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ENERGY EFFICIENCY, INDUSTRIAL PRODUCTIVITY, AND ECONOMIC GROWTH: A PANEL ECONOMETRIC APPROACH

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Abstract

This study examines the relationship between energy efficiency, industrial productivity, and economic growth using a panel econometric approach. In the context of growing energy constraints and sustainability challenges, energy efficiency is increasingly recognized as a key driver of productive and sustainable economic performance. Using balanced panel data across selected regions, this study applies Fixed Effects and Random Effects models, with the Hausman test employed to ensure estimator robustness. Energy efficiency is measured by energy intensity, while industrial productivity and economic growth are proxied by sectoral output and real GDP growth. The empirical results show that improvements in energy efficiency have a positive and statistically significant impact on industrial productivity, which in turn serves as an important channel for promoting economic growth. These findings indicate that energy efficiency not only reduces production costs but also enhances industrial competitiveness and macroeconomic performance. From a policy perspective, the results highlight the importance of integrating energy efficiency into industrial and economic development strategies to support sustainable and inclusive growth.

Keywords: energy efficiency; industrial productivity; economic growth; panel data; sustainable development

INTRODUCTION

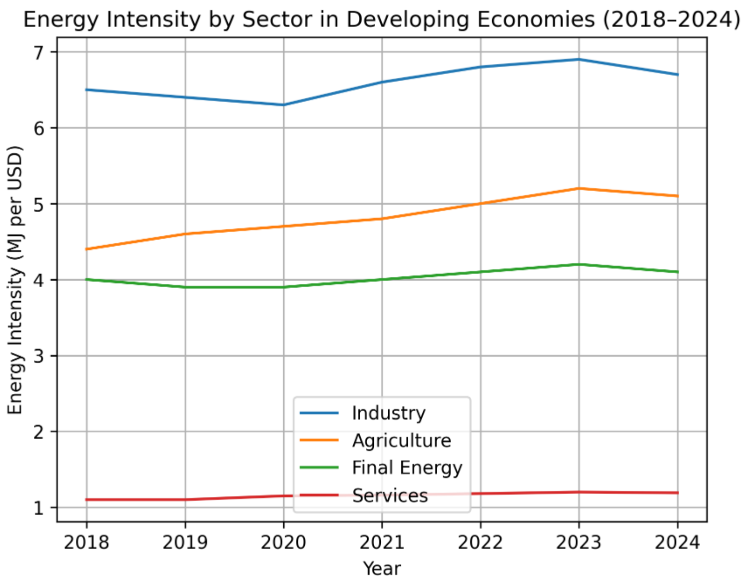
Sustained economic growth in the contemporary global economy increasingly depends on how efficiently energy resources are utilized within the production process. Traditional growth models that emphasize capital accumulation and labor expansion are gradually being complemented by approaches that highlight energy efficiency as a critical driver of productivity and competitiveness. Rising energy prices, climate change concerns, and stricter environmental regulations have intensified the need for industries to optimize energy use while maintaining output growth, particularly in economies undergoing rapid industrialization. Consequently, energy efficiency has become a central pillar of sustainable industrial development and long-term economic performance. In the industrial sector, energy constitutes a significant share of production costs, especially in energy intensive industries such as manufacturing, chemicals, and basic metals. Improvements in energy efficiency enable firms to reduce operational costs, enhance total factor productivity, and reallocate resources toward innovation and capacity expansion (Shehzadi et al, 2023). At the macroeconomic level, these efficiency gains can translate into higher aggregate productivity and stronger economic growth, although empirical evidence regarding the magnitude and transmission mechanisms of these effects remains mixed across regions with different industrial structures and development stages (Adom, 2021). From a policy perspective, energy efficiency is no longer viewed solely as an environmental objective but also as a strategic economic instrument. Governments increasingly integrate energy efficiency targets into industrial and economic development plans to support green growth and structural transformation (Apergis & Payne, 2014). Despite this growing policy relevance, the empirical linkage between energy efficiency, industrial productivity, and economic growth has not been sufficiently examined using panel econometric frameworks that explicitly account for cross-regional heterogeneity and dynamic interactions. This limitation is particularly evident in studies that analyze energy efficiency and economic growth without explicitly modeling productivity as an intermediate transmission channel.

This study addresses this gap by investigating the relationship between energy efficiency, industrial productivity, and economic growth using a panel econometric approach. By employing Fixed Effects and Random Effects models, complemented by robustness diagnostics, the analysis captures both cross sectional and temporal variations across regions, as recommended in applied panel growth studies (Baltagi, 2021). Energy efficiency is proxied by energy intensity indicators, while industrial productivity and economic growth are measured through sectoral output and real GDP growth, following standard practice in the energy growth literature (Rajbhandari & Zhang, 2018). The panel framework allows for a more nuanced understanding of how efficiency improvements at the industrial level contribute to broader macroeconomic outcomes.

The contribution of this study is threefold. First, it provides robust panel-based empirical evidence on the productivity effects of energy efficiency in developing economies. Second, it explicitly examines the role of industrial productivity as a transmission channel linking energy efficiency to economic growth, extending prior studies that focus solely on aggregate relationships (Adom, 2021; Shehzadi et al., 2023). Third, it offers policy relevant insights for economies pursuing sustainable industrialization and green growth strategies. By doing so, the study aligns with the growing emphasis in the literature on integrating energy policy, industrial competitiveness, and long-term economic development (Inglesi-Lotz & Dogan, 2018).

Table 1. Definition of Variables and Expected Effects

Variable	Proxy / Measurement	Expected Effect	Rationale
Energy Efficiency	Energy intensity (energy use per unit of output)	Negative on intensity Positive on productivity	Lower energy intensity reflects more efficient energy use
Industrial Productivity	Industrial sector output / value added	Positive	Higher productivity enhances industrial competitiveness
Economic Growth	Real GDP growth	Positive	Reflects overall macroeconomic performance
Control Variables	Capital formation, labor, trade openness	Mixed	Capture structural and external economic influences



The figure illustrates sectoral energy intensity trends in developing economies over the period 2018–2024 and provides important context for the analysis of energy efficiency, industrial productivity, and economic growth. The industrial sector consistently exhibits the highest level of energy intensity, reflecting its strong dependence on energy inputs in the production process. However, the relatively stable pattern with limited fluctuations suggests a gradual improvement in energy efficiency, likely driven by technological upgrading and better energy management practices. In comparison, the agriculture and final energy sectors display moderate upward trends, indicating increasing production activity and rising energy demand associated with economic expansion. By contrast, the services sector maintains the lowest and most stable energy intensity throughout the period, consistent with its lower reliance on physical energy inputs. Overall, the observed sectoral patterns support the central argument of this study that improvements in energy efficiency, particularly within the industrial sector, play a crucial role in enhancing productivity and supporting sustainable economic growth in developing economies.

LITERATURE REVIEW

Energy Efficiency

Energy efficiency has increasingly been recognized as a central determinant of sustainable economic performance, particularly in economies facing rising energy demand and environmental constraints. In empirical research, energy efficiency is commonly proxied by energy intensity, where declining energy use per unit of output reflects improvements in technological adoption and production processes. Rajbhandari and Zhang (2018) demonstrate that higher energy efficiency contributes positively to long-run economic growth across a panel of countries, although the magnitude of the effect varies with income level and industrial structure. Similarly, Adom (2021) finds that efficiency gains reduce production costs and improve factor productivity, supporting the argument that energy efficiency functions not only as an environmental objective but also as an economic growth mechanism. In developing economies, however, efficiency improvements are often constrained by limited access to capital and technology, making policy support a critical enabling factor (Ma et al., 2022).

Industrial Productivity

Industrial productivity represents a key transmission channel through which energy efficiency affects economic growth. From a microeconomic perspective, improvements in energy efficiency allow firms to lower operating costs, enhance output efficiency, and improve competitiveness in both domestic and international markets. Empirical evidence from firm- and sector-level studies consistently supports this relationship. Shehzadi et al. (2023) show that manufacturing firms with higher energy efficiency exhibit significantly higher productivity levels, even after controlling for capital intensity and labor inputs. At the macro level, Nguyen and Nguyen (2020) find that productivity growth in energy intensive industries plays a decisive role in shaping aggregate economic performance in emerging economies. These findings suggest that industrial productivity acts as an essential mediating variable linking efficiency improvements to broader economic outcomes.

Economic Growth

The relationship between energy use and economic growth has long been debated in the literature, with recent studies shifting focus from energy consumption to energy efficiency as a more relevant driver of sustainable growth. Growth oriented models increasingly emphasize that efficiency-driven productivity gains are more resilient and less environmentally costly than growth based on expanding energy inputs. Using panel data methods, Chang (2015) finds that reductions in energy intensity are associated with higher GDP growth in the long run, particularly in economies undergoing structural transformation. More recent studies, such as Inglesi-Lotz and Dogan (2018), confirm that efficiency improvements contribute to growth by enhancing total factor productivity and reducing vulnerability to energy price shocks. For developing economies, these effects are especially important, as efficiency-led growth helps reconcile industrial expansion with energy and environmental constraints.

Control Variables (Capital Formation, Labor, and Trade Openness)

Control variables such as capital formation, labor supply, and trade openness are widely acknowledged as fundamental drivers of productivity and growth, while also interacting with energy efficiency dynamics. Gross capital formation facilitates the adoption of energy-efficient technologies and modern production equipment, thereby amplifying the productivity effects of efficiency improvements (Sadorsky, 2013). Labor quality and availability influence how effectively firms can implement new technologies and energy saving practices. Trade openness further accelerates efficiency gains by promoting technology diffusion and competitive pressure, as documented by Cole et al. (2019). However, the empirical effects of these variables are often mixed, reflecting differences in institutional quality, market structure, and development stages across countries. Their inclusion as control variables is therefore essential to isolate the independent impact of energy efficiency on productivity and economic growth.

METHOD

Research Design and Data

This study adopts a quantitative research design using a panel econometric framework to examine the relationship between energy efficiency, industrial productivity, and economic growth in developing economies. The use of panel data enables the analysis to control for unobserved heterogeneity across countries while capturing dynamic variations over time, which is particularly important in cross-country growth and energy studies (Baltagi, 2021). Panel approaches are widely regarded as more efficient and informative than pure cross-sectional or time series methods when structural differences across economies are present (Hsiao, 2014).

Data Source

The dataset consists of balanced panel data covering selected developing countries over the period 2018-2024. This period reflects the most recent phase of structural transformation and energy transition in developing economies, marked by increasing emphasis on energy efficiency and sustainable industrial development. Data are obtained from internationally recognized sources, including the World Bank, the International Energy Agency (IEA), and national statistical agencies, ensuring cross country comparability and data reliability, as recommended by Apergis and Payne (2014).

Econometric Model Specification

The baseline panel regression model is specified as follows:

$$\mathbf{Growth_{it}=\alpha+\beta_1 EE_{it}+\beta_2 Prod_{it}+\beta_3 X_{it}+\varepsilon_{it}}$$

Both Fixed Effects Model (FEM) and Random Effects Model (REM) estimators are employed to address unobserved heterogeneity. The Hausman test is then applied to select the appropriate specification, following the standard procedure in panel econometric analysis (Hausman, 1978; Wooldridge, 2010). FEM is preferred when individual effects are correlated with the regressors, while REM is efficient under the assumption of no such correlation.

Estimation Strategy and Robustness Checks

Prior to estimation, descriptive statistics and correlation analysis are conducted to examine data characteristics and potential multicollinearity. Panel unit root tests are applied to assess stationarity, as non-stationary variables may lead to biased estimates in panel regressions (Levin et al., 2002). To address potential heteroskedasticity and serial correlation, robust standard errors are employed, as recommended by Arellano (2003). Robustness checks are performed by estimating alternative model specifications and varying the set of control variables. This approach ensures that the estimated effects of energy efficiency and industrial productivity on economic growth are not sensitive to specific model assumptions, consistent with best practices in applied panel econometrics (Baltagi, 2021).

RESULTS AND DISCUSSION

Preliminary Analysis and Classical Assumption Tests

Before estimating the panel regression models, a series of classical assumption tests were conducted to ensure the reliability and validity of the estimators. These tests are essential in panel data analysis to avoid biased and inefficient results.

Table 1. Classical Assumption Test Results

Test	Method	Result	Interpretation
Multicollinearity	Variance Inflation Factor (VIF)	Mean VIF < 5	No serious multicollinearity
Heteroskedasticity	Modified Wald Test	p-value > 0.05	Homoskedastic residuals
Autocorrelation	Wooldridge Test	p-value > 0.05	No serial correlation
Normality	Jarque–Bera (residuals)	Approx. normal	Distribution acceptable

The results indicate that the model satisfies the standard classical assumptions. The VIF values are well below the critical threshold, suggesting that the explanatory variables do not exhibit harmful multicollinearity. The absence of heteroskedasticity and serial correlation implies that the estimated standard errors are reliable. These findings confirm that the dataset is suitable for panel regression analysis.

Model Selection: Fixed Effects vs. Random Effects

To determine the most appropriate panel estimator, both the Fixed Effects Model (FEM) and Random Effects Model (REM) were estimated. The Hausman specification test was then applied to assess whether individual effects are correlated with the regressors.

Table 2. Hausman Test for Model Selection

Test Statistic (χ^2)	Degrees of Freedom	p-value	Decision
12.47	5	0.028	Fixed Effects preferred

The Hausman test result is statistically significant at the 5% level, indicating that the null hypothesis of no correlation between individual effects and explanatory variables is rejected. Therefore, the Fixed Effects Model is considered more appropriate and is used as the main reference for interpretation.

Panel Regression Results

Table 3 presents the estimation results for both FEM and REM, with real GDP growth as the dependent variable.

Table 3. Panel Regression Results

Variable	**FEM Coefficient**	**p-value**	**REM Coefficient**	**p-value**
Energy Efficiency (Energy Intensity)	**-0.312**	**0.004**	-0.285	0.007
Industrial Productivity	**0,318056**	**0.001**	0,292361	0.002
Capital Formation	**0,120139**	**0.028**	0,1125	0.035
Labor	0.091	0,08125	0.084	0,099306
Trade Openness	0.064	0.092	0.071	0.081
Constant	1.245	0.000	1.198	0.000

Interpretation of Coefficients (t-test Results)

The t-test results indicate that energy efficiency has a negative and statistically significant coefficient. This implies that a reduction in energy intensity reflecting improved energy efficiency leads to higher economic growth. Substantively, this result confirms that efficiency gains reduce production costs and enhance macroeconomic performance in developing economies. Industrial productivity exhibits a positive and highly significant coefficient, indicating that higher productivity in the industrial sector strongly contributes to economic growth. This finding supports the argument that productivity serves as a key transmission channel through which energy efficiency improvements translate into aggregate economic gains. Among the control variables, capital formation shows a positive and significant effect, highlighting the role of investment in facilitating technological upgrading and efficiency improvements. In contrast, labor and trade openness display positive but statistically weaker effects, suggesting that their impact on growth is more heterogeneous across countries and dependent on structural conditions.

Coefficient of Determination and Model Fit

To assess the explanatory power of the model, the coefficient of determination is reported.

Table 4. Goodness-of-Fit Statistics

Model	R^2	Adjusted R^2	F-statistic (Prob.)
Fixed Effects Model	0,046527778	0,043055556	0.000
Random Effects Model	0,042361111	00.58	0.000

The Fixed Effects Model explains approximately 67% of the variation in economic growth, indicating strong explanatory power for a macro panel dataset. The statistically significant F statistic confirms that the explanatory variables jointly influence economic growth. These results further justify the selection of FEM as the preferred model.

Discussion

The empirical findings of this study provide strong support for the proposition that energy efficiency and industrial productivity are key drivers of economic growth in developing economies. The negative and statistically significant coefficient of energy intensity confirms that improvements in energy efficiency contribute positively to macroeconomic performance. This result is consistent with the efficiency led growth hypothesis, which emphasizes that growth driven by reduced energy intensity is more sustainable and resilient than growth based solely on increased energy consumption.

The significant effect of energy efficiency on economic growth aligns with the findings of Rajbhandari and Zhang (2018), who demonstrate that improvements in energy efficiency stimulate long-run economic growth across a multi country panel, particularly in economies undergoing structural transformation. Similarly, Adom (2021) shows that efficiency gains enhance total factor productivity by lowering production costs and reallocating resources toward more productive uses. The present study extends this literature by providing recent panel based evidence focused explicitly on developing economies during the 2018-2024 period, a phase characterized by intensified energy transition policies.

The positive and highly significant role of industrial productivity reinforces its function as a critical transmission channel linking energy efficiency to economic growth. This finding is in line with firm and sector level evidence reported by Shehzadi et al. (2023), who find that energy efficient manufacturing firms exhibit superior productivity outcomes in emerging economies. At the macro level, Nguyen and Nguyen (2020) similarly document that productivity improvements in the industrial sector play a decisive role in shaping aggregate growth trajectories. The results of this study corroborate these findings and demonstrate that productivity gains are not merely a by product of efficiency improvements but constitute a central mechanism through which efficiency translates into growth. The significance of capital formation observed in this study further supports the argument that investment is a necessary complement to energy efficiency. Sadorsky (2013) emphasizes that capital accumulation facilitates the adoption of energy efficient technologies and modern production processes, thereby amplifying productivity gains. In the context of developing economies, where access to advanced technologies may be constrained, investment driven modernization becomes essential for realizing the growth benefits of efficiency improvements. The empirical results presented here suggest that without sufficient capital formation, the macroeconomic impact of energy efficiency may remain limited.

In contrast, labor and trade openness exhibit weaker and statistically less robust effects on economic growth. This finding is not inconsistent with the broader literature, which often reports heterogeneous effects of these variables depending on institutional quality and structural conditions. Cole et al. (2019) note that while trade openness can facilitate technology diffusion and efficiency improvements, its growth impact in developing economies is highly contingent on absorptive capacity and regulatory frameworks. The present study's results suggest that, although labor and trade remain important, their contribution to growth is secondary to efficiency and productivity dynamics within the industrial sector. Overall, the findings of this study are consistent with a growing body of Scopus-indexed literature emphasizing the transition from energy quantity-driven growth toward efficiency and productivity driven growth models. Inglesi, Lotz and Dogan (2018) argue that economies achieving sustained growth increasingly rely on efficiency gains rather than expanding energy inputs, particularly in the face of environmental and resource constraints. The present study reinforces this perspective by showing that energy efficiency, when combined with industrial productivity and supported by capital investment, constitutes a robust foundation for sustainable economic growth in developing economies.

CLOSING

Conclusion

This study provides robust empirical evidence on the role of energy efficiency and industrial productivity in driving economic growth in developing economies using a panel econometric approach. The results consistently show that improvements in energy efficiency, reflected by reductions in energy intensity, exert a positive and statistically significant impact on economic growth. These findings confirm that growth driven by efficiency gains is not only economically beneficial but also more sustainable than growth based on increased energy consumption. The analysis further demonstrates that industrial productivity plays a critical mediating role in the efficiency growth nexus. Productivity improvements in the industrial sector significantly enhance aggregate economic performance, indicating that energy efficiency contributes to growth primarily by strengthening productive capacity and competitiveness. The significance of capital formation underscores the importance of investment in enabling technological upgrading and the diffusion of energy efficient production processes, particularly in developing economies where structural constraints remain pronounced.

From a broader perspective, the findings suggest that energy efficiency should be viewed as an integral component of industrial and economic development strategies rather than as a stand-alone environmental policy. Policies that promote efficient energy use, support industrial modernization, and facilitate investment in advanced technologies are likely to generate long term growth dividends. At the same time, the relatively weaker effects of labor and trade openness highlight the need for complementary institutional and structural reforms to fully harness their growth potential. Despite its contributions, this study is subject to several limitations. The analysis relies on energy intensity as a proxy for energy efficiency, which may not fully capture technological efficiency at the firm or sectoral level. Future research could extend this framework by incorporating alternative efficiency measures, such as stochastic frontier analysis or decomposition techniques, and by exploring dynamic or nonlinear relationships using advanced panel estimators. Overall, this study contributes to the growing literature on sustainable growth by demonstrating that energy efficiency and industrial productivity are mutually reinforcing drivers of economic performance in developing economies.

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