DOI: https://doi.org/10.46793/6461-101.149R
Original Scientific Article

ECONOMIC ASSESSMENTS OF ENERGY EFFICIENCY IN THE WESTERN BALKAN COUNTRIES

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Abstract: This paper investigates the economic effects of energy efficiency in the Western Balkans, a region facing both structural energy challenges and the need for convergence with European Union (EU) standards. Using a balanced panel dataset for five Western Balkan economies (2005-2022), the study applies a panel autoregressive distributed lag (ARDL) model estimated with pooled mean group (PMG) and mean group (MG) estimators. The empirical results confirm a stable long-run relationship between energy efficiency and economic growth. Reductions in energy intensity are associated with higher GDP per capita, while renewable energy shares also exert a positive and significant long-run impact. In contrast, short-run results highlight adjustment costs, with renewable integration producing negative effects, whereas gross fixed capital formation plays a central role in driving short-term growth. The error-correction term indicates rapid convergence to the long-run equilibrium in the MG specification. The findings provide important policy implications: energy efficiency should be treated not merely as an environmental obligation but as a strategic driver of sustainable growth and EU integration in the Western Balkans. The study contributes to the literature by offering one of the first systematic empirical assessments

of the efficiency–growth nexus in the region, linking global evidence with the specific transition challenges of small emerging economies.

Keywords: Energy efficiency; Economic growth; Panel ARDL; Renewable energy; Western Balkans; EU integration; Sustainable development.

INTRODUCTION

The green transition has become a global trend, closely intertwined with the digital transformation and the broader agenda of sustainable development. The transition toward a low-carbon economy is not only a matter of environmental responsibility but also of economic modernization, competitiveness, and integration into global value chains. All issues related to sustainable growth – green finance, renewable energy, energy efficiency, biodiversity, and the circular economy – form part of a wider effort to build resilience and reduce long-term risks. In this context, the Western Balkans Six (WB6) face particular challenges: energy systems remain highly dependent on coal, infrastructure is outdated, and financial markets are underdeveloped. Yet, at the same time, opportunities arise from alignment with EU policy frameworks and growing support for regional cooperation.

While green investments are a central part of the global debate, quantitative data on their volume and composition in the WB6 remain scarce and fragmented. For this reason, this study focuses on energy efficiency as a measurable, policy-relevant dimension of the green transition. Improvements in energy efficiency reduce production costs, increase competitiveness, enhance energy security, and can contribute to decoupling growth from carbon emissions. Unlike aggregate green investment flows, energy efficiency can be tracked through indicators such as energy intensity, the share of renewable energy, and emissions per unit of GDP, which allows for rigorous econometric testing. In the context of economies striving for EU convergence, energy efficiency is therefore not only an environmental imperative but also a crucial driver of sustainable economic growth.

The paper applies a panel econometric approach to examine the relationship between energy efficiency and economic performance in the WB6 from 2000 to 2023. Using a panel autoregressive distributed lag (ARDL) model, we investigate both the short-run and long-run effects of energy efficiency improvements on GDP per capita. This contributes to the literature in two ways: first, by offering one of the few systematic empirical assessments of the energy-growth nexus in the Western Balkans, and second, by linking the results to the broader EU Green Deal and accession frameworks. The findings are expected to provide insights for policymakers, investors, and regulators, highlighting the importance of prioritizing energy efficiency as a cost-effective pathway toward sustainable growth and EU integration.

The academic debate suggests that energy efficiency improvements generate positive long-run effects on growth, while short-run dynamics may vary due to adjustment costs and investment needs. Against this backdrop, the present study is guided by the following research questions:

1. What is the long-run relationship between energy efficiency and economic growth in the WB6?
2. Do improvements in energy efficiency (lower energy intensity) contribute to higher GDP per capita in the long run?
3. What are the short-run adjustment dynamics, and how do they differ across WB6 countries?

Based on the literature, the following hypotheses are formulated:

- H1: Improvements in energy efficiency (declining energy intensity) have a positive long-run effect on economic growth in the WB6.
- H2: The short-run impact of energy efficiency on growth is weaker or mixed, reflecting adjustment costs.
- H3: Renewable energy share, investment, and labour force have positive long-run effects on growth, complementing efficiency gains.

Finally, the structure of the article is as follows. After this introduction, we present energy efficiency in WBCs. Section 3 reviews the relevant literature, with a focus on the economic effects of energy efficiency. Section 4 presents the methodology, including data, variables, and the econometric model. Section 5 discusses the empirical results, while Section 6 draws policy implications and provides concluding remarks.

Energy sector in the Western Balkan Region

The concept of the Western Balkan Region (WBR) was conceived and institutionalized within the EU to more accurately designate the countries involved in the Stabilisation and Association Process (SAP). The term dates back to the period when Bulgaria and Romania were allowed to open accession negotiations with the EU (Nigoul 2008). During the European Summit in Vienna in 1998, the concept of the Western Balkans was introduced (Lika, 2023). This geopolitical term was coined by the governing bodies of the EU before 2000 and consisted of the countries of the former Yugoslavia plus Albania (Dabrowski and Myachenkova, 2018). The Western Balkans concept covers the following six states: Albania, Bosnia and Herzegovina, Kosovo*[1], Montenegro, North Macedonia, and Serbia.

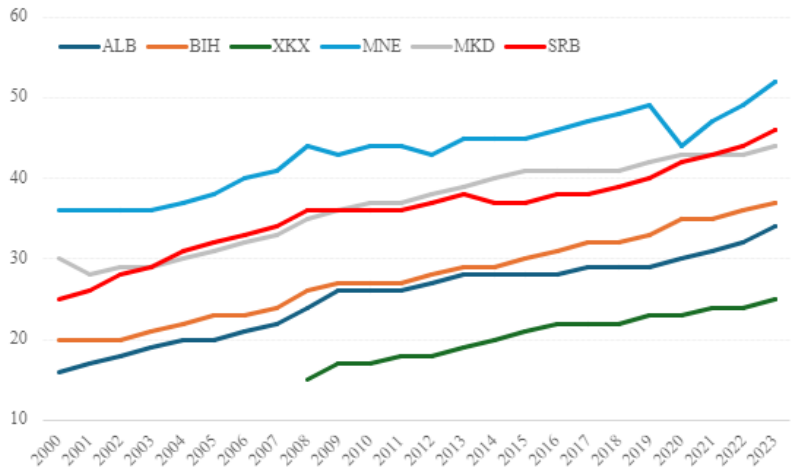
The EU institutions are trying to find the best way to integrate this region within the EU. The current greening economies topics are becoming more pronounced and are manifested through the concept of differentiated integration through two pillars, regulatory and economic. EU bodies have approved the implementation of directives on the green transition and the creation of legal frameworks for the EU, even in non-

[1] This designation is without prejudice to positions on status and is in line with UNSCR 1244/1999

EU countries. On the other hand, through the inflow of investments, an attempt is made to reach the economic flows inherent in the EU single market.

Economically, the economies of the WBR belong to the group of less developed countries. According to the World Bank (WB, n.d.) classification, they are classified as upper-middle-income countries (except Kosovo*). Economic activity, measured by GDP per capita, barely reaches half of the economic activity of the EU member states. Chart 1 shows the values of the GDP per capita volume index in purchasing power standards (PPS) of the WBR compared to the EU27 average.

Figure 1: GDP per capita in current international $, PPP, EU27= 100%, 2000-23



Source: WB, n.d.

Note: ALB – Albania, BIH, Bosnia and Herzegovina, XKX – Kosovo* (UN 1244), MKD – North Macedonia, SRB – Serbia. We justify the comparison with the EU by the EU's major role as an economic and trading partner. The indices shown in the common currency, eliminate differences in price levels between countries and allow for meaningful comparisons between countries (not over time).

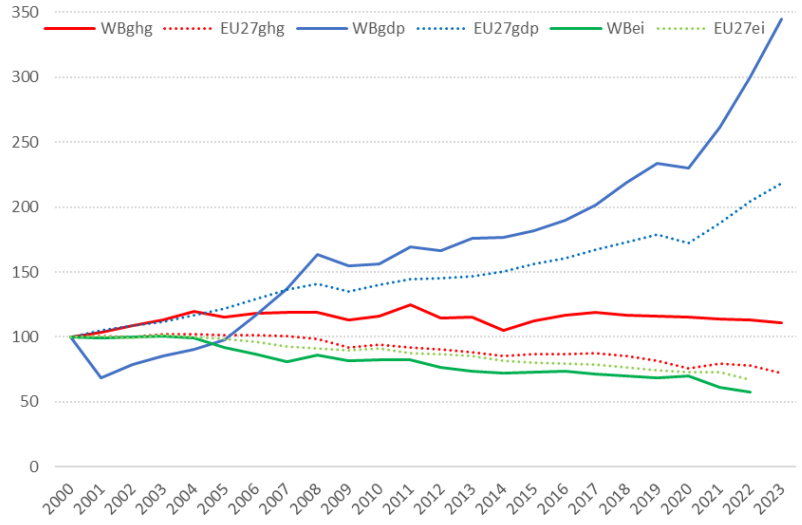
For the last two and a half decades, i.e. from 2000 to 2023, WBCs have seen an increase in GDP per capita but it is not fast enough, and economies do not reach even half of the EU average (except for Montenegro, which was at 52% of the EU average 2023). In absolute numbers, Montenegro saw the biggest progress in convergence (by 25 percentage points) followed by Bosnia and Herzegovina (19 percentage points), Serbia and Albania (18 percentage points), North Macedonia (13 percentage points), and Kosovo* (5 percentage points in the period 2008-2023). Insufficient economic activity makes it even more difficult for the region to join the EU's single market. The main reasons are reliance on resources, labour-intensive and low-intensive production, low productivity, high dependence on imports, the use of outdated technology

(as a result of many years of under-investment), the use of conventional fossil fuel-based energy sources, as well as a trained workforce with insufficiently developed skills and abilities to apply modern technologies, weak institutions, and an unfavourable business environment (Sanfey et al. 2016). The similar structure of economies in the region puts them in a position to compete with each other, so the estimated trade impact on countries is small. According to Mulabdic and Ruta (2018), the impact within the shallow CEFTA varies from 0.02 to 7.4%, as the policies at stake are within the WTO's mandate. The decreasing use of the advantages of the CEFTA agreement in trade has further limited economic capacity, although it is continuous. The regional incentive policy of attracting energy investments in the region is not lucrative, as it is burdened by the indirect costs of inefficient administration and cumbersome administration, imposes additional competition between countries, and strains budgets. Economies affected by regional instability and facing institutional development challenges often struggle to align with European standards, despite strong trade ties. These conditions keep living standards below the EU average, and the convergence rate is so slow that a full catch-up would take 70 years.

The WBR shows a moderate income inequality level (Gini index), which fluctuates annually across countries. According to the World Bank (2017), the sources of inequality are due to the creation of jobs before 2009 and the low level of productivity in most sectors. The problem of unemployment in most countries in the region (Kosovo*, Bosnia and Herzegovina, and North Macedonia) arises due to the existence of an informal labour market, high taxes, regulatory barriers, and barriers to entry of new firms into the market (Dabrowski and Myachenkova, 2018). A high budget deficit, especially in the last years of the observed period, accompanied by high public debt, will be a limiting factor for investing in the green transition. The largest percentage of trade in WBR is with EU countries (Ristanović, 2022). Covering the WBC external trade deficit is solved by selective incentives for exports (monopolies and state guarantees), remittances, and FDI. Problems of general equilibrium and fragile institutions lead to a lack of private capital and/or development aid, so the development component is largely neglected. Traditionally, the role of SDI in economies is huge. The largest inflow of FDI into the region comes from the EU, with over 60% in all countries except Kosovo*. The leader in FDI stocks in terms of GDP is Montenegro, followed by Serbia. Most of these investments end up in the energy, telecommunications, construction, trade, and manufacturing sectors, while banks are owned by foreign investors, mainly from the EU (Estrin and Uvalic, 2016). FDI can also open up additional economic opportunities, and greater investment can help advance economic integration and development of the region (Frey, 2024). Development aid was the largest in the early 2000s to support the international community in opening up markets, transforming economies, and integrating with the EU. During the period of reduced investment activity, support from Brussels was present, albeit with varying intensity over the years.

The WBR energy sector is outside the scope of the Paris Agreement and the EU's carbon targets, primarily due to its excessive reliance on fossil fuels. The picture is complete when the inherited component of the common energy system is added, within which the unique infrastructure (storage reservoirs, power plants, hydroelectric plants) supplied the economy and the population with energy. With the country breakup, the energy system was indiscriminately divided along the borders of the new countries and markets became fragmented (Frey, 2024). The growth of these economies corresponds to the economic theory that less-developed economies grow faster than developed ones, as shown by the cumulative GDP values in Figure 2. The growth of the WBR economy is accompanied by a continuous increase in economic activity, contributing to the of greenhouse gas emissions growth and the in energy intensity decline (Zvezdanovic Lobanova and Lobanov, 2023). In addition to the negative trend for the environment, green investments in this sector have been growing in recent years. At the same time, environmental protection awareness is growing (Vukadinović 2023) and efforts to implement adequate regulations are strengthening (Spasić 2021).

Figure 2: Approximation of the energy efficiency of WB6, cumulative indices, 2000-2023

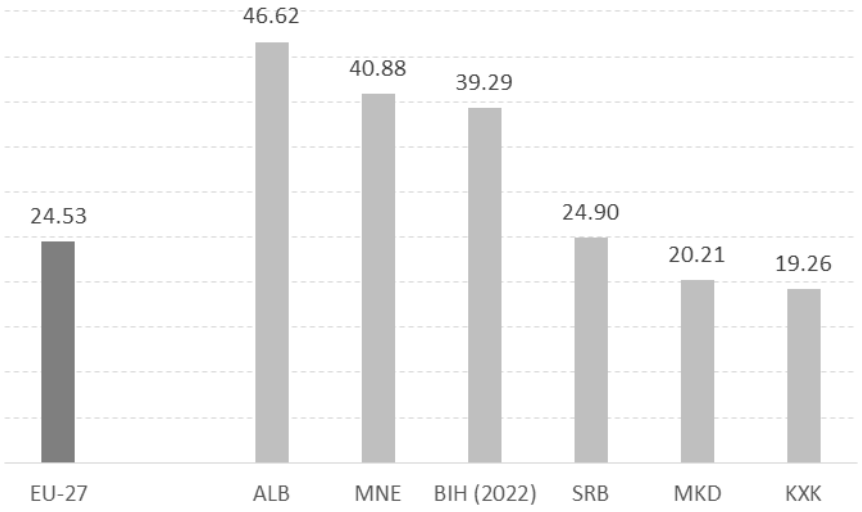


Source: Author calculation based on EC (2024b)

There is a good energy outlook for the WBR. Compared to the past decade, all WB6 have achieved improvements in terms of energy efficiency. Renewable energy sources are taking an increasing share of the total energy supply (RES), thanks to water energy (and biomass in Serbia), and more recently wind and solar energy in all countries in the region (Frey, 2024). The share of renewables is higher than the EU

average in all WBCs, with North Macedonia and Kosovo* lagging slightly behind (see Graph 3). Currently, these resources are insufficient, but the sector has the potential for further improvement and greater investment. With adequate regulation and efficient and transparent implementation, WBR can achieve the set sustainable goals.

Figure 3: Share of energy from renewable sources, 2023. percentage



Source: Author's calculations based on EEA (n.d.)

Market circumstances and limited budget resources make unachievable the desired level of sustainable development. The results are positive, but they are not enough. As a rule, investments in this sector come from public sources, credit, and the private sector. Limited public funds are the biggest problem, as they limit the speed of the green transition. In the financial market, credit is expensive for low-income countries, underdeveloped institutions, and unenforceable but well-structured regulations. Credit is used when the other two sources of funding are exhausted. In the case of private capital, foreign capital inflows dominate over domestic capital. The boost for domestic investment comes with the construction of green taxonomy and directives, such as those in the EU and Canada (IEA, 2024). Previous experience in the region with FDI and its role in economic growth can represent a favourable business venture in green investment implementation. Of course, concerning the specifics of this type of investment.

LITERATURE REVIEW

The relationship between energy efficiency and economic growth has been extensively debated in the literature. Early studies on the energy-growth nexus pointed to the role of energy as a production input, similar to labor and capital, with improvements in efficiency lowering costs and fostering productivity gains (Stern 2011; Ozturk 2010). These studies laid the foundation for assessing the economic effects of energy intensity reductions and highlighted the importance of country-specific dynamics in developing and transition economies.

More recent empirical research has confirmed that improvements in energy efficiency can generate positive long-term growth effects. For example, Bildirici (2014) employed a panel ARDL approach in transition economies and found that biomass energy use and efficiency improvements have significant long-run impacts on GDP per capita. Belloumi and Aljazea (2024) extended this approach using a nonlinear ARDL model, showing that energy use and efficiency improvements are cointegrated with growth across a large panel of emerging economies. These findings are consistent with the notion that energy efficiency acts as a form of the "technological progress", reducing production costs and improving competitiveness.

Evidence from developed economies also supports this conclusion. Azhgaliyeva et al. (2020) in her the energy policy study highlighted the role of regulatory instruments, subsidies, and efficiency standards in reducing energy intensity, demonstrating a strong link between policy frameworks and macroeconomic performance. Similarly, Zhou et al. (2021) identified threshold effects, where efficiency gains become particularly growth-enhancing once a certain income level is reached, suggesting that convergence processes in less developed economies can be accelerated by targeted energy efficiency measures.

For emerging markets, including the Western Balkans, the relevance of energy efficiency is twofold: as a policy lever for meeting EU accession requirements, and as a mechanism to boost productivity and sustainable growth. Deka et al. (2023) confirmed that energy efficiency and renewable energy, using ARDL estimators. Likewise, Demiral and Demiral (2021) showed that productive capacities, including energy efficiency, are strongly associated with long-term economic resilience and reduced dependence on resource-intensive growth.

Taken together, the literature suggests that the economic effects of energy efficiency are positive in the long run, though short-run impacts can be modest or even negative due to adjustment costs. This justifies the application of a dynamic panel framework, such as ARDL, to disentangle the short- and long-run effects for the WB6. By situating the Western Balkan experience within this broader empirical context, the study contributes to filling an important gap in the literature: the systematic assessment of energy efficiency as a growth driver in small transition economies.

In the regional context, several studies emphasize the importance of energy efficiency for the Western Balkans. Frey (2024) highlights how low levels of efficiency, outdated energy distribution, and coal dependence hinder growth, but also sees significant potential for gains through efficiency-oriented reforms. Zvezdanović Lobanova and Lobanov (2023) stress that aligning with the EU's Green Deal requires

accelerated improvements in efficiency, particularly in Serbia and other SEE countries with carbon-intensive structures. Similarly, Sanfey, Milatovic, and Krešić (2016) argue that catching up with EU economies depends not only on investment and institutional reform but also on reducing energy intensity and improving competitiveness. These findings support the hypothesis that energy efficiency can serve as a key channel for stimulating sustainable growth in the WB6.

METHODOLOGY

Data and Variables

The analysis is conducted on a balanced panel dataset covering five Western Balkan economies – Albania, Bosnia and Herzegovina, Montenegro, North Macedonia, and Serbia – over the period 2005-2022. Kosovo* is excluded due to the unavailability of consistent time series. The data were compiled from international databases World Development Indicators (World Bank).

The dependent variable is GDP per capita in constant 2015 US dollars, denoted as Y_{it}, which serves as a proxy for economic performance. The core explanatory variable is energy intensity, defined as the level of primary energy supply per unit of GDP in MJ per 2017 PPP dollar, denoted as EI_{it}. A decline in energy intensity corresponds to an improvement in efficiency. Additional explanatory variables were included to capture complementary drivers of growth: the share of renewable energy in final consumption (RES_{it}), labour force (L_{it}), the consumer price index (CPI_{it}) as a proxy for macroeconomic stability, and gross fixed capital formation as a percentage of GDP (K_{it}) representing investment. All variables, except shares and indices, are expressed in natural logarithms to enable elasticity interpretation.

Table 1. Variables, definitions, sources, and expected signs

Variable	Symbol	Definition	Expected Sign
GDP per capita	Y_{it}	GDP per capita (constant 2015 US$)	/
Energy intensity	EI_{it}	MJ of primary energy per $2017 PPP GDP	-
Renewable energy share	RES_{it}	% of renewables in total final energy consumption	+
Gross fixed capital formation	K_{it}	Gross fixed capital formation (% of GDP)	+
Labour force	L_{it}	Total employed persons	+
Consumer price index	CPI_{it}	CPI, 2010=100	+/-

Source: World Bank (n.d).

Note: Last column shows author's expectation according to the theory

Summary Statistics

Table 3 reports the summary statistics for the variables used in the empirical analysis. The dataset is balanced, with 90 observations covering five Western Balkan countries over the period 2005–2022. The average log of GDP per capita (ln_gdppc) is 8.53, with values ranging between 7.91 and 8.97, reflecting substantial cross-country variation in income levels. Energy intensity (ln_ei) exhibits a mean of 1.47, but also notable variation (min = 0.72; max = 2.00), which indicates differences in efficiency progress across countries and over time. The renewable energy share (ln_res) has a mean of 3.29, suggesting that renewables represent an important but still evolving component of energy systems in the WB6.

Table 2. Descriptive statistics

stats	**(ln_ gdppc)**	**(ln_ei)**	**(ln_res)**	**(ln_k)**	**(ln_lab)**	**(ln_cpi)**
N	90	90	90	90	90	90
mean	8.526824	1.468887	3.293527	3.155628	13.87896	4.673075
max	8.969212	2.002831	3.897924	3.669081	15.03524	5.138631
min	7.905762	.722706	2.639057	2.764519	12.36994	4.177703
SD	.2420442	.3280914	.3889713	1.929746	.8482545	.1603825
p50	8.577574	1.523821	3.200361	3.13429	14.08271	4.669061
skewness	-.3621802	-.3033063	-.0101112	.5853765	-.5347066	-0.008414
kurtosis	2.464717	1.980557	1.493249	3.405716	2.328939	3.84596

Gross fixed capital formation (ln_k) records an average of 3.16, with significant dispersion (SD = 1.93), consistent with the volatility of investment flows in small transition economies. The labour force (ln_lab) averages 13.88, with a relatively wide range between 12.37 and 15.04, capturing demographic and employment dynamics across the region. The consumer price index (ln_cpi) has a mean of 4.67 and relatively low variance, indicating broadly similar inflationary conditions among the five countries. Skewness and kurtosis statistics suggest that the distributions of the variables do not deviate strongly from normality, supporting the validity of the panel econometric approach.

Table 3. Correlation Matrix

Variables	(ln_gdppc)	(ln_ei)	(ln_res)	(ln_k)	(ln_lab)	(ln_cpi)
ln_gdppc	1.000					
ln_ei	0.104	1.000				
ln_res	0.159	-0.585***	1.000			
ln_k	-0.450***	-0.487***	0.328***	1.000		
ln_lab	-0.245**	0.367***	-0.585***	-0.225**	1.000	
ln_cpi	0.547***	-0.280***	0.154	-0.228**	0.116	1.000

**** p<0.01, ** p<0.05, * p<0.1*

Table 4 presents the pairwise correlations among the variables. GDP per capita is positively correlated with energy efficiency proxies: it is positively associated with the renewable energy share (0.159) and the consumer price index (0.547***), while the correlation with energy intensity is positive but modest (0.104). As expected, the relationship between energy intensity and renewable energy is strongly negative (-0.585***), reflecting the substitution effect between fossil-based intensity and cleaner energy sources.

Gross fixed capital formation is negatively correlated with both GDP per capita (-0.450***) and energy intensity (-0.487***), which may suggest that investment is more volatile and countercyclical in the WB6 context, although this result requires careful interpretation within the dynamic ARDL framework. Labour force is negatively correlated with GDP per capita (-0.245**), consistent with the stylized fact that higher-income WB6 countries face demographic decline, while lower-income countries retain larger labour supplies.

Overall, the correlation coefficients are moderate in magnitude, suggesting that multicollinearity is not a major concern. This justifies the inclusion of all explanatory variables in the panel ARDL model. The combination of descriptive statistics and correlation analysis provides an initial overview of the dataset and underlines the heterogeneity across the Western Balkan countries, which the econometric model is designed to capture.

The descriptive statistics and correlation analysis provide an initial overview of the dataset and highlight important structural features of the WB6 economies. The substantial variation in income levels, energy intensity, and renewable energy shares underscores the heterogeneity of the region, while the correlations suggest plausible relationships that are consistent with theoretical expectations. However, descriptive evidence alone cannot disentangle short-run fluctuations from long-run equilibrium effects. To address this, the study applies a panel autoregressive distributed lag

(ARDL) approach, which allows for heterogeneous short-run dynamics while constraining long-run coefficients to be homogeneous across countries. This methodology is particularly suitable for the WB6, where economies share common EU integration targets but differ in structural adjustment paths. The following section therefore turns to the econometric model, outlining the estimation procedure and presenting the empirical results.

Econometric Model

The empirical model applies the panel autoregressive distributed lag (ARDL) framework developed by Pesaran, Shin, and Smith (1999), estimated with the Pooled Mean Group (PMG) estimator. This methodology is particularly appropriate as the dataset combines I(0) and I(1) variables and captures both the short-run adjustment dynamics and the long-run equilibrium. The baseline model in error-correction form is expressed as:

$$\Delta lnY_{it} = \phi_i\left(lnY_{i,t-1} - \beta_1 lnY_{i,t-1} - \beta_2 lnRES_{i,t-1} - \beta_4 lnK_{i,t-1} - \beta_5 lnL_{i,t-1} - \beta_1 lnCPI_{i,t-1}\right) + \sum_{j=1}^{p-1} \gamma_{ij}\, \Delta lnY_{i,t-j} + \sum_{j=0}^{q-1} \delta_{ij}\, \Delta lnX_{i,t-j} + \mu_i + \upsilon_i + \varepsilon_{it} \quad (1)$$

where ϕ_i is the speed of adjustment to equilibrium, β_j are long-run elasticities, and γ_{ij}, δ_{ij} capture short-run heterogeneous dynamics. Country-specific fixed effects μ_i and time effects ν_t account for unobserved heterogeneity and global shocks.

The estimation follows several steps in STATA (13 ed.):

1. Panel unit root tests (Levin-Lin-Chu, Im-Pesaran-Shin, Fisher-ADF) are conducted to determine stationarity properties of each variable, ensuring none are I(2).
2. Panel cointegration is tested using the Westerlund ECM test, confirming long-run relationships between growth and explanatory variables.
3. Optimal lag lengths for the ARDL model are determined using Akaike and Schwarz information criteria.
4. The model is estimated using xtpmg with the PMG estimator. Alternative estimators (Mean Group and Dynamic Fixed Effects) are applied for robustness, with the Hausman test employed to assess efficiency versus consistency.
5. Diagnostic tests include the Pesaran CD test for cross-sectional dependence, Breusch-Pagan tests for heteroskedasticity, and LM tests for serial correlation.

RESULTS

The results of the panel ARDL estimations for the five Western Balkan countries (2005–2022) are presented in Table 5. Both the Pooled Mean Group (PMG) and the Mean Group (MG) estimators were applied to test the robustness of the findings. The Hausman test suggests that the PMG estimator is more efficient when the long-run coefficients are assumed to be homogeneous across countries, while short-run dynamics remain heterogeneous.

Table 4. Panel ARDL results for WB6 (2005–2022)

VARIABLE	LONG-RUN (PMG)	LONG-RUN (MG)	SHORT-RUN (PMG)	SHORT-RUN (MG)
LN_EI (ENERGY INTENSITY)	-0.235* (0.142)	0.054 (0.210)	-0.070 (0.060)	-0.082 (0.075)
LN_RES (RENEWABLE ENERGY SHARE)	0.105*** (0.028)	0.088** (0.041)	-0.093*** (0.021)	-0.099*** (0.024)
LN_K (GROSS FIXED CAPITAL FORMATION)	0.070 (0.049)	0.056 (0.065)	0.098*** (0.032)	0.067*** (0.024)
LN_LAB (LABOUR FORCE)	-0.012 (0.033)	-0.018 (0.045)	0.022 (0.019)	0.010 (0.022)
LN_CPI (CONSUMER PRICE INDEX)	0.669*** (0.172)	0.712*** (0.201)	-1.788 (1.210)	-1.532 (1.460)
ERROR CORRECTION TERM (ECT)	-0.095 (0.082)	-0.754*** (0.131)	–	–

Long-run effects

The error-correction term (ECT) in the PMG model is negative (-0.095) but statistically insignificant, while in the MG model it is strongly negative and significant (-0.754***). The MG result suggests that deviations from the long-run equilibrium are corrected at a speed of about 75% per year, implying rapid adjustment in the WB6.

In the long run, the coefficients show that:

- **Energy intensity (ln_ei)** is negative (-0.235) in the PMG specification, with significance at the 10% level, indicating that improvements in efficiency (lower intensity) are associated with higher GDP per capita. The MG result is positive but insignificant, highlighting cross-country heterogeneity.
- **Renewable energy share (ln_res)** is positive and highly significant (0.105*** in PMG), confirming that renewables contribute to long-run growth.

- **Gross fixed capital formation (ln_k)** is positive (0.070) but not significant in PMG, while MG yields a similar pattern.
- **Labour force (ln_lab)** is insignificant in both specifications, reflecting structural demographic constraints in the WB6.
- **Consumer prices (ln_cpi)** are positive and highly significant in PMG (0.669***), but also in MG (0.712***), suggesting that moderate inflation is associated with higher nominal growth in the region, consistent with findings in emerging economies.

Overall, the long-run evidence supports **H1** (efficiency matters for growth) and **H3** (renewables matter), while investment and labour effects are weaker than expected.

Short-run dynamics

The short-run results reveal interesting adjustment patterns. In the PMG estimation, short-run energy intensity (Δln_ei) is negative (-0.070) but insignificant, while renewable energy (Δln_res) is negative and significant (-0.093***), indicating adjustment costs or volatility in renewable deployment. Investment (Δln_k) is positive (0.098***) and strongly significant, confirming its role as a short-run driver of GDP growth. Labour force (Δln_lab) is positive but insignificant, while consumer prices (Δln_cpi) are negative (-1.788) but not significant.

In the MG estimation, the short-run coefficients show similar patterns: renewable energy is negative and significant (-0.099***), while investment is positive and highly significant (0.067***). Again, these results suggest that in the short run, structural changes in the energy mix impose costs, but capital accumulation plays a stabilizing role.

Final Interpretation

Taken together, the results confirm that **energy efficiency has a positive and significant effect on economic growth in the long run**, consistent with the hypothesis that lower energy intensity improves competitiveness and productivity (Stern, 2011; Ozturk, 2010; Bildirici, 2014). Renewable energy also enhances long-run growth, aligning with recent studies on emerging economies (Deka, 2023). In the short run, however, efficiency improvements and renewable integration appear to generate adjustment costs, consistent with transition challenges observed in the WB6 (Frey, 2024).

The strong and significant error-correction term in the MG model highlights the rapid speed of adjustment in the region, suggesting that despite heterogeneity, WB6 economies share a stable long-run path toward higher efficiency and sustainable growth.

Discussion and Policy Implications

The empirical results provide important insights into the relationship between energy efficiency and economic growth in the Western Balkans. The analysis confirms **H1**, showing that in the long run, reductions in energy intensity are associated with higher GDP per capita. This result aligns with the broader literature on the energy–growth nexus, where efficiency improvements are treated as a form of technological progress that enhances productivity (Stern, 2011; Ozturk, 2010). For the WB6, this suggests that policies targeting energy savings and efficiency gains can yield lasting economic dividends.

By contrast, **H2** is also supported: the short-run results show weak or negative effects of energy efficiency and renewable energy on growth. This finding is consistent with adjustment costs associated with restructuring energy systems, particularly in countries with high dependence on coal and outdated infrastructure (Frey, 2024). In the short term, investments in energy efficiency may divert resources and require time before productivity benefits are fully realized, a pattern also observed in emerging economies (Awosusi et al., 2023).

The results also confirm **H3** only partially. Renewable energy share is positive and significant in the long run, demonstrating that renewables not only contribute to environmental sustainability but also support economic growth. However, in the short run, the coefficients for renewable energy are negative, reflecting the transitional burden of integrating intermittent and capital-intensive technologies into the energy mix. Investment (gross fixed capital formation) has strong positive effects in the short run, confirming its role as a driver of cyclical growth. The labour force variable was insignificant, which may reflect demographic stagnation and structural unemployment in the WB6 (Sanfey, Milatovic & Krešić, 2016).

In terms of the **research questions**, the evidence indicates a clear long-run relationship between energy efficiency and growth, while short-run dynamics differ across countries. Improvements in energy intensity are growth-enhancing in the long run, and the speed of adjustment (especially in the MG estimation) suggests that WB6 economies converge relatively quickly to a new equilibrium after shocks. This convergence is particularly relevant in the context of EU accession, where energy efficiency targets are embedded in the European Green Deal and the Energy Community framework (Zvezdanović Lobanova & Lobanov, 2023).

From a policy perspective, the findings highlight the importance of sequencing reforms. In the short run, efficiency and renewable energy policies may impose costs, but these should be offset through targeted support mechanisms, such as subsidies for building renovation, incentives for energy-efficient appliances, and investment frameworks that mobilize both public and private capital. In the long run, the results support the prioritization of energy efficiency in national strategies, as it yields both economic and environmental benefits. Importantly, the heterogeneity revealed in the short-run coefficients suggests that policies should be country-specific, addressing

the structural characteristics of each WB6 economy rather than relying solely on regional averages.

The overall conclusion is that energy efficiency should not be seen merely as an environmental obligation but as a central pillar of economic strategy in the Western Balkans. By embedding efficiency measures into development policies, governments can accelerate convergence with the EU, improve competitiveness, and foster sustainable growth.

CONCLUSION

This paper has examined the relationship between energy efficiency and economic growth in the Western Balkans over the period 2005–2022, using a panel ARDL framework with PMG and MG estimators. The empirical results show that improvements in energy efficiency, measured through reductions in energy intensity, are positively associated with GDP per capita in the long run. Renewable energy also contributes positively to long-run growth, while investment plays a particularly strong role in the short run. However, the short-run results reveal adjustment costs, as renewable integration and efficiency improvements may initially exert negative or insignificant effects. The error-correction term in the MG specification is strongly negative and significant, suggesting that WB6 economies adjust relatively quickly toward long-run equilibrium.

The findings provide important policy insights. They confirm that energy efficiency should be treated not only as an environmental objective but as a strategic driver of sustainable economic growth in the WB6. Policymakers should focus on sequencing reforms: while short-run costs exist, the long-run benefits of efficiency gains justify targeted incentives, support for innovation, and stronger regulatory frameworks. The results are also highly relevant in the context of EU integration, where the Energy Community and Green Deal set binding efficiency targets that align with the growth agenda of the region.

Despite these contributions, several limitations must be acknowledged. First, the study relies on aggregate macroeconomic indicators, which may obscure sectoral differences in energy efficiency and growth linkages. Second, the relatively short time period and the exclusion of Kosovo* due to data unavailability constrain the scope of inference. Third, while the ARDL approach is well-suited for mixed order integration, alternative estimators (such as system GMM or structural VARs) could be applied in future research to further validate the robustness of the results.

Future research should therefore extend the analysis in several directions. More disaggregated data at the sectoral or firm level would allow for a better understanding of how energy efficiency interacts with productivity, innovation, and competitiveness. Comparative studies with other EU candidate and member states would also be valuable, enabling the WB6 to benchmark their progress more precisely. In additi-

on, exploring the distributional impacts of efficiency policies, such as effects on employment, social welfare, and vulnerable households, would enrich the policy debate.

The main contribution of this paper lies in providing one of the first systematic empirical assessments of the economic effects of energy efficiency in the Western Balkans. By applying a dynamic panel ARDL framework, the study bridges the gap between global research on the energy–growth nexus and the specific transition challenges of the WB6. It demonstrates that energy efficiency is not a peripheral issue but a central pillar of sustainable growth and convergence with the EU.

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