

Article

Total Energy Production and Financial Development: Evidence from Selected EMEs

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Abstract

This study examines the dynamic relationship between financial development and total energy production in emerging market economies (EMEs) using a balanced panel of 20 countries over the period 2000–2020. Unlike much of the existing literature that focuses on energy consumption or specific energy types, this paper conceptualises total energy production as an aggregate supply-capacity indicator that captures infrastructure investment, capital intensity, and long-run energy system expansion. Employing a panel autoregressive distributed lag model with the Pooled Mean Group (ARDL–PMG) estimator, the analysis distinguishes between long-run equilibrium relationships and heterogeneous short-run adjustment dynamics. The results reveal a stable long-run reciprocal relationship between financial development and total energy production, suggesting that deeper financial systems are associated with higher energy production capacity over time, while expansion in energy production is also linked to financial deepening. Short-run dynamics, however, are asymmetric, indicating the presence of adjustment frictions and investment lags in capital-intensive energy sectors. Robustness checks using a two-step System GMM estimator confirm the qualitative consistency of the main findings after accounting for potential endogeneity and simultaneity. Overall, the results highlight the importance of financial system development in supporting aggregate energy supply expansion in EMEs, while underscoring the need to account for transitional constraints and differing adjustment speeds across sectors and countries. The findings offer policy-relevant insights for aligning financial development with energy infrastructure investment during periods of structural transformation.

Keywords: total energy production; financial development; emerging market economies; panel cointegration; energy-led growth; financial markets; energy transition; transition finance



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1. Introduction

Energy commodities such as crude oil, natural gas, coal, and electricity remain central to production systems, trade performance, and fiscal stability in many emerging market economies (EMEs). In these economies, total energy production is not merely an input into economic growth; it also functions as a tradable commodity supply activity that influences trade balances, fiscal revenues, industrial competitiveness, and long-term development trajectories [1]. Unlike energy consumption indicators, which primarily reflect demand conditions and end-use behaviour, total energy production captures the supply side of the energy system, including extraction, generation, infrastructure investment, and production capacity [2].

This distinction has important empirical implications for the finance–energy nexus. Energy consumption mainly reflects household use, industrial demand, and income-driven energy needs, whereas total energy production reflects supply-side capacity, long-lived capital assets, and investment decisions. Financial development is therefore expected to influence production through capital mobilisation, project finance, risk allocation, and investment timing, rather than only through consumer credit or demand expansion. This distinction is particularly important in EMEs, where energy production depends heavily on infrastructure financing, policy stability, and access to long-term capital. Consequently, a production-based measure may reveal stronger long-run relationships and slower short-run adjustment than consumption-based studies because energy supply capacity responds gradually to financial conditions and investment cycles.

Since 2000, the EMEs have seen an increase in energy demand and supply now accounting for over 80% of global energy demand, driven by rapid industrialisation and evolving financial systems [3]. At the same time, geopolitical shocks, decarbonisation commitments, and structural shifts towards renewable energy have resulted in heightened volatility in commodity markets [4,5]. These dynamics have intensified the need for sustained capital investment in energy production infrastructure. Financial development plays a pivotal role in determining the commodity supply outcomes, due to capital intensive nature and long gestation period in energy production infrastructure [6–8]. These developments highlight the importance of energy commodity supply capacity in economies where energy production forms a significant component of export revenues and fiscal stability, and the complementary role of financial markets.

Financial development can affect production through several well established channels. Deeper financial systems may reduce the cost of capital, improve access to long-term project finance, strengthen risk pricing and hedging capacity, and allocate resources more efficiently across capital intensive energy projects. These mechanisms suggest a positive long-run relationship from financial development to total energy production, especially in EMEs where energy investment is often constrained by limited domestic savings, high borrowing costs, and shallow capital markets. At the same time, expansion in the energy sector may stimulate financial deepening by increasing demand for credit, insurance, and investment intermediation [9–15].

Global energy production is also shifting toward low-carbon sources. Renewables are expected to generate more than one-third of global electricity by 2025, while renewables and nuclear energy are forecast to account for approximately 46% of global electricity generation by 2026 [16–19]. These changes highlight the need to align financial development with sustainable energy production in EMEs, where structural and institutional capacities remain uneven. The economics of energy investment have also shifted, with recent evidence showing that renewable power has become the most cost-effective option for new electricity generation in many markets [17]. Table 1 summarises comparative cost indicators for renewable and fossil-based power generation.

The economics of energy investment have also shifted as [17] reported that renewables are the most cost-effective option for new electricity generation in 2024, based on the levelised cost of electricity (LCOE). About 91% of newly built utility-scale renewable energy projects produce power at a lower cost than most of the cheapest new fossil-fuel-based options.

Financial development serves two primary purposes in most emerging market economies (EMEs). First, it encourages investment through capital accumulation, project de-risking, and improved bankability. Second, it boosts energy consumption via the credit channel for consumers [19,20]. Most EMEs still depend on fossil fuels, such as coal, crude oil, and traditional biomass, to meet their energy needs [21]. Therefore, examining the re-

ciprocal relationship between total energy production and financial development is crucial for designing effective policies and investment strategies.

Table 1. Summarises these comparative cost indicators for renewable and fossil-based power generation.

Technology	Total Installed Costs (2010)	Total Installed Costs (2024)	% Change	Capacity Factor (2010)	Capacity Factor (2024)	% Change	LCOE (2010)	LCOE (2024)	% Change
Bioenergy	3082	3242	5%	72	73	1%	0.086	0.087	1%
Geothermal	3083	4015	30%	87	88	1%	0.055	0.060	9%
Hydropower	1494	2267	52%	44	48	9%	0.044	0.057	30%
Solar PV	5283	691	−87%	15	17	13%	0.417	0.043	−90%
CSP	10703	3677	−66%	30	41	37%	0.402	0.092	−77%
Onshore Wind	2324	1041	−55%	27	34	26%	0.113	0.034	−70%
Offshore Wind	5518	2852	−48%	38	42	11%	0.208	0.079	−62%

Notes: CSP = concentrated solar power; PV = photovoltaic; LCOE = levelized cost of electricity; kW = kilowatt; kWh = kilowatt-hour; USD = United States dollar. Capacity factor measures actual electricity output relative to maximum potential output. **Source:** Adapted from International Renewable Energy Agency (IRENA, 2025), *Renewable Power Generation Costs in 2024*.

The preceding discussion emphasises the importance of financial markets in boosting energy production and security. In the energy–finance system, financial institutions serve as intermediaries that gather capital for large-scale energy projects. The increasing focus on transition finance underscores its essential role in developing innovative products for hard-to-reduce sectors, carbon markets, and carbon-pricing mechanisms.

Emerging-market financial systems remain in development and face structural challenges. High interest rates increase the cost of capital and discourage private investment, while elevated risk premiums limit long-term funding. These issues slow down energy-sector investment in EMEs. This situation calls for a thorough examination of the energy production–finance relationship in EMEs, an area that has rarely been studied using multi-country data. Most existing research focuses on single-country time-series analysis or pooled OLS estimation, methods that fail to account for cross-country heterogeneity and long-run equilibrium patterns [22,23].

Despite extensive research on the energy finance nexus, the literature on energy production remains scarce, the empirical evidence remains skewed toward energy consumption, renewable energy use, or electricity demand [24,25]. As a result, relatively little is known about how financial development interacts with aggregate energy supply capacity, particularly across structurally diverse EMEs. This gap is important because a production-based approach is better suited to examining the financing of energy infrastructure, investment cycles, and long-term supply expansion than consumption-based models that emphasise short-run demand behaviour [26]. Moreover, many existing studies rely on single-country time-series models or static panel approaches that do not jointly account for long-run equilibrium, short-run adjustment, and cross-country heterogeneity. This study addresses that gap by examining whether financial development and total energy production are linked through a stable long-run relationship across EMEs while allowing for short-run dynamics to differ across countries.

This study contributes to the literature in three ways [27]. First, it reconceptualises the energy–finance nexus by treating total energy production as an indicator of aggregate energy supply capacity, rather than relying on consumption-based proxies that primarily capture short-run demand conditions. In doing so, the paper aligns the analysis more closely with the financing, infrastructure, and capacity-expansion decisions that shape energy systems in emerging economies. Second, it provides multi-country evidence for 20 EMEs over the period 2000–2020, a setting in which financing frictions, institutional diversity, and structural transformation make the energy–finance relationship particularly relevant. Third, by jointly examining long-run relationships and short-run adjustment within a dynamic panel framework, the study shows that the finance–energy nexus in

EMEs is better understood as a time-dependent process rather than a single contemporaneous association [23,25,28–30].

The rest of this paper is organised as follows: Section 2 reviews relevant theoretical and empirical literature; Section 3 explains the econometric methodology; Section 4 presents the empirical results; Section 5 discusses the results; and Section 6 concludes and offers policy recommendations.

2. Theoretical and Empirical Literature

The relationship between total energy production and financial development is expected to be bidirectional, but mechanisms may differ across time horizons. This section summarises the key theoretical frameworks that support the proposed relationships and provides a conceptual basis for the empirical analysis.

2.1. Financial Development and Total Energy Production

The finance-led view, first proposed by [17] and later expanded by [28,29], posits that financial development promotes economic growth by mobilising savings and facilitating effective resource allocation [30]. In the context of the energy–finance relationship, a well-developed financial system directs capital efficiently into large-scale energy projects, encouraging investment in production and infrastructure [31]. Consequently, the hypothesis posits a positive causal relationship between financial development and energy output.

Given the capital-intensive nature of energy projects, financial development channels capital to the sector and sustains supply expansion. Hence, deeper financial systems can increase the production capacity of energy commodities by providing the long-term financing required for energy-sector development [32].

This framework is closely related to the supply-leading hypothesis, which recognises bi-directional causality between energy and finance [21]. The supply-leading view holds that financial development stimulates energy production by mobilising capital and improving risk allocation. In contrast, the demand-following view posits that growth in the energy sector drives demand for financial services and instruments. Empirical studies by [20,33] support the coexistence of these mechanisms across EMEs. This is one reason why total energy production is a useful analytical variable in this paper: unlike consumption-based measures, it reflects the financing and capacity-expansion decisions that underpin the growth of the energy system.

2.2. Total Energy Production and Financial Development

The reverse mechanism is captured by the energy-led or demand-following view. This theory posits the reverse causal direction, from energy production to financial development. Expanding energy production increases productivity and income, thereby enhancing financial intermediation and market depth [34]. As energy output grows, financial activity expands to accommodate higher investment and consumption demand. The growth in energy commodity production deepens financial markets through increased capital flows and financial intermediation [32].

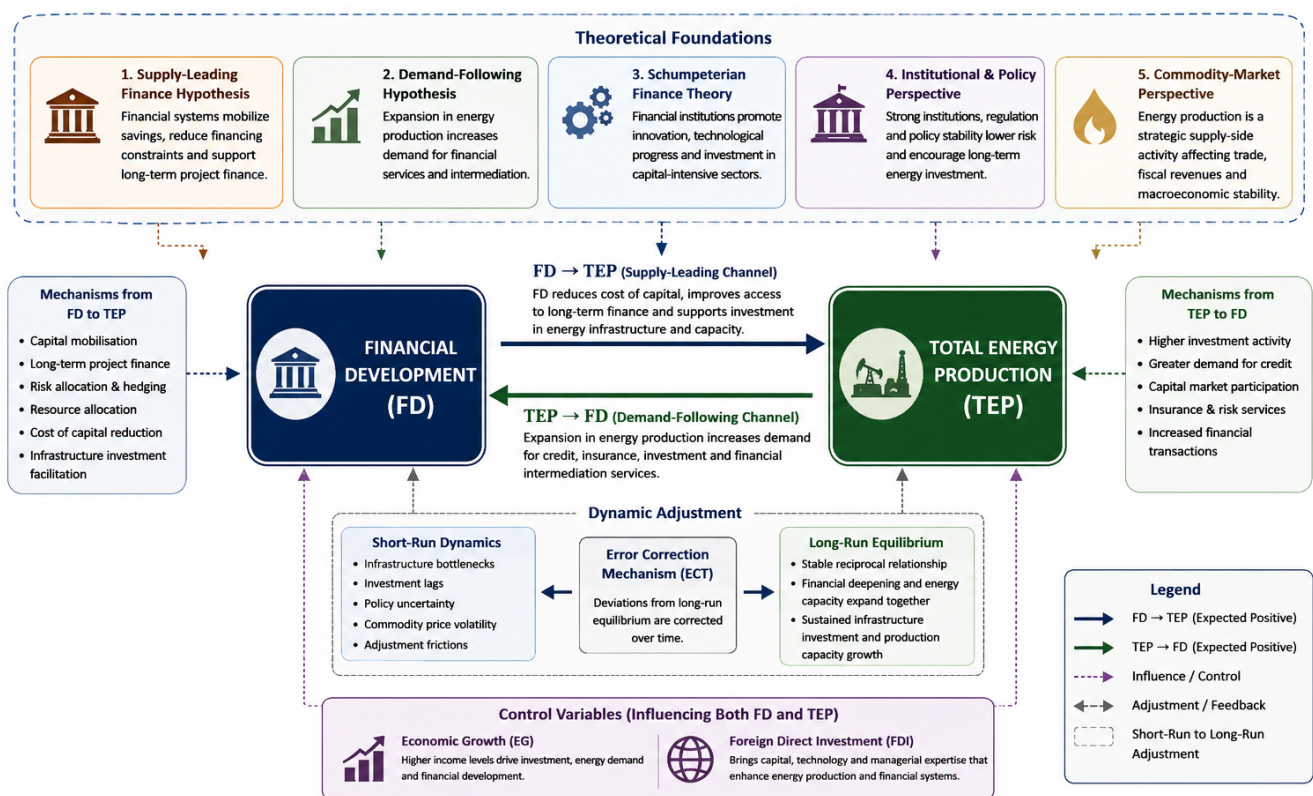
2.3. Long-Run Equilibrium and Short-Run Adjustment

The endogenous growth theory propounded by [35,36], states that economic growth originates internally through technological innovation and human capital development. Investment in the energy sector enhances productivity and innovation, leading to sustained long-term growth. As the energy sector expands into other industries, it reinforces overall economic performance, highlighting the crucial role of financial systems in supporting innovation-driven energy growth. The financial sector supports technological innovation that increases both efficiency and sustainability of energy commodity production. The

broader logic of endogenous growth concerns the behaviour of the finance–energy nexus across different time horizons. Energy production responds slowly to shocks because it depends on long-lived assets, sunk investment, regulatory approvals, infrastructure constraints, and technological adjustment, for example [37]. Financial development may also respond asymmetrically over time, particularly in EMEs where liquidity conditions, policy uncertainty, and macro-financial volatility are significant [38]. These sectoral rigidities imply that the finance–energy nexus is best understood as a dynamic process in which short-run adjustment may differ from long-run equilibrium [34–36,39–44].

2.4. Conceptual Framework

The conceptual framework illustrates the theoretical relationship between financial development and total energy production in emerging market economies. It highlights the main channels through which financial development supports energy-sector investment and production, while also recognising the potential feedback effects of energy production on financial development. Figure 1 summarises these relationships and the key mechanisms examined in the study.



Note: Solid arrows represent the expected long-run relationships. Dashed arrows represent influences, controls, and adjustment processes.

Source: Authors' compilation.

Figure 1. Conceptual Framework: Linking Financial Development and Total Energy Production.

2.5. Empirical Literature Review

There is extensive empirical literature on the energy–finance nexus; it is fragmented and methodologically uneven. There is greater focus on energy consumption than on energy production, despite the latter being more directly linked to infrastructure financing, capacity expansion, and long-term development dynamics. The findings are sensitive to model specification, country coverage, and estimation techniques, resulting in mixed conclusions regarding the direction and strength of the finance–energy relationship.

Empirical studies that have found a positive unidirectional effect of financial development on the energy sector generally highlight that financial systems alleviate capital

constraints and support energy-sector expansion, particularly in emerging economies [34]. This evidence is derived from energy consumption models, which may overstate short-run demand effects while underestimating supply-side constraints [31,45].

From a methodological perspective, earlier studies that rely on static panel estimators or single-country time-series models are subject to endogeneity bias and have limited external validity. While more recent contributions employ Panel ARDL–PMG, FMOLS, or System GMM techniques to address heterogeneity and simultaneity, few studies jointly account for cross-country heterogeneity, long-run equilibrium relationships, and dynamic adjustment processes when modelling energy production. As a result, the empirical evidence remains inconclusive, particularly for emerging market economies where structural differences are pronounced [20,39].

Three gaps therefore remain in the literature. First, there is limited multi-country evidence on the relationship between financial development and total energy production as a supply-capacity variable. Second, broader aggregate measures of energy production remain underexplored relative to renewable-energy or consumption-based proxies. Third, there is insufficient attention to whether financial development and energy production are linked through a stable long-run relationship while permitting heterogeneous short-run dynamics across countries. This study addresses these gaps by focusing explicitly on total energy production in 20 EMEs and by employing a dynamic error-correction framework designed to distinguish long-run equilibrium from short-run adjustment [40,46,47].

This study contributes to the literature by examining the dynamic relationship between financial development and total energy production across 20 EMEs from 2000 to 2020. Unlike previous studies that focus mainly on energy consumption, the present study conceptualises total energy production as a supply-capacity and commodity-market variable linked to infrastructure investment, project finance, and long-run production expansion. The study also contributes methodologically by applying a panel ARDL–PMG framework that distinguishes between long-run equilibrium relationships and heterogeneous short-run adjustment dynamics across countries.

Table 2 summarises selected empirical studies examining the relationship between financial development and energy-sector outcomes across different countries and methodological approaches.

Table 2. Summary of the Total Energy Production—Financial Development Nexus Empirical Findings.

Authors	Countries	Methodology	Results
[34]	22 EMEs	Panel regression	Financial development → energy consumption
[31]	South Africa	ARDL+ Granger	Finance → energy in the long run
[20]	Mena & BRICS	Panel FMOLS	Bidirectional causality
[39]	EMEs	Panel ARDL–PMG	Finance ↔ renewable energy
[48]	Developing Countries	Panel ARDL	Threshold effect: finance boosts renewables
[46]	Developing Countries	System GMM	Conditional effect via institutions
[47]	African (49 Countries)	PMG Estimator	Weak/no direct effect of finance on energy output

Source: Authors, 2026.

2.6. Hypothesis Development

The study is guided by five hypotheses.

H1. *Financial development positively influences long-run total energy production by improving access to capital, reducing financing constraints, and facilitating large-scale investment in energy infrastructure across EMEs.*

H2. *The short-run relationship between financial development and total energy production may be unstable or asymmetric because energy production systems in EMEs are exposed to infrastructure rigidities, commodity price volatility, policy uncertainty, and investment gestation lags.*

H3. *Total energy production positively influences financial development through increased investment activity, capital-market participation, and financial intermediation associated with energy-sector expansion.*

H4. *The strength of the long-run relationship between financial development and total energy production differs across EMEs depending on institutional quality, financial-market depth, and the structural composition of energy systems.*

H5. *Financial development is expected to exert stronger long-run effects in economies with capital-intensive energy production systems, particularly where energy expansion depends heavily on external financing and long-term infrastructure investment.*

These hypotheses provide a clearer link between the theoretical arguments and the empirical strategy adopted in the paper.

3. Data and Methodology

3.1. Data and Variables

This study employs a balanced panel dataset covering 20 emerging market economies (EMEs) over the period 2000–2020. The selected countries are Egypt, Kenya, Nigeria, South Africa, China, India, Indonesia, Iran, Malaysia, the Philippines, Thailand, the United Arab Emirates, Saudi Arabia, Hungary, Russia, Turkey, Argentina, Brazil, Chile, Colombia, and Mexico. The sample was selected based on three criteria: data availability across the study period, IMF classification as emerging market economies, and representation across major regions, including Africa, Asia, the Middle East, Europe and Eastern Europe, Latin America, and North America. This geographic and developmental diversity allows the analysis to capture structural differences across EMEs while maintaining a balanced panel suitable for dynamic estimation.

The empirical framework focuses on the dynamic relationship between total energy production (TEP) and financial development (FD). These two variables are treated as the core endogenous variables of the study because the analysis examines their potential bidirectional linkage. Economic growth (EG) and foreign direct investment (FDI) are included as control variables, given their relevance to energy-sector expansion and macro-financial conditions.

From a commodity-economics perspective, total energy production captures the aggregate supply capacity of the energy sector, including both fossil-fuel and renewable sources. It reflects the ability of an economy to produce energy for domestic use and external markets, and is therefore more closely aligned with infrastructure investment and supply-side dynamics than consumption-based energy measures. Financial development is measured using the Financial Development Index, which captures the depth, access, and efficiency of financial institutions and markets. Economic growth, proxied by real GDP per capita, controls for differences in income levels and productive capacity, while FDI captures external capital inflows that may support investment in energy infrastructure and related sectors.

Although total energy production reflects realised output rather than installed production capacity, it remains an appropriate proxy for energy-sector development in EMEs. In commodity-dependent and infrastructure-constrained economies, realised production is closely linked to financing conditions, investment cycles, extraction capability, genera-

tion infrastructure, and operational efficiency. Unlike installed-capacity measures, which may overstate effective supply because of underutilisation or infrastructure bottlenecks, realised production captures the actual energy commodity supply entering domestic and international markets. Nevertheless, production capacity and realised output are not conceptually identical, and future research may incorporate installed generation capacity or disaggregated renewable-energy infrastructure indicators to refine the analysis.

Table 3 presents the variables employed in the study, their definitions, roles in the empirical model, data sources, and expected relationships.

Table 3. Summary of Variables and Indicators.

Variable	Description	Role in the Model	Source	Expected Relationship
FD	Financial Development Index	Core endogenous variable	IMF Financial Development Database	Bidirectional relationship with TEP
TEP	Total Energy Production (MMBtu)	Core endogenous variable	International Energy Agency (IEA)	Bidirectional relationship with FD
EG	Real GDP per capita	Control variable	World Development Indicators	Positive or negative
FDI	Foreign direct investment	Control variable	World Development Indicators	Positive

Source: Author's Compilation, 2025.

The data were obtained from internationally comparable sources. Total energy production was sourced from the International Energy Agency (IEA); the Financial Development Index was obtained from the IMF Financial Development Database; and real GDP per capita and FDI were drawn from the World Development Indicators (WDIs). The panel was constructed to minimise missing observations. Where isolated internal gaps occurred, linear interpolation was applied only to short gaps within an existing country series and was not used to extrapolate values before the first available observation or after the last available observation. Interpolation was therefore limited to preserving continuity in otherwise available series rather than creating data outside the observed sample range. Because interpolation may bias long-run estimates when missingness is systematic, the results should be interpreted with this limitation in mind. To improve comparability and reduce heteroskedasticity, variables measured in strictly positive continuous levels were transformed into natural logarithms. Specifically, TEP and EG were log-transformed because both variables are strictly positive over the sample period. FD was retained in its original index form because it is already a bounded composite indicator measuring financial depth, access, and efficiency. FDI, measured as net inflows as a percentage of GDP, was retained in level form because the series includes zero and negative values for some countries and years. Accordingly, coefficients on logged variables can be interpreted as elasticities, whereas coefficients involving FD and FDI should be interpreted as semi-elastic or level effects rather than direct percentage changes.

The model includes EG and FDI as macroeconomic control variables because both are associated with energy-sector financing, industrial expansion, and capital formation in EMEs. Although additional factors such as energy prices, institutional quality, technological progress, and regulatory effectiveness may also influence energy production, comparable long-run panel data for all sampled countries were not consistently available over the study period. The study therefore adopts a parsimonious specification commonly used in panel ARDL studies while acknowledging that omitted structural factors may influence the estimated relationships.

3.2. Methodology

To examine the dynamic relationship between financial development and total energy production, the empirical strategy follows four steps. First, panel unit-root tests are applied to determine the integration properties of the variables and to confirm that none of the series is integrated beyond order one. Second, the long-run relationship between financial

development and total energy production is examined within a panel ARDL framework using an error-correction representation. Third, long-run and short-run dynamics are estimated using the Pooled Mean Group (PMG) estimator. Fourth, a two-step System GMM estimator is used as a robustness check to account for potential endogeneity, simultaneity, and dynamic persistence. The panel ARDL–PMG framework is appropriate for this study because it allows the variables to be integrated at either $I(0)$ or $I(1)$, provided that none is integrated at $I(2)$. This is important in macro-panel studies where variables often exhibit different stationarity properties. The approach also distinguishes between long-run equilibrium relationships and short-run adjustment dynamics, making it suitable for examining the finance–energy nexus in heterogeneous EMEs.

Given the cross-country nature of the sample, common global shocks, energy-market fluctuations, and financial spillovers may influence the variables across countries. Although formal second-generation tests for cross-sectional dependence are not applied in this study, this limitation is acknowledged. The results are therefore interpreted as average long-run panel relationships rather than country-isolated effects. Future research may extend the analysis by applying second-generation panel unit-root and cointegration tests that explicitly account for cross-sectional dependence.

3.2.1. Panel ARDL–PMG Estimation

The study employs the panel ARDL–PMG estimator developed by Pesaran, Shin, and Smith [49,50]. The PMG estimator is suitable because it allows for short-run coefficients, intercepts, and error-correction terms to differ across countries while constraining long-run coefficients to be homogeneous across the panel. This distinction is important because EMEs differ in financial depth, energy-resource endowments, institutional quality, and industrial structure. These differences may affect the short-run adjustment path, while the long-run relationship between financial development and energy production may still operate through common channels such as capital mobilisation, project finance, risk allocation, and infrastructure investment.

The Akaike Information Criterion (AIC), Bayesian Information Criterion (BIC), and Schwarz Bayesian Criterion (SBC) were used to guide lag-length selection. The choice between the PMG, Mean Group (MG), and Dynamic Fixed Effects (DFEs) estimators was assessed using the Hausman specification test. The PMG estimator was preferred where the long-run homogeneity restriction was not rejected and where it provided more efficient estimates than less restrictive alternatives [51–54].

Model Specification and Estimation Techniques: The ARDL model was specified as follows:

$$TEP_{it} = \alpha_i + \sum_{j=1}^p \lambda_{ij} TEP_{i,t-j} + \sum_{j=0}^q \beta_{1ij} FDI_{i,t-j} + \sum_{j=0}^q \beta_{2ij} EGI_{i,t-j} + \sum_{j=0}^q \beta_{3ij} FDI_{i,t-j} + \varepsilon_{it}$$

where i denotes country, t denotes year, α_i captures country-specific effects, p and q denote lag lengths, and ε_{it} is the error term. The lag structure is selected using the Akaike Information Criterion (AIC), Bayesian Information Criterion (BIC), and Schwarz Bayesian Criterion (SBC).

Following Pesaran et al. (2001) [48], the ARDL model is reparameterised into an error-correction form to distinguish long-run equilibrium relationships from short-run dynamics:

$$\Delta FDI_{it} = \varphi_i (FDI_{i,t-1} - \alpha_{1i} TEP_{i,t-1} - \alpha_{2i} EGI_{i,t-1} - \alpha_{3i} FDI_{i,t-1}) + \sum_{j=1}^{p-1} \beta_{1ij} \Delta FDI_{i,t-j} + \sum_{j=0}^{q-1} \beta_{2ij} \Delta TEP_{i,t-j} + \sum_{j=0}^{q-1} \beta_{3ij} \Delta EGI_{i,t-j} + \sum_{j=1}^{p-1} \beta_{4ij} \Delta FDI_{i,t-j} + \mu_i + \varepsilon_{it} \quad (1)$$

To examine the reverse relationship, a corresponding equation is estimated with total energy production as the dependent variable:

$$\Delta TEP_{it} = \varnothing_i (TEP_{i,t-1} - \gamma_{1i} FD_{i,t} - \gamma_{2i} EG_{i,t} - \gamma_{3i} FDI_{i,t-1}) + \sum_{j=1}^{p-1} \delta_{ij} \Delta TEP_{i,t-j} + \sum_{j=0}^{q-1} \beta_{1i} \Delta FDI_{i,t-j} + \sum_{j=0}^{q-1} \beta_{2i} \Delta EG_{i,t-j} + \sum_{j=0}^{q-1} \beta_{3i} \Delta FDI_{i,t-j} + \mu_i + \varepsilon_{i,t} \quad (2)$$

where the variables are defined as follows: ΔFDI_{it} = The change in Financial Development for country i at time t ; $\varnothing_i (FD_{i,t-1} - \gamma_{1i} TEP_{i,t} - \gamma_{2i} EG_{i,t})$ = The error correction term, which captures the long-run equilibrium relationship between financial development (FD), Total energy production, and economic growth (EG). The term $\varnothing_i$ represents the speed at which the system returns to equilibrium; $\sum_{j=1}^{p-1} \delta_{ij} \Delta FDI_{i,t-j}$ = The lagged changes in financial development, accounting for short-term dynamics; $\sum_{j=0}^{q-1} \beta_{1i} \Delta TEP_{i,t} + \sum_{j=0}^{q-1} \beta_{2i} \Delta EG_{i,t}$ = The short-run effects of changes in TEP and economic growth, respectively; $\mu_i + \varepsilon_{i,t}$ = The country-specific fixed effect; $\varepsilon_{i,t}$ = The error term or disturbance.

3.2.2. Robustness Check: Two-Step System GMM

Although the ARDL–PMG framework is suitable for estimating long-run and short-run dynamic relationships, concerns may remain regarding simultaneity, reverse feedback, omitted-variable bias, and dynamic persistence. To assess the robustness of the baseline findings, this study estimates a two-step System Generalised Method of Moments (System GMM) model. The robustness model is specified as follows:

$$FD_{it} = \alpha FDI_{i,t-1} + \beta_1 TEP_{it} + \beta_2 EG_{it} + \beta_3 FDI_{it} + \mu_i + \varepsilon_{i,t}$$

Diagnostic tests, including Arellano–Bond AR(1) and AR(2) for autocorrelation and Hansen and Sargan tests for instrument validity, confirm that the model is well specified and instruments are exogenous. The model specification is expressed as follows:

Where FD_{it} = financial development; $FDI_{i,t-1}$ = captures persistence in financial development; TEP_{it} = Total Energy Production; EG_{it} = economic growth; FDI_{it} = Foreign Direct Investment; μ_i = unobserved country-specific effects; $\varepsilon_{i,t}$ = Error term capturing unobserved factors.

The validity of the System GMM estimates is assessed using the Arellano–Bond AR(1) and AR(2) serial-correlation tests, together with the Hansen and Sargan tests of overidentifying restrictions. The absence of second-order serial correlation and the validity of instruments are necessary conditions for interpreting the GMM estimates as reliable robustness evidence.

Results from the GMM estimation are presented in Appendix A, Table A1, alongside the ARDL–PMG estimates. The GMM results are used to assess whether the main long-run associations remain qualitatively consistent after accounting for endogeneity and dynamic persistence. Because the GMM and PMG estimators address different aspects of the data-generating process, differences in coefficient size and significance are interpreted cautiously rather than treated as evidence of exact numerical confirmation.

4. Results

4.1. Panel Unit Root Tests Results

Before estimating the panel ARDL model, panel unit-root tests were conducted to determine the order of integration of the variables. The study employs four commonly used tests: Levin–Lin–Chu (LLC), Im–Pesaran–Shin (IPS), ADF–Fisher, and PP–Fisher. The results, reported in Appendix A, Table A1, indicate that the variables are non-stationary in levels but become stationary after first differencing. Accordingly, all series are treated as integrated of order one, $I(1)$ [55,56]. These findings satisfy the requirements of the panel ARDL framework, which permits variables integrated at $I(0)$ and $I(1)$, provided that none is integrated at $I(2)$. The consistent results across multiple testing approaches strengthen

confidence in the stationarity properties of the variables and justify proceeding with the panel ARDL–PMG estimation. Although first-generation panel unit-root tests may be sensitive to cross-sectional dependence, they remain widely used in macro-panel studies involving emerging economies. Given the balanced structure and moderate size of the dataset, the tests are used as baseline evidence on integration properties. Nevertheless, the results should be interpreted with caution because common global shocks and international commodity-market dynamics may generate cross-country dependence that is not explicitly modelled in the present framework.

The detailed unit-root results are reported in Appendix A, Table A2 [57,58].

4.2. Descriptive Statistics

Appendix A, Table A3 presents the descriptive statistics for the study variables across the selected EMEs. The results reveal substantial heterogeneity in macroeconomic conditions, financial systems, and energy-production structures across countries. Financial development exhibits relatively moderate dispersion, suggesting that although differences in financial depth exist across EMEs, the Financial Development Index remains comparatively stable within the sample. By contrast, total energy production displays considerable variation, with high standard deviation and strong positive skewness. This reflects structural differences in industrial scale, energy-resource endowments, infrastructure capacity, and production capability among the sampled economies. Large energy-producing economies coexist alongside smaller and energy-import-dependent economies, generating substantial cross-country dispersion in the data.

Economic growth and foreign direct investment also exhibit asymmetric distributions and wide ranges, particularly in countries exposed to volatile capital flows, commodity-price fluctuations, and uneven industrial development. These characteristics are common in macroeconomic panel datasets involving commodity-producing emerging economies.

To improve comparability and reduce heteroskedasticity, strictly positive variables were transformed into logarithmic form where appropriate. Nevertheless, the presence of skewness and extreme observations suggests that the estimated coefficients should be interpreted as average panel relationships rather than uniform country-specific effects.

4.3. Correlation Analysis

Appendix A, Table A4 reports the Pearson correlation coefficients among the study variables. The results provide preliminary insights into the direction of association between financial development, total energy production, economic growth, and foreign direct investment.

The correlation between financial development and total energy production is positive and statistically significant, suggesting that economies with more developed financial systems tend to exhibit higher levels of realised energy production. This preliminary association is consistent with the broader argument that financial systems may support energy-sector investment through capital mobilisation, project financing, and improved financial intermediation.

The results also indicate that pairwise correlations among the explanatory variables remain below conventional multicollinearity thresholds. This suggests that multicollinearity is unlikely to distort the baseline panel estimations significantly. However, because correlation analysis does not account for dynamic interactions, omitted variables, or country-specific heterogeneity, the results are interpreted only as descriptive evidence rather than proof of causal relationships.

Variance Inflation Factors (VIFs) were also computed for the baseline specifications, and all values were below commonly accepted thresholds, indicating that multicollinearity does not materially affect the estimation results.

4.4. PMG Estimation Results

Table 4 presents the Pooled Mean Group (PMG) estimation results, analysing the long-run and short-run causal relationships between financial development (FD) and total energy production (TEP), while controlling for economic growth (EG) and foreign direct investment (FDI) across 20 EMEs from 2000 to 2020.

Table 4. Summary of Long-Run and Short-Run Effects between Financial Development and Total Energy Production.

Direction	Long-Run Effect	Short-Run Effect	Causal Interpretation
EG → FD	(0.0196) ***	(0.0678 **)	Economic Growth stimulates financial development in both the short and long run.
TEP → FD	(0.724) ***	(−0.270 ***)	Energy production promotes financial development in the long run, while short-run adjustment shows a temporary adverse effect.
FD → TEP	(1.830) **	(0.112 *)	Financial development enhances total energy production in both horizons.
FD → EG	(0.830) ***	(−1.139)	Financial development drives long-run economic growth, but short-run effects are negligible.
ECT (FD)	(−0.277) ***	-	27.7% speed of adjustment toward the long-run equilibrium for financial development.
ECT (TEP)	(−0.0952) ***	-	9.5% adjustment speed, indicating slower convergence in total energy production.

Robust standard errors i, * $p < 0.05$, ** $p < 0.01$, and *** $p < 0.001$. Notes: Appendix A, Table A1 provides complete short-run coefficients, diagnostic tests, and robustness estimates.

Section 5 below explains the results, including short-run dynamics, robustness tests, and implications for the energy–finance nexus in EMEs.

5. Discussion

The empirical results indicate a reciprocal long-run association between financial development and total energy production in EMEs, with asymmetric short-run adjustment dynamics. The PMG estimates suggest that financial development is positively associated with realised energy production over time, while total energy production is also positively linked to financial deepening. These findings are consistent with earlier evidence that financial development supports energy-sector expansion by improving access to credit, mobilising capital, and reducing financing constraints. Sadorsky's study on emerging economies, for example, shows that financial development influences energy outcomes through credit, stock-market, and banking channels [16]. Similarly, Brunnschweiler provides evidence that financial systems can support renewable-energy development by improving investment conditions in developing and transition economies [19].

The positive long-run association from financial development to total energy production is also consistent with studies emphasising the role of finance in renewable-energy investment and energy-system transformation. Kutan et al. show that financial development is important for financing renewable-energy projects in major emerging market economies [25], while Paramati et al. find that foreign direct investment and stock-market development support clean-energy use across emerging markets [26]. More recent evidence

also supports this interpretation. Qin et al. show that financial development contributes to renewable-electricity expansion in China's carbon-neutrality pathway [13], and Xie et al. demonstrate that financial markets and instruments influence the transition toward low-carbon electricity production [15]. These studies support the argument that financial development can facilitate energy-sector investment, although the present study extends this literature by focusing on aggregate total energy production rather than energy consumption or renewable energy alone.

The reverse long-run association, from total energy production to financial development, is also economically plausible. Expansion in energy production can increase demand for credit, insurance, investment intermediation, and capital-market participation. This is particularly relevant in commodity-producing EMEs, where energy-sector activity often generates large investment requirements and creates opportunities for financial institutions to intermediate capital. This interpretation is consistent with the demand-following view, under which real-sector expansion stimulates financial development. Omri et al. report evidence of interconnected relationships among financial development, energy, trade, and growth in MENA countries [23], while Donou-Adonsou et al. provide recent evidence that financial development remains closely linked to energy-related outcomes in developing economies [24].

The short-run results are more nuanced. The negative short-run coefficient from total energy production to financial development should be interpreted cautiously. One possible explanation is that short-run increases in energy production may coincide with temporary financing pressures, infrastructure bottlenecks, policy uncertainty, or delayed investment returns in capital-intensive sectors. This interpretation is consistent with the broader energy-investment literature, which recognises that energy projects involve long gestation periods and high upfront capital costs. However, these mechanisms are not directly tested in the present model. The result should therefore be understood as evidence of short-run adjustment asymmetry rather than definitive proof of infrastructure rigidity or regulatory constraints.

The relatively slower error-correction adjustment in the total energy production equation is also consistent with the structural characteristics of the energy sector. Energy production depends on long-lived capital assets, extraction infrastructure, generation capacity, transmission networks, and regulatory approvals. These features make energy supply less flexible in the short run than financial variables, which may adjust more rapidly through changes in credit allocation, market liquidity, and investment flows. This supports the interpretation that the finance–energy nexus in EMEs operates differently across time horizons.

The robustness analysis using the two-step System GMM estimator provides additional evidence for the baseline findings, but the results should not be interpreted as exact confirmation of the PMG estimates. The signs of the main relationships are broadly consistent, although coefficient magnitudes and significance levels differ across specifications. This is expected because PMG focuses on long-run equilibrium and short-run adjustment, whereas System GMM emphasises dynamic persistence and controls for potential endogeneity using internal instruments. The robustness results therefore support the qualitative stability of the main associations but do not establish strict causality.

Overall, the findings contribute to the literature by showing that financial development and total energy production are linked through a long-run dynamic relationship in EMEs. The results align with earlier energy–finance studies while extending them through a production-based framework. This distinction is important because total energy production captures realised supply outcomes associated with infrastructure investment, commodity

production, and long-term energy-system expansion, whereas energy consumption mainly reflects demand-side behaviour [16,59,60].

6. Conclusion, Policy Recommendations, and Future Recommendations

6.1. Conclusions

This study examined the dynamic relationship between financial development and total energy production in a panel of 20 emerging market economies over the period 2000–2020. Unlike much of the existing literature, which focuses primarily on energy consumption, the study conceptualised total energy production as a supply-capacity and commodity-market variable linked to infrastructure investment, project finance, and long-run production expansion. Using the panel ARDL–PMG framework, the analysis distinguished between long-run equilibrium relationships and heterogeneous short-run adjustment dynamics across countries.

The empirical results indicate the existence of a stable long-run association between financial development and total energy production. Higher levels of financial development are associated with increased realised energy production, while expansion in energy production is also linked to financial deepening over time. These findings are consistent with the broader view that financial systems can facilitate energy-sector investment through capital mobilisation, project financing, and improved investment intermediation, particularly in capital-intensive energy industries.

The results further show that short-run dynamics differ from long-run relationships. The short-run adjustment process appears asymmetric, with energy production responding more slowly to disequilibrium than financial development. This outcome reflects the structural characteristics of energy production, which depends on long-lived infrastructure, regulatory approvals, and large-scale investment projects. The negative short-run association from energy production to financial development may indicate temporary adjustment pressures, although this interpretation should be treated cautiously because the study does not directly model infrastructure rigidity or regulatory uncertainty.

The robustness analysis using the two-step System GMM estimator provides additional support for the main findings, although coefficient magnitudes and significance levels vary across specifications. These differences suggest that the estimated relationships partly reflect structural heterogeneity, macroeconomic scale effects, and differences in financial and energy systems across EMEs. Accordingly, the findings should be interpreted as evidence of long-run dynamic associations rather than definitive proof of strict causality.

Overall, the study contributes to the literature by shifting attention from energy demand toward aggregate energy supply capacity and by demonstrating that the finance–energy nexus in EMEs is shaped by long-run investment dynamics, infrastructure financing, and commodity-market conditions.

6.2. Policy Recommendations

The findings carry several policy implications for emerging market economies seeking to expand energy production capacity while strengthening financial systems.

First, policymakers should strengthen long-term financing mechanisms for energy infrastructure. Because energy production projects are highly capital intensive and involve long investment horizons, deeper domestic financial markets can improve access to long-term funding and reduce financing constraints. Financial instruments such as infrastructure bonds, green bonds, sustainability-linked loans, and blended-finance mechanisms may help mobilise capital toward energy production projects.

Second, stronger coordination between energy policy and financial-sector policy is necessary. Ministries responsible for energy, finance, and industrial development should

align energy-investment strategies with financial-market development plans. This coordination is particularly important in EMEs where infrastructure financing gaps and shallow capital markets constrain energy-sector expansion.

Third, EMEs should strengthen institutional quality and regulatory predictability in the energy sector. Stable regulatory frameworks, transparent pricing mechanisms, and credible investment policies can reduce uncertainty and improve project bankability. This is especially important for renewable-energy investment, which often depends heavily on long-term financial commitments and risk-sharing arrangements.

Fourth, policymakers should support the development of transition finance mechanisms to facilitate investment in cleaner energy production technologies. Recent global energy trends indicate the increasing importance of renewable energy financing, low-carbon infrastructure, and sustainable investment instruments. Financial systems that effectively channel capital toward energy transition projects may strengthen both long-run production capacity and broader economic resilience.

Finally, because the relationship between financial development and energy production differs across EMEs, policy interventions should remain context specific. Economies with deeper financial markets and stronger institutional frameworks may benefit more rapidly from energy–finance integration, while financially constrained economies may require phased reforms, targeted infrastructure financing, and regional investment cooperation mechanisms.

6.3. Limitations and Future Research

Despite the robustness of the empirical framework, several limitations should be acknowledged.

First, the analysis relies on aggregate national-level data and does not distinguish between renewable and non-renewable energy production. Future studies should disaggregate energy production by source in order to capture sector-specific investment dynamics and transition-finance effects more accurately.

Second, although the study includes key macroeconomic controls, additional variables such as energy prices, institutional quality, technological innovation, governance effectiveness, and regulatory conditions were not explicitly incorporated because of data limitations across the sampled EMEs. These factors may influence both financial development and energy production outcomes and should be explored in future research using expanded datasets and alternative modelling approaches.

Third, the study employs first-generation panel unit-root techniques and does not explicitly model cross-sectional dependence. Future research could strengthen the analysis by applying second-generation panel econometric techniques that account for common global shocks, international financial spillovers, and commodity-market interdependence across countries.

Finally, future studies may investigate non-linearities, threshold effects, and country-specific heterogeneity in the finance–energy relationship using panel threshold models, quantile regressions, or smooth-transition frameworks. Extending the dataset beyond 2020 may also provide additional insight into the post-pandemic energy transition and the growing role of sustainable finance in EMEs.

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Appendix A

Appendix A.1. Cointegrating and Causal Relationship Between Financial Development and Total Energy Production

Table A1. Long-Run and Dynamic Relationships Between Financial Development and Total Energy Production.

	PMG	PMG	PMG	PMG	Two-Step System GMM
Variables	D.FD	D.TEP	D.EG	D.FDI	FD
Long-Run					
EG	0.0196 *** (−4.77)	0.0447 *** (2.78)		−0.206 (−1.92)	0.0105 ** (0.00407)
TEP	0.724 *** (15.95)		0.807 *** (0.80)	0.330 (0.21)	0.0552 ** (0.0204)
FD		1.830 (7.17)	8.030 *** (3.87)	−1.447 (−0.79)	0.532 *** (0.116)
FDI	0.00145 (1.40)	−0.000424 (−0.26)	0.0141 (0.85)		0.000201 *** (0.0000531)
ECT	−0.277 *** (−4.23)	−0.0952 *** (−4.54)	−0.106 ** (−3.05)	−0.596 *** (−8.27)	
Short-Run					
D.EG	0.0678 ** (2.75)	0.0919 (1.94)		−1.133 (−0.66)	
D.TEP	−0.270 *** (−2.32)		0.845 (0.68)	−12.09 (0.64)	
FD		0.112 * (1.98)	−1.139 (−1.15)	13.69 (1.02)	
D. FDI	0.000645 (0.55)	0.0000282 (0.02)	0.0143 (0.63)		
_cons	−0.208 *** (−4.33)	0.0523 ** (−4.75)	0.0800 ** (1.85)	2.662 *** (3.65)	
Dummy1					0.00432 (0.00497)
Dummy2					0.0205 *** (0.00333)
N	399	399	399	399	359
Groups	-	-	-	-	20
Instruments	-	-	-	-	14
Arellano Bond AR 1	-	-	-	-	−2.97
Arellano Bond AR 2	-	-	-	-	−0.51
Sargan Test					41.38
Hansen Test	-	-	-	-	9.69
Hausman	44.75 ***	39.55 ***	64.80 ***	9.42 *	

t statistics in parentheses, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$: Source: Author's compilation using STATA.

Appendix A.2. Unit Root Tests

Table A2. Panel unit root test using LLC. (2) Panel unit root tests using IPS. (3) Panel unit root testing using ADF—Fisher Chi-square. (4) Panel unit root testing using PP—Fisher Chi-square.

Variable	No Trend	Intercept and Trend	Individual Effects	Decision
(1)				
EG	−9.00243 ***	−1.63121 ***	−14.8932 ***	I (1)
TEP	−8.95893 ***	−3.51018 ***	−2.01543 ***	I (1)
FDI	−3.73481 ***	−3.84931 ***	−3.59057 ***	I (1)
FD	−12.5368 ***	−5.76010 ***	−7.01951 ***	I (1)
(2)				
EG	-	−7.32238 ***	−8.86368 ***	I (1)
TEP	-	−1.63121 ***	−2.01543 ***	I (1)
FDI	-	−3.15388 ***	−4.64037 ***	I (1)
FD	-	−6.80194 ***	−8.89608 ***	I (1)
(3)				
EG	162.126 ***	119.625 ***	165.202 ***	I (1)
TEP	153.122 ***	96.8223 ***	123.489 ***	I (1)
FDI	58.5960 ***	69.1745 ***	95.5074 ***	I (1)
FD	205.413 **	121.031 ***	155.718 ***	I (1)
(4)				
EG	288.937 ***	183.140 ***	211.156 ***	I (1)
TEP	206.953 ***	96.8223 ***	191.210 ***	I (1)
FDI	62.4167 ***	99.6138 ***	125.058 ***	I (1)
FD	342.526 ***	282.882 ***	338.690 ***	I (1)

***, and ** indicate that the null hypothesis of unit root tests is rejected at 5% and 10%, respectively. All tests are based on first differences (except where indicated otherwise). The probabilities for all tests assume asymptotic normality, except for Fisher tests, which are computed using the asymptotic Chi-square distribution. TEP is total energy production, FD is the financial development index, and EG is gross domestic product per capita. Source: Author's compilation using Stata version 18 (StataCorp LLC, College Station, TX, USA).

Appendix A.3. Descriptive Statistics

Table A3. Summary Descriptive Statistics for Financial Development, Total Energy Production, Economic Growth, and Foreign Direct Investment in Emerging Market Economies (2000–2020).

	Mean	Median	Minimum	Maximum	Std. Dev	Skewness	Kurtosis	Jarque–Bera	Observ
FD	0.42	0.42	0.09	0.74	0.14	0.08	2.39	6.90	419
TEP	12.05	5.20	0.02	127.00	22.13	13.78	27.32	2768.91	419
EG	8264.37	6141.83	755.48	59,986.44	9618.28	3.51	13.50	4062.22	419
FDI	3.08	219	−40.09	106.60	7.81	7.76	93.34	146,682.60	419

Source: Author's analysis. Descriptive statistics are calculated on all available annual data for the 2000–2020 period. Notes: std. Dev = standard deviation, Observ = number of observations, FD = financial development index, TEP = Total energy production, EG = GDP per capita (Constant 2015 USD), FDI = foreign direct investment (net inflows as a% of GDP).

Appendix A.4. Correlation Analysis

Table A4. Correlation Analysis of Financial Development, Total Energy Production, Economic Growth, and Foreign Direct Investment.

Variables	FD	EC	EG	FDI
FD	1			
TEP	0.2556 ***	1		
EG	−0.2951 ***	−0.0266	1	
FDI	0.0977 **	−0.0564	−0.0788	1

Source: Author, 2025. Notes: *** and ** indicate statistical significance at the 1% and 5% levels, respectively.

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