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Urbanization, Environmental Degradation, and Sustainable Urban Development: Evidence from the Belt and Road Initiative Economies

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Abstract

Rapid urbanization across Belt and Road Initiative (BRI) economies presents a dual challenge: harnessing urban agglomeration economies for inclusive economic growth while managing the environmental consequences of concentrated economic activity, infrastructure expansion, and energy consumption growth. This study empirically examines the relationships between urbanization, economic growth, and environmental degradation — specifically CO_2 emissions, particulate matter (PM2.5) concentration, and water quality — across 58 BRI economies over 2000–2022, with an explicit focus on the role of sustainable urban development policies in moderating urbanization's environmental footprint. A nonlinear panel estimation framework incorporating EKC specifications, threshold regression, and spatial panel econometrics — accounting for geographic environmental spillovers across BRI economies — is employed. Results demonstrate a robust inverted U-shaped EKC relationship between urbanization and CO_2 emissions, with an urbanization turning point at approximately 58% urban population share, beyond which additional urbanization becomes carbon-decoupling. Renewable energy integration, green building standards, and public transportation investment significantly shift the urbanization-emission relationship downward, enabling emission reduction at lower urbanization rates than the baseline EKC predicts. Spatial analysis reveals significant cross-border environmental spillovers: urbanization-driven emissions in one BRI economy significantly increase pollution levels in neighboring economies, with spillover effects covering an average geographic range of approximately 380 kilometers. Green BRI policy frameworks significantly moderate these cross-border spillovers.

Keywords: urbanization, environmental Kuznets curve, BRI economies, spatial econometrics, CO_2 emissions, sustainable urban development, green transition

1. Introduction

The Belt and Road Initiative (BRI), China's ambitious infrastructure and economic cooperation program spanning more than 140 countries, encompasses some of the world's most rapidly urbanizing economies. Across BRI member states in Asia, Africa, the Middle East, and Eastern Europe, urbanization rates are projected to increase from approximately 50% in 2020 to 65–70% by 2040 — an urban population addition equivalent to more than 1 billion new urban residents over two decades (UN DESA, 2022). This urbanization trajectory is simultaneously one of the most powerful engines of economic development — through agglomeration economies, knowledge spillovers, specialization gains, and infrastructure scale efficiencies — and one of the most consequential drivers of environmental change, through increased energy consumption, industrial concentration, urban heat island effects, and land use transformation.

Understanding the urbanization-environment nexus in BRI economies is of global environmental significance. BRI member states collectively account for approximately 55% of global CO_2 emissions and face some of the world's most severe air and water quality challenges. China, the BRI's initiating economy, has explicitly recognized the tension between its development ambitions and environmental commitments through its Green BRI initiative, which seeks to embed environmental standards into BRI infrastructure financing and project selection. Whether BRI infrastructure investment accelerates or retards the urbanization-environment relationship — through its effects on energy infrastructure choice, transportation modal composition, and urban planning models — is a question of urgent empirical relevance.

The Environmental Kuznets Curve framework provides the organizing theoretical structure for this analysis. If urbanization follows the EKC pattern — initially increasing and then decreasing environmental degradation as income and urbanization levels rise — then the primary policy question is how to shift the turning point leftward (achieving environmental improvement at lower urbanization rates) and downward (reducing environmental damage at all urbanization levels). Green urban development policies — renewable energy integration, green building standards, public transit investment, compact city planning — are theoretically predicted to achieve both effects by reducing the energy and emission intensity of urban economic activity.

The spatial dimension of this analysis reflects the geographic structure of BRI economies. Environmental externalities — particularly air pollution and water quality — do not respect national boundaries; they diffuse spatially through atmospheric and hydrological systems. Urbanization-driven industrial activity in one BRI economy can generate trans-boundary pollution in neighboring economies, creating environmental spillovers that cannot be addressed through national policies alone. Spatial panel econometrics, which accounts for these geographic interdependencies, provides the appropriate analytical framework for BRI environmental analysis — yet has rarely been applied to urbanization-environment questions in this context.

2. Literature Review

2.1 Urbanization and Environmental Quality

The theoretical relationship between urbanization and environmental quality is complex and multi-directional. Scale effects of urbanization — concentrating economic activity, energy use, and waste generation — predict positive urbanization-pollution associations. Composition effects — urbanization-driven structural shifts from energy-intensive agriculture and manufacturing to lower-intensity services — predict negative associations at higher income levels. Technique effects — urbanization-driven technology adoption and regulatory capacity that reduce emission intensity — similarly predict negative associations at higher development levels. The EKC literature documents this nonlinearity empirically for multiple pollutants including CO_2 (Stern, 2004), SO_2 (Grossman & Krueger, 1995), and particulate matter (Copeland & Taylor, 2004).

Specifically for urbanization, Martínez-Zarzoso and Maruotti (2011) found an inverted N-shape (rather than U-shape) relationship between urbanization and CO_2 for developing countries. Liddle and Lung (2010) found that urbanization significantly increased emissions in developing but not in developed countries. Cole and Neumayer (2004) found that urbanization reduced emissions in advanced economies through composition and technique effects. The heterogeneity of findings across studies reflects genuine cross-country variation in the urbanization-environment relationship, motivating the threshold and heterogeneity analysis in the present study.

2.2 BRI Infrastructure and Environmental Implications

The environmental implications of BRI infrastructure investment have been debated extensively but empirically studied sparingly. Hughes et al. (2021) documented that early BRI energy investments were heavily weighted toward fossil fuel infrastructure, potentially "locking in" carbon-intensive energy systems in recipient economies. Gallagher et al. (2021) found that BRI lending was associated with increased coal power investment in recipient economies, though subsequent years showed a shift toward renewables following China's 2021 pledge to stop financing overseas coal projects. Li et al. (2023) found mixed evidence on whether BRI infrastructure investment reduced or increased local pollution levels, with effects depending critically on infrastructure type (transportation vs. energy) and local governance quality.

2.3 Spatial Econometrics in Environmental Economics

Spatial panel econometrics has been increasingly applied to environmental economics to account for geographic interdependencies. Piras (2010) demonstrated that ignoring spatial dependence in panel models can produce biased and inconsistent estimates when true error processes are spatially correlated. In environmental contexts, spatial dependence arises from trans-boundary pollution (physical diffusion), common regulatory pressures (policy contagion), and shared production networks (economic linkages). Spatial Durbin Models (SDM), Spatial Autoregressive Models (SAR), and Spatial Error Models (SEM) provide alternative specifications, with model selection guided by Lagrange Multiplier (LM) tests.

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3. Research Gap

Three gaps motivate this study. First, spatial econometric analysis of urbanization-environment relationships has not been applied to BRI economies, leaving cross-border environmental spillovers unquantified. Second, the specific role of green urban development policies (renewable energy, green buildings, public transit) as EKC turning point shifters has not been quantified in the BRI context. Third, the threshold-based nonlinearity in urbanization's environmental impact has not been tested alongside EKC and spatial specifications in an integrated framework for BRI economies.

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4. Objectives and Hypotheses

Objective 1: Test the EKC hypothesis for urbanization-CO_2 relationships in BRI economies.

Objective 2: Identify the urbanization turning point and test whether green urban policies shift it.

Objective 3: Quantify cross-border environmental spillovers using spatial panel econometrics.

Objective 4: Assess the role of BRI green policy frameworks in moderating cross-border spillovers.

H1: There is an inverted U-shaped (EKC) relationship between urbanization and CO_2 emissions in BRI economies.

H2: Green urban development policies significantly lower the urbanization-CO_2 turning point.

H3: There are significant positive spatial spillovers of urbanization-driven CO_2 emissions across BRI economies.

H4: Green BRI policy adoption significantly reduces cross-border environmental spillovers.

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5. Methodology

Annual panel data for 58 BRI economies were compiled for 2000–2022 from World Bank WDI, IEA, WHO Global Ambient Air Quality Database, and Chinese Ministry of Commerce BRI databases. The spatial weight matrix was constructed using inverse distance weighting based on geographic centroids (400km bandwidth). CO_2 emissions, PM2.5, and water quality index were the dependent variables. Urbanization rate, GDP per capita, GDP per capita squared, renewable energy share, green building index (custom composite), public transit investment share, BRI green policy score, and industrialization rate were independent variables. EKC specifications included urbanization and its square. Spatial Durbin Models were estimated using maximum likelihood. Threshold regression tested for discrete nonlinearities.

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6. Data Analysis and Findings

Table 1: EKC Estimation Results — CO_2 Emissions

Variable	**FE (1)**	**SDM Spatial (2)**	**FE + Green Policies (3)**
Urbanization Rate	0.087***	0.076***	0.071***
	(0.021)	(0.019)	(0.020)
Urbanization²	-0.00075***	-0.00065***	-0.00082***
	(0.00019)	(0.00017)	(0.00021)
Renewable Energy Share	-0.187***	-0.167***	-0.198***
	(0.041)	(0.037)	(0.044)
Green Building Index	—	—	-0.134**
			(0.054)
Public Transit Investment	—	—	-0.098*
			(0.049)
Spatial Lag (W×CO_2)	—	0.234***	—
		(0.054)	
EKC Turning Point	58.0% urban	58.5% urban	43.3% urban
Observations	1,218	1,218	987

Note: *** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$. *Column (3) reports model with green policy variables; reduced N reflects data availability.*

The EKC turning point of 58.0% urbanization (H1 confirmed) is reduced to 43.3% when green urban policies are incorporated (H2 confirmed), indicating that green urban development policies enable emission decoupling approximately 15 percentage points earlier in the urbanization process.

Table 2: Spatial Spillover Effects (SDM Decomposition)

Effect Type	**CO_2 Emissions**	**PM2.5**
Direct (own-country urbanization → own emissions)	0.076***	0.054***
Indirect/Spillover (neighbors' urbanization → own emissions)	0.041**	0.029**
Total Effect	0.117***	0.083***
Spillover Range (km, 90% decay)	380	420

Note: H3 confirmed — significant positive spatial spillovers with approximately 380–420 km geographic range.

Table 3: Green BRI Policy Moderation of Spatial Spillovers

Interaction	Spillover Coefficient	p-value
BRI Green Policy × Spatial Lag	-0.087	0.003

Note: H4 confirmed — BRI green policy adoption significantly reduces cross-border emission spillovers.

7–11. Discussion Through Conclusion

The EKC confirmation for BRI urbanization-emissions, combined with the green policy turning point reduction, provides the first spatial-econometric evidence that sustainable urban development policies can genuinely accelerate environmental-economic decoupling in the BRI context. The spatial spillover finding — that roughly one-third of the total urbanization-emission effect propagates to neighboring economies — underscores the regional public goods character of BRI environmental management: individual country green policy adoption generates environmental benefits that extend across borders, strengthening the case for regionally coordinated green BRI standards. The Green BRI policy moderation of spillovers suggests that China's green BRI initiative has measurable cross-border environmental benefits, providing empirical support for its continued and expanded implementation. Future research should examine the specific infrastructure types (renewable energy, urban rail, smart grid) that deliver the greatest spillover-reducing environmental dividends per BRI investment dollar.

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