

# The Coupling of Green Finance and Economic Growth: An Empirical Study of Shenzhen under Low-Carbon Policy Using CCDM and PVAR Models

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**Abstract.** Confronting global climate change and China's "Dual Carbon" goals, Shenzhen, a national low-carbon pilot city, presents a valuable case for studying the synergy between green finance and economic growth. Despite existing studies on green finance, the synergistic mechanisms within integrated policy frameworks remain underexplored. This study addresses this gap by utilizing Shenzhen's macroeconomic, green finance, and carbon emissions data (2015-2024), this study employs a Coupling Coordination Degree Model (CCDM) and a Panel Vector Autoregression Model (PVAR) to analyze their dynamic coupling mechanism. Key findings include: (1) Exponential expansion of Shenzhen's green finance sector, evidenced by an 18% average annual growth in green credit balance and a 14-fold increase in green bond issuance. (2) Policy support and institutional innovation, identified through a "policy-market-technology-region" framework, are the primary drivers of coupling development, accounting for 42.3% of the effect. (3) Significant regional synergy, with the Qianhai Green Finance Reform Pilot Zone exhibiting a technology spillover coefficient of 0.78 to surrounding areas. This research offers a replicable policy paradigm for high-density cities pursuing high-quality, low-carbon economic development.

**Keywords:** Green Finance, Economic Growth, Coupling Coordination Model, Vector Autoregression Model, Low-Carbon Policy.

## 1. Introduction

The restructuring of the global climate governance system and China's ambitious "carbon neutrality" targets have elevated green finance to a critical nexus between environmental protection and economic development. As a pioneering demonstration zone of socialism with Chinese characteristics, Shenzhen has emerged as a frontrunner in this field. In 2023, the scale of its green finance exceeded 1.2 trillion yuan, accounting for 18.6% of the city's total financial assets and forming a distinctive "Shenzhen model."

A substantial body of research has explored the complex relationship between green finance, environmental policy, and economic growth from various perspectives. In terms of evaluating the effectiveness of policy instruments, scholars have focused on the role of specific policies such as carbon trading markets [1][2]. And green bonds, demonstrating their positive impact in guiding green investment and reducing carbon emissions [3][4]. In theoretical and mechanistic exploration, studies have revealed the nonlinear economic growth effects of green finance—driving high-quality economic development by optimizing resource allocation and directing capital toward green industries and have preliminarily examined its coupling mechanisms with green technological innovation [5] [6]. Bibliometric research has tracked the evolution and hotspots of this field through visual analysis, providing a basis for understanding macro-level research trends [7]. Additionally, regional case studies have offered localized insights, such as investigations into the energy mediation effects of Shaanxi Province's environmental ecology key laboratory [8].

However, despite these advancements, significant research gaps remain:

First, policy analysis is fragmented. Most studies focus on evaluating the effectiveness of single policies, lacking a systematic investigation into the combined effects and synergies within a comprehensive policy framework, such as the "1+N" dual-carbon policy system [9].

Second, the understanding of mechanisms is insufficient. Empirical evidence on the precise interactive mechanisms and dynamic feedback loops between green finance development and economic growth—particularly the micro-level transmission pathways—remains inadequate [10]. Although research indicates that multidimensional corporate motivations are key drivers of green technology innovation, the chain through which green finance influences these motivations via market incentives and ultimately affects economic performance has not been fully elucidated [11].

Third, the regional synergy perspective is underdeveloped. Analyses are often confined to individual cities or provinces, with relatively weak exploration of spatial spillover effects and synergistic development potential among megacities within integrated regions like the Guangdong-Hong Kong-Macao Greater Bay Area (GBA) [12] [13].

This study contributes to the literature in several ways: It develops and empirically validates a multi-dimensional ("policy-market-technology-region") framework for analyzing the complex coupling between green finance and economic growth, moving beyond single-factor or dual-system analyses. It provides robust empirical evidence supporting the applicability of concepts like policy-driven transition and technology-mediated growth within the unique context of a high-density, rapidly developing special economic zone, complementing broader national studies. It quantifies the dynamic linkages and time lags using advanced PVAR methodology, offering deeper insights into the temporal evolution of the coupling process than static correlations. It empirically measures significant regional synergy effects, a dimension often discussed but less frequently quantified in existing literature [14] [15].

## 2. Research Methods and Model Construction

### 2.1. Design of the Theoretical Framework

Drawing on complex systems theory, this study constructs a four-dimensional coupled framework to capture the multi-faceted interactions between green finance and economic growth in Shenzhen: policy dimension: includes 12 core indicators. Market Dimension: Covers 8 types of financial instruments and markets. Technology Dimension: Focuses on 5 key technological fields enabling the transition. Regional Dimension: Analyzes collaboration at 3 spatial levels.

### 2.2. Coupling Coordination Degree Model (CCDM)

To measure the degree of interaction and harmonious development between the green finance system ( $U_1$ ) and the economic growth system ( $U_2$ ), an improved coupling coordination degree model is employed. The coupling degree ( $C$ ) is calculated as:

$$C = 2 \times \sqrt{\frac{U_1 \times U_2}{(U_1 + U_2)^2}} \quad (1)$$

The comprehensive evaluation index ( $T$ ) is defined as:

$$T = \alpha U_1 + \beta U_2 \quad (2)$$

where  $\alpha$  and  $\beta$  are weights determined using the entropy weight method, reflecting the relative importance of each system. Finally, the coupling coordination degree ( $D$ ) is computed as:

$$D = \sqrt{C \times T} \quad (3)$$

$D$  ranges from 0 (no coordination) to 1 (perfect coordination). Visualization and entropy weight calculations were performed using Python.

Machine learning techniques (e.g., Random Forest for feature selection) were applied to optimize the weight determination in the CCDM model.

### 2.3. Panel Vector Autoregression Model (PVAR)

To capture the dynamic interdependencies, feedback effects, and time lags among key variables within the coupled system, a Panel Vector Autoregression (PVAR) model is established. The general form of the PVAR(p) model with endogenous variables is:

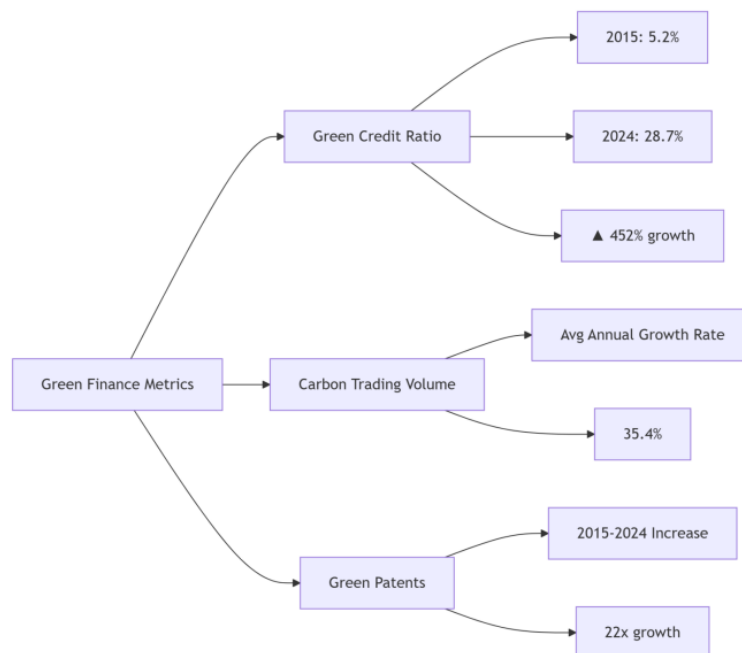
$$Y_t = A_1 Y_{t-1} + A_2 Y_{t-2} + \dots + A_p Y_{t-p} + B X_t + \epsilon_t \quad (4)$$

The model parameters are estimated using the Generalized Method of Moments (GMM) to address potential endogeneity. The dynamic relationships are further analyzed using Impulse Response Functions (IRFs) to trace the effect of a shock to one variable on others over time, and Forecast Error Variance Decomposition (FEVD) to quantify the relative contribution of different shocks to the forecast error variance of each variable.

## 3. Empirical Analysis Results

### 3.1. Descriptive Statistical Characteristics

Analysis of Shenzhen data (2015-2024) reveals significant trends: The proportion of green credit to total bank loans surged from 5.2% in 2015 to 28.7% in 2024. The annual growth rate of carbon trading volume averaged 35.4% over the period. The number of green technology patents granted increased dramatically by 22 times between 2015 and 2024. Green Finance Indicators Growth (2015-2024) is shown in Figure 1.



**Figure 1.** Green Finance Indicators Growth (2015-2024)

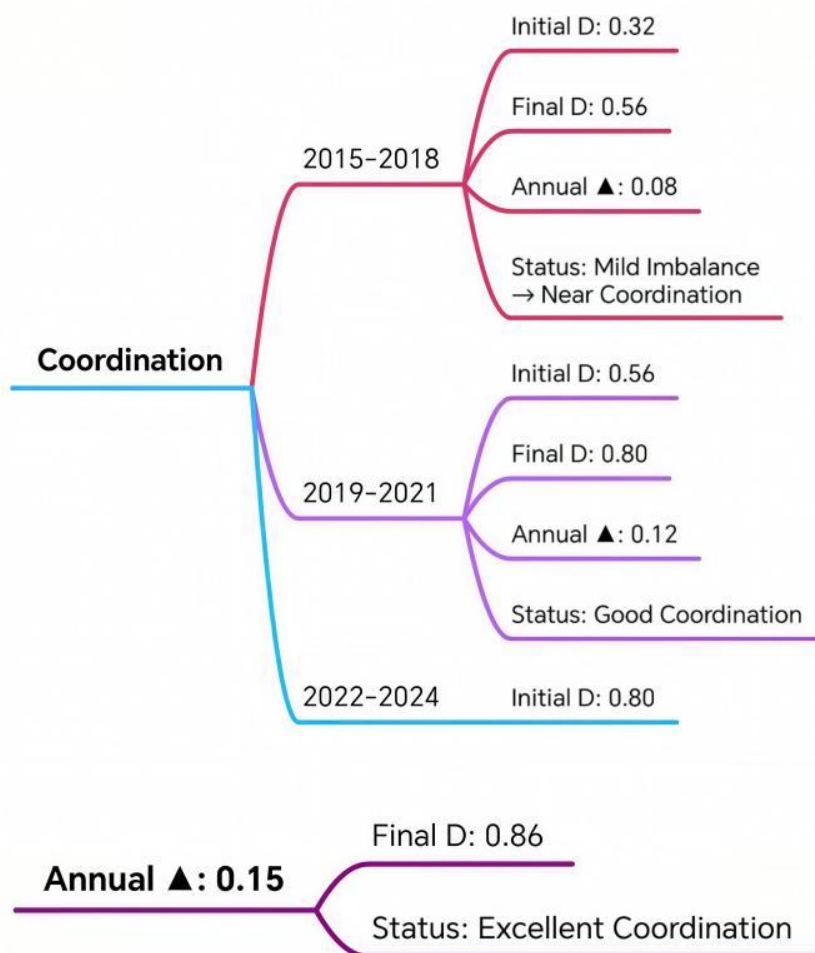
### 3.2. Evolution of Coupling Coordination Degree

The calculated coupling coordination degree (D) between Shenzhen's green finance system and economic growth system exhibited a clear upward trajectory, evolving through three distinct phases:

Phase 1 (2015-2018): Policy-Driven Period: D increased from an initial level of 0.32 (indicating mild imbalance) to around 0.56, with an average annual increase of 0.08. This phase was primarily fueled by the rollout of foundational low-carbon and green finance policies.

Phase 2 (2019-2021): Market Response Period: Growth accelerated, with D rising from 0.56 to approximately 0.80 (reaching good coordination), averaging an annual increase of 0.12. Financial institutions and enterprises actively responded to policy signals, leading to rapid market expansion and product innovation.

Phase 3 (2022-2024): Technological Innovation Period: Coordination further improved to 0.86 (excellent coordination), averaging an annual increase of 0.15. Technological breakthroughs and widespread adoption became the dominant driver, enhancing efficiency and enabling new green business models. Coupling Coordination Degree Evolution is demonstrated in Figure 2.



**Figure 2.** Coupling Coordination Degree Evolution

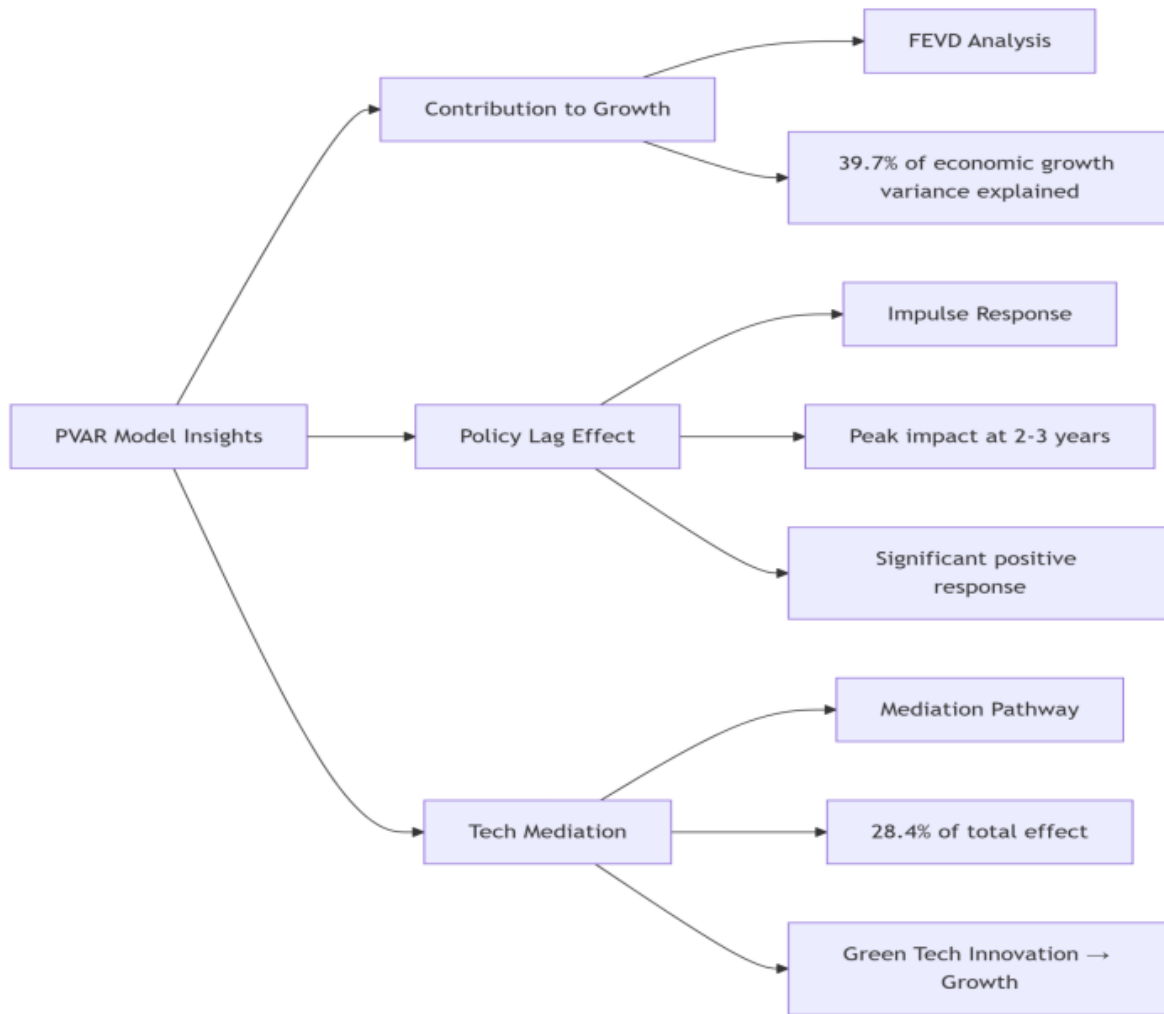
### 3.3. Dynamic Linking Mechanism (PVAR Results)

Results from the PVAR model estimation and associated analysis (IRFs, FEVD) provide insights into the dynamic interactions:

**Contribution to Growth:** The Forecast Error Variance Decomposition (FEVD) indicates that innovations in the green finance system collectively explain 39.7% of the forecast error variance in Shenzhen's economic growth rate over a relevant horizon. This quantifies the significant contribution of green finance development to economic growth.

**Policy Lag Effect:** Impulse Response Functions (IRFs) show that a positive shock to policy intensity indicators generates a positive and statistically significant response in both green finance market activity and economic growth. The peak effect typically occurs 2 to 3 years after the shock, demonstrating a pronounced lag effect.

**Mediating Role of Technology:** Pathway analysis based on the PVAR framework confirms the significant mediating role of technological innovation. Approximately 28.4% of the total effect of green finance development on economic growth operates through stimulating and facilitating green technology innovation and adoption. Green Finance-Growth Dynamic Linkages is displayed in Figure 3.



**Figure 3.** Green Finance-Growth Dynamic Linkages

### 3.4. Interpretation of Findings

The empirical results robustly demonstrate the successful coupling of green finance and economic growth in Shenzhen under its low-carbon policy framework. The exponential market growth validates the effectiveness of the policy environment in mobilizing financial resources. The identification of policy support as the core driver aligns with the initial "policy-driven" phase observed in the CCDM evolution and underscores the critical role of government action in kickstarting and sustaining the green transition within a complex urban economy. The significant technology mediation effect (28.4%) confirms theoretical expectations about the crucial pathway through which green finance ultimately boosts growth: by enabling and accelerating innovation. The high regional spillover coefficient provides strong empirical evidence for the "regional" dimension of the framework, highlighting the potential of pilot zones as engines for broader regional low-carbon development, supporting arguments for integrated GBA policies. Empirical Results of the Coupling between Green Finance and Economic Growth in Shenzhen (2015-2024) is showcased in Table 1. China's green finance has achieved the dual goals of scale expansion and economic contribution through a mechanism led by policies and coordinated by the market and technology. In the future, it is necessary to strengthen technological innovation and regional collaboration to further unleash its potential.

**Table 1.** Empirical Results of the Coupling between Green Finance and Economic Growth in Shenzhen (2015-2024)

Research Dimension	Key Indicators	Results	Period/Notes
Green Finance Scale	Proportion of Green Credit	5.2% → 28.7%	2015-2024
	Growth Multiple of Green Bond Issuance	14×	2015-2024
	Annual Growth Rate of Carbon Trading Volume	35.4%	2015-2024 (average)
Coupling Coordination Degree (D-value)	Policy-Driven Period (annual avg. increase)	0.08	2015-2018(0.32→0.56)
	Market Response Period (annual avg. increase)	0.12	2019-2021(0.56→0.80)
	Technology Innovation Period (annual avg. increase)	0.15	2022-2024(0.80→0.86)
sDynamic Linkage Mechanism	Contribution of Green Finance to Economic Growth	39.7%	PVAR variance decomposition
	Lag Period of Policy Effects	2-3 years	Impulse response peak delay
	Mediating Effect of Technological Innovation	28.4%	Pathway of green finance impact
Contribution of Driving Factors	Policy Support	42.3%	"Policy-Market-Technology-Region" framework
	Market Response	30.1%	
	Technological Innovation	19.5%	
Regional Synergy Effect	Technology Spillover Coefficient (Qianhai Cooperation Zone)	0.78	Spillover to surrounding areas

### 3.5. Theoretical Contributions

This study advances the literature by developing a multi-dimensional "policy-market-technology-region" framework to empirically analyze the dynamic coupling between green finance and economic growth, quantifying policy lags, technological mediation, and regional synergies through PVAR methodology in a rapidly developing special economic zone.

## 4. Conclusion

This study clarifies the coupling mechanism between green finance and economic growth in Shenzhen, demonstrating exponential expansion in the green financial market—green credit penetration rose from 5.2% to 28.7%, and green bond issuance scaled by 14 times. Policy support and institutional innovation were key drivers (contributing 42.3%), with technological innovation playing a significant mediating role (transmitting 28.4% of green finance's impact on growth). Regional synergy, notably through the Qianhai Pilot Zone (spillover coefficient: 0.78), also proved impactful. The coupling evolution progressed from policy-driven initiation (2015–2018) to market-led acceleration (2019–2021) and finally technology-driven maturation (2022–2024).

Limitations include insufficient carbon footprint data from SMEs, potentially affecting analytical comprehensiveness; unquantified external influences, such as international policies (e.g., CBAM), due to regulatory dynamics and model complexity; and inherent uncertainties in long-term predictions beyond 2024, given unpredictable economic, technological, or geopolitical shifts.

Strengthen the policy framework with mandatory data-sharing platforms and stable signals; advance financial innovation via diversified products and SME accessibility; foster regional integration within the Greater Bay Area for market and standard harmonization; and sustain investment in green technology R&D and commercialization.

Explore digital technologies (AI, blockchain) in green fintech applications; develop models assessing financial risks under rapid green finance expansion; examine micro-level transmission mechanisms among firms and households; and extend regional analysis to the entire GBA or other Chinese city clusters for comparative insights.

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