Stud.* **2010**, *17*, 87–93.
9. Zhou, Q.; Shi, W.; Guo, Q.H. The influential mechanism of urban Environmental and Green Infrastructure Investments on Urban High Quality Economic Growth. *Acta Ecol. Sin.* **2021**, *41*, 8820–8832.
10. Forman, R.T. Some general principles of landscape and regional ecology. *Landsc. Ecol.* **1995**, *10*, 133–142. [CrossRef]
11. Rottle, N.D. Factors in the landscape-based greenway: A Mountains to Sound case study. *Landsc. Urban Plan* **2006**, *76*, 134–171. [CrossRef]
12. Jin, R.; Gui, L.L.; Liu, W.J.; Wan, Y.L.; Ran, J.; Zeng, Y. Progress and Trend of Thermal Comfort of Urban Green Infrastructure: Based on CiteSpace Software. *Econ. Geogr.* **2023**, *43*, 84–92.
13. Shao, D.W.; Liu, Z.Q.; Wang, J.D. A Review of Overseas Green Infrastructure Studies. *Planners* **2016**, *32*, 5–11.
14. Kambites, C.; Owen, S. Renewed prospects for green infrastructure planning in the UK. *Plan. Pract. Res.* **2006**, *21*, 483–496. [CrossRef]
15. De Vries, S.; Verheij, R.A.; Groenewegen, P.P.; Spreeuwenberg, P. Natural environments—Healthy environments? An exploratory analysis of the relationship between greenspace and health. *Environ. Plan. A* **2003**, *35*, 1717–1731. [CrossRef]
16. Environmental Protection Agency. *Low Impact Development (LID): A Literature Review*; EPA: Washington, DC, USA, 2000.
17. Pugh, T.A.; MacKenzie, A.R.; Whyatt, J.D.; Hewitt, C.N. Effectiveness of green infrastructure for improvement of air quality in urban street canyons. *Environ. Sci. Technol.* **2012**, *46*, 7692–7699. [CrossRef] [PubMed]
18. Akbari, H. Shade trees reduce building energy use and CO_2 emissions from power plants. *Environ. Pollut.* **2002**, *116*, S119–S126. [CrossRef]
19. Bowler, D.E.; Buyung-Ali, L.; Knight, T.M.; Pullin, A.S. Urban greening to cool towns and cities: A systematic review of the empirical evidence. *Landsc. Urban Plan* **2010**, *97*, 147–155. [CrossRef]
20. Gómez-Baggethun, E.; Barton, D.N. Classifying and valuing ecosystem services for urban planning. *Ecol. Econ.* **2013**, *86*, 235–245. [CrossRef]
21. Von Döhren, P.; Haase, D. Ecosystem disservices research: A review of the state of the art with a focus on cities. *Ecol. Indic.* **2015**, *52*, 490–497. [CrossRef]
22. Jia, X.F.; Dai, F. Review of Progress in Research on Green Infrastructure in China. *Landsc. Archit.* **2015**, *12*, 118–124.
23. Lin, L.F.; Yang, Q.W. Does Green Infrastructure Investment Reduce Carbon Emissions. *Mod. Econ. Res.* **2022**, *29*, 29–37.
24. Niu, T.; Zhao, S.G. An Empirical Study of the Relationship between Urban Environmental Infrastructure Investment and Economic Growth. *Urban Dev. Stud.* **2010**, *17*, 128–131.
25. Jiang, H.Q.; Cao, D.; Wang, J.N.; Guo, X.M. The Study on Action Principle of Environmental Protection Investment on National Economy and the Contribution Models. *Res. Environ. Sci.* **2005**, *18*, 71–74.
26. Xie, J. Infrastructure Construction and China's Regional Total Factor Productivity: Based on 285 Prefecture-level Cities of Spatial Econometric Analysis. *Sci. Decis. Mak.* **2018**, *24*, 71–94.
27. Erdoğan, S.; Gedikli, A.; Cevik, E.I.; Erdoğan, F. Eco-friendly technologies, international tourism and carbon emissions: Evidence from the most visited countries. *Technol. Forecast. Soc.* **2022**, *180*, 121705. [CrossRef]
28. Li, L.; Liu, L.; Gu, Z.; Sun, Z.; Zhang, Q. Examining the relationships between carbon emissions and land supply in China. *Ecol. Inf.* **2022**, *70*, 101744. [CrossRef]

29. Pu, Z.; Fei, J. The impact of digital finance on residential carbon emissions: Evidence from China. *Struct. Chang. Econ. D* **2022**, *63*, 515–527. [CrossRef]
30. 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]
31. Gao, D.; Tan, L.; Mo, X.; Xiong, R. Blue Sky Defense for Carbon Emission Trading Policies: A Perspective on the Spatial Spillover Effects of Total Factor Carbon Efficiency. *System* **2023**, *11*, 382. [CrossRef]
32. Li, G.; Gao, D.; Shi, X.X. How does information and communication technology affect carbon efficiency? Evidence at China's city level. *Energy Environ.* **2023**, *34*, 0958305 × 2311564. [CrossRef]
33. Ma, L.; Shi, D.; Pei, Q. Carbon transformation of China's energy in 2015–2050: Renewable energy development and feasible path. *China Popul. Resour. Environ.* **2018**, *28*, 8–18.
34. Xiao, F.; Pang, Z.; Yan, D.; Kong, Y.; Yang, F. How does transportation infrastructure affect urban carbon emissions? An empirical study based on 286 cities in China. *Environ. Sci. Pollut. R* **2023**, *30*, 10624–10642. [CrossRef] [PubMed]
35. Chen, W.Y. The role of urban green infrastructure in offsetting carbon emissions in 35 major Chinese cities: A nationwide estimate. *Cities* **2015**, *44*, 112–120. [CrossRef]
36. Guo, Z.; Wang, Q.; Zhao, N.; Dai, R. Carbon emissions from buildings based on a life cycle analysis: Carbon reduction measures and effects of green building standards in China. *Low-Carbon Mater. Green Constr.* **2023**, *1*, 9. [CrossRef]
37. Rehman, S.; Rehman, E.; Mumtaz, A.; Jianglin, Z. A multicriteria decision-making approach in exploring the nexus between wind and solar energy generation, economic development, fossil fuel consumption, and CO_2 emissions. *Front. Environ. Sci. Switz.* **2022**, *9*, 819384. [CrossRef]
38. Gao, D.; Li, Y.; Tan, L. Can environmental regulation break the political resource curse: Evidence from heavy polluting private listed companies in China. *J. Environ. Plan. Man.* **2023**, *66*, 1–27. [CrossRef]
39. Xie, R.; Fang, J.; Liu, C. The effects of transportation infrastructure on urban carbon emissions. *Appl. Energy* **2017**, *196*, 199–207. [CrossRef]
40. Nowak, D.J.; Crane, D.E. Carbon storage and sequestration by urban trees in the USA. *Environ. Pollut.* **2002**, *116*, 381–389. [CrossRef]
41. Zhang, W.; Li, G.X. Impact of environmental protection investment on sustainable development in China. *China Popul. Resour. Environ.* **2016**, *26*, 25–33.
42. Zhao, H.; Chen, S.; Zhang, W. Does digital inclusive finance affect urban carbon emission intensity: Evidence from 285 cities in China. *Cities* **2023**, *142*, 104552. [CrossRef]
43. Chen, W.; Wang, G.; Xu, N.; Ji, M.; Zeng, J. Promoting or inhibiting? New-type urbanization and urban carbon emissions efficiency in China. *Cities* **2023**, *140*, 104429. [CrossRef]
44. Zhang, J.; Wu, G.; Zhang, J. The Estimation of China's provincial capital stock: 1952–2000. *Econ. Res. J.* **2004**, *39*, 35–44.
45. Wang, F. Does the construction of smart cities make cities green? Evidence from a quasi-natural experiment in China. *Cities* **2023**, *140*, 104436. [CrossRef]
46. Du, W.; Li, M.; Fan, Y.; Liang, S. Can public environmental concern inhibit the market entry of polluting firms: Micro evidence from China. *Ecol. Indic.* **2023**, *154*, 110528. [CrossRef]
47. Yu, C.; Long, H.; Zhang, X.; Tan, Y.; Zhou, Y.; Zang, C.; Tu, C. The interaction effect between public environmental concern and air pollution: Evidence from China. *J. Clean. Prod.* **2023**, *391*, 136231. [CrossRef]
48. Wu, M.; Huang, J. Campaign-Style Governance Effective? Civilized City Campaign and Urban Sanitation. *J. World Econ.* **2022**, *45*, 212–232.
49. Zhang, N.; Yu, K.; Chen, Z. How does urbanization affect carbon dioxide emissions? A cross-country panel data analysis. *Energy Policy* **2017**, *107*, 678–687. [CrossRef]
50. Zhang, W.; Xu, H. Effects of land urbanization and land finance on carbon emissions: A panel data analysis for Chinese provinces. *Land Use Policy* **2017**, *63*, 493–500. [CrossRef]
51. Cui, X.; Xu, N.; Yan, X.; Zhang, W. How does social credit system constructions affect corporate carbon emissions? Empirical evidence from Chinese listed companies. *Econ. Lett.* **2023**, *231*, 111309. [CrossRef]