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Does Financial Development Reduce Emissions? The Role of Renewable Energy. Evidence from High-Governance Economies

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ABSTRACT

Financial development represents an increasingly recognized yet empirically contested mechanism for addressing climate change. This study investigates the relationship between financial sector deepening and carbon dioxide emissions in sixty high-governance countries from 1995 to 2019. Employing dynamic generalized method of moments estimation, we find that a 1% increase in financial development growth reduces CO_2 emission growth by 3.30%, while renewable energy expansion contributes an additional 1.74% reduction. These effects remain robust across alternative specifications and estimation techniques. The negative relationship emerges specifically in countries with strong institutional frameworks, suggesting that governance quality conditions whether financial systems channel capital toward environmentally beneficial investments. Our findings indicate that financial sector policies represent viable complements to traditional environmental regulations in well-governed economies, demonstrating compatibility between financial deepening and climate mitigation under strong governance conditions.

Keywords: Financial Development, CO_2 Emissions, Renewable Energy, Governance Quality, GMM, Climate Policy
JEL Classification: Q54, G20, O44, Q43

1. INTRODUCTION

Global carbon dioxide emissions reached 37.15 billion metric tons in 2022 (Global Carbon Project, 2023), representing a 0.9% increase from 2021 levels despite two decades of intensified climate policy interventions. This persistent upward trajectory occurs as renewable energy deployment has expanded significantly to achieve 30% of global electricity generation in 2023 (IEA, 2023). Carbon pricing mechanisms now cover approximately 23% of global emissions (Munich Re, 2023). However, these traditional policy instruments have proven insufficient to bend the emissions curve toward the 1.5°C pathway mandated by the Paris Agreement. This implementation gap necessitates critical examination of complementary mechanisms through which economies can accelerate low-carbon transitions. Financial sector development emerges as a potentially transformative yet empirically underexplored channel for environmental improvement.

The theoretical foundations linking financial development to environmental outcomes operate through multiple competing channels that generate ambiguous net effects. Well-functioning financial systems can catalyze green transitions by mobilizing capital for renewable energy infrastructure. They reduce financing costs for clean technology adoption and enable innovation through venture capital and long-term credit provision (Tamazian et al., 2009; Zhang, 2011; Paramati et al., 2021). Recent evidence demonstrates that green finance mechanisms create powerful incentives for corporate environmental responsibility while simultaneously reducing capital costs for clean technology deployment (Hassan & Khan, 2024; Seraj et al., 2025). Financial market sophistication further facilitates green industrial transitions by channeling investments toward environmentally beneficial sectors. This process accelerates the structural transformation necessary for decarbonization.

Nevertheless, expanded credit availability may simultaneously increase emissions through consumption-driven scale effects. Easier access to financing stimulates energy-intensive purchases, industrial expansion, and resource extraction (Sadorsky, 2010). This consumption channel operates particularly strongly when financial deepening occurs alongside rapid industrialization. Credit expansion finances carbon-intensive infrastructure and manufacturing capacity before clean alternatives become economically viable. This theoretical ambiguity necessitates rigorous empirical investigation to determine which mechanisms dominate under specific institutional conditions.

Institutional quality emerges as the fundamental conditioning variable determining whether financial development reduces or exacerbates environmental degradation. Research focusing on emerging economies with weak governance structures consistently identifies positive associations between financial sector expansion and carbon emissions. These findings suggest that scale effects overwhelm efficiency gains when regulatory oversight remains inadequate (Shahbaz et al., 2013; Charfeddine & Kahia, 2019). Studies of BRICS countries demonstrate that financial development contributes to environmental degradation alongside economic growth. Credit expansion primarily finances carbon-intensive industrialization rather than clean energy transitions when environmental regulations lack enforcement mechanisms (Chishty et al., 2025). Recent evidence examining ASEAN economies confirms that corruption control and regulatory effectiveness determine whether financial flows support sustainable development or environmental degradation (Mai et al., 2025; Khan et al., 2024). This pattern highlights the importance of how financial resources are allocated rather than mere credit expansion.

The moderating role of institutional quality extends beyond simple governance indicators to encompass specific dimensions of financial market development and regulatory capacity. Analyses examining the nexus between institutional quality and financial development demonstrate that credit markets influence environmental outcomes through fundamentally different channels depending on governance strength (Supriyadi et al., 2024). Well-governed economies successfully direct credit toward green investments and renewable energy deployment. Poorly governed systems experience primarily consumption-driven environmental degradation. The effectiveness of climate finance in developing countries depends critically on complementary factors including governance quality and institutional capacity (Ming et al., 2025). Research on Sub-Saharan African countries reinforces this institutional perspective by demonstrating that good governance fundamentally moderates the relationship between economic development and carbon emissions (Mindia et al., 2024).

Analyses of developed markets with robust institutional frameworks identify predominantly negative associations between financial development and emissions. Mature financial systems successfully channel capital toward cleaner technologies and facilitate structural economic transformation toward less carbon-intensive activities (Claessens and Feijen, 2007; Paramati et al., 2021). This divergence across income groups suggests that institutional quality fundamentally moderates how credit markets influence environmental outcomes (Jiakui et al., 2023; Wang et al., 2022). The electricity market liberalization experience provides compelling evidence of institutional quality's importance in enabling financial mechanisms to support environmental objectives. Successful decarbonization requires not only financial resources but also institutional frameworks that align market incentives with climate policy objectives.

Despite growing recognition of institutional quality's moderating role, existing literature suffers from critical limitations that constrain policy inference and motivate our research approach. The vast majority of cross-country studies examine heterogeneous samples combining economies with vastly different governance capacities, potentially confounding estimates of financial development's true environmental impact (Zhang et al., 2024; Iorember et al., 2024; Avci et al., 2024). When researchers pool countries ranging from weak to strong institutional frameworks, coefficient estimates reflect average effects that may not accurately characterize the relationship in any particular governance context. This heterogeneity problem becomes especially acute when examining financial development, as the mechanisms through which credit markets influence emissions depend fundamentally on effective environmental regulation, transparent financial supervision, and functioning rule of law (Paramati et al., 2021; Ofori et al., 2023).

While recent studies acknowledge institutional quality as important, few isolate samples exclusively within high-governance contexts where regulatory mechanisms operate effectively (Nwani, 2022; Yasin et al., 2025; Achuo et al., 2024). This sampling limitation leaves unresolved a critical policy question facing developed nations: does financial development reduce emissions when institutions function as designed, or do scale effects dominate even in well-governed economies (He et al., 2025; Alkhawaja and Dsouza, 2025)? Without empirical evidence from homogeneously high-governance samples, policymakers in advanced economies lack clear guidance on whether accelerating financial deepening supports or undermines their climate commitments (Bakhsh et al., 2021; Satrianto et al., 2024).

This study addresses these limitations by examining exclusively high-governance economies where institutional mechanisms operate as designed. We analyze a balanced panel of 60 countries characterized by strong rule of law, effective government, robust regulatory quality, and corruption control over the period 1995-2019 (Kaufmann et al., 2011). This sampling strategy isolates the finance-environment relationship within institutional contexts where financial markets function efficiently and environmental regulations receive consistent enforcement. By restricting analysis to countries scoring above the 67th percentile on composite governance indicators, we eliminate the confounding effects of institutional heterogeneity that plague existing cross-country studies (Claessens and Feijen, 2007; Tamazian et al., 2009). This approach provides the first clean test of whether financial development serves as an emission-reducing mechanism when supporting institutional infrastructure exists.

Our empirical strategy employs system Generalized Method of

Moments estimation to address endogeneity concerns inherent in the finance-environment nexus (Ming et al., 2025; Arellano and Bond, 1991). We control for renewable energy consumption, economic development, and human capital investment to isolate financial development's independent environmental effects (Al-Kasasbeh et al., 2025; Afshan et al., 2025; Widianingsih et al., 2025).

Results reveal that financial development significantly reduces carbon emissions in high-governance economies, with effects operating alongside complementary emission reductions from renewable energy deployment (Paramati et al., 2021; Hassan and Khan, 2024). The findings demonstrate that when regulatory frameworks function effectively, financial sector deepening facilitates rather than impedes environmental progress (Ali et al., 2024; Balcilar et al., 2023; Ahmad et al., 2025). These results suggest that financial sector policies represent underutilized instruments for achieving emission reduction targets when embedded within strong governance frameworks (He et al., 2025).

The remainder of this paper proceeds as follows. Section 2 describes data sources, variable construction, and econometric methodology. Section 3 presents main empirical results with robustness checks. Section 4 discusses economic interpretation and policy implications. Section 5 concludes.

2. LITERATURE REVIEW

2.1. Theoretical Foundations: Financial Development and Environmental Outcomes

The relationship between financial sector development and environmental quality operates through multiple theoretical channels that generate competing predictions about net environmental effects. The green channel hypothesis posits that well-functioning financial systems facilitate environmental improvement by mobilizing capital for renewable energy infrastructure (Tamazian et al., 2009; Zhang, 2011). These systems reduce financing costs for clean technology adoption and enable innovation through venture capital provision. Advanced financial systems create specialized green financing instruments including environmental bonds, sustainability-linked loans, and climate-focused investment funds. These instruments directly channel resources toward emission-reducing activities. Recent theoretical extensions emphasize how financial market sophistication enables price discovery mechanisms for environmental risk (Hassan and Khan, 2024). This creates incentives for corporate decarbonization through market discipline rather than regulatory mandate alone.

However, competing theoretical perspectives highlight potentially adverse environmental consequences of financial deepening. The scale effect hypothesis suggests that expanded credit availability stimulates consumption growth, industrial expansion, and resource extraction (Sadorsky, 2010). These forces collectively increase emissions. Financial development lowers borrowing costs for households and firms. This facilitates purchases of energy-intensive durables and construction of carbon-intensive infrastructure. It also enables expansion of manufacturing capacity before clean alternatives achieve economic viability. This consumption channel operates particularly strongly during rapid industrialization phases. Credit expansion finances initial buildout of productive capacity during these periods. The net environmental impact of financial development thus depends critically on which channel dominates under specific economic and institutional conditions.

The institutional conditioning hypothesis provides a synthesis framework. Governance quality determines whether financial development operates primarily through green or scale channels. Effective environmental regulation transforms how financial institutions evaluate investment opportunities (Jiakui et al., 2023). It internalizes environmental costs into project assessment frameworks. Strong rule of law ensures contract enforcement for long-term green investments. Corruption control prevents regulatory capture by carbon-intensive industries. Government effectiveness enables coordinated implementation of green finance policies across multiple agencies. Regulatory quality establishes clear frameworks for environmental disclosure and climate risk assessment. These institutional dimensions collectively determine whether expanding credit markets support or undermine environmental objectives.

Empirical investigations of emerging and developing economies consistently identify positive associations between financial development and carbon emissions. This suggests scale effects dominate efficiency gains when governance structures remain weak. Research examining BRICS countries demonstrates that credit expansion primarily finances carbon-intensive industrialization rather than clean energy transitions (Shahbaz et al., 2013; Charfeddine & Kahia, 2019; Singh et al., 2022). This pattern emerges when environmental regulations lack enforcement mechanisms. Financial deepening in these contexts enables rapid economic growth through investment in heavy industry and manufacturing capacity. Such investments lock in high-emission development pathways. Importantly, the positive finance-emissions relationship persists even after controlling for economic development. This suggests financial sector expansion independently contributes to environmental degradation beyond simple income effects.

Recent evidence reinforces these patterns while revealing important heterogeneity across financial instruments. Analysis of BRICS economies from 2001 to 2023 finds contrasting effects (Chishty et al., 2025). Domestic credit to the private sector exhibits positive associations with emissions. This confirms traditional scale effect channels. However, green technological innovation demonstrates emission-reducing effects. This suggests potential for transitioning toward environmentally beneficial financial flows even in emerging contexts. The contrast highlights a critical insight. The composition of financial development matters as much as aggregate depth. Broad money supply growth generates different environmental impacts than targeted green finance mechanisms or innovation-supporting credit allocation.

Research on ASEAN economies extends these findings by explicitly examining governance dimensions as moderating variables. Corruption control and regulatory effectiveness emerge as critical determinants of whether financial flows

support sustainable development or environmental degradation (Mai et al., 2025). Financial development reduces emissions only when complemented by strong governance institutions that channel credit toward productive environmental investments rather than resource extraction or energy-intensive consumption. The interaction between finance and governance suggests that policies promoting financial deepening in weak institutional contexts may inadvertently accelerate environmental harm unless accompanied by regulatory strengthening. This finding carries important implications for development strategies in emerging economies where financial sector expansion often outpaces institutional capacity building.

2.2. Finance Mechanism in Developing Countries

Climate finance mechanisms in developing countries exhibit similarly conditional effectiveness. Examination of 74 developing nations from 2015 to 2021 reveals that climate finance impacts depend critically on complementary factors including income levels, institutional capacity, and baseline environmental conditions (Ming et al., 2025; Chen & Liu, 2023). Financial flows directed toward climate mitigation generate stronger emission reductions in contexts with effective governance and technical capacity to deploy resources efficiently. Countries lacking these institutional prerequisites often experience limited environmental benefits from climate finance despite substantial monetary transfers. These patterns suggest that financial mechanisms alone cannot overcome underlying governance deficiencies that prevent effective environmental policy implementation.

Sub-Saharan African countries provide additional evidence of governance quality's fundamental role in shaping finance-environment relationships. Good governance moderates the relationship between economic development and carbon emissions by enabling more efficient resource allocation and enforceable environmental standards (Mindia et al., 2024; Ganda, 2024). Financial development in well-governed African economies supports clean energy deployment and technological upgrading. Poorly governed economies experience primarily consumption-driven environmental degradation as credit expansion finances immediate consumption and resource extraction without offsetting efficiency improvements. The divergent experiences within Africa illustrate how institutional quality conditions can overwhelm geographic or resource endowment similarities in determining environmental trajectories.

Analyses of developed markets with robust institutional frameworks identify predominantly negative associations between financial development and emissions. This contrasts sharply with emerging economy findings. The difference suggests efficiency gains overwhelm scale effects when supporting governance exists. Mature financial systems successfully channel capital toward cleaner technologies (Claessens & Feijen, 2007; Musa et al., 2021). They facilitate structural economic transformation toward less carbon-intensive activities. Financial market sophistication in developed economies enables long-term contracting for renewable energy projects. It also supports efficient risk assessment for clean technology ventures. Liquid markets for environmental assets including carbon permits and renewable energy certificates emerge in these contexts. These mechanisms create continuous incentives for emission reduction beyond 1-time regulatory interventions.

Research examining OECD economies demonstrates that the green channel dominates through multiple transmission mechanisms. Financial deepening and green technology jointly reduce emissions when embedded within strong institutional frameworks (Paramati et al., 2021; Wang et al., 2022; Wang et al., 2024; Adebayo & Ullah, 2024). Stock market development facilitates venture capital for clean technology startups. Bond markets enable large-scale renewable energy project finance. Banking sector depth provides working capital for energy efficiency improvements. Insurance markets distribute climate risks and incentivize adaptation investments. These diverse channels collectively enable comprehensive economy-wide decarbonization that would not occur through environmental regulation alone (Li & Zhang, 2024).

Renewable energy deployment in developed countries exhibits strong complementarity with both financial development and institutional quality. Financial sector depth enables the long-term investment horizons required for renewable energy infrastructure (Widianingsih et al., 2025; Al-Kasasbeh et al., 2025; Dong et al., 2024; Ahmed et al., 2023). Regulatory quality ensures stable policy frameworks that reduce investment risk. Banking systems in well-governed economies develop specialized expertise in renewable energy project finance. Capital markets provide liquidity through green bonds and infrastructure funds. These mechanisms amplify renewable energy's emission-reducing effects by lowering financing costs and accelerating deployment (Wang et al., 2022).

Emerging evidence on green finance mechanisms reveals how specific financial innovations target environmental improvement. Sustainable investments, environmental taxation, and green innovations exhibit synergistic effects in promoting environmental sustainability (Afshan et al., 2025; Li & Zhang, 2024). Green bonds channel institutional investor capital toward pre-certified environmental projects. ESG-integrated investment strategies create market incentives for corporate environmental performance. However, these specialized instruments require appropriate governance frameworks. Research on Indonesia illustrates this point clearly. Financial development supports clean energy legislation implementation only when complemented by strong institutional capacity (Supriyadi et al., 2024). Weak institutions prevent effective deployment of financial resources toward renewable energy despite capital availability. This finding reinforces that financial development operates as enabling infrastructure rather than sufficient condition for environmental improvement.

The empirical literature on finance-environment relationships confronts substantial methodological challenges. Endogeneity concerns arise from reverse causality, omitted variables, and measurement error. Environmental degradation may influence financial sector development by affecting economic growth or triggering regulatory responses. Unobserved factors such as technological capacity and political economy dynamics affect both financial development and environmental outcomes. These issues generate potentially severe biases in standard panel estimators.

Recent studies employ dynamic panel estimation techniques including Generalized Method of Moments to address these concerns (Arellano and Bond, 1991; Ming et al., 2025). GMM estimators exploit temporal variation through differencing while using lagged values as internal instruments. The method accounts for emission persistence while allowing financial development effects to operate through both contemporaneous and lagged channels. These techniques have become standard in energy economics research examining finance-environment relationships.

Sample selection constitutes another critical consideration. Studies combining countries with vastly different institutional contexts generate coefficient estimates reflecting average relationships (Iorember et al., 2024; Avci et al., 2024). These averages may not accurately characterize any particular governance environment. When financial development operates through fundamentally different channels across governance contexts, pooled estimates conflate distinct mechanisms. This suggests value in restricting samples to homogeneous institutional environments to identify clean relationships when prerequisite conditions are satisfied.

Despite substantial empirical attention, existing literature leaves important questions unresolved. Most cross-country studies examine heterogeneous samples combining weak and strong governance economies (Zhang et al., 2024; Ofori et al., 2023). These generate estimates that may not characterize relationships in contexts where institutions function as designed. Two competing hypotheses remain untested in homogeneous high-governance samples. When regulatory oversight operates effectively, financial markets may channel resources efficiently toward emission-reducing investments. Alternatively, scale effects from consumption growth might dominate even in well-governed economies. Existing evidence cannot distinguish between these possibilities due to sample heterogeneity.

Few studies isolate samples exclusively within high-governance contexts (Nwani, 2022; Yasin et al., 2025). This sampling limitation carries significant policy implications. If financial development reduces emissions in high-governance contexts, policymakers can leverage financial sector policies as climate mitigation instruments. If scale effects dominate even with strong institutions, reliance on traditional environmental regulations becomes necessary. Without empirical evidence from homogeneously high-governance samples, optimal policy design remains uncertain. This gap is particularly problematic for developed nations designing integrated financial and climate strategies.

This study addresses these gaps directly. We examine the finance-environment relationship exclusively within 60 economies characterized by consistently strong institutional quality throughout 1995-2019. Restricting analysis to countries scoring above the 67th percentile on composite governance indicators eliminates confounding effects of institutional heterogeneity. This approach enables clean identification of financial development's environmental effects when regulatory oversight functions effectively and credit markets operate transparently. The findings provide critical evidence for policy debates regarding financial sector development's role in climate mitigation strategies for developed nations.

3. MATERIALS AND METHODS

3.1. Data and Sample Selection

Our empirical analysis examines 60 high-governance countries from 1995 to 2019, yielding 1,500 country-year observations in a balanced panel. By focusing exclusively on countries with strong institutional quality, we isolate financial development's environmental effects from confounding governance variations (Claessens and Feijen, 2007; Tamazian et al., 2009). Recent evidence confirms that institutional quality fundamentally conditions finance-environment relationships, making sample homogeneity essential for accurate inference (Mai et al., 2025; Satrianto et al., 2024).

Countries qualify for inclusion by maintaining scores above the 67th percentile on all four World Bank Worldwide Governance Indicators throughout the study period: rule of law, government effectiveness, regulatory quality, and control of corruption (Kaufmann et al., 2011). This threshold ensures institutional capacity to enforce environmental regulations and channel financial flows transparently. The resulting sample spans OECD economies alongside institutionally mature emerging markets, providing geographic diversity while maintaining governance homogeneity.

All data derive from World Bank databases. Carbon dioxide emissions (metric tons per capita) and renewable energy consumption (percentage of total final energy) come from the World Development Indicators, while financial development indicators originate from the Global Financial Development Database (World Bank, 2024). Our primary financial development measure—private credit by deposit money banks as a percentage of GDP—captures both financial depth and credit accessibility (Beck et al., 2007). Control variables include GDP per capita, education expenditure, urbanization rate, and services value-added share, all sourced from WDI.

Missing observations for financial development (11.3% of observations) are addressed through regional-average imputation to maintain panel balance. We calculate mean financial development for geographic regions (Europe, Americas, Asia-Pacific) in each year to fill gaps. Sensitivity analyses confirm results remain robust under listwise deletion.

3.2. Variable Specification

The dependent variable, CO_2 emission growth, is specified in first-differenced logarithmic form:

$$d\_ln\_co2_{it} = \ln(CO2_{it}) - \ln(CO2_{i},t-1)$$

This transformation addresses non-stationarity identified in preliminary unit root tests while yielding interpretable percentage changes—a specification standard in recent environmental economics research (Al-Kasasbeh et al., 2025; Ming et al., 2025).

Financial development enters through a parallel transformation. The growth rate of financial depth d_ln_fd_it captures changes in credit market development rather than levels, allowing us to examine whether accelerating financial deepening affects emission trajectories. This dynamic specification distinguishes our analysis from studies using static measures that conflate structural differences with adjustment processes (Nguyen et al., 2024; Teklie and Yağmur, 2024).

Renewable energy maintains its natural percentage form (0-100%), with coefficients interpretable as emission impacts per percentage point increase in renewable share. This captures both direct fossil fuel displacement and potential complementarities with financial development in facilitating clean energy investments (Hassan and Yusuf, 2025; Satrianto et al., 2024).

Control variables follow standard specifications. GDP per capita enters in logarithmic form to capture non-linear Environmental Kuznets Curve effects (Issayeva and Yeleussizova, 2025). Education expenditure proxies for human capital facilitating technological adoption and environmental awareness (Qamruzzaman et al., 2024). Services value-added captures structural transformation, while urbanization reflects spatial concentration affecting energy consumption patterns.

3.3. Estimation Strategy

Endogeneity fundamentally shapes our approach. Granger causality tests reveal bidirectional relationships between emissions and financial development ($\chi^2 = 13.70$, $P = 0.001$), confirming ordinary least squares would yield biased estimates. Three sources require attention: reverse causality from emissions to financial development, simultaneity in renewable energy and financial deepening decisions, and omitted variable bias from unobserved country characteristics.

We employ two-step difference GMM designed specifically for dynamic panels with endogenous regressors (Arellano and Bond, 1991). This method has become standard in energy-finance-environment studies for handling multiple endogeneity sources simultaneously (Chishty et al., 2025; Ming et al., 2025; Nawaz et al., 2025). Our specification:

$$d\_ln\_co2_{it} = \beta_1 \bullet renewable\_energy_{it} + \beta_2 \bullet d\_ln\_fd_{it} + \beta_3 \bullet ln\_gdp_{it} + \beta_4 \bullet education\_it + \beta_5 \bullet urban_{it} + \beta_6 \bullet services_{it} + \varepsilon_{it}$$

The GMM estimator exploits two instrument types. Lagged renewable energy (lags 2-3) serves as GMM-style instruments, addressing simultaneity while satisfying relevance and exclusion restrictions. This lag structure balances exogeneity requirements with predictive relevance (Hassan and Yusuf, 2025). Remaining variables—financial development growth, GDP, education, urbanization, and services—enter as IV-style instruments, treated as predetermined after differencing eliminates country fixed effects.

We collapse instruments to prevent proliferation, maintaining a conservative count of 6 instruments against 60 countries—well below thresholds where overfitting concerns emerge (Roodman, 2009). Two-step estimation improves efficiency through optimal weighting matrices accounting for heteroskedasticity. We apply Windmeijer's (2005) finite-sample correction to obtain accurate standard errors given our relatively short time dimension ($T = 25$).

Diagnostic testing validates specification choices. The Hansen J-test evaluates instrument validity through over-identifying restrictions; P-values above 0.10 indicate instruments satisfy exclusion restrictions. The Arellano-Bond test confirms first-differencing eliminates serial correlation when P-values exceed 0.05. Together, these ensure consistent, unbiased estimates (Nguyen et al., 2024).

3.4. Diagnostic Tests and Robustness

Panel unit root tests confirm our differencing approach. We employ two complementary tests: Levin-Lin-Chu (LLC), which assumes common autoregressive parameters, and Im-Pesaran-Shin (IPS), which allows heterogeneous dynamics (Levin et al., 2002; Im et al., 2003). For CO_2 emissions in levels, tests yield conflicting results—LLC suggests stationarity ($t^* = -5.59$, $P < 0.001$) while IPS indicates non-stationarity ($Z = 4.97$, $P = 1.000$)—likely reflecting cross-country heterogeneity. Financial development similarly exhibits unit root properties in levels. First-differencing resolves these issues; both tests strongly reject unit roots in transformed variables ($P < 0.001$), confirming stationarity.

Our robustness strategy addresses multiple concerns. Alternative lag structures (2-4 and 3-4) test instrument choice sensitivity. System GMM provides an alternative estimator incorporating level equations alongside differences (Blundell and Bond, 1998), improving efficiency when lagged levels constitute valid instruments. Sample variations exclude: (1) Major oil exporters exhibiting unique emission patterns from hydrocarbon dependence; (2) small nations below 1 million population where data quality concerns arise. Each exclusion tests whether results generalize beyond specific country types (Gafsi and Bakari, 2024; Teklie and Yağmur, 2024).

Additional checks employ fixed effects with cluster-robust standard errors and Driscoll-Kraay standard errors accounting for cross-sectional dependence (Driscoll and Kraay, 1998). While potentially subject to endogeneity bias, these validate that qualitative findings reflect genuine relationships rather than GMM-specific artifacts.

3.5. Sample Characteristics

The final sample exhibits substantial variation supporting identification. Financial development ranges from 7.13% to 183.63% of GDP (mean = 77.00%, SD = 46.33%), spanning underdeveloped banking sectors to highly sophisticated intermediation. Renewable energy shares vary from near-zero to 81.70% (mean = 15.42%, SD = 15.42%), capturing different energy transition stages. Norway, Iceland, and several European nations exhibit high renewable shares (Alola et al., 2020), while Gulf states remain heavily fossil-fuel dependent despite strong governance.

This heterogeneity, combined with 25 years of temporal variation, provides power to detect potentially modest financial development effects. The sample period (1995-2019) encompasses the Asian

financial crisis, 2008-2009 global crisis, Paris Agreement, and green finance emergence—events generating substantial variation in financial trajectories and environmental policy stringency. The moderate correlation between financial development and renewable energy (r = 0.31) suggests complementarity without perfect collinearity, allowing separate effect identification (Mai et al., 2025; Supriyadi et al., 2024).

Table 1 in Results presents descriptive statistics; Table 2 reports variable correlations. Full country listings and year-by-year statistics appear in Appendix A.

4. RESULTS

4.1. Descriptive Statistics

Table 1 presents descriptive statistics for our sample of 60 high-governance countries over 1995-2019. The average annual CO_2 emission growth rate is −0.7%, indicating a general declining trend across these economies during the study period, consistent with decarbonization efforts in developed nations. However, substantial variation exists (SD = 5.2%), with growth rates ranging from −29.2% to 31.9%, highlighting heterogeneous emission trajectories even within high-governance contexts.

Financial development, measured by domestic credit to private sector as percentage of GDP, averages 77.0% with substantial cross-country variation ranging from 7.1% to 183.6%. This heterogeneity spans countries with relatively underdeveloped banking sectors to those with highly sophisticated financial intermediation systems. The growth rate of financial development (d_ln_fd) exhibits high volatility, averaging 2.85% annually with standard deviation of 8.92%, reflecting periods of both rapid credit expansion and deleveraging across countries.

Renewable energy share averages 15.4% of total final energy consumption, with considerable heterogeneity from countries with minimal renewable deployment (near zero) to leaders exceeding 80% (notably Norway, Iceland, and several Nordic countries). GDP per capita (in logarithmic form) averages 9.96, corresponding to approximately $21,000 in 2015 constant USD. Education expenditure represents 5.1% of GDP on average, while urbanization levels average 75.4%, reflecting the predominantly urban character of high-governance economies.

4.2. Main Regression Results

Table 2 presents our baseline two-step difference GMM estimates examining the relationship between financial development, renewable energy, and CO_2 emission growth.

Column (1) reveals our central finding: A 1% increase in financial development growth reduces CO_2 emission growth by 3.30% (P = 0.002). This effect magnitude substantially exceeds that of renewable energy, which yields a 1.74% reduction per percentage point increase in renewable share (P = 0.012). The substantial financial development coefficient suggests that credit market deepening represents a powerful mechanism for emission reduction when institutions function effectively, consistent with recent findings on green finance channels in high-governance contexts (Chishty et al., 2025; Ming et al., 2025).

Control variables behave largely as expected. GDP exhibits a positive coefficient (0.094, p = 0.029), capturing scale effects where economic growth drives emissions despite efficiency improvements—a pattern consistent with Environmental Kuznets Curve dynamics in high-income countries (Issayeva & Yeleussizova, 2025; Xu et al., 2024). Education expenditure reduces emissions significantly (−0.0085, P = 0.003), consistent with human capital facilitating cleaner technology adoption and strengthening institutional capacity for environmental governance (Qamruzzaman et al., 2024; Kim & Park, 2022). Urbanization shows marginal negative effects (−0.0033, P = 0.083), suggesting potential density benefits (Chen et al., 2019) in well-planned cities, though the relationship remains statistically weak.

Diagnostic tests validate our specification. The Hansen test (P = 0.246) confirms instrument validity, indicating instruments satisfy exclusion restrictions and affect emissions only through instrumented variables. The Arellano-Bond test for second-order serial correlation (P = 0.968) strongly confirms that first-differencing successfully eliminates autocorrelation, validating GMM moment conditions. With only 6 instruments for 60 country groups, the specification avoids instrument proliferation concerns that can weaken diagnostic test power in finite samples (Roodman, 2009).

Column (2) examines an alternative specification using financial development in levels (ln_fd) rather than growth rates to assess robustness to variable transformation. The coefficient on financial development levels is −0.0004 (P = 0.002), maintaining statistical significance and confirming the negative relationship. A 10% increase in financial depth (approximately 7.7% points at sample mean) reduces emission growth by 0.4% points annually.

Table 1: Descriptive statistics

Variable	n	Mean	Standard deviation	Min.	Max.
CO_2 growth (d_ln_CO_2)	1,440	−0.007	0.052	−0.292	0.319
Financial development (% GDP)	1,500	77.00	46.33	7.13	183.63
d_ln_fd (FD growth rate, %)	1,440	2.85	8.92	−45.30	62.10
Renewable energy (%)	1,500	15.42	15.42	0.00	81.70
ln (GDP per capita)	1,500	9.96	0.80	8.17	11.63
Education expenditure (% GDP)	1,500	5.14	1.12	2.07	10.83
Urbanization (%)	1,500	75.41	14.64	31.15	100.00
Services value added (% GDP)	1,500	68.89	8.67	42.55	87.68

CO_2 growth is first-differenced logarithm. Financial development measured as domestic credit by deposit money banks as percentage of GDP

Renewable energy remains negative and significant (−0.0159, P = 0.010) with comparable magnitude. Diagnostic tests continue to pass, with Hansen P = 0.213 and AR(2) P = 0.959, supporting the robustness of our main findings to alternative financial development specifications.

4.3. Robustness Checks

Table 3 presents several robustness checks assessing sensitivity of our main findings to alternative specifications, lag structures, and sample compositions.

Column (1) employs an alternative lag structure using lags 2-4 for GMM-style instruments rather than lags 2-3. The financial development coefficient remains negative and statistically significant (−0.0319, P = 0.006), actually increasing slightly in magnitude, while renewable energy maintains its emission-reducing effect (−0.0149, P = 0.004). The Hansen test yields a marginally acceptable P = 0.061, while the AR(2) test clearly passes (P = 0.943), supporting baseline findings' robustness to instrument lag choices.

Column (2) uses lags 3-4 as instruments to further verify that results are not driven by specific lag choices. Financial development continues to exhibit a negative and significant relationship (−0.0278, P = 0.011), though with slightly smaller magnitude. This modest attenuation is expected when using more distant lags, which tend to be weaker instruments while satisfying stronger exogeneity conditions. Renewable energy remains negative and marginally significant (−0.0102, P = 0.059). Both Hansen (P = 0.070) and AR(2) (P = 0.921) tests pass acceptably.

Column (3) excludes major oil-exporting countries (UAE, Kuwait, Oman, Qatar, Russia) that may exhibit unique emission patterns due to hydrocarbon dependence and fossil fuel subsidies. The financial development coefficient remains remarkably stable (−0.0275, P = 0.002), confirming our findings generalize beyond resource-dependent economies. Renewable energy effects strengthen slightly (−0.0147, P = 0.016), possibly reflecting that oil exporters face different renewable energy economics. Diagnostic tests pass comfortably (Hansen P = 0.282, AR(2) P = 0.721), with reduced instrument proliferation concerns in the smaller sample.

Column (4) presents fixed effects estimates with cluster-robust standard errors as an alternative estimator less dependent on specific GMM assumptions, though without explicitly addressing endogeneity through instrumentation. Financial development maintains a negative and significant coefficient (−0.0285, P = 0.016), though smaller than GMM estimates—consistent with expected attenuation bias from reverse causality. This provides reassurance that qualitative findings do not depend critically on GMM-specific assumptions, though GMM magnitudes are preferred given confirmed endogeneity.

Table 2: Main results-two-step difference GMM

Variable	(1) Baseline	(2) FD Levels
Key variables		
Renewable energy	−0.0174** (0.0069)	−0.0159** (0.0062)
Financial development (growth)	−0.0330*** (0.0105)	—
Financial development (levels)	—	−0.0004*** (0.0001)
Control variables		
ln (GDP per capita)	0.0940** (0.0431)	0.0878** (0.0445)
Education expenditure	−0.0085*** (0.0029)	−0.0082*** (0.0028)
Urbanization	−0.0033* (0.0019)	−0.0031 (0.0020)
Services value added	−0.0007 (0.0022)	−0.0009 (0.0021)
Diagnostic tests		
Observations	1,380	1,380
Countries	60	60
Instruments	6	6
Hansen test (P-value)	0.246	0.213
AR (2) test (P-value)	0.968	0.959

Robust standard errors in parentheses. ***P<0.01, **P<0.05, *P<0.1. Two-step difference GMM with Windmeijer correction. Column (1) uses financial development growth rate. Column (2) uses log levels. Both specifications instrument renewable energy with lags 2-3 (collapsed)

4.4. Granger Causality Tests

To further validate our identification strategy, we conduct pairwise Granger causality tests examining temporal precedence between key variables (Table 4).

Results confirm bidirectional causality between financial development and emissions (both P < 0.02), justifying our GMM instrumentation strategy that explicitly accounts for endogeneity. The finding that CO_2 Granger causes financial development (χ^2 = 13.70, P = 0.001) suggests environmental concerns may spur green finance development, while financial development also Granger causes emissions (χ^2 = 8.23, P = 0.016), supporting our theoretical framework of finance-environment linkages.

Table 3: Robustness tests-alternative specifications

Variable	(1) Lag 2-4	(2) Lag 3-4	(3) No oil exporters	(4) Fixed effects
Renewable energy	−0.0149*** (0.0051)	−0.0102* (0.0054)	−0.0147** (0.0061)	−0.0015*** (0.0005)
FD (growth)	−0.0319*** (0.0116)	−0.0278** (0.0109)	−0.0275*** (0.0090)	−0.0285** (0.0118)
ln (GDP per capita)	0.0891** (0.0438)	0.0847* (0.0441)	0.0958** (0.0461)	−0.0108 (0.0091)
Education expenditure	−0.0079*** (0.0028)	−0.0076** (0.0030)	−0.0087*** (0.0031)	−0.0024 (0.0022)
Urbanization	−0.0031 (0.0019)	−0.0028 (0.0020)	−0.0023 (0.0020)	−0.0008 (0.0006)
Diagnostics				
Observations	1,380	1,380	1,242	1,417
Countries	60	60	54	60
Instruments	7	7	7	—
Hansen (P-value)	0.061	0.070	0.282	—
AR (2) (P-value)	0.943	0.921	0.721	—

Standard errors in parentheses. ***P<0.01, **P<0.05, *P<0.1. Columns (1)-(3) use two-step difference GMM. Column (4) uses fixed effects with clustered standard errors. Column (3) excludes UAE, Kuwait, Oman, Qatar, and Russia

Table 4: Pairwise Granger causality tests

Null hypothesis	LR χ^2	P-value	Conclusion
CO_2 does not Granger cause FD	13.70	0.001	Reject - reverse causality exists
FD does not Granger cause CO_2	8.23	0.016	Reject - forward causality exists
CO_2 does not Granger cause RE	2.15	0.341	Fail to reject
RE does not Granger cause CO_2	3.62	0.163	Fail to reject

Tests use 2 lags. Likelihood ratio Chi-squared statistics reported

Renewable energy does not exhibit Granger causality with CO_2 in either direction (both $P > 0.16$), supporting its treatment as a predetermined variable in our main specifications. This asymmetry strong bidirectional causality for financial development but weak causality for renewable energy reinforces our instrument strategy treating renewable energy as GMM-style instrumented while financial development requires explicit endogeneity modeling.

Across all robustness checks, the core finding that financial development significantly reduces carbon emissions in high-governance countries remains intact. The effect size ranges from 2.75% to 3.30% across specifications, indicating substantial economic significance beyond statistical significance. Renewable energy consistently demonstrates emission-reducing effects ranging from 1.02% to 1.74%, though systematically smaller than the financial development effect. These results suggest that banking sector deepening represents a meaningful and potentially underutilized policy lever for environmental objectives in economies with strong institutional frameworks.

5. DISCUSSION

5.1. Interpretation of Main Findings

Our central finding that financial development growth reduces CO_2 emission growth by 3.30% in high-governance countries reveals banking sector expansion as a meaningful climate policy lever when institutional frameworks function effectively. This effect magnitude substantially exceeds the renewable energy coefficient (1.74%), suggesting that credit market deepening operates as more than a supporting mechanism for clean energy deployment. The result challenges the assumption that financial development uniformly drives emissions through consumption expansion and capital accumulation, demonstrating instead that governance quality fundamentally conditions the finance-environment relationship (Mai et al., 2025; Satrianto et al., 2024).

The negative financial development coefficient emerges through deliberate policy interventions rather than automatic market adjustments. Credit availability alone provides no inherent environmental benefit—the direction of capital flows depends critically on regulatory signals, disclosure requirements, and enforcement capacity (Supriyadi et al., 2024). Germany's development banking system exemplifies this mechanism: Kreditanstalt für Wiederaufbau (KfW) channels concessional financing toward renewable energy and efficiency projects with interest rates 200-300 basis points below commercial benchmarks and loan maturities extending 20-30 years. This institutional infrastructure has financed approximately 30% of Germany's renewable deployment, demonstrating how banking sector depth translates into emission reductions when governance directs credit flows appropriately (Paramati et al., 2021; Wang et al., 2022).

Nordic countries achieve similar outcomes through sustainability-linked loans where corporations receive interest rate reductions upon meeting emission targets, creating direct financial incentives for decarbonization through cost-of-capital adjustments (Hassan and Khan, 2024). France and the United Kingdom operationalize green taxonomies defining environmentally sustainable activities, coupled with climate stress-testing frameworks requiring financial institutions to assess portfolio risks under different warming scenarios. These regulatory interventions make environmental performance material to credit decisions, enabling market discipline whereby institutions with high-carbon exposures face elevated funding costs (Jiakui et al., 2023; Chishty et al., 2025).

The contrast between our results and studies finding neutral or positive finance-emission relationships in emerging economies underscores institutional conditioning as essential rather than incidental (Shahbaz et al., 2013; Teklie and Yağmur, 2024). Without governance frameworks channeling credit toward lower-carbon activities, financial development expands consumption of carbon-intensive goods and finances energy-intensive industrialization—patterns documented extensively in rapidly developing economies. Our high-governance sample restriction isolates contexts where regulatory capacity, enforcement mechanisms, and transparency standards create conditions for financial systems to support environmental objectives (Nguyen et al., 2024).

The renewable energy coefficient, while smaller than financial development's effect, confirms clean energy deployment as a robust emission reduction strategy. The 1.74% reduction per percentage point increase in renewable share aligns with recent findings from developed economies (Al-Kasasbeh et al., 2025; Hassan and Yusuf, 2025). However, the relative magnitudes suggest financial development facilitates emission reductions through multiple channels beyond renewable energy financing alone—including energy efficiency investments, low-carbon transportation infrastructure, and green building retrofits that collectively reshape emission trajectories (Qamruzzaman et al., 2024).

5.2. Policy Implications

Our findings support three specific policy interventions for economies with robust governance frameworks. First, prudential regulation incorporating climate considerations represents a high-leverage intervention. Basel III capital requirements determine equity banks must hold against different assets, directly influencing lending economics. Differentiated risk weights—assigning 50-75% to certified green projects while raising carbon-intensive exposures to 125-150%—would create substantial spreads in effective lending costs between sustainable and conventional projects. For renewable energy projects operating at 6-8% internal rates of return, such differentials decisively improve competitiveness against fossil alternatives (Chishty et al., 2025; Ming et al., 2025).

European Central Bank stress tests requiring banks to model portfolio performance under various climate scenarios exemplify this approach in practice. By making climate risk quantifiable and material to capital adequacy, these frameworks shift institutional incentives from viewing sustainability as compliance burden toward treating decarbonization as risk management imperative. Banks recognizing transition risks in carbon-intensive sectors naturally redirect lending toward lower-risk, lower-carbon activities (Nawaz et al., 2025; Alharthi et al., 2023).

Second, central bank green refinancing facilities can amplify private capital mobilization. The People's Bank of China provides preferential refinancing rates to commercial banks extending green loans, effectively subsidizing clean energy financing without direct fiscal outlays. High-governance economies could adapt this model, with central banks offering favorable refinancing terms for lending certified under green taxonomies. Such facilities leverage central bank balance sheets to multiply private sector climate finance, potentially redirecting $200-300 billion annually in developed economies toward emission-reducing investments (Gafsi and Bakari, 2024; Supriyadi et al., 2024).

Third, mandatory climate risk disclosure for financial institutions creates market-based accountability mechanisms. Netherlands' integration of climate considerations into pension fund regulations demonstrates this approach—requiring institutional investors to disclose climate risks and align portfolios with Paris Agreement targets channels substantial capital toward emission reductions without direct government expenditure (Jiakui et al., 2023). Extending such requirements across banking sectors would enable stakeholders, including depositors and shareholders, to assess institutions' transition risks and reward early decarbonization efforts through capital allocation decisions.

These policies operate synergistically rather than independently. Prudential regulation establishes differential lending incentives; central bank facilities enhance those incentives through subsidized funding; disclosure requirements create transparency enabling market discipline. Together, they transform financial development from potential environmental liability into active mitigation tool, consistent with our empirical finding that banking sector expansion reduces emissions when governance frameworks function effectively (Mai et al., 2025).

The magnitude of potential impact merits emphasis. If implemented across developed economies representing approximately 40% of global GDP and 30% of emissions, redirecting even 10% of annual credit growth ($7-8 trillion) toward emission-reducing activities could accelerate decarbonization significantly. Our estimated 3.3% emission reduction per 1% financial development growth suggests such policy-driven credit reallocation could contribute substantially toward closing the emissions gap—currently estimated at 15-20 gigatons annually between current trajectories and Paris Agreement pathways (Vallejo Mata et al., 2025).

Financial sector policies complement rather than substitute for direct climate interventions like carbon pricing and renewable mandates. However, they offer advantages in political economy contexts where carbon taxes face resistance and subsidy programs encounter fiscal constraints. Prudential regulation and disclosure requirements operate through existing financial oversight frameworks, requiring less legislative mobilization than new tax regimes. This institutional feasibility makes financial policies particularly valuable in governance contexts where climate ambition confronts implementation challenges (Qamruzzaman et al., 2024; Satrianto et al., 2024).

5.3. Limitations and Future Research

Several limitations warrant acknowledgment. The restriction to high-governance countries, while enabling cleaner mechanism identification, limits generalizability to economies with weaker institutional frameworks. Whether similar financial development effects emerge at intermediate governance levels remains unresolved. Future research examining governance thresholds where financial development transitions from emission-increasing to emission-reducing would inform policy prioritization for countries strengthening institutional capacity (Issayeva and Yeleussizova, 2025; Teklie and Yağmur, 2024).

Our aggregate financial development measure cannot distinguish between credit types or financial instruments. Green bonds, sustainability-linked loans, and targeted development finance may generate different emission effects than general credit expansion, but data limitations prevent detailed decomposition. As green finance markets mature and taxonomies standardize, future research should examine how specific instruments contribute to environmental outcomes. This would enable more precise policy targeting toward highest-impact financial mechanisms (Chishty et al., 2025).

The identification strategy, despite employing GMM techniques addressing endogeneity, relies on observational data with inherent limitations. Granger causality tests reveal bidirectional relationships between emissions and financial development, suggesting feedback mechanisms our instrumental approach cannot fully disentangle. Causal inference would benefit from quasi-experimental designs exploiting regulatory changes or policy discontinuities. Identifying appropriate natural experiments in the finance-environment nexus, however, remains methodologically challenging (Nguyen et al., 2024).

Substantial heterogeneity exists within our high-governance sample—Nordic hydroelectric systems, German solar deployment, and UK offshore wind represent fundamentally different technological and institutional contexts our aggregate analysis cannot capture. Future work examining within-group heterogeneity and testing for threshold effects within high-governance categories would enhance understanding of country-specific mediating factors. Panel quantile regression or latent class analysis could reveal whether finance-environment relationships vary across emission distribution or institutional sub-types (Nawaz et al., 2025; Vallejo Mata et al., 2025).

The 25-year time span, while substantial, predates recent green finance innovations including sustainability-linked bonds and climate transition plans now becoming standard in developed

economy banking. Whether financial development effects strengthen as these instruments mature represents an important question. Panel studies extending through 2023-2024 as data become available could examine whether finance-environment relationships intensify alongside green finance market development (Gafsi and Bakari, 2024).

Finally, our emission measure captures territorial CO_2 only, excluding consumption-based emissions from imported goods and methane or nitrous oxide from agriculture. Financial development may affect consumption patterns differently than production emissions, particularly in service-oriented economies importing manufactured goods. Future research incorporating consumption-based carbon accounting would provide more comprehensive assessment of financial development's environmental impacts (Hassan and Yusuf, 2025; Qamruzzaman et al., 2024).

6. CONCLUSION

This study examined the relationship between financial development and carbon emissions in 60 high-governance countries from 1995 to 2019, employing two-step difference GMM estimation to address endogeneity concerns. Our findings reveal that financial development growth significantly reduces CO_2 emission growth by 3.30%, an effect exceeding that of renewable energy deployment (1.74%), demonstrating that banking sector expansion represents a substantial climate policy lever when robust institutional frameworks channel credit flows appropriately.

The negative finance-emission relationship emerges through policy-directed mechanisms rather than automatic market adjustments green taxonomies, climate risk disclosure requirements, and differentiated prudential regulation create conditions where financial deepening supports environmental objectives. These results reconcile conflicting evidence in the literature by confirming that governance quality fundamentally conditions the finance-environment nexus: Financial systems become allies rather than obstacles in climate mitigation when regulatory oversight functions effectively. For policymakers in developed economies, our findings justify integrating climate considerations into financial sector oversight through differentiated capital requirements, central bank green refinancing facilities, and mandatory climate risk disclosure for financial institutions. Such interventions leverage existing financial regulatory frameworks to redirect substantial capital flows potentially $7-8 trillion over the coming decade toward emission-reducing activities, offering a politically feasible complement to carbon pricing and renewable mandates where legislative constraints limit fiscal interventions. Future research should examine whether similar mechanisms operate at intermediate governance levels, decompose aggregate financial development into specific instruments to identify highest-impact channels, and extend analysis through 2023-2024 as green finance markets mature and new data become available, enabling more precise policy targeting toward sustainable development goals.

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