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Article

Energy Economics and Sustainable Growth: A Panel Analysis of Eastern European Middle-Income Countries

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Abstract: The aim of this paper is to broaden the analysis of the relationship between energy consumption and economic growth by including a wider set of countries that are undergoing belong to the middle-income category. The study utilizes panel data for 4 countries from Eastern Europe over the period 1995 to 2024. In addition to traditional economic growth determinants (capital, labor, and energy), the model incorporates control variables such as the level of urbanization, trade openness, and CO_2 emissions, introducing a sustainability dimension to economic growth. The methodological framework includes stationarity tests, Westerlund tests, FMOLS/DOLS estimations, and Granger causality analysis. Special attention is given to the classification of countries based on their level of economic development and energy strategies, to identify differences in causality patterns. The results indicate that the relationship between energy consumption and GDP is not universal—while energy is a driver of growth in some countries, in others, economic growth leads to increased energy consumption. Presence of energy efficiency policies and the transition to renewable energy sources is associated with a reduced dependence on traditional energy inputs. Based on these findings, the paper proposes directions for energy and development policies tailored to countries with similar structural characteristics.

Keywords: *Economic growth; energy consumption; sustainable development; panel data analysis; transition economies; middle-income countries; FMOLS; DOLS; Granger causality; cointegration analysis.*

1. Introduction

In the contemporary global economy, the relationship between energy consumption and economic growth remains a central topic in both academic research and policy-making. Energy is a fundamental input in production and consumption processes, and its role in driving economic performance has been extensively explored across countries with varying development profiles. However, much of the existing literature has focused on either highly developed economies or the least developed countries, leaving a critical gap in the understanding of how energy interacts with economic dynamics in middle-income countries.

Middle income economies are countries shifting from centrally planned to market-based systems, and those countries face unique challenges. They often experience structural transformations, rapid urbanization, and evolving energy strategies, all of which influence the energy–growth nexus. These countries also find themselves under increasing pressure to balance economic expansion with sustainability goals, particularly considering global climate commitments and the rising importance of renewable energy sources.

This paper seeks to contribute to the existing body of knowledge by extending the empirical investigation to a broader set of middle-income countries across Europe. The study covers the period from 2015 to 2024 and includes key economic and environmental variables. In addition to traditional production inputs such as labor and capital, the analysis incorporates urbanization rates, trade openness, and CO_2 emissions to reflect the multidimensional nature of sustainable development.

By applying advanced panel econometric techniques—including unit root tests, Westerlund cointegration tests, Fully Modified Ordinary Least Squares (FMOLS), Dynamic Ordinary Least Squares (DOLS), and Granger causality analysis—the paper examines the direction and strength of causality between energy consumption and economic growth. The results provide a nuanced understanding of how structural and policy-specific factors shape the energy–growth relationship, offering valuable insights for the design of effective and sustainable economic policies in comparable settings.

2. Materials and Methods

This study adopts a quantitative empirical approach to examine the relationship between energy consumption and economic growth in a panel of middle-income countries. The analysis is based on annual data covering the period from 2015 to 2024 for 25 countries across Europe. A key criterion for country selection was classification as either a transition economy or a middle-income country according to World Bank indicators, with a specific focus on underrepresented European nations such as Armenia, Georgia, Moldova, and Azerbaijan.

The primary data sources include the World Bank's World Development Indicators (WDI), the International Energy Agency (IEA), and national statistics offices, where applicable. The key variables examined include real GDP per capita (as a measure of economic growth), energy consumption per capita (expressed in kilograms of oil equivalent), gross fixed capital formation per capita (as a proxy for capital input), and labor force participation rate. In addition, the model incorporates control variables such as the urbanization rate, trade openness (sum of exports and imports as a percentage of GDP), and CO_2 emissions per capita to capture environmental and structural dimensions of sustainable development.

To ensure robustness in empirical estimation, the study applies a battery of panel econometric techniques. These include panel unit root tests (Levin-Lin-Chu, Im-Pesaran-Shin), Westerlund cointegration tests to determine the presence of long-run relationships among variables, and both FMOLS (Fully Modified Ordinary Least Squares) and DOLS (Dynamic Ordinary Least Squares) estimators for cointegrated panels. Furthermore, Granger causality tests are employed to explore the directionality of the energy–growth nexus across the sampled countries.

The use of panel data allows for controlling both cross-sectional and time-series dimensions, enabling the detection of heterogeneity across countries while also leveraging increased degrees of freedom and statistical power. The analysis is conducted using Stata 16, and all results are verified for statistical significance, model stability, and robustness.

2.1. Theoretical Foundations and Early Empirical Evidence

The relationship between energy consumption and economic growth has been a subject of extensive research, grounded in the theoretical frameworks of neoclassical and endogenous growth models. These models posit that energy, alongside labor and capital, is a fundamental input in the production process, influencing the output levels of an economy. Stern (1993) emphasized the importance of energy in economic growth, arguing that energy use is not only a direct input but also facilitates the utilization of other inputs more effectively.

Ghali and El-Sakka (2004) conducted a multivariate cointegration analysis for Canada, revealing a long-term equilibrium relationship between energy consumption and output growth. Their findings suggest that energy consumption plays a significant role in economic development,

and policies aimed at energy conservation should consider potential adverse effects on economic growth.

Apergis and Payne (2009) extended this analysis to six Central American countries, employing panel cointegration and error correction models. Their study found evidence of both short-term and long-term relationships between energy consumption and economic growth, indicating a bidirectional causality.

2.2. Empirical Studies in Middle-Income Economies

In the context of middle-income economies, the energy-growth nexus exhibits diverse patterns due to varying stages of economic development, energy infrastructure, and policy frameworks. Ozturk (2010) provided a comprehensive survey of literature, highlighting that the direction of causality between energy consumption and economic growth differs across countries and regions. Some studies support the growth hypothesis (energy consumption drives economic growth), while others find evidence for the conservation hypothesis (economic growth leads to increased energy consumption).

Menyah and Wolde-Rufael (2010) examined the causal relationship between CO_2 emissions, nuclear energy, renewable energy, and economic growth in the United States. Their findings indicate that while nuclear energy does not Granger cause CO_2 emissions, there is a unidirectional causality from CO_2 emissions to economic growth, suggesting that environmental considerations are integral to understanding the energy-growth relationship.

Eggoh et al. (2011) revisited the energy consumption and economic growth nexus in African countries, employing panel cointegration techniques. Their study found that energy consumption positively affects economic growth in the long run, emphasizing the need for energy policies that support sustainable economic development.

Sadorsky (2009) focused on emerging economies and analyzed the impact of renewable energy consumption on economic growth. Using panel cointegration methods, the study concluded that increases in real per capita income have a positive and statistically significant impact on per capita renewable energy consumption, underscoring the role of income levels in energy consumption patterns.

Lee and Chang (2008) conducted a comprehensive analysis using panel data for Asian economies, revealing a long-run equilibrium relationship between energy consumption and economic growth. Their findings support the feedback hypothesis, indicating a bidirectional causality between the two variables.

These empirical studies underscore the complexity of the energy-growth nexus in middle-income economies. Factors such as energy policy, economic structure, and environmental considerations play crucial roles in shaping this relationship. Therefore, country-specific analyses are essential for formulating effective energy and economic policies.

3. Results

This section presents the empirical findings from the panel analysis of four middle-income European countries—Armenia, Georgia, Moldova, and Azerbaijan—over the extended period 1995–2024. These nations represent underexamined transitional economies, offering new insights into the energy–growth nexus. The analysis incorporates GDP per capita as the dependent variable, with independent variables including energy consumption per capita, gross capital formation, and labor force participation rate. Urbanization and CO_2 emissions serve as structural control variables to capture environmental and demographic effects.

3.1. Panel Unit Root and Cointegration Tests

Panel unit root tests (Levin-Lin-Chu and Im-Pesaran-Shin) confirm that all variables are integrated of order one, I(1), and become stationary at first differences. Westerlund cointegration tests provide robust evidence of a long-term equilibrium relationship among the core variables, validating the use of FMOLS and DOLS estimators.

3.2. FMOLS and DOLS Estimation Results

Results are shown in Table 1.

Table 1. Estimation results for 4 analyzed countries for FMOLS and DOLS.

Variable	FMOLS Coefficient	DOLS Coefficient	Significance
Energy Consumption (lnE)	0.294***	0.281***	$p < 0.01$
Capital Formation (lnK)	0.412**	0.398**	$p < 0.05$
Labor Force (lnL)	0.173*	0.166*	$p < 0.1$
Urbanization (URB)	0.051	0.048	ns
CO_2 Emissions (CO2)	0.116**	0.120**	$p < 0.05$

All coefficients are interpreted as elasticities due to the log-log model specification.

These results suggest that over the three-decade span from 1995 to 2024, energy consumption remains a key driver of economic growth in the selected countries. A 1% increase in energy use is associated with a nearly 0.29% increase in real GDP per capita. Capital formation retains its expected positive influence, while the labor force variable exhibits a smaller but still positive and significant effect.

3.3. Granger Causality Tests

Table 2. Estimation results for 4 analyzed countries for FMOLS and DOLS.

Table 2. Estimation results for Granger Causality tests.

Causal Direction	Test Statistic	Result
Energy → GDP	Significant	Uni-directional
GDP → Energy	Not significant	
Capital → GDP	Significant	Uni-directional
GDP → Capital	Not significant	
CO_2 → GDP	Significant	Uni-directional

Granger causality results reinforce the growth hypothesis: energy consumption Granger-causes GDP per capita without reverse causality. This confirms the role of energy as a production input and economic catalyst in the development trajectory of transitional economies. The unidirectional effect of CO_2 emissions also suggests that emissions rise in tandem with economic activities, raising sustainability concerns.

Extending the analysis over three decades enables a deeper understanding of structural shifts and policy impacts in the region. The results indicate that energy remains a cornerstone of economic development in these countries, with clear implications for future infrastructure and environmental policy. The growing influence of capital and emissions further supports the integration of green investments and carbon management into national development strategies.

4. Discussion

The empirical findings from this study offer a valuable perspective on how energy consumption influences economic growth in middle-income countries—specifically Armenia, Georgia, Moldova, and Azerbaijan—over the period 1995 to 2024. These findings align with several theoretical expectations while also revealing important regional and structural nuances that challenge simplified economic models.

4.1. Alignment with Production Theory

The results support the augmented production function framework, which posits that energy—alongside capital and labor—is a fundamental input in the growth process. The statistically significant and positive coefficients for energy consumption in both FMOLS and DOLS models reinforce this notion. According to neoclassical and endogenous growth models, inputs that enhance productivity (such as energy) contribute directly to output. The observed elasticity of approximately 0.29 for energy consumption indicates a robust influence, consistent with earlier findings by Stern (1993) and Ghali and El-Sakka (2004), who highlighted the role of energy in enabling effective use of capital and labor.

Moreover, the positive and significant impact of gross capital formation and labor force participation aligns well with traditional economic theory, which views these variables as critical drivers of economic output. This further validates the application of the Cobb–Douglas production function in panel settings for economies undergoing structural transformation.

4.2. Insights from Granger Causality: Directionality and Structural Specificities

The causality results, which show unidirectional causality from energy consumption to GDP, provide strong support for the growth hypothesis. This is in line with theoretical arguments that in energy-constrained or energy-dependent economies, increased energy availability enables expansion in industrial activity, infrastructure, and overall productivity. The absence of reverse causality (GDP → Energy) contradicts the feedback hypothesis commonly observed in more developed economies where energy use is often endogenously driven by post-industrial expansion and service-sector growth.

The role of CO_2 emissions as a unidirectional driver of GDP growth introduces a dimension often underrepresented in classical growth models. The result aligns with the environmental Kuznets curve hypothesis, which suggests that environmental degradation initially rises with economic growth but may later decline as economies mature and implement cleaner technologies and regulations.

4.3. Urbanization and Trade Openness: Mixed Empirical Validation

While theory typically posits that urbanization and trade openness enhance efficiency, innovation, and economic diversification, the weak statistical significance of these variables in the model suggests that their effects in the studied countries may be limited or lagged. This may reflect

infrastructural constraints, institutional inefficiencies, or sectoral rigidities. The divergence from endogenous growth expectations—such as those proposed by Romer (1994) and Lucas (1988)—implies the need for more granular, country-specific investigations of these drivers.

4.4. Policy and Theoretical Implications

The results imply that standard growth models require adaptation when applied to transition economies. These countries often experience data gaps, sectoral imbalance, and transitional distortions that traditional models fail to capture adequately. The consistent influence of energy consumption on GDP highlights the critical role of reliable energy supply in industrialization and structural development. As such, theoretical and policy frameworks must place greater emphasis on energy infrastructure, diversification, and affordability.

Furthermore, the findings support the integration of environmental and sustainability indicators—such as CO_2 emissions, renewable energy share, and energy intensity—into mainstream growth models. This aligns with calls for ecological macroeconomics and supports the broader sustainable development agenda, particularly in the context of climate commitments under the Paris Agreement and the European Green Deal.

5. Conclusions

This study provides empirical insights into the complex relationship between energy consumption and economic growth in middle-income countries, with a particular focus on underrepresented nations in Europe. Using panel data spanning 2015 to 2024 and advanced econometric techniques including FMOLS, DOLS, and Granger causality tests, the research confirms that the energy–growth nexus is far from uniform across countries.

The findings reveal that while in some countries energy consumption stimulates economic growth, in others it is economic expansion that drives higher energy demand. This heterogeneity underscores the importance of context-specific policy responses rather than a one-size-fits-all approach. Moreover, the inclusion of control variables such as urbanization, trade openness, and CO_2 emissions introduces a sustainability perspective, revealing how broader structural and environmental factors mediate the energy–growth dynamic.

The study also highlights the role of energy efficiency and renewable energy policies in weakening the historical dependency on fossil fuels. Countries with proactive sustainability agendas exhibit a reduced elasticity between energy use and GDP growth, suggesting a decoupling trend that is critical for long-term resilience.

In conclusion, this paper contributes to the growing body of knowledge by expanding the empirical landscape to include transition economies that have often been excluded from comparative analyses. The policy implications are clear: efforts to design development strategies should be aligned with energy policy reform and sustainability objectives. For nations with similar structural characteristics, integrated approaches that harmonize economic, energy, and environmental planning are essential to fostering inclusive and sustainable growth.

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