

**Green Finance and Economic Growth Across Global Financial Centres: Evidence from
Econometric and Machine Learning Methods**

**Finanças Verdes e Crescimento Económico nos Centros Financeiros Globais: Evidências a partir
de Métodos Econométricos e de Aprendizagem Automática**

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ABSTRACT: As financial systems undergo green transformation, systematic performance evaluation becomes increasingly important for policy formulation and strategic planning. Drawing on global surveys of finance professionals and a validation framework incorporating 127 instrumental indicators across sustainability, business climate, infrastructure, and human capital, Z/Yen publishes the Global Green Finance Index (GGFI). Using GGFI measures of both depth and quality for 99 international financial centres (after data preprocessing; note that GGFI 16, October 2025, covers 94 centres), this study examines their relationship with economic growth from 2018H1 to 2024H2. Economic growth is measured by real GDP per capita growth rates derived from the World Bank (2026) Databank. A panel vector autoregression (PVAR) model is employed to estimate dynamic interactions between green finance development and economic growth. Model stability and specification validity are confirmed through AR root tests for joint stationarity and LM tests for residual serial correlation. Impulse response functions show that real GDP per capita growth initially fluctuates following shocks to GGFI depth and quality during the first six semi-annual periods, then converges toward a persistent positive response. Cumulative impulse responses remain non-negative, and Granger causality tests indicate a one-way causal relationship running from

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GGFI to economic growth, with only weak evidence of feedback from economic growth to green finance quality ($p < 0.10$). Robustness checks using purchasing-power-parity-adjusted GDP per capita growth yield consistent results. To account for potential nonlinearities and cross-regional heterogeneity, the analysis further applies Double Machine Learning (DML) with Random Forest and Gradient Boosting learners. The DML estimates indicate a statistically significant positive average marginal effect of GGFI on global GDP growth. However, continent-level analysis reveals heterogeneity. The positive association is robust and highly significant in the Asia-Pacific region, while statistically insignificant in Europe and North America during the sample period (average marginal effect ≈ 1.55 – 1.57 basis points per unit increase in GGFI). These findings suggest that the growth effects of green finance are not uniform across financial centres but vary with regional structural conditions and development stages. A dummy variable capturing the Covid-19 period (2020H1-2023H2) does not produce statistically significant effects across model specifications.

KEYWORDS: Green finance; economic growth; panel vector autoregression; double machine learning.

RESUMO: À medida que os sistemas financeiros passam por uma transformação verde, a avaliação sistemática do desempenho torna-se cada vez mais importante para a formulação de políticas e o planeamento estratégico. Com base em inquéritos globais a profissionais de finanças e numa estrutura de validação que incorpora 127 indicadores instrumentais relacionados com sustentabilidade, clima de negócios, infraestrutura e capital humano, a Z/Yen publica o Índice Global de Finanças Verdes (GGFI). Utilizando as medidas de profundidade e qualidade do GGFI para 99 centros financeiros internacionais (após pré-processamento dos dados; note-se que o GGFI 16, de outubro de 2025, cobre 94 centros), este estudo analisa a sua relação com o crescimento económico de 2018H1 a 2024H2. O crescimento económico é medido pelas taxas de crescimento do PIB real per capita, derivadas do Banco Mundial (2026). Emprega-se um modelo de vetores autorregressivos em painel (PVAR) para estimar as interações dinâmicas entre o desenvolvimento do financiamento verde e o crescimento económico. A estabilidade do modelo e a validade da especificação são confirmadas através de testes de raízes AR para estacionaridade conjunta e testes LM para autocorrelação serial dos resíduos. As funções de resposta ao impulso mostram que o crescimento do PIB real per capita inicialmente oscila após choques na profundidade e qualidade do GGFI durante os primeiros seis períodos semestrais, convergindo posteriormente para uma resposta positiva persistente. As respostas ao impulso acumuladas permanecem

não negativas, e os testes de causalidade de Granger indicam uma relação causal unidirecional do GGFI para o crescimento económico, com apenas evidência fraca de retroalimentação do crescimento para a qualidade do financiamento verde ($p < 0,10$). Verificações de robustez usando o crescimento do PIB per capita ajustado pela paridade do poder de compra apresentam resultados consistentes. Para considerar possíveis não linearidades e heterogeneidades regionais, a análise aplica ainda o método de Double Machine Learning (DML) com modelos de Floresta Aleatória e de Boosting de Gradiente. As estimativas do DML indicam um efeito marginal médio positivo estatisticamente significativo do GGFI no crescimento global do PIB. No entanto, a análise por continente revela heterogeneidade. A associação positiva é robusta e altamente significativa na região Ásia-Pacífico, enquanto é estatisticamente insignificante na Europa e na América do Norte durante o período de amostra (efeito marginal médio $\approx 1,55$ – $1,57$ pontos base por unidade de aumento do GGFI). Estes resultados sugerem que os efeitos do crescimento do financiamento verde não são uniformes entre os centros financeiros, variando consoante as condições estruturais regionais e os estágios de desenvolvimento. Uma variável fictícia que capta o período da Covid-19 (2020H1-2023H2) não produz efeitos estatisticamente significativos em diferentes especificações do modelo.

PALAVRAS-CHAVE: Finanças verdes; crescimento económico; vetor autorregressivo de painel; aprendizagem automática dupla.

Introduction

The 2015 Paris Agreement has awakened global environmental consciousness and motivated immediate actions to tackle climate risks. While the agreement has been in place for a decade and has seen some progress in national commitments and development strategies, current implementation remains insufficient, and the world has yet to meet its climate goals. The financial sector plays an important supporting role in the transition to a green economy. Effective green finance is necessary to allocate funds to environmental goods and services management and development, to prevent and reduce environmental damage, to finance public environmental policies, and to sustain the institutional infrastructure for green financial investments. During the green transition of the financial system, assessment of its performance and progress is crucial for decision-making and policymaking. For this purpose, global efforts such as Z/Yen (2026) have tracked the depth and the quality of green finance of 108 financial centres (data used here cover 99 centres after preprocessing, consistent with earlier GGFI editions). Based on worldwide

surveys of finance professionals and validation using over 127 instrumental factors that evaluate the financial centres' sustainability, business environment, infrastructure, and human capital, the think tank created the Global Green Finance Index (GGFI). For example, the top ten instrumental factors with the highest correlations are the Urban Mobility Readiness Index, the Future Growth Report, the IESE Cities in Motion Index, the Quality of Living City Rankings, Sustainable Economic Development, the Green Future Index, and the Energy Transition Index. World Energy Trilemma Index, Sustainable Cities Index, and the Global Green Economy Index.

The relationship between green finance and economic development has attracted considerable attention in numerous previous studies. The answer is not definitive under the classical theory of the Environmental Kuznets Curve (EKC), which posits that environmental problems worsen and then reverse as an economy develops. Many studies have found that green finance drives economic growth (Wen et al., 2025; Yu et al., 2026; Zhou & Guo, 2026). The logic is that through green finance, environmental and financial resources are directed to economically sustainable activities. Green finance connects the economy, environment, and society in a sustainable development plan that combines private and public economic activities. Green finance decouples environmental deterioration and economic growth. Other studies, on the other hand, pointed out the obstacles that green finance brought to a country's economic development (Ali et al., 2025; Liu & Fu, 2023; Ouyang et al., 2023). With the GGFI serving as a comprehensive key performance indicator, and economic growth rates computed using data from the World Bank (2026) DataBank, this paper empirically assesses how green finance in financial hubs worldwide may impact economic growth.

In terms of value and originality, this paper offers a global empirical assessment of the dynamic relationship between green finance and economic growth across major financial centres. Existing studies predominantly focus on single-country or regional samples, limiting cross-system comparison and obscuring structural differences across economies. By analysing 99 international financial hubs within a unified empirical framework, this study extends the literature beyond national case studies and provides systematic cross-regional evidence.

In addition, the paper contributes methodologically by reconciling conventional econometric modelling with machine learning-based causal estimation. The integration of vector autoregression (VAR) analysis with Double Machine Learning (DML) allows the study to combine interpretable dynamic structure with flexible modelling of nonlinearities and heterogeneous effects. Rather than positioning econometrics and data science as competing approaches, the paper demonstrates how they can be used in

complementary ways to validate findings and uncover regional variation. In the context of international climate commitments and the Sustainable Development Goals, where coordinated financial transformation across jurisdictions is increasingly emphasised, rigorous and methodologically plural evidence on the macroeconomic implications of green finance is essential for both policymakers and practitioners.

1. Literature Review

The EKC posits that environmental degradation initially intensifies alongside income growth and subsequently declines after a threshold level of development is reached. Within this theoretical framework, green finance is often examined as a mechanism to accelerate the shift from pollution-intensive growth toward cleaner production patterns. Empirical research has presented mixed conclusions regarding whether green finance consistently enhances economic growth while improving environmental performance. This study performed a Scopus search on 15 January 2026 using the exact TITLE-ABS-KEY string (“green finance” AND “economic growth”) limited to 2016–2026, yielding 65 documents; after excluding 6 retracted items (identified via Scopus retraction notices), 59 papers were retained.

1.1 Positive Relationship Between Green Finance and Economic Growth

A considerable body of empirical work reported that green finance was associated with economic expansion. Cross-country panel studies employing dynamic estimators, such as System GMM, ARDL, and MMQR, found that green bonds, green credit, and renewable energy financing contributed positively to GDP growth while reducing carbon emissions (e.g., Wen et al., 2025; Yu et al., 2026; Zhou & Guo, 2026). These findings were observed across OECD, BRICS, G7, and G20 samples.

China-based studies frequently identified technological upgrading and structural transformation as transmission channels. Difference-in-differences analyses of green finance pilot zones showed measurable increases in regional GDP (Nie et al., 2024). Efficiency-based models, including DEA and Malmquist-Luenberger productivity indices, indicated that green finance improved green total factor productivity and supported industrial upgrading (Feng, 2024; Zhang et al., 2025). Spatial econometric models further suggested that green finance generated interregional spillovers, enhancing carbon efficiency beyond the originating province (Jia et al., 2025; Lv et al., 2025).

Evidence from emerging economies also supported a positive linkage. Studies on Vietnam, Ghana, Morocco, and South Asian economies report that green lending and bond issuance correlate with

renewable energy expansion and output growth (Ngo et al., 2021; Balogun & Dhakir, 2025; Dahhou et al., 2025; Ali et al., 2023). In EKC terms, these findings implied that green finance might help economies approach the descending segment of the curve through cleaner capital allocation.

1.2 Negative or Nonlinear Relationship Between Green Finance and Economic Growth

Not all studies confirmed a uniformly positive relationship. Some research identifies short-term trade-offs or nonlinear effects. Evidence from quantile regression across 169 countries suggested that green finance might negatively affect economic growth in certain income distributions, while institutional quality moderated the effect (Ali et al., 2025). Provincial analysis in China revealed that green finance could reduce growth rates in specific quantiles or periods, even while enhancing growth quality (Liu & Fu, 2023; Ouyang et al., 2023).

Nonlinear relationships were frequently reported. U- and inverted U-shaped patterns emerged in the interaction among green credit, environmental regulation, and productivity (Huang, 2022). Threshold and spatial Durbin models showed that regions with higher levels of green finance reached the EKC turning point earlier, whereas less-developed regions remained on the rising segment (Zhou & Guo, 2026). Sector-specific threshold models in China's ocean economy indicated diminishing marginal returns to green finance once industrial scale or research funding surpass certain levels (Li & Huang, 2025).

These findings aligned with EKC reasoning: green finance might initially impose adjustment costs by redirecting capital away from carbon-intensive sectors before generating net economic benefits.

1.3 Mediating Mechanisms and Contextual Heterogeneity

A third strand of literature focuses on mechanisms. Technological innovation frequently mediated the green finance-growth nexus. Cross-country mediation analysis indicated that green technology channels the effects of green finance toward green growth (Praveen et al., 2025). Similar mediation effects were reported in Chinese provincial data (Liu et al., 2023).

Digital finance and fintech integration appeared to reinforce the effectiveness of green finance (Zhuang, 2024; Nenavath & Mishra, 2023). Human capital, education, and regulatory quality also conditioned outcomes (Ogunsola & Zwane, 2026; Guan et al., 2025). In resource-dependent economies, natural resource extraction might offset gains from green finance unless complemented by renewable energy investment and institutional reform (Tan et al., 2023; Mohsin & Jamaani, 2023).

Regional heterogeneity was a recurring finding. Developed or market-oriented regions exhibited stronger growth and efficiency responses to green finance than less-developed areas (Feng, 2024; Ye et al., 2023). Global time-series evidence further indicated that renewable energy exerted a stronger emission-reducing effect than green finance alone, suggesting implementation gaps in financial mechanisms (Gherbi et al., 2024).

Overall, the literature indicates that green finance interacts with innovation capacity, institutional quality, digital infrastructure, and energy structure. Its economic consequences varied across contexts and stages of development.

1.4 Methodological Approaches: Economic Modelling and Interdisciplinary Techniques

The empirical literature on green finance and economic growth has been methodologically dominated by quantitative economic modelling. Most studies relied on panel econometric frameworks designed to address endogeneity, heterogeneity, and cross-sectional dependence. Dynamic panel estimators, such as System GMM, have been widely used in cross-country and regional analyses (e.g., Wen et al., 2025; Tan et al., 2023). Panel ARDL and CS-ARDL approaches were frequently applied to distinguish long-run and short-run dynamics in country panels and regional samples (Rahman & Salimullah, 2026; Xiao & Tabish, 2025; Mohsin & Jamaani, 2023). Quantile-based techniques, including Method of Moments Quantile Regression (MMQR) and QARDL, were adopted to capture distributional heterogeneity and nonlinear effects consistent with EKC reasoning (Ali et al., 2025; Yu et al., 2026; Hua & Tong, 2026).

Time-series econometrics remained central in single-country studies. ARDL-ECM and vector error correction models were commonly used to examine cointegration and causal direction among green finance, renewable energy, and growth variables (Tran, 2022; Bughio et al., 2025; Dahhou et al., 2025). Difference-in-differences (DID) models were applied to policy evaluation contexts, such as the green finance reform pilot zones in China (Nie et al., 2024). Spatial econometric techniques, including spatial Durbin models and threshold panel models, were employed to account for spillover effects and nonlinear regional dynamics (Jia et al., 2025; Lv et al., 2025).

Production and efficiency analysis constitute another important methodological cluster. Data Envelopment Analysis (DEA), Super-SBM models, and Malmquist-Luenberger productivity indices were used to estimate carbon emission efficiency and green total factor productivity (Huang, 2022; Feng, 2024). Meta-frontier DEA and coupling coordination models were applied to evaluate interactions among green

finance, higher education, and green economic growth (Ma, 2022). Entropy-weighted composite indices and panel VAR (PVAR) models were also used to measure green finance development and its dynamic interrelationships with economic variables (Ye et al., 2023; Xu et al., 2023).

Beyond conventional econometrics, several studies introduced computational and data-intensive techniques. Deep learning regression models and Bayesian neural networks were employed to examine environmental determinants in emerging economies (Naveed et al., 2025). MapReduce-based big data frameworks are used to calculate entropy and coupling measures for large-scale green finance indicators (Guo et al., 2024). Scientometric and bibliometric tools, including VOSviewer and Bibliometrix, were used to map the thematic evolution of green finance research (Marín-Rodríguez et al., 2024).

Although quantitative methods predominate, qualitative and mixed-method approaches appeared in selected cases. Case-based research using documentary analysis and semi-structured interviews investigates institutional arrangements such as government guidance funds in green industrial development (Xue et al., 2023). Conceptual and policy-oriented discussions were also present in early foundational contributions to green finance discourse (Soundarrajan & Vivek, 2016; Kumari et al., 2024).

Overall, the methodological landscape reflects a strong anchoring in applied macroeconomics, development economics, and environmental economics. At the same time, interdisciplinary elements of computational modelling, scientometrics, and qualitative governance analysis have been increasingly incorporated to capture institutional design, technological mediation, and spatial heterogeneity within the green finance-growth nexus.

2. Methodology

2.1 Data Collection

The GGFI data used in this study are sourced from GGFI reports published by Z/Yen (2026). The GGFI is constructed using a combination of survey responses from finance professionals and a broad set of instrumental indicators that capture the structural characteristics of financial centres. The index distinguishes between two core dimensions - depth and quality. GGFI depth, the main index, reflects the scale, activity, and market penetration of green financial products and services within a financial centre, including green bonds, sustainable investment vehicles, and climate-related financial initiatives. GGFI quality captures the broader enabling environment for green finance, incorporating sustainability performance, regulatory frameworks, business climate, infrastructure, and human capital factors that support long-term green financial development. By separating market scale from institutional and

structural conditions, the GGFI framework allows this study to evaluate both the quantitative expansion and qualitative maturity of green finance across international financial hubs.

National economic growth is computed based on GDP data from the World Bank (2026) DataBank. Specifically, data on GDP per capita (constant 2015 US\$) and GDP per capita (PPP, constant 2021 international \$) are collected.

After data preprocessing, the panel dataset contains 1105 observations of 99 financial centres, spanning the period from 2018H1 to 2024H2.

2.2 Data Analyses

This paper applies a PVAR model to investigate the dynamic relationship between the depth and the quality of GGFI and economic growth. Before the VAR analysis, standard diagnostics, including the AR root test to verify joint stationarity of the series and the LM test to confirm the absence of serial correlation in the residuals, are performed to ensure the stability and validity of the VAR model. Impulse responses computed using the standard Cholesky method are reported in addition to the estimation output. To ensure the robustness of the results, the analysis is performed over alternative measures of economic growth, and the dummy variable of the COVID-19 periods (2020H1 to 2023H2) is included as an exogenous variable in the estimation to control for its potential effects.

The specification of the VAR model of order $p = 8$ is as follows:

$$Z_t = \beta_0 + \sum_{i=1}^p \beta_i Z_{t-i} + \epsilon_t, \quad (1)$$

where Z_t is a (2×1) vector of the variables that measure economic growth and the depth and quality of green finance. β_0 is a (2×1) intercept vector and β_i 's are (2×2) coefficient matrices. ϵ_t is a (2×1) vector of unobservable i.i.d. zero-mean errors. The two endogenous variables are the first-differenced natural logarithms of real GDP per capita ($\Delta \ln GDP_{PC}$ i.e., the growth rate) and of the GGFI index ($\Delta \ln GGFI$).

A conventional PVAR framework assumes homogeneous dynamic coefficients across cross-sectional units and eliminates region-specific fixed effects during estimation by demeaning or transforming the data. While this approach effectively captures average dynamic interdependencies among variables, it does not directly estimate heterogeneous region-level effects. In the context of global financial centres, such homogeneity assumptions may mask structural differences in institutional quality, regulatory environments, digital infrastructure, and sustainability capacity. Financial hubs vary

considerably in development stage and governance structure, implying that the transmission mechanism from green finance to economic growth may not be uniform. Consequently, reliance solely on a standard PVAR may obscure nonlinearities, interaction effects, and cross-regional heterogeneity embedded in the data-generating process.

To address these limitations, this study incorporates estimation techniques drawn from data science, particularly the DML framework. DML allows for flexible modelling of high-dimensional controls and nonlinear relationships while preserving valid causal inference through orthogonalization procedures. This methodological strategy follows recent applications in sustainability and green growth research. Wu et al. (2024) employed DML on city-level panel data to estimate the impact of FinTech development on inclusive green growth, using a continuous treatment variable and machine learning algorithms to control for confounding factors. Similarly, Yuan and Liu (2024) applied DML with city and time fixed effects to evaluate the causal effect of the “Made in China 2025” strategy on green economic growth, incorporating flexible learners such as Random Forest and Gradient Boosting to enhance robustness.

Building on these approaches, the present study supplements conventional econometric modelling with DML-based estimation to allow for heterogeneous, potentially nonlinear, region-specific effects in the relationship between green finance development and economic growth across global financial centres.

3. Results

3.1 VAR Model

3.1.1 Selection and Baseline Estimation

Based on the Akaike Information Criterion (AIC), Schwarz Criterion (SC), and Hannan-Quinn Criterion (HQ), a VAR model with eight lags is selected. The choice of VAR(8) reflects the semi-annual structure of the dataset (2018H1-2024H2) and allows sufficient dynamic adjustment while preserving degrees of freedom. The stability condition is satisfied, as all inverse roots of the characteristic polynomial lie within the unit circle. LM tests confirm the absence of serial correlation in the residuals, and there is no evidence of heteroskedasticity, undermining model validity.

Table 1 reports the estimated VAR(8) results using first-differenced logarithms of real GDP per capita growth ($\Delta \ln(GDP)$) and GGFI growth ($\Delta \ln(GGFI)$). The adjusted R^2 values are 0.688 for the GDP equation and 0.836 for the GGFI equation, indicating substantial explanatory power. The overall F-

statistics are statistically significant at the 1% level in both equations, suggesting joint significance of the lagged regressors.

The GDP equation exhibits a clear oscillatory pattern across lags. The first lag of GDP growth is positive and highly significant (0.9596, $p < 0.01$), followed by alternating negative and positive coefficients up to the seventh lag. This alternating pattern reflects cyclical adjustment dynamics in economic growth over semi-annual periods. The magnitudes of the coefficients gradually decline, suggesting convergence toward the long-run equilibrium.

The direct short-run impact of GGFI growth on GDP growth is limited in the first four lags. However, beginning at lag 5, GGFI exerts statistically significant positive effects on GDP growth (lags 5-8), with coefficients ranging from 0.0398 to 0.0642. These delayed effects imply that improvements in green finance depth require several periods before translating into measurable economic expansion.

In the GGFI equation, own-lag effects are predominantly negative and significant in early lags, indicating mean-reverting dynamics in green finance growth. The interaction between past GDP growth and GGFI growth appears statistically weak, suggesting that green finance development is not primarily driven by contemporaneous economic fluctuations.

	<i>GDP</i> Growth Equation	<i>GGFI</i> Growth Equation
$\Delta \ln GDP_{PC\ t-1}$	0.959581** (-0.06269)	0.035045 (-0.08985)
$\Delta \ln GDP_{PC\ t-2}$	-0.44861** (-0.07993)	0.026023 (-0.11457)
$\Delta \ln GDP_{PC\ t-3}$	0.390181** (-0.0728)	-0.16241 (-0.10434)
$\Delta \ln GDP_{PC\ t-4}$	-0.40615** (-0.06991)	0.027179 (-0.10021)
$\Delta \ln GDP_{PC\ t-5}$	0.383268** (-0.06411)	-0.01682 (-0.0919)
$\Delta \ln GDP_{PC\ t-6}$	-0.22183** (-0.06337)	-0.03143 (-0.09083)
$\Delta \ln GDP_{PC\ t-7}$	0.190563** (-0.06077)	0.007075 (-0.0871)

$\Delta \ln GDP_{PC\ t-8}$	-0.02856 (-0.04382)	-0.06155 (-0.06281)
$\Delta \ln GGFI_{t-1}$	0.036259 (-0.04395)	-0.16839** (-0.063)
$\Delta \ln GGFI_{t-2}$	0.037534 (-0.04255)	-0.18409** (-0.06098)
$\Delta \ln GGFI_{t-3}$	-0.05544 (-0.04189)	-0.05857 (-0.06005)
$\Delta \ln GGFI_{t-4}$	0.064013 (-0.04707)	-0.22356 (-0.06747)
$\Delta \ln GGFI_{t-5}$	0.064176** (-0.02307)	-0.10747** (-0.03307)
$\Delta \ln GGFI_{t-6}$	0.058088** (-0.02113)	-0.11172** (-0.03029)
$\Delta \ln GGFI_{t-7}$	0.039751* (-0.0191)	-0.01142 (-0.02738)
$\Delta \ln GGFI_{t-8}$	0.048326** (-0.01604)	0.047398* (-0.02299)
Intercept	0.028229** (-0.01029)	-0.01452 (-0.01474)
R^2	0.711005	0.847761
Adjusted R^2	0.688	0.835643
F	30.90711	69.95604

Table 1. Estimation of the VAR(8) Model - GGFI Growth and Real GDP per Capita Growth

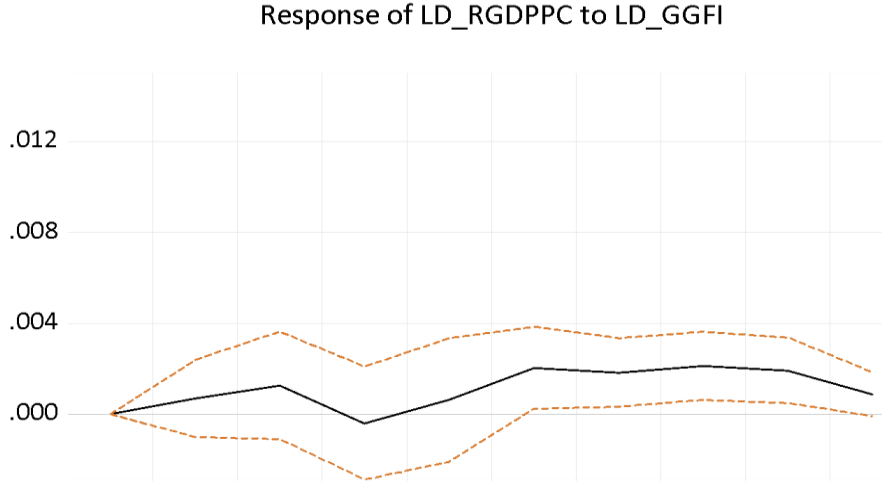
Note: * $p < 0.05$, ** $p < 0.01$.

3.1.2 Impulse Response Analysis

As shown in Figure 1, impulse response functions computed using the standard Cholesky decomposition further clarify the dynamic transmission mechanism. A one-standard-deviation shock to GGFI growth initially generates mild fluctuations in GDP growth during the first six periods. The response alternates in sign, consistent with the oscillatory coefficients observed in the VAR estimates. After approximately six semi-annual periods (three years), the response stabilises and becomes persistently positive. The long-run effect remains positive, indicating that the development of green finance

contributes positively to economic growth once transitional adjustments are complete. The accumulated impulse responses are non-negative throughout the forecast horizon, reinforcing the conclusion that the net long-term impact of green finance on GDP per capita growth is expansionary rather than contractionary.

(a)



(b)

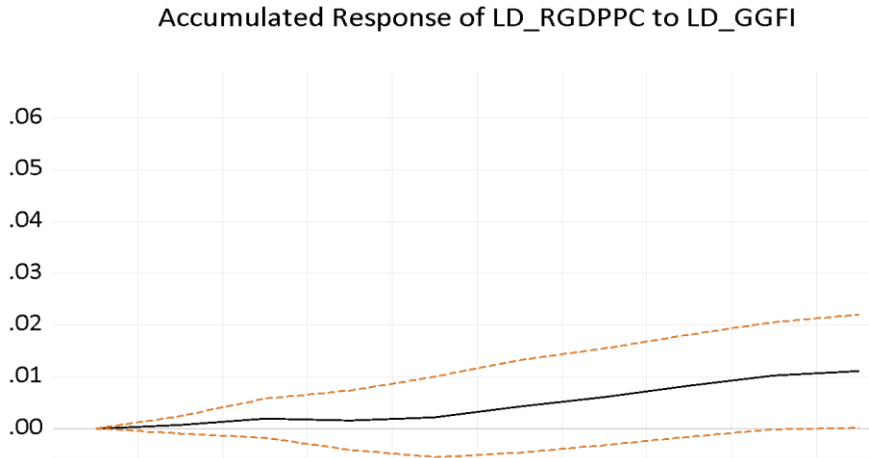


Figure 1. Impulse Responses of Real GDP per Capita Growth to GGFI Growth

3.1.3 Granger Causality

Table 2 presents the Granger causality test results. The null hypothesis that GGFI does not Granger-cause GDP growth is rejected at the 10% level ($\chi^2 = 15.1198$, $p = 0.0569$). In contrast, the null that GDP growth does not Granger-cause GGFI cannot be rejected ($p = 0.3761$). These results indicate a predominantly unidirectional causal relationship running from green finance development to economic growth.

Dependent Variable	Excluded	χ^2	Prob.
$\Delta \ln(GDP)$	$\Delta \ln(GGFI)$	15.1198	0.0569
$\Delta \ln(GGFI)$	$\Delta \ln(GDP)$	8.61166	<0.10

Table 2. VAR Granger Causality Tests – GGFI Growth and Real GDP per Capita Growth

3.1.4 Robustness Checks: Quality Dimension and Alternative Growth Measure

To assess whether the results depend on the depth dimension of GGFI, the model is re-estimated using the quality sub-index (see Table 3). The adjusted R^2 values remain high (0.689 for GDP and 0.795 for quality), confirming model consistency.

In the GDP equation, lagged quality growth exerts a statistically significant positive effect beginning at lag 5 and continuing through lag 8. The magnitude of the coefficients is comparable to that of the baseline specification, suggesting that both the depth and quality of green finance contribute to economic performance with similar delayed dynamics.

In the quality equation, several own-lag coefficients are negative and statistically significant, again indicating partial adjustment behaviour. Some feedback effects of GDP growth on green finance quality appear with mid-lags, though they are weaker and less consistent than the forward causal direction.

	GDP Growth Equation	Green Finance Quality Growth Equation
$\Delta \ln GDP_{PC t-1}$	0.927459** (-0.06263)	-0.01078 (-0.08182)
$\Delta \ln GDP_{PC t-2}$	-0.41291** (-0.07979)	0.072467 (-0.10425)
$\Delta \ln GDP_{PC t-3}$	0.377457** (-0.07373)	-0.21642* (-0.09633)

$\Delta \ln GDP_{PC t-4}$	-0.38454** (-0.06967)	0.180877* (-0.09102)
$\Delta \ln GDP_{PC t-5}$	0.361054** (-0.06332)	-0.01197 (-0.08273)
$\Delta \ln GDP_{PC t-6}$	-0.18959** (-0.06458)	0.032114 (-0.08437)
$\Delta \ln GDP_{PC t-7}$	0.158493* (-0.06168)	-0.10224 (-0.08058)
$\Delta \ln GDP_{PC t-8}$	-0.02394 (-0.04417)	-0.0256 (-0.0577)
$\Delta \ln quality_{t-1}$	0.046992 (-0.04424)	-0.16975** (-0.05779)
$\Delta \ln quality_{t-2}$	-0.0522 (-0.04084)	-0.01278 (-0.05336)
$\Delta \ln quality_{t-3}$	-0.01047 (-0.03869)	-0.11927* (-0.05054)
$\Delta \ln quality_{t-4}$	0.012621 (-0.03797)	-0.20197** (-0.04961)
$\Delta \ln quality_{t-5}$	0.061208** (-0.01908)	-0.05422* (-0.02493)
$\Delta \ln quality_{t-6}$	0.047836** (-0.01741)	-0.04968 (-0.02275)
$\Delta \ln quality_{t-7}$	0.04699** (-0.01635)	0.017053 (-0.02136)
$\Delta \ln(quality)_{t-8}$	0.038573** (-0.01431)	0.040983 (-0.01869)
Intercept	0.029343** (-0.00813)	-0.00129 (-0.01062)
R^2	0.711746	0.809979
Adjusted R^2	0.6888	0.794853
F	31.01881	53.54859

Table 3. Estimation of the VAR(8) Model - – Green Finance Quality Growth and Real GDP per Capita Growth

Note: * $p < 0.05$, ** $p < 0.01$.

Granger causality tests in Table 4 confirm that the primary direction of causality runs from green finance to economic growth. However, when focusing specifically on the quality dimension, there is weak evidence ($p < 0.10$) of limited feedback from economic growth to the quality of green finance, suggesting that higher-income environments may incrementally improve the qualitative aspects of green finance.

Dependent Variable	Excluded	χ^2	Prob.
$\Delta \ln(GDP)$	$\Delta \ln(GGFI)$	15.1198	0.0569
$\Delta \ln(GGFI)$	$\Delta \ln(GDP)$	8.61166	0.3761

Table 4. VAR Granger Causality Tests - Green Finance Quality and Real GDP per Capita Growth

As an additional robustness check, purchasing power parity (PPP) real GDP per capita growth is used as an alternative dependent variable (see Appendix Tables A1 and A2). Stating that the results are not sensitive to the measurement of economic growth.

Furthermore, a dummy variable capturing the Covid-19 period (2020H1-2023H2) is included in alternative specifications (see Appendix Tables A1 and A2). Across all equations and model variants, the dummy variable is not statistically significant. This suggests that, within the VAR framework, the pandemic did not structurally alter the dynamic relationship between green finance development and economic growth in the sampled financial hubs.

3.2 Double Machine Learning

To complement the linear dynamic analysis, DML is applied using flexible tree-based learners, Random Forest and Gradient Boosting, with repeated 5-fold cross-fitting ($n_{rep} = 5$). The treatment variable is the (log) GGFI level; the outcome is the annualised real GDP per capita growth rate; high-dimensional controls include continent fixed effects, time fixed effects, and all 127 instrumental indicators underlying the GGFI as well as World Bank macro covariates; panel structure is handled via double demeaning before cross-fitting. This approach allows flexible control of nonlinear relationships and high-dimensional interactions while retaining valid statistical inference for the parameter of interest. The estimated coefficient represents the average marginal effect (AME) of a one-unit increase in GGFI on annual GDP per capita growth.

As shown in Table 5, at the global level ($N = 944$), the AME is positive and statistically significant across both learners. The Random Forest specification yields an AME of 0.000157 ($p = 0.033$), while

Gradient Boosting produces 0.000155 ($p = 0.032$). The 95% confidence intervals are nearly identical and exclude zero, indicating statistical precision. When rescaled ($\times 10^4$), the effect corresponds to approximately 1.55-1.57 basis points of additional GDP growth for each unit increase in GGFI. Although numerically modest, this magnitude should be interpreted with the composite nature of GGFI in mind, which captures broad institutional and structural characteristics of financial centres rather than marginal financial flows. The consistency across learners suggests that the positive association is not driven by a particular functional form or modelling choice. Even after allowing for nonlinearities and complex interactions among covariates, the positive global relationship remains stable.

Continent-level estimates reveal substantial heterogeneity. In the Asia-Pacific region ($N = 199$), the positive association is both economically larger and statistically stronger. The AME ranges between 0.000393 and 0.000400 ($p \leq 0.006$ across learners), equivalent to approximately 3.9-4.0 basis points of additional annual GDP growth per GGFI unit increase. This magnitude exceeds the global average effect by more than twofold. The statistical strength and cross-learner consistency indicate that the relationship between green finance development and economic growth is particularly pronounced in this region. Such findings are consistent with the structural characteristics of Asia-Pacific financial centres, where rapid digitalisation, policy-driven green investment, and ongoing industrial upgrading may amplify the growth returns to green finance expansion.

In contrast, estimates for Europe ($N = 361$) and North America ($N = 178$) are not statistically significant for both learners, with p -values exceeding 0.20 and confidence intervals including zero. Coefficients fluctuate around zero, indicating that marginal changes in GGFI are not associated with measurable short-run effects on GDP growth in these mature financial systems. One interpretation is that green finance may already be embedded within established institutional frameworks, such that incremental improvements yield limited additional growth. Alternatively, the economic effects of green finance in advanced economies may operate through environmental performance, resilience, or long-term productivity channels rather than immediate GDP acceleration.

For Central Asia ($N = 78$), the point estimates are positive, and Gradient Boosting yields a marginally significant result at the 10% level ($AME \approx 0.000632$, $p = 0.076$), while Random Forest remains statistically insignificant. The wider confidence intervals reflect a smaller sample size and greater cross-sectional variability. In Africa ($N = 65$), the estimates are statistically insignificant and imprecise for both learners, again likely due to limited observations and heterogeneity among financial centres. Note that the

sum of continent-specific observations (881) is less than the global N = 944 because Oceania and South America are retained only in the pooled global specification.

Region/Sample	Learner	AME ($\times 10^4$)	SE ($\times 10^4$)	t-statistic	p-value	95% CI ($\times 10^4$)	N
Global	RandomForest	1.57**	0.74	2.13	0.033	[0.15, 3.01]	944
	GradientBoost	1.55**	0.72	2.15	0.032	[0.14, 2.97]	
Asia-Pacific	RandomForest	4.00***	1.32	3.02	0.003	[1.13, 6.59]	199
	GradientBoost	3.93***	1.41	2.80	0.005	[1.18, 6.69]	
Europe	RandomForest	-1.67	1.31	-1.28	0.202	[-4.23, 0.89]	361
	GradientBoost	-1.31	1.15	-1.14	0.253	[-3.56, 0.94]	
North America	RandomForest	-0.24	1.89	-0.13	0.900	[-3.93, 3.46]	178
	GradientBoost	0.23	1.56	0.14	0.885	[-2.84, 3.29]	
Central Asia	RandomForest	4.69	3.08	1.52	0.128	[-0.53, 10.72]	78
	GradientBoost	6.32*	3.56	1.78	0.076	[-0.70, 13.29]	
Africa	RandomForest	1.37	2.56	0.54	0.592	[-3.65, 6.40]	65
	GradientBoost	-0.50	3.95	-0.13	0.900	[-7.10, 7.24]	

Table 5. DML Estimates of the Average Marginal Effect of GGFI Growth on Real GDP per Capita Growth

Notes: AME is the average marginal effect of a 1-unit increase in GGFI on annual GDP growth rate. Estimates are obtained using DML according to Chernozhukov et al. (2018) with Random Forest and Gradient Boosting as flexible learners. Repeated 5-fold cross-fitting ($n_{rep}=5$) is applied to improve stability. Standard errors are debiased. *** $p < .01$. ** $p < .05$. * $p < .10$. Oceania and South America are omitted due to insufficient observations (< 50).

Overall, the DML results confirm a small but statistically significant positive global association between green finance development and economic growth, while revealing marked regional differences. The positive effect is concentrated in the Asia-Pacific region, whereas it is not statistically detectable in Europe and North America within the sample period. By relaxing the homogeneity assumptions of conventional panel models and allowing flexible nonlinear adjustments, the DML framework uncovers heterogeneity that would otherwise remain concealed. These findings complement the VAR analysis by demonstrating that the growth impact of green finance is not uniform across financial centres but instead depends on regional structural conditions and development stages.

3.3 Findings

The empirical evidence supports several central conclusions. First, the development of green finance, both in depth and quality, has delayed but persistent positive effects on economic growth. The PVAR results show that initial responses fluctuate before converging to a sustained positive path, while cumulative impulse responses remain non-negative. Second, the dynamic adjustment process is characterised by short-run oscillations followed by long-run stabilisation, indicating that transitional reallocations of capital precede steady growth gains. Third, causality primarily runs from green finance to economic growth, with only limited and weak feedback effects from economic performance to green finance quality.

The DML results further refine these conclusions by relaxing the PVAR's homogeneity assumption and uncovering cross-regional heterogeneity. At the global level, DML estimation identifies a small but statistically significant positive average marginal effect of GGFI on GDP growth, robust across Random Forest and Gradient Boosting learners. However, the magnitude and statistical significance of this relationship vary across regions. The positive association is strongest and highly significant in the Asia-Pacific region, whereas it is statistically insignificant in Europe and North America over the sample period. These findings suggest that the growth effects of green finance are not uniform but depend on regional structural conditions, institutional maturity, and stages of economic development.

Taken together, the results indicate that strengthening green finance infrastructure across financial centres contributes to sustained economic expansion once transitional adjustment costs are absorbed, though the magnitude of this contribution varies across regions. The combined evidence from dynamic econometric modelling and data-driven causal estimation supports the view that green finance functions as a growth-enhancing mechanism, particularly in economies undergoing structural transformation and financial deepening.

4. Conclusion

Based on common model selection criteria, a VAR(8) specification selected by AIC, SC, and HQ criteria was adopted to capture the semi-annual dynamics between green finance development and economic growth. The adjusted R-squared values are close to 0.7 in the GDP equations, indicating satisfactory explanatory power. Impulse response analysis shows that real GDP per capita growth initially fluctuates following shocks to GGFI depth and quality during the first six periods, after which the responses converge toward a persistent positive path. Cumulative impulse responses remain non-negative

throughout the forecast horizon, suggesting that transitional adjustments do not reverse the long-run growth contribution of green finance. Granger causality tests indicate that the direction of causality primarily runs from green finance to economic growth, with only limited, weak feedback effects from economic performance to the quality of green finance. The results remain robust when PPP GDP per capita is used as an alternative growth measure. Although both GGFI and GDP growth slowed during 2020, as reflected in descriptive patterns, this temporary deceleration does not alter the positive dynamic relationship identified in the econometric estimations. The inclusion of a COVID-19 dummy variable does not yield statistically significant effects across specifications.

To account for potential nonlinearities and cross-regional heterogeneity, DML estimation was employed with Random Forest and Gradient Boosting learners, using repeated cross-fitting. The DML results identify a small but statistically significant positive average marginal effect of GGFI on global GDP growth, consistent across model specifications. However, the continent-level analysis reveals substantial variation. The positive association is strongest and highly significant in the Asia-Pacific region, while statistically insignificant in Europe and North America during the sample period. These findings indicate that the growth impact of green finance is not uniform across financial centres but depends on regional structural conditions, stages of economic development, and institutional maturity.

Taken together, the combined evidence from dynamic panel modelling and data-driven causal estimation supports several conclusions. Green finance development, in both depth and quality, contributes to economic growth through delayed but persistent effects. The adjustment process involves short-run oscillations followed by long-run stabilisation, reflecting transitional capital reallocation. Moreover, the magnitude of the growth contribution varies across regions, with stronger effects observed in financial systems undergoing structural transformation and financial deepening. Strengthening green finance infrastructure, therefore, supports sustained economic expansion, although its effectiveness is conditioned by regional economic structures and development paths.

4.1 Research Limitations and Suggestions for Future Research

This paper uses national GDP per capita growth rates to measure economic development, assuming that the green finance performance of regional financial centres contributes to national economic outcomes. However, region-specific indicators, such as metropolitan GDP, financial sector value added, or local employment in green industries, are not consistently available across the 99 financial centres studied. As a result, the analysis cannot fully isolate the localised economic contribution of each financial

hub. Future research should incorporate subnational macroeconomic indicators to better capture spatial spillover effects and region-specific growth dynamics.

Advanced economies also tend to host more financial centres than emerging economies, which may introduce a structural imbalance in the sample. Although continent-level analysis partially addresses heterogeneity, unequal representation may influence global average estimates. Subsequent studies could adopt weighting schemes or stratified sampling approaches to further examine distributional effects across income groups.

Another limitation concerns the measurement of green finance itself. The GGFI is a composite index derived from survey-based perceptions and instrumental indicators. While comprehensive, it reflects both objective metrics and subjective assessments of financial centre performance. Future research could compare GGFI-based results with alternative green finance proxies, such as green bond issuance volumes, sustainable investment flows, or taxonomy-aligned credit ratios, to test consistency across measurement frameworks.

The VAR model employs eight lags to capture semi-annual dynamics, thereby substantially reducing the effective degrees of freedom. While this specification is justified by model selection criteria and dynamic adjustment considerations, longer time-series data would allow more precise estimation of long-run relationships. In addition, GGFI data are available only from 2018 onward, limiting the ability to assess structural shifts over extended business cycles. As green finance institutions mature, future datasets covering longer horizons may reveal different adjustment speeds or structural break patterns.

Although the DML approach addresses high-dimensional confounding and nonlinearities, it estimates average marginal effects and does not fully characterise structural mechanisms. The present study identifies heterogeneous regional patterns but does not explicitly model interaction terms between institutional quality, digital infrastructure, and green finance development. Future research could integrate structural modelling, causal forests, or hierarchical Bayesian frameworks to further examine heterogeneous treatment effects.

Finally, while the analysis identifies a positive association and Granger-causal direction from green finance to economic growth, it does not fully disentangle underlying transmission channels. Mechanisms such as technological innovation, industrial upgrading, renewable energy deployment, or financial deepening are inferred but not directly estimated within the empirical framework. Incorporating mediation analysis or sector-level panel data would enhance understanding of the pathways through which green finance influences macroeconomic performance.

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REFERENCES

Ali, A., Li, J., Zhang, J. & Chishti, M. (2024). Exploring the impact of green finance and technological innovation on green economic growth: Evidence from emerging market economies. *Sustainable Development*, 32(6), 6392-6407, ISSN 0968-0802, <https://doi.org/10.1002/sd.3031>

Ali, M., Igunnu, P., Seraj, M. & Raza, A. (2025). Effect of green finance and institutional quality on economic growth: an evidence from novel MMQR approach. *SN Business and Economics*, 5(10), ISSN 2662-9399, <https://doi.org/10.1007/s43546-025-00911-x>

Ali, M., Seraj, M., Türüç, F., Tursoy, T. & Raza, A. (2023). Do banking sector development, economic growth, and clean energy consumption scale up green finance investment for a sustainable environment in South Asia: evidence for newly developed RALS cointegration. *Environmental Science and Pollution Research*, 30(25), 67891-67906, ISSN 0944-1344, <https://doi.org/10.1007/s11356-023-27023-z>

Balogun, F.B. & Dhakir, A. (2025). Impact of green finance on long-term sustainable economic growth evidence from Ghana. *Perspectives in Agile Sustainable Practices and Business Value*, 222-236, <https://doi.org/10.4324/9781003619918-21>

Belgacem, S.B., Adam, N., Khatoun, G. & Pawar, P. (2023). Do green finance, low-carbon energy transition, and economic growth help in environmental investment?: Empirical evidence from emerging economies in Asia. *Geological Journal*, 58(9), 3259-3267, ISSN 0072-1050, <https://doi.org/10.1002/gj.4712>

Bughio, A., Teng, Y. & Shar, R. (2025). The short- and long-run causal correlation between green finance, renewable energy consumption, and economic growth. *Energy and Environment*, 36(2), 888-907, ISSN 0958-305X, <https://doi.org/10.1177/0958305X231187036>

Chernozhukov, V., Chetverikov, D., Demirer, M., Duflo, E., Hansen, C., Newey, W., & Robins, J. (2018). Double/debiased machine learning for treatment and structural parameters.

Dahhou, N., Bahetta, S., Bouyghrissi, S. & Kharbouch, O. (2025). Renewable Energy, Green Finance, and Economic Growth in Morocco: Evidence from an ARDL Approach. *International Journal of Energy Economics and Policy*, 15(3), 98-106, ISSN 2146-4553, <https://doi.org/10.32479/ijeep.18522>

Feng, C., Zhong, S. & Wang, M. (2024). How can green finance promote the transformation of China's economic growth momentum? A perspective from internal structures of green total-factor productivity. *Research in International Business and Finance*, 70, ISSN 0275-5319, <https://doi.org/10.1016/j.ribaf.2024.102356>

Gherbi, E.A.H. Khalifa, G. & Kwilinski, A. (2024). Mitigating CO2 Emissions through Economic Growth, Green Finance, and Renewable Energy: Evidence from an ARDL Analysis. *Forum Scientiae Oeconomia*, 12(4), 99-121, ISSN 2300-5947, https://doi.org/10.23762/FSO_VOL12_NO4_6

Guan, X., Hassan, A. & Nassani, A. (2025). Investigating the Role of Environmental Taxes, Green Finance, Natural Resources, Human Capital, and Economic Growth on Environmental Pollution Using Panel Quantile Regression. *Sustainability Switzerland*, 17(3), ISSN 2071-1050, <https://doi.org/10.3390/su17031094>

Guo, S., Zhang, T. & Cui, J. (2024). Coupled coordination analysis of green finance on economic growth based on big data. *Applied Mathematics and Nonlinear Sciences*, 9(1), ISSN 2444-8656, <https://doi.org/10.2478/amns.2023.2.00194>

Han, J. & Gao, H. (2024). Green finance, social inclusion, and sustainable economic growth in OECD member countries. *Humanities and Social Sciences Communications*, 11(1), ISSN 2662-9992, <https://doi.org/10.1057/s41599-024-02662-w>

Hua, Y. & Tong, T. (2026). Renewable energy integration in the Belt and Road Initiative: Government expenditure, green finance, and economic growth. *Renewable Energy*, 256, ISSN 0960-1481, <https://doi.org/10.1016/j.renene.2025.123980>

Huang, D. (2022). Green finance, environmental regulation, and regional economic growth: from the perspective of low-carbon technological progress. *Environmental Science and Pollution Research*, 29(22), 33698-33712, ISSN 0944-1344, <https://doi.org/10.1007/s11356-022-18582-8>

Huang, L., Cao, Y. & Zhu, Y. (2023). Is there any recovery power for economic growth from green finance? Evidence from OECD member countries. *Economic Change and Restructuring*, 56(6), 3909-3926, ISSN 1573-9414, <https://doi.org/10.1007/s10644-022-09458-5>

Jia, J., Yu, X. & Lv, K. (2025). Green finance and carbon emission efficiency under the constraint of economic growth targets: a spatial econometric and threshold effect study based on 30 provinces in mainland China. *Frontiers in Energy Research*, 13, ISSN 2296-598X, <https://doi.org/10.3389/fenrg.2025.1592581>

Khan, N.H., He, W., Min, A. & Ramsey, T. (2025). Reconciling environmental sustainability in emerging economies: evidence from China on the role of water transportation, green finance, renewable energy, and economic growth. *Environment Development and Sustainability*, ISSN 1387-585X, <https://doi.org/10.1007/s10668-025-07017-2>

Kumari, K.G. Shantha, Mukthar, K. & Rahhani, G. (2024). Green Finance in India: Driving Sustainable Development and Economic Growth. *Studies in Systems Decision and Control*, 537, 283-293, ISSN 2198-4182, https://doi.org/10.1007/978-3-031-62106-2_23

Li, H. , Malim, N., Xie, X. & Du, X. (2025). Interaction Effects of Green Finance and Digital Platforms on China's Economic Growth. *Sustainability Switzerland*, 17(18), ISSN 2071-1050, <https://doi.org/10.3390/su17188171>

Li, J. , Dong, K., Taghizadeh-Hesary, F. & Wang, K. (2022). 3G in China: How green economic growth and green finance promote green energy?. *Renewable Energy*, 200, 1327-1337, ISSN 0960-1481, <https://doi.org/10.1016/j.renene.2022.10.052>

Li, Y. & Huang, Y. (2025). Research on the impact of green finance on China's ocean economic growth under the "dual carbon" goal. *Frontiers in Marine Science*, 12, ISSN 2296-7745, <https://doi.org/10.3389/fmars.2025.1552567>

Liu, B. & Pan, X. (2024). Green finance, energy transition, and natural resources of real estate sector: driving eco-sustainability and sustainable economic growth. *Economic Change and Restructuring*, 57(2), ISSN 1573-9414, <https://doi.org/10.1007/s10644-024-09602-3>

Liu, D. (2023). Does green finance and natural resources agglomeration have potential for green economic growth? Evidence from Asian perspective. *Resources Policy*, 84, ISSN 0301-4207, <https://doi.org/10.1016/j.resourpol.2023.103720>

Liu, J. & Fu, Q. (2023). Green finance, energy consumption, urbanisation, and economic growth: Quantile based evidence from China. *Environmental Science and Pollution Research*, 30(37), 88155-88166, ISSN 0944-1344, <https://doi.org/10.1007/s11356-023-28590-x>

Liu, S. & Liu, M. (2020). Green Finance, Economic Growth and Environmental Change : Is it Possible for the Environmental Index in the Northwest to Fulfill the "Paris Agreement" ? . *Modern*

Economic Science, 42(1), 71-84, ISSN 1002-2848,
<https://www.scopus.com/inward/record.uri?partnerID=HzOxMe3b&scp=85123775910&origin=inward>

Liu, X., Zhao, T. & Li, R. (2023). Studying the green economic growth with clean energy and green finance: The role of financial policy. *Renewable Energy*, 215, ISSN 0960-1481, <https://doi.org/10.1016/j.renene.2023.118971>

Lv, K., Yu, X. & Jia, J. (2025). How does "big government"-guided economic growth target setting affect carbon emission efficiency? A market mechanism perspective from green finance. *Environment Development and Sustainability*, ISSN 1387-585X, <https://doi.org/10.1007/s10668-025-06829-6>

Ma, M., Zhu, X., Liu, M. & Huang, X. (2023). Combining the role of green finance and environmental sustainability on green economic growth: Evidence from G-20 economies. *Renewable Energy*, 207, 128-136, ISSN 0960-1481, <https://doi.org/10.1016/j.renene.2023.02.046>

Ma, W. (2022). Research on the coupling and coordination of green finance, higher education, and green economic growth. *Environmental Science and Pollution Research*, 29(39), 59145-59158, ISSN 0944-1344, <https://doi.org/10.1007/s11356-022-20026-2>

Manigandan, P., Alam, M., Alam, N. & Ozturk, I. (2025). The impact of green finance, green innovations, natural resources, and environmental innovations on sustainable economic growth in India: Fresh evidence from novel fourier-based approach. *Environment Development and Sustainability*, ISSN 1387-585X, <https://doi.org/10.1007/s10668-025-06349-3>

Marín-Rodríguez, N.J., González-Ruiz, J. & Botero, S. (2024). Evolution of Green Finance: Mapping Its Role as a Catalyst for Economic Growth and Innovation. *Journal of Risk and Financial Management*, 17(11), ISSN 1911-8074, <https://doi.org/10.3390/jrfm17110507>

Mohsin, M. & Jamaani, F. (2023). Unfolding impact of natural resources, economic growth, and energy nexus on the sustainable environment: Guidelines for green finance goals in 10 Asian countries. *Resources Policy*, 86, ISSN 0301-4207, <https://doi.org/10.1016/j.resourpol.2023.104238>

Mohsin, M., Iqbal, N. & Iram, R. (2024). The Nexus Between Green Finance and Sustainable Green Economic Growth. *Energy Research Letters*, 5(3), ISSN 2652-6433, <https://doi.org/10.46557/001c.78117>

Naveed, H.M., Sharif, A., Bashir, F., Al-Faryan, M. & Pan, Y. (2025). Assessing the connectedness between green finance, financial developments, traditional energy consumption, economic growth, population aging and environmental degradation in RECP economies: A deep learning-based

analysis. *Journal of Environmental Management*, 393, ISSN 0301-4797, <https://doi.org/10.1016/j.jenvman.2025.126963>

Nenavath, S. & Mishra, S. (2023). Impact of green finance and fintech on sustainable economic growth: Empirical evidence from India. *Heliyon*, 9(5), ISSN 2405-8440, <https://doi.org/10.1016/j.heliyon.2023.e16301>

Ngo, T.Q., Doan, P., Vo, L., Tran, H. & Nguyen, D. (2021). The influence of green finance on economic growth: A COVID-19 pandemic effects on Vietnam Economy. *Cogent Business and Management*, 8(1), ISSN 2331-1975, <https://doi.org/10.1080/23311975.2021.2003008>

Nie, C., Yao, T. & Feng, Y. (2024). The impact of green finance on economic growth: Evidence from the green finance reform and innovation pilot zone. *American Journal of Economics and Sociology*, 83(4), 709-736, ISSN 0002-9246, <https://doi.org/10.1111/ajes.12573>

Ogunsola, A.J. & Zwane, T. (2026). Green Finance as a Catalyst for Sustainable Economic Growth in Emerging Market Economies: An Analytical Investigation of Key Drivers. *Sustainable Finance*, 59-86, ISSN 2522-8285, https://doi.org/10.1007/978-3-032-13446-2_4

Ouyang, H., Guan, C. & Yu, B. (2023). Green finance, natural resources, and economic growth: Theory analysis and empirical research. *Resources Policy*, 83, ISSN 0301-4207, <https://doi.org/10.1016/j.resourpol.2023.103604>

Praveen, B., Rath, B. & Akram, V. (2025). A new way of thinking about the nexus between green energy and green economic growth: The mediating role of green finance and green technology. *Journal of Environmental Management*, 390, ISSN 0301-4797, <https://doi.org/10.1016/j.jenvman.2025.126235>

Rahman, M.H. & Salimullah, A. (2026). Effect of Economic Growth, Financial Development, and Renewable Energy Consumption on Environmental Pollution in ASEAN Countries: What is the Role of Green Finance and Green Energy?. *World Development Sustainability*, 8, ISSN 2772-655X, <https://doi.org/10.1016/j.wds.2026.100271>

Sadiq, M., Amayri, M., Paramaiah, C., Mai, N., Ngo, T. & Phan, T. (2022). How green finance and financial development promote green economic growth: deployment of clean energy sources in South Asia. *Environmental Science and Pollution Research*, 29(43), 65521-65534, ISSN 0944-1344, <https://doi.org/10.1007/s11356-022-19947-9>

Singh, V. & Mishra, N. (2022). Impact of Green Finance on National Economic Growth During the COVID-19 Pandemic. *Energy Research Letters*, 3(3), ISSN 2652-6433, <https://doi.org/10.46557/001c.29975>

Soundarrajan, P. & Vivek, N. (2016). Green finance for sustainable green economic growth in india. *Agricultural Economics Czech Republic*, 62(1), 35-44, ISSN 0139-570X, <https://doi.org/10.17221/174/2014-AGRICECON>

Tan, J., Su, X. & Wang, R. (2023). The impact of natural resource dependence and green finance on green economic growth in the context of COP26. *Resources Policy*, 81, ISSN 0301-4207, <https://doi.org/10.1016/j.resourpol.2023.103351>

Tran, Q.H. (2022). The impact of green finance, economic growth and energy usage on CO2 emission in Vietnam – a multivariate time series analysis. *China Finance Review International*, 12(2), 280-296, ISSN 2044-1398, <https://doi.org/10.1108/CFRI-03-2021-0049>

Wang, G. (2024). RESEARCH ON GREEN FINANCE ON INDUSTRIAL TRANSFORMATION AND HIGH-QUALITY ECONOMIC GROWTH: EVIDENCE FROM THE NEW ENERGY INDUSTRY IN SOUTHWEST CHINA. *International Journal of Economics and Finance Studies*, 16(3), 351-364, ISSN 1309-8055, <https://doi.org/10.34109/ijefs.202416317>

Wen, B., He, Y., Jing, X. & Haroon, M. (2025). Advancing renewable energy and green finance for economic growth and ecological resilience. *Energy Strategy Reviews*, 59, ISSN 2211-467X, <https://doi.org/10.1016/j.esr.2025.101747>

World Bank. (2026). *World Development Indicators* [Database]. <https://databank.worldbank.org/source/world-development-indicators>

Wu, B., Ding, Y., Xie, B., & Zhang, Y. (2024). FinTech and inclusive green growth: a causal inference based on DML. *Sustainability*, 16(22), 9989.

Xiao, C. & Tabish, R. (2025). Green Finance Dynamics in G7 Economies: Investigating the Contributions of Natural Resources, Trade, Education, and Economic Growth. *Sustainability Switzerland*, 17(4), ISSN 2071-1050, <https://doi.org/10.3390/su17041757>

Xu, J., She, S., Gao, P. & Sun, Y. (2023). Role of green finance in resource efficiency and green economic growth. *Resources Policy*, 81, ISSN 0301-4207, <https://doi.org/10.1016/j.resourpol.2023.103349>

Xue, Y., Wang, H. & Yang, Q. (2023). Accelerating Urban Green Economic Growth Through Government Guidance Funds: Case Study of a National Green Finance Pilot City. *Lecture Notes in Operations Research*, 1084-1096, ISSN 2731-040X, https://doi.org/10.1007/978-981-99-3626-7_83

Ye, M., Cai, J., Wang, K. & Wang, X. (2023). Green finance, economic growth, and carbon emissions: a PVAR analysis. *Environmental Science and Pollution Research International*, 30(56), 119419-119433, ISSN 1614-7499, <https://doi.org/10.1007/s11356-023-30719-x>

Yin, X. & Xu, Z. (2022). An empirical analysis of the coupling and coordinative development of China's green finance and economic growth. *Resources Policy*, 75, ISSN 0301-4207, <https://doi.org/10.1016/j.resourpol.2021.102476>

Yu, J., Long, H., Shahzad, I. & Wang, J. (2026). Driving sustainable development in BRICS through green finance and economic growth: A quantile regression perspective. *Journal of Innovation and Knowledge*, 11, ISSN 2530-7614, <https://doi.org/10.1016/j.jik.2025.100879>

Yuan, J., & Liu, S. (2024). A DML model for measuring the impact of the Made in China 2025 strategy on green economic growth. *Scientific Reports*, 14(1), 12026.

Z/Yen Group Limited. (2026). *Publications*. <https://www.longfinance.net/programmes/financial-centre-futures/global-green-finance-index/ggfi-publications/>

Zhang, D., Mohsin, M., Rasheed, A., Chang, Y. & Taghizadeh-Hesary, F. (2021). Public spending and green economic growth in BRI region: Mediating role of green finance. *Energy Policy*, 153, ISSN 0301-4215, <https://doi.org/10.1016/j.enpol.2021.112256>

Zhang, Y., Peng, C. & Ming, K. (2025). IMPACT OF GREEN FINANCE ON GREEN TOTAL FACTOR PRODUCTIVITY: IMPLICATIONS FOR ECONOMIC GROWTH AND SUSTAINABLE ENVIRONMENT. *Singapore Economic Review*, 70(7), 1995-2027, ISSN 0217-5908, <https://doi.org/10.1142/S0217590824500152>

Zhong, W. (2022). Assessing the Nexus Between Green Economic Recovery, Green Finance, and CO2 Emission: Role of Supply Chain Performance and Economic Growth. *Frontiers in Environmental Science*, 10, ISSN 2296-665X, <https://doi.org/10.3389/fenvs.2022.914419>

Zhou, J. & Guo, Y. (2026). The impact of green finance on economic growth and environmental quality. *Finance Research Letters*, 87, ISSN 1544-6123, <https://doi.org/10.1016/j.frl.2025.109087>

Zhuang, T. (2024). Appraising sustainability and economic growth through Fintech, green finance and natural resource in Asian economies: A CS-ARDL study. *Resources Policy*, 97, ISSN 0301-4207, <https://doi.org/10.1016/j.resourpol.2024.105276>