Energy Proceedings
Vol 47, 2024
ISSN 2004-2965

Green Bonds and Urban Carbon Emission Reductions: An Analysis of Impact in Chinese Cities#

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ABSTRACT

Green bonds are a rapidly expanding and important green financing tool, but their impact on carbon emission reduction remains in question, particularly at the more granular level of cities. This study examines the relationship between green bonds and emission mitigation at the city level, using data on green bond issuance in 226 Chinese cities from 2006 to 2019. The findings reveal a positive correlation between the issue of green bonds and urban decarbonization, while this positive correlation is not uniformly observed in regions with relatively poor economic development, limited technological innovation and outdated industrial structure. This indicates that green bonds do not help those most in need. Furthermore, no significant mediating or moderating effects of urban industrial structures and technological innovation have been observed, suggesting that the current size and quality of green bond market is not enough to bring about changes in the industrial structure and low-carbon innovation. We also identify urban energy structure and related green finance policy such as Low-Carbon City pilot policy can jointly enhance the mitigation effect of green bond. In this regard, policymakers should take into account the variations among regions and the coordination between policies. Green bonds need to improve their role in reducing financing costs and risks for green projects, allowing funds to be directed to areas where they are most needed.

Keywords: Green bond, green finance, Effectiveness, Carbon emission, Mitigation effect, Urban decarbonization

NONMENCLATURE

Abbreviations	
LCC	Low Carbon Pilot Cities policy
GDP	Gross Domestic Product

1. INTRODUCTION

Climate change is one of the major threats to human beings around the world. A conservative estimate of USD 8.1–9 trillion annually by 2030 is necessary to prevent the most dangerous consequences. However, numerous studies have stated that a substantial financial gap exists to meet these goals. Green bonds are among the most promising green finance instruments to accelerate the transition to a low-carbon economy. Issuances of global green bonds have grown rapidly from $4.2 billion to $487.1 billion between 2012 and 2022. Despite the rapidly expanding market, multiple barriers, including lack of cost competitiveness, information asymmetry, and additionality issues, have resulted in doubts about the true impact of green bonds on the environment and carbon emissions [2].

It's crucial to highlight that this financing challenge is not just a global issue but is also evident at the more granular level of cities. Urban areas, which are pivotal in the fight against climate change, face their own unique financial barriers to implementing sustainable solutions. This challenge of securing adequate green finance for city-level initiatives has garnered attention, with discussions on this topic shedding light on the need for targeted solutions. Currently, the majority of green finance does not flow to the sectors and regions most in need. Therefore, this study attempts to explore to what extent, green bonds help urban decarbonization in Chinese cities and examine relevant mechanisms, by developing an annual city-level panel data for a sample of 226 cities in China.

The remaining parts of this paper are organized as follows: Section 2 presents the methodology for the benchmark model and related mechanism model; Section 3 describes the main results and discussion; and Section 4 offers conclusions and policy implications.

This is a paper for the 10th Applied Energy Symposium: Low Carbon Cities & Urban Energy Systems (CUE2024), May. 11-13, 2024, Shenzhen, China.

2. METHODOLOGY

2.1 Benchmark model

This research adopts the benchmark model to examine the direct effect of green bond on carbon emission. For city i in year t, the benchmark model is proposed as Eq. (1),

$$CO_{2it} = \alpha + \beta GB_{it} + \gamma X_{it} + C_i + \theta_{pt} + \varepsilon_{it} \quad (1)$$

Where CO_{2it} is a dependent variable, referring to carbon emissions per capita of cities in the logarithm form. GB_{it} is an independent variable, which is the natural logarithm of the total annual green bond issue quantity in each city. X_{it} is a set of control variables that may affect urban carbon emissions, shown in Table.1. The city fixed effect C_i is included in the model to control for any unobserved heterogeneity that might obscure the association between green bonds and the logarithm of emissions per capita. θ_{pt} is the province-level linear trend included in the model, which could help identify unobserved factors such as differentiated development at the province level. ε_{it} is an unobserved error term. Thus, the primary coefficient of our interest is captured by β, which represents the abatement effect of green bond at the city level.

2.2 Heterogeneity analysis

Full sample benchmark regression exists potential risk obscuring vital details in many cases. Therefore, heterogeneity in regional economic disparities is discussed, and sub-sample analyses are applied to evaluate impacts of urban industry structure, and R&D expenditure on the relationship between green bonds and urban carbon mitigation. These further analyses aim to examine whether green bond guide the capital to the region most in need and characterize the relevant channel through which green bonds help decrease carbon emission.

Economic development influences both regional carbon emissions, as suggested by the Environmental Kuznets Curve (EKC), and the accessibility of green finance. Industries are urged to phase out heavily polluting capacities and embrace green technological innovations, enhancing their structure and reducing emissions. Green bonds, under resource allocation theory, can expedite this transition by directing private capital towards climate-friendly initiatives [2].

2.3 Moderating effect of energy structure

The development of renewable energy can promote carbon emission reduction, while it faces more barriers and risks in the process of financing compared to traditional fossil fuel energy projects [3]. Green finance can help promote renewable energy development, thus optimizing city's energy structure.

To test the moderating effect on green bond, the interaction of green bond and urban energy structure are introduced into the benchmark model [5]. For city i at year t, the moderation models are as Eq. (2).

$$lnCO_{2it} = \alpha + \beta_1 lnGB_{it} + \beta_2 lnGB_{it} \times lnENG_{it} + \gamma X_{it} + C_i + \theta_{pt} + \varepsilon_{it} \quad (2)$$

Where ENG_{it} denotes energy structure for city i at year t. β_1 and β_2 are the coefficients. β_2 as the coefficient of the cross term, represents the moderating effect. If the coefficients of the interaction terms are significantly negative, it suggests that city's energy structure can enhance the effectiveness of green bond in reducing carbon emission.

2.4 Mixed effect of low-carbon pilot policies

Since 2010, China has launched a low-carbon city pilot policies (LCC) which is a municipal-level pilot climate policy aiming at reducing carbon emissions, and then the 2nd and 3rd batches of low-carbon pilot cities were identified in 2012 and 2017, respectively. The government takes a systematic approach to support industrialization and marketisation for low-carbon transitions. Both green bond and LCC policy have been recognized as important tool to reduce carbon emission and promote low-carbon transition, and green bond may overlap with LCC policy in urban decarbonization.

To test whether the impact of green bonds on urban decarbonization is enhanced by low-carbon city pilot policy, this study establishes a model to evaluate how green bonds respond to low-carbon city pilot policy as Eq. (3), understanding the interaction between climate policy and green bond issuance and providing information on the effectiveness of climate policy. We allow the impact of LCC policy to vary by different batches after the LCC policy conducted.

$$CO_{2it} = \alpha + \beta_2 GB_{it} \times LCC_{nit} \times Post_{nt} + \gamma X_{it} + C_i + \theta_{pt} + \varepsilon_{it} \quad (3)$$

Where CO_{2it} is the logarithm of carbon emissions per capita emitted at city i in year t. GB_{it} refers to the green bond issue quantity at city i in year t. LCC_{nit} is a dummy variable equal to 1 if city i launched as the nth batch of low-carbon pilot city at year t or onward, and 0 otherwise. $Post_t$ is an indicator equal to 1 if the year is the time when nth batch of low-carbon pilot city launched, and 0 otherwise. X_{it} denotes a set of control variables, shown in Table.1. The city fixed effect C_i is included in the model, and the provincial fixed effect is captured by θ_{pt}. ε_{it} is an unobserved error term.

β_1 is the coefficient of the cross term that captures the interaction impact of LCC policy and green bond on urban carbon emission.

2.5 Variables and data description

This study constructs a panel database of 226 cities across 30 provinces in China, spanning 2006 to 2019. The urban decarbonization is measured by carbon emissions per capita, with data sourced from the China Emission Accounting Databases (CEADs) [4]. It utilizes green bond data from the Green Bond Environmental Performance Information Database by China Central Depository & Clearing Co., Ltd. (CCDC), noting that while China issued its first labeled green bond in 2015, the database includes bonds from 2006 identified as compliant with various green guidelines.

Follow prior literature, the control factors are energy consumption (Eng), R&D expenditure (R&D), finance reserve (FIN), industry structure (IND) and foreign direct investment (FDI) [1]. and collected from China's Statistical Yearbooks and urban and energy Statistical Yearbooks. We also include the real GDP to capture the environmental Kuznets curve phenomenon [1]. Additionally, policy data regarding Low Carbon City (LCC) policies are sourced from official government publications.

Table. 1 Definitions and units of variables.

Variable	Definition
Dependent variables	
GB (log)	Green bond issuance (hundred million *Yuan*)
GBQ (log)	Green bond issue quantity
Independent variables	
CO_2 (log)	Carbon emission per capita (million tonnes per capita)
City-level control variables	
GDP (log)	Real GDP (base year=2006, log)
R&D (log)	R&D expenditure (10 million *Yuan*)
Eng (log)	Total energy consumption (10,000 tonnes of coal equivalent)
FIN (log)	Financial development level. The deposit and loan balance of local financial institutions (10 million *Yuan*)
FDI (log)	The degree of openness. Foreign direct investment (10 million USD)
IND (log)	Industry structure (Proportion of added value of the tertiary industry in GDP)
Province-level control variables	
PGDP (%)	GDP share of the province (%)
Policy-related variables	
LCC	Dummy variable that equals 1 if city i was Low-carbon City Pilot from year t or 0 otherwise
subsample-related variables	
ENG	Energy structure (coal consumption / total energy consumption) (10,000 tonnes of coal equivalent)
R&D	R&D expenditure (10 million *Yuan*)
IND	Industry structure (Proportion of added value of the tertiary industry in GDP)

3. RESULTS AND DISCUSSIONS

3.1 Main results of benchmark regression

Table.2 illustrates regression estimates from Eq. (1), showing significant positive coefficients for green bonds initially, but turning negative at the 1% significance level after introducing control variables. Specifically, a 1% increase in green bond issue quantity and issuance correlates with a respective 7.85% and 2.77% reduction in urban carbon emissions in China. Additionally, the analysis shows the coefficients of total energy consumption, trade openness, industry structure, and GDP are significant, indicating these factors may influence regional carbon emission.

Table.2 Main results of benchmark regression

Emission per cap	(1) Issuance (excl. controls)	(2) Quantity (excl. controls)	(3) Issuance (incl. controls)	(4) Quantity (incl. controls)
GB issuance	0.0243***		-0.0277***	
	(0.00662)		(0.00636)	
GB issue quantity		0.0537***		-0.0785***
		(0.0188)		(0.0165)
Real GDP			0.00568	0.00852
			(0.127)	(0.127)
R&D expenditure			0.00839	0.00859
			(0.0101)	(0.0101)
Energy use			0.655***	0.646***
			(0.124)	(0.124)
Financial development			0.0753	0.0766
			(0.0755)	(0.0749)
FDI			-0.0283**	-0.0285**
			(0.0119)	(0.0119)
Industry structure			-0.123*	-0.123*
			(0.0723)	(0.0722)
GDP share of the Province			-6.068***	-5.973***
			(1.917)	(1.890)
City FE	Y	Y	Y	Y
Prv FE	Y	Y	Y	Y
Obs.	3,164	3,164	3,164	3,164
Within Adj. R2	0.005	0.003	0.320	0.321

Notes: standard errors in parenthesis are robust. *** significant at 1% level, ** significant at 5% level, * significant at 10% level.

3.2 Regional heterogeneity

The heterogeneity analysis, based on regional economic development and spatial distribution, investigates whether green bonds support the regions in greatest need. By categorizing cities into developed and undeveloped based on real GDP, we find significant relationship between green bonds and urban carbon reduction in developed areas, but not in undeveloped ones, aligning with prior research [1].

Columns (3)-(5) further examines the relationship between green bonds and urban carbon reduction varies significantly across different regions in China: significant at 1% in the eastern regions, modestly significant at 10% in central areas, and insignificant in the western regions. These results strongly support the results shown in columns (1)-(2) since the overall level of economic development is relatively higher in eastern area than central and western areas in China [5].

Table.3 Heterogeneity of economic development and spatial distribution

	(1) Undeveloped city	(2) Developed city	(3) Eastern area	(4) Central area	(5) Western area
GB issue quantity	-0.0731	-0.0586***	-0.0909***	-0.0600*	-0.0195
	(0.0622)	(0.0144)	(0.0235)	(0.0308)	(0.0371)
Real GDP	0.180	0.189	-0.0495	0.144	-0.199
	(0.195)	(0.183)	(0.193)	(0.196)	(0.292)
R&D expenditure	0.00510	0.00535	-0.00247	0.0186	0.00503
	(0.0136)	(0.0111)	(0.0188)	(0.0185)	(0.0129)
Energy use	0.483**	0.612***	0.961***	0.395**	0.887***
	(0.205)	(0.111)	(0.276)	(0.173)	(0.237)
Financial development	0.0583	-0.127	0.0411	0.0523	0.106
	(0.0996)	(0.111)	(0.119)	(0.114)	(0.179)
FDI	-0.0255	-0.0212*	-0.0234	-0.0387	-0.0184
	(0.0190)	(0.0116)	(0.0168)	(0.0239)	(0.0207)
Industry structure	-0.158*	0.000820	-0.0164	-0.171	-0.181
	(0.0830)	(0.140)	(0.170)	(0.110)	(0.119)
GDP share of the Province	-18.48**	-4.952**	-11.95**	-7.059*	-4.405**
	(9.321)	(2.225)	(5.303)	(3.852)	(2.009)
City FE	Y	Y	Y	Y	Y
Prv FE	Y	Y	Y	Y	Y
Obs.	1,575	1,579	1,274	1,218	672
Within Adj. R2	0.361	0.218	0.363	0.287	0.327

Notes: standard errors in parenthesis are robust. *** significant at 1% level, ** significant at 5% level, * significant at 10% level. The sub sample is divided equally into two groups based on median of real GDP.

The analysis reveals a significant association between green bonds and urban carbon reduction in economically developed cities, with diminished effectiveness in less developed regions. Developed areas benefit from robust financial markets and advanced environmental policies that facilitate green bond issuance and drive green innovation. Fig.1 illustrates that economically prosperous regions in China are primarily on the eastern coast, whereas the western regions, characterized by limited financial resources and smaller economic scales, lag in sustainability initiatives [3].

Additionally, when it comes to the areas that more urgently need green finance, the western regions depend on high-carbon-intensity energy sources, requiring more green finance support for a low-carbon transition. The absence of adequate financial support in these less developed areas poses a significant challenge to balancing economic growth with environmental sustainability.

Therefore, this heterogeneity analysis demonstrates the uneven distribution of green bond development across China, highlighting that the regions in greatest need—characterized by high carbon intensity and significant climate vulnerability—often suffer from underdeveloped economies and financial markets, thereby diminishing the potential mitigation impacts of green bonds.

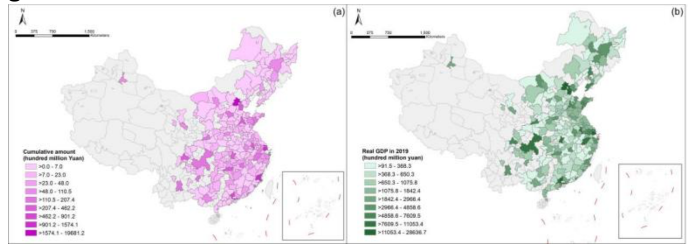

Fig.1 (a) Cumulative issuance of green bonds from 2006-2019 in China; (b) Real GDP in 2019 in Chinese cities.

3.3 Impact of green innovation, industry structure and energy structure

This section explores how energy structure, industry structure, and technological innovation influence the correlation between green bonds and urban carbon mitigation. Results in columns (1)-(2) of Table.4 suggest that the green bond significantly reduces carbon emission in cities with different energy structure and the difference is slight, indicating the association between green bonds and carbon emission is universal and extensive. Therefore, we further examine the potential moderating effect of energy structure in column (3). The coefficients of green bond and the cross term are both significantly negative at the 1% and 10% significance level respectively, indicating the impact of green bonds on urban carbon mitigation varies depending on the levels of urban energy structure [5]. This is in line with previous findings that renewable energy use is a moderating factor in the green finance effect on carbon mitigation [6].

Table.4 The moderating effect of energy structure

	Sub-sample analysis		Moderating effect of energy structure
	(1)	(2)	(3)
Carbon emission per cap	Lower ENG	Higher ENG	Cross term (ENG*GB)
GB issue quantity	-0.0761***	-0.0579***	-0.127***
	(0.0218)	(0.0197)	(0.0352)
SUEST test	-0.018		
	(0.257)		
ENG * GB quantity			-0.0337*
			(0.0204)
Real GDP	-0.204	0.335*	0.00488
	(0.189)	(0.176)	(0.127)
R&D expenditure	0.0122	-0.00681	0.00900
	(0.0101)	(0.0184)	(0.0101)
Energy use	0.765***	0.670***	0.643***
	(0.154)	(0.197)	(0.124)
Financial development	0.191*	-0.132	0.0800
	(0.104)	(0.126)	(0.0751)
FDI	-0.0111	-0.0380**	-0.0288**
	(0.0147)	(0.0168)	(0.0118)
Industry structure	0.0593	-0.295***	-0.124*
	(0.0995)	(0.0904)	(0.0720)

GDP share of the Province	-4.729***	-9.499*	-6.125***
	(1.614)	(5.109)	(1.882)
City FE	Y	Y	Y
Prv FE	Y	Y	Y
Obs.	1,574	1,574	3,164
Within Adj. R^2	0.388	0.288	0.322

Notes: standard errors in parenthesis are robust. *** significant at 1% level, ** significant at 5% level, * significant at 10% level. lower group and higher group are defined by average of urban energy structure, industry structure, and R&D expenditure.

The results in column (1)-(2) and (4)-(5) in Table.5 demonstrate that the impact of green bonds on carbon emission reduction is only significant in city with higher proportion of tertiary industry in GDP and substantial technology innovation expenditures at a 1% significance level. However, changes in these areas do not affect the impact of green bonds on urban carbon mitigation since there is no moderating effects of industry structure or technological innovation.

Although green bonds can enhance energy structure upgrades and reduce urban carbon emissions in the short term, they do not significantly impact promoting technological innovation and upgrading industry restructure. Given the complexity of green technological innovation, transforming industry structure is a long-term process [3]. The limited scale of the green bond market, compared to the traditional bond market, may explain this inadequacy. Additionally, the limited impact of green bonds in less innovative regions might come from insignificant financing advantages and an imperfect market mechanism. High financing costs and investment risks, compounded by immature standards, regulations, and disclosure mechanisms, hinder efficient capital allocation and dilute the mitigation effects of green bonds compared to conventional bonds.

Table.5 Impact of industry structure and technology innovation

Carbon emission per cap	(1) Lower IND	(2) Higher IND	(3) Cross term (IND*GB)	(4) Lower R&D	(5) Higher R&D	(6) Cross term (RD*GB)
GB issue quantity	-0.0310	-0.0814***	0.191	0.0619	-0.0582***	0.146
	(0.0518)	(0.0179)	-0.283	(0.0741)	(0.0137)	-0.0917
Real GDP	0.0494	0.0497	0.0064	-0.0679	0.361*	0.00869
	(0.188)	(0.177)	(0.127)	(0.172)	(0.192)	(0.125)
R&D expenditure	0.00763	0.00784	0.00839	-0.0127	0.0238	0.00989
	(0.0100)	(0.0140)	(0.0101)	(0.0107)	(0.0207)	(0.0101)
Energy use	0.668***	0.733***	0.645***	0.761***	0.356**	0.633***
	(0.160)	(0.166)	(0.124)	(0.183)	(0.141)	(0.124)
Financial development	0.0688	-0.0116	0.0779	0.134	-0.187	0.0775
	(0.117)	(0.110)	(0.0751)	(0.0878)	(0.120)	(0.074)
FDI	-0.0297*	-0.00494	-0.0283**	-0.0199	-0.0281**	-0.0286**
	(0.0177)	(0.0112)	(0.0118)	(0.0153)	(0.0133)	(0.0118)
Industry structure	-0.218*	0.0718	-0.122*	-0.0511	-0.124	-0.126*
	(0.125)	(0.146)	(0.0722)	(0.0834)	(0.117)	(0.0721)
GDP share of the Province	-12.79***	-5.356**	-5.876***	-7.114***	-5.188**	-5.871***
	(4.103)	(2.092)	(1.902)	(1.745)	(2.602)	(1.829)
IND * GB quantity			-0.0662			
			(0.0695)			
R&D * GB quantity						-0.0181**
						(0.00745)
City FE	Y	Y	Y	Y	Y	Y
Prv FE	Y	Y	Y	Y	Y	Y
Obs.	1,576	1,552	3,164	1,537	1,575	3,164
Within Adj. R^2	0.370	0.292	0.321	0.365	0.147	0.323

Notes: standard errors in parenthesis are robust. *** significant at 1% level, ** significant at 5% level, * significant at 10% level.

3.4 Mixed effect of Low-Carbon City pilot policies

To examine the relationship between green bonds and urban decarbonization under LCC policy, this section first conducts a sub-sample analysis to report the effect of green bond before and after the 1st batch of LCC, shown in Columns (1)-(2) of Table.6, demonstrating that the impact of green bond issuance is significantly negative post-LCC policy implementation at the 1% level, but not significant prior to the policy.

We further explore the interact effect of three batches of LCC policy and green bonds based on Eq.(3), and reports p-values from testing the statistical difference of the cross terms using time gradient regression that the coefficients among cross term are comparable. It reveals consistently significant effects at the 1% level, though the impact diminishes across the batches, with coefficients decreasing from -0.0963 to -0.0322.

This decreasing trend suggests that LCC policy initially enhances green bonds' decarbonization impact and the effect reduces over time. Previous research also found significant reductions in carbon intensity in pilot cities under LCC policy [7]. Since 2010, China has launched 81 national low-carbon city pilot projects to encourage low-carbon investments, boosting technological innovations and sustainable urban development. Our study confirms that LCC policy can jointly affect and enhance the development of green bond issuance in the pilot cities.

Table.6 Mixed effect of low-carbon pilot policies

Carbon emission	(1)	(2)	(3)	(4)	(5)

per cap	Before 2010	After 2010	1st Batch	2st Batch	3rd Batch
GB issue quantity	0.0187	-0.0478***			
	(0.0471)	(0.0140)			
GBxPilotxPost2010			-0.0963***		
			(0.0353)		
GBxPilotxPost2012				-0.0531***	
				(0.0151)	
GBxPilotxPost2017					-0.0322***
					(0.00774)
City FE	Y	Y	Y	Y	Y
Prv FE	Y	Y	Y	Y	Y
Obs.	904	2,260	3,164	3,164	3,164
Within Adj. R2	0.278	0.091	0.319	0.320	0.320

Notes: standard errors in parenthesis are robust. *** significant at 1% level, ** significant at 5% level, * significant at 10% level.

4. CONCLUSIONS

Green bond has been treated as an important tool in transition to low-carbon economy, while it remains unclear whether green bond promote carbon emission reduction at the city level. This study examines the relationship between green bonds and urban decarbonization, using a panel database covering 226 cities from 30 provinces in China from 2006 to 2019. Overall, the study suggest that green bonds can be a potential powerful tool in addressing climate change. Yet, the regions that most require financial support for decarbonization—typically those with less economic development, outdated industrial structures, and minimal green technology innovation—do not benefit as substantially as developed regions, suggesting a need for considering the difference among cities.

Furthermore, while green bonds facilitate emission reductions in cities with advanced industrial structures and innovation, they don't broadly impact the economy or technology due to limited market scale and quality. Expanding the market, lowering costs, and improving standards are essential for establishing a more mature green bond market to promoting low-carbon transitions.

We identify that urban energy structure and related green finance policy such as Low-Carbon City pilot policy can jointly enhance the mitigation effect of green bond, demonstrating that policy collaboration can help green financial instruments play a greater role.

In conclusion, while green bonds hold promises in urban decarbonization efforts, their full potential is yet unrealized. Enhancing the effectiveness of green bonds requires not only expanding their market and reducing financial disparities but also fostering policy environments that support comprehensive low-carbon transitions. This study advocates for a strategic refinement of green finance policies to better harness the transformative power of green bonds in achieving sustainable urban development.

ACKNOWLEGDEMENT

The authors would like to acknowledge all the reviewers who help us to improve the paper.

DECLARATION OF INTEREST STATEMENT

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. All authors read and approved the final manuscript.

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