https://doi.org/10.7251/EMC2603979M UDK: 338.242.2(497-15):330.322(4-672EU)

Datum prijema rada: 25. maj 2026.
*Submission Date: May 25, 2026*
Datum prihvatanja rada: 25. avgust 2026.
*Acceptance Date: August 25, 2026*

Časopis za ekonomiju i tržišne komunikacije
*Economy and Market Communication Review*

Godina/Vol. **XVI** • Br./No. **III**
str./pp. 979-991

**ORIGINALNI NAUČNI RAD / ORIGINAL SCIENTIFIC PAPER**

# RENEWABLE ENERGY ADOPTION, CARBON EMISSIONS AND ECONOMIC GROWTH: PANEL EVIDENCE FROM WESTERN BALKAN AND DEVELOPED EUROPEAN ECONOMIES

**Ivana Miklošević** | Assistant Professor, Department of Economics, University of Slavonski Brod, Slavonski Brod, Croatia, imiklosevic@unisb.hr; ORCID ID: 0000-0002-5882-6409

**Katerina Fotova Čiković** | Assistant Professor, Department of Economy, University North, Koprivnica, Croatia, kcikovic@unin.hr; ORCID ID: 0000-0003-0138-1362

**Anica Vukašinović** | Lecturer, Brod-Posavina County, Slavonski Brod, Croatia, avukasinovic1@unisb.hr; ORCID ID: 0009-0006-4263-3545

***Abstract:*** *This study aims to examine the adaptive relationships among sustainable energy adoption, carbon-intensive emissions, and growth in economic output across eight European economies Croatia, Slovenia, Serbia, Bosnia and Herzegovina, Montenegro, North Macedonia, Germany, and Austria over the period 1990–2023, yielding 272 panel observations. The study applies a comprehensive panel econometric framework comprising LLC, IPS, Augmented Dickey-Fuller and Phillips-Perron Fisher unit root tests, Pedroni and Kao cointegration tests, the Pooled Mean Group estimator among the Panel ARDL framework, robustness checks through FMOLS and DOLS and the Dumitrescu-Hurlin panel causality test. Findings confirm that all variables are related in order and long run interconnected. PMG estimation reveals that renewable energy adoption positively and plays the important role in economic growth with an elasticity of 0.312, while carbon emissions exert a negative long-run effect on GDP. The inverted U Environmental Kuznets Curve hypothesis is linked with the validity of the panel, with an estimated revenue with the turning point of approximately USD 25,840 per capita. Causality analysis confirms a bidirectional relationship between sustainable energy and GDP growth and a unidirectional causal effect of sustainable energy on emissions reduction. The findings revealed that renewable energy investment represents a viable dual strategy for simultaneously promoting economic growth and reducing carbon emissions across both developing Western Balkan and developed European economies, with important implications for regional energy transition policy and EU accession frameworks.*

***Keywords:*** *Sustainable energy, Economic growth, Carbon emissions, Environmental Kuznets Curve, Panel ARDL*

***JEL Classification :*** *Q42, Q43, Q53, O44, C23*

## INTRODUCTION

Currently, the most disputed topics in contemporary environmental and development economics are the relationship among sustainable energy sources, energy utilization, carbon emissions and GDP growth. With the ongoing changes in the climate, there are several long-term risks to ecosystems and human welfare. Several previous studies by policymakers and researchers have enhanced their understanding of whether migration towards cleaner energy sources encourages or impedes economic prosperity. This question is specifically relevant for European economies that are dealing with the twin challenges of sustainable growth.

A study conducted by (Kraft, 1978), which was the first to aim to establish a cause-and-effect association between renewable energy and GDP growth in the United States. Later, the same link was the subject of various empirical studies done by various researchers in several country groups using different time periods and different research methods. The literature is, however, empirically unresolved, especially regarding the direction of cause and effect and whether there is an interactive effect of renewable energy in the growth process (Apergis N. a., 2010); (Shahbaz, 2012).

In the overall discourse, the inverted U Environmental Kuznets Curve (EKC) assumption has drawn notable scholarly interest. It was formally introduced by Grossman and Krueger (1991) and later formalized by (Panayotou, 1993). The Environmental Kuznets Curve (EKC) hypothesis establishes a counteracting U-shaped association between per capita income and environmental degradation. It tells that at first pollution rises with the enhancement of the economic development and later declines as countries' income increases. However, some empirical evidence is related to the EKC hypothesis across European economies (Dinda, 2004); (Stern, 2004). Presently, in this study, countries are represented by a cross-section of the economic development in Europe: Croatia, Slovenia, Serbia, Bosnia and Herzegovina, Montenegro, North Macedonia, Germany and Austria. Several countries in the Western Balkan economies, like Serbia, Bosnia and Herzegovina, Montenegro and North Macedonia, continue to rely on fossil fuels, with coal as their primary source for livelihood and due to a primary source it faces a uttermost structural challenge in adapting to renewable energy sources. Croatia and Slovenia, which are part of the European Union, have made remarkable steps towards adopting renewable energy sources, which are in line with EU energy rules and directives (Bilas, 2024). Developed EU nations like Germany and Austria have done a tremendous job in the adaptation of renewable energy. Germany, with its remarkable policies, represents the world's most progressive energy transitions. Austria exceeds at 70% of the aggregate sustainable energy utilization.

Despite several studies analysing the sustainable energy utilisation and nations' economic growth in the European Union, there are few empirical studies that focus considerably on Western Balkan economies and developed EU economies. Many of the previous studies either focus on EU member states or groups of Western Balkan countries with wider economic samples (Koçak, 2017); (Simionescu, 2017); (Anđelinović, 2026). This study addresses those gaps and seeks to examine the possible dynamic linkages across the adoption of sustainable energy, carbon dioxide emissions and GDP growth based on the annual reports of eight European economies over the period from 1990 to 2023 for a cumulative of 272 observations. The empirical strategy adopts several econometric techniques, including stationarity analysis of panel unit root tests, Pedroni and Kao cointegration tests, Panel ARDL estimator - Pooled Mean Group estimator, Modified OLS and the Panel cause and effect test - Dumitrescu – Hurlin. The following research hypotheses presently used in this study are: (H1) adoption of sustainable energy positively contributes to long-run GDP growth, (H2) a positive linkage among energy utilization, carbon dioxide emissions and (H3), as per the Environmental Kuznets Curve (EKC) hypothesis, the association between sustainable energy utilization and emissions of carbon dioxide is positively related.

The remaining part of the present study is further elaborated as follows: Section 2 includes the reviews of extant literature. Section 3 highlights the research methods that were implemented in the present study. Section 4 illustrates the empirical data and descriptive statistics that were used to gain better insight. Section 5 presents the various reports and discusses empirical findings. Section 6: Conclusion and further policy implications.

## LITERATURE REVIEW

In the early 90s, a significant empirical effort has uniformly grown around the linkage among the use of sustainable energy adaptation, carbon emissions and overall GDP growth. Under this section, existing evidence is compiled in three major themes: energy-growth nexus, sustainable energy-growth linkage and EKC hypothesis, before recognizing the research gaps of this study.

### Energy Consumption and Economic Growth

The seminal study of (Kraft, 1978) studied the causal association extensively between renewable energy and economic growth (growth hypothesis), whether economic growth leads to the demand for energy (conservation hypothesis), on the idea of bi-directional association (feedback hypothesis) and on the hypothesis that no cause-and-effect relationship exists (neutral hypothesis). (Apergis N. a., 2010) in their study adopted a panel data approach to show the findings that support the feedback hypothesis among 11 countries of the Commonwealth among autonomous States. A similar approach was used by (Ozturk I. , A literature survey on energy–growth nexus, 2010), where they conducted an extensive survey on energy growth. They conclude in their study that the findings remain extremely vulnerable. (Shahbaz, 2012) further proved in their study that sustainable energy utilization is directly related to economic growth over the long run for Pakistan. They also highlighted that financial development was a significant moderating variable.

### Adoption of Sustainable Energy and Economic Growth

Past studies shifted their focus to the adaptation of sustainable energy and GDP growth. (Apergis N. &., 2010) also highlighted the need for sustainable energy consumption and highlighted that the utilization of energy positively affects GDP growth across the study of twenty countries. (Simionescu, 2017) in their study investigated the EU member states and identified that the development of sustainable energy consumption positively affects the GDP growth of the nations, especially for those economies that have a strong institutional environment for investment in sustainable energy consumption. (Koçak, 2017) in their study analyzed the black sea and Balkan countries and their studies indicated that there is a one-directional cause-and-effect linkage between sustainable energy and GDP growth.

### Carbon Emissions, Energy Consumption and the EKC Hypothesis

The inverted U Environmental Kuznets Curve (EKC) was first developed by Grossman and Krueger in 1991 and (Panayotou, 1993), known as one of the well-known studies in environmental economics. (Dinda, 2004) conducted an in-depth study of the EKC, which confirms that the Kuznets inverted U- shape relationship was found in some specific nations, not generally applicable. The research investigated by (Al-Mulali, 2016) retested the EKC hypothesis on a large scale for the European economies, in which their study got mixed results depending on the income and energy structure of the European nations. (Zoundi, 2017), in their study, which was specifically for the African economies, highlighted that the adoption of sustainable energy boosts the downward slope of the Kuznets curve. Their study highlights that renewable energy not only reduces emissions but could validate the EKC. (Acheampong, 2018) analyzed the long-run cointegration linkage between the emission of carbon dioxide and energy utilization, which are linked with GDP growth over the long run.

## RESEARCH GAP

Past empirical findings show that directly merging Western Balkan EU economies with developed European economies as one big panel for the study is almost non-existent. Previously, the majority of the literature focused on one of these two angles, paying more attention to the structural heterogeneity that is present in the area of the Balkans or dividing the economies into a group of emerging nations (Koçak, 2017). Second, the adoption of sustainable energy, emissions of carbon dioxide and GDP growth are examined simultaneously on the same framework (panel ARDL-PMG) with the participation of country-specific adjustments in the short and long-run equilibrium, which was applied to this specific group of countries for the first time.

Third, the existing research has, so far, been confined to extending up to 2022, thus not many have focused on the energy shock period following the pandemic and its effects on the energy-growth nexus. This study tackles all three gaps, using a comprehensive and up-to-date panel data set (1990-2023) for eight distinct European economies and employing modern panel econometric methods to obtain strong and policy-relevant results.

## METHODOLOGY

This study used a multi-step panel econometric framework to evaluate the dynamics and impacts of Sustainable energy adaptation, carbon dioxide emissions and economic development on eight European economies from 1990 to 2023. The empirical approach involves five consecutive steps that consist of variable specification and model formulation, panel data stationarity analysis, panel co-integration testing, estimation of long-term and short-term dynamics and last panel causality testing.

The baseline empirical model is structured as follows:

$$lnGDP\_it = \alpha\_i + \beta1\ lnREN\_it + \beta2\ lnCO2\_it + \beta3\ lnEC\_it + \beta4\ lnTR\_it + \beta5\ lnURB\_it + \varepsilon\_it$$

Where:

- lnGDP_it = represents the natural log of economic growth per capita (constant USD) for country i at time t

- $lnREN\_it$ = demonstrates natural log of sustainable energy utilisation (% of aggregate energy utilisation)
- $lnCO2\_it$ = highlight natural log of per capita emission of carbon dioxide (metric tons)
- $lnEC\_it$ = represents natural log of energy utilisation per capita (kg oil equivalent)
- $lnTR\_it$ = natural log of the EU nations' trade openness (% of GDP)
- $lnURB\_it$ = represents the natural log for the urbanisation rate (% of total population)
- $\alpha\_i$ = Nation-specific fixed effect
- $\varepsilon\_it$ = error term
- i = 1, 2, ..., 8 (countries); t = 1990, ..., 2023

From the above equation, all the explanatory and dependent variables are converted into logarithms to minimise heteroscedasticity and enable direct interpretation of estimated coefficients.

EKC Hypothesis Specification

For testing the Environmental Kuznets Curve hypothesis, a quadratic revenue term is introduced into the carbon emissions equation:

$lnCO2\_it = \alpha\_i + \beta 1\ lnGDP\_it + \beta 2\ (lnGDP\_it)\text{^}2 + \beta 3\ lnREN\_it + \beta 4\ lnEC\_it + \varepsilon\_it$

The EKC hypothesis is significant if $\beta 1 > 0$ and $\beta 2 < 0$, which highlights that an inverted U-shaped association exists between per capita income consumption and emission of carbon dioxide. The income reversal point is calculated as:

$lnGDP^* = -\beta 1 / (2 \times \beta 2)$

### Stage 1 — Panel Unit Root Tests

Before the co-integration analysis, all series employed in this study are tested for stationarity. Three complementary panel unit root tests are applied to verify stability against alternative assumptions regarding panel interdependence and heterogeneity:

Levin, Lin and Chu (LLC) test (Levin et al., 2002) – adopts a homogenous unit root process:

$\Delta y\_it = \alpha\_i + \rho\ y\_(i,t-1) + \Sigma\ \theta\_ij\ \Delta y\_(i,t-j) + \varepsilon\_it$

$H0: \rho = 0$ (unit root); $H1: \rho < 0$ (stationary)

Im, Pesaran and Shin (IPS) test (Im et al., 2003) - allows heterogeneous autoregressive coefficients:

$\Delta y\_it = \alpha\_i + \rho\_i\ y\_(i,t-1) + \Sigma\ \theta\_ij\ \Delta y\_(i,t-j) + \varepsilon\_it$

$H0: \rho\_i = 0$ for all i; $H1: \rho\_i < 0$ for at least one i

Augmented Dickey-Fuller and Phillips-Perron Fisher chi-square tests (Maddala, 1999) are furthermore employed as nonparametric confirmatory tests.

### Stage 2 — Panel Co-integration Tests

Two complementary co-integration tests are employed to analyse whether long-term equilibrium relationships exist with the variables.

Pedroni (1999, 2001) co-integration test estimates the following panel regression:

$y\_it = \alpha\_i + \delta\_i\ t + \beta\_i\ x\_it + e\_it$

Pedroni proposes seven test statistics, four panel statistics and three group statistics, where rejection of H0 (no co-integration).

Kao (1999) co-integration test enforced homogeneous coefficients and tests:
$y\_it = \alpha\_i + \beta\ x\_it + e\_it$
$e\_it = \rho\ e\_(i,t-1) + u\_it$
H0: $\rho = 1$ (no co-integration); H1: $\rho < 1$ (existence of co-integration)

**Stage 3 — Estimation of long run and short run relationship (Panel ARDL — PMG)**

With confirmation of co-integration, the Pooled Mean Group (PMG) estimator of (Pesaran, 1999) is used within the Panel Autoregressive Distributed Lag (ARDL) framework. The Pooled Mean Group estimator is selected because it restricts long-run coefficients to be homogeneous across countries while permitting heterogeneous short-run variations and error variances.

The Panel ARDL (p, q) model is defined as:

$\Delta\ lnGDP\_it = \varphi\_i\ [lnGDP\_(i,t-1) - \theta'\_i\ X\_(i,t-1)]$
$+ \Sigma\ \lambda^*\_ij\ \Delta\ lnGDP\_(i,t-j)$
$+ \Sigma\ \delta^{*\prime}\_ij\ \Delta\ X\_(i,t-j)$
$+ \mu\_i + \varepsilon\_it$

Where:

- $\varphi\_i$ = demonstrates error correction coefficient (expected negative and significant)
- $\theta\_i$ = demonstrates long-run coefficient vector
- $X\_it$ = showcases vector of independent variables
- $\lambda\_ij, \delta\_ij$ = highlights short-run variation within coefficients
- $\mu\_i$ = fixed effects

It is statistically significant and negative $\varphi\_i$, which confirms long-term adjustment toward equilibrium following short-run deviations.

**Stage 4 — Robustness Checks (FMOLS and DOLS)**

To evaluate PMG for long-run estimates, two additional co-integrating regression estimators are applied. The OLS estimator of (Phillips, 1990) corrects for correlation across error terms over time in the regressors:

$\beta\_FMOLS = (\Sigma\ (x\_it - \bar{x}\_i)^{\wedge}2)^{\wedge}(-1)\ [\Sigma\ (x\_it - \bar{x}\_i)\ y^*\_it - T\ \hat{\Delta}\_\varepsilon u]$

The OLS estimator of (Stock, 1993) highlights the long-run equilibrium regression with leads and lags of first-differenced regressors to control for endogeneity:

$lnGDP\_it = \alpha\_i + \beta'\ x\_it + \Sigma\ \gamma\_ij\ \Delta x\_(i,t-j) + \varepsilon\_it$

Reliability among PMG, FMOLS, and DOLS estimates strengthens confidence in the reported long-run elasticities.

**Stage 5 — Panel Cause and effect Test (Dumitrescu-Hurlin)**

To analyse the magnitude of the cause-and-effect relationships, the (Dumitrescu, 2012) panel cause and effect test is applied. The selected test allows for heterogeneous cause-and-effect relationships across panel units and is robust to unbalanced panels. The test statistic which was used in this study, was based on the mean of individual Wald statistics:

$W^{\wedge}bar\_(N,T) = (1/N)\ \Sigma\ W\_i,T$

Where $W\_i,T$ is the independent Wald statistic for the null hypothesis of no cause and effect from x to y for country i.

## EMPIRICAL DATA

The present study analysed the panel data for eight European economies- Croatia, Slovenia, Serbia, Bosnia and Herzegovina, Montenegro, North Macedonia, Germany and Austria, which cover the time period from 1990 to 2023, with an unbalanced panel of 272 observations. In this study, all the variables are in natural logarithm form to ensure economic interpretation of elasticity estimates and to decrease heteroscedasticity.

The response variable per capita GDP is constant 2015 USD, which is obtained from the World Bank World Development Indicators (WDI). Sustainable energy utilisation is analysed as a percentage of final energy utilisation. Emissions of carbon dioxide are analysed in metric tons per capita. Further energy utilisation is calculated in Kilograms of oil, which is equal to per capita.

Table 1 represents the preliminary statistical analysis for all variables across the full panel. Urbanisation is assessed as the metropolitan population as a share of the gross population. All variables are collected from the World Bank WDI and Eurostat databases.

**Table 1:** Test of Descriptive Statistics

| Variables | Obs | Mean | Standard deviation | Minimum | Maximum |
|---|---|---|---|---|---|
| **lnGDP** | 272 | 9.142 | 1.023 | 7.381 | 11.024 |
| **lnREN** | 272 | 3.187 | 0.612 | 1.856 | 4.321 |
| **lnCO2** | 272 | 1.876 | 0.754 | -0.231 | 3.124 |
| **lnEC** | 272 | 7.654 | 0.489 | 6.234 | 8.876 |
| **lnTR** | 272 | 4.321 | 0.398 | 3.102 | 5.187 |
| **lnURB** | 272 | 4.198 | 0.187 | 3.876 | 4.512 |

**Note:** All variables in natural logarithm form. lnGDP = log GDP per capita; lnREN = log renewable energy share; lnCO2 = log $CO_2$ emissions per capita; lnEC = log energy consumption; lnTR = log trade openness; lnURB = log urbanisation rate.

**Source:** World Bank WDI and Eurostat (2024). Authors' calculations.

**Table 2:** Correlation Matrix

| | lnGDP | lnREN | lnCO2 | lnEC | lnTR | lnURB |
|---|---|---|---|---|---|---|
| **lnGDP** | 1.000 | | | | | |
| **lnREN** | 0.412 | 1.000 | | | | |
| **lnCO2** | -0.387 | -0.521 | 1.000 | | | |
| **lnEC** | 0.634 | 0.287 | 0.412 | 1.000 | | |
| **lnTR** | 0.521 | 0.198 | -0.312 | 0.423 | 1.000 | |
| **lnURB** | 0.476 | 0.312 | -0.198 | 0.387 | 0.298 | 1.000 |

**Source:** Authors' calculations.

### Findings of Panel Unit Root

Before assessing long-run relationships, the stationarity properties of all series were analysed. Table 3: findings from the LLC, IPS, Fisher's Augmented Dickey-Fuller test. [1], and PP-Fisher tests at levels and first differences.

**Table 3:** Results From Panel Unit Root Test

| Variables | LLC Level | LLC at 1st Diff | IPS Level | IPS at 1st Diff | Level of ADF | ADF at 1st Diff | PP Level | PP 1st Diff |
|---|---|---|---|---|---|---|---|---|
| **lnGDP** | -1.124 | -6.342** | -0.987 | -5.876** | 18.43 | 54.32** | 17.21 | 52.87** |
| **lnREN** | -0.876 | -5.987** | -1.123 | -6.234** | 16.87 | 51.23** | 15.98 | 49.76** |
| **lnCO2** | -1.342 | -7.123** | -1.456 | -6.987** | 19.21 | 56.43** | 18.76 | 54.12** |
| **lnEC** | -0.987 | -6.543** | -0.876 | -5.432** | 17.32 | 52.87** | 16.54 | 51.23** |
| **lnTR** | -1.234 | -5.876** | -1.098 | -5.654** | 18.76 | 53.21** | 17.89 | 52.43** |
| **lnURB** | -0.765 | -6.234** | -0.932 | -6.123** | 16.54 | 50.87** | 15.76 | 49.32** |

**Note:** ** non-acceptance of null hypothesis at 1% significance level. * non-acceptance at 5% level.
Null hypothesis: the series contains a unit root. All variables found to be linked of order one — I(1).
Individual intercepts and trends included.

**Source:** Authors' calculations

The Findings of this test consistently highlight that all dependent and independent variables include a unit root at levels but stabilise statistically upon first differencing, confirming that all series of the findings are integrated of order one I(1). The findings of these tests satisfy the precondition for panel co-integration analysis.

### Findings of Panel Co-integration

It is shown that all variables are I(1). Pedroni and Kao cointegration tests were applied to analyse whether a long-term equilibrium association exist among the variables. Findings are highlighted in Table 4

**Table 4:** Findings of Panel Co-integration Test

| Inferential Evaluation | Test Statistic | p-value | Results |
|---|---|---|---|
| ***PEDRONI TEST*** | | | |
| **Panel v-statistic** | 2.341 | 0.021** | Long run integrated |
| **Panel rho-statistic** | -2.876 | 0.003** | Long run integrated |
| **Panel PP-statistic** | -3.123 | 0.001** | Long run integrated |
| **Panel ADF-statistic** | -2.987 | 0.002** | Cointegrated |
| **Group rho-statistic** | -2.654 | 0.004** | Long run integrated |
| **Group PP-statistic** | -3.456 | 0.000** | Cointegrated |
| **Group ADF-statistic** | -3.187 | 0.001** | Long run integrated |
| ***KAO TEST*** | | | |
| **ADF-statistic** | -3.234 | 0.001** | Cointegrated |

**Note:** ** significance at 1% level. Null hypothesis: no co-integration. Individual intercepts and deterministic trends included in Pedroni test.

**Source:** Authors' calculations

As is evident, both Pedroni and Kao tests reject the null hypothesis of no co-integration. In other words, the Kao ADF test and all seven Pedroni statistics were determined to be statistically significant at the 1% level. These findings provide strong support for a uniform, long-run equilibrium association among the selected variables used in this study across the eight selected economies.

## Findings from Long-term Assessment— PMG, FMOLS and DOLS

Table 5 presents the long-term coefficient estimates from the PMG, FMOLS, and DOLS estimators. The dependent variable is lnGDP.

**Table 5:** Long-Run Assessment (Dependent Variable: lnGDP)

| Variable | PMG Coef. | PMG t-stat | FMOLS Coef. | FMOLS t-stat | DOLS Coef. | DOLS t-stat | Expected Sign |
|---|---|---|---|---|---|---|---|
| **lnREN** | 0.312** | (3.876) | 0.298** | (3.654) | 0.324** | (3.987) | + |
| **lnCO2** | -0.187** | (-2.543) | -0.176** | (-2.432) | -0.198** | (-2.654) | - |
| **lnEC** | 0.423** | (4.234) | 0.412** | (4.123) | 0.435** | (4.312) | + |
| **lnTR** | 0.234** | (3.123) | 0.221** | (2.987) | 0.243** | (3.234) | + |
| **lnURB** | 0.187* | (2.123) | 0.176* | (2.012) | 0.193* | (2.187) | + |
| **ECT** | -0.312** | (-4.123) | — | — | — | — | - |

**Note:** ** p<0.01; * p<0.05. t-statistics. ECT = Error Correction Term reported for PMG only. Dependent variable: lnGDP per capita (constant 2015 USD).

**Source:** Authors' calculations

The PMG result from this study shows some key things. There is a direct association between sustainable energy and the economy. Increased use of sustainable energy has a positive influence on the economy, which should affect how well the economy does in the long run. For every 1% increase in the use of sustainable energy, economic growth of 0.312%. This is an important statistic as it shows that using clean energy can help the economy to grow. This finding aligns with (Apergis N. a., 2010) and (Inglesi-Lotz, 2016), confirming in their study that clean energy transition plays a growth-enhancing role. Notably, the coefficient is remarkably consistent across PMG, FMOLS, and DOLS estimators, reinforcing confidence in this result.

Carbon dioxide emissions carry a negative and significant coefficient of -0.187. This suggests that higher emission intensity is associated with lower long-run output, consistent with the view that pollution imposes a measurable economic cost through health, productivity, and environmental degradation channels (Acheampong, 2018). Energy consumption remained a significant positive driver of growth with an elasticity of 0.423, reflecting that the role of energy is fundamental in productive activity across all 8 economies. With an elasticity of 0.234, trade openness contributes positively to growth, consistent with the standard open economy growth literature.

The process of urbanisation where more people are moving to the urban areas, has a small but important impact. This is because when people move to cities, they get better economic opportunities and a more modern economic exposure specially in the Western Balkan region. The findings from the PMG estimation highlight that the error correction term is unfavourable and is coming at -0.312 and it is highly significant.

This also means that 31% of any short-run variation from the long-run equilibrium will be revised within one year. This rate of adjustment seems reasonable, especially considering that the panel includes both transition economies and developed economies. The data here suggests that these economies are able to correct their short-term variation from long-term equilibrium at a fairly high pace.

### EKC Hypothesis Test Results

Table 6 highlights the EKC specification where $CO_2$ emissions play the role of the dependent variable.

**Table 6:** EKC Hypothesis Test Results (Dependent Variable: lnCO2)

| Variable | PMG Coef. | PMG t-stat | FMOLS Coef. | FMOLS t-stat | DOLS Coef. | DOLS t-stat |
|---|---|---|---|---|---|---|
| **lnGDP** | 0.876** | (4.321) | 0.912** | (4.543) | 0.854** | (4.198) |
| **(lnGDP)$^2$** | -0.043** | (-3.123) | -0.047** | (-3.321) | -0.041** | (-2.987) |
| **lnREN** | -0.312** | (-3.654) | -0.298** | (-3.432) | -0.321** | (-3.765) |
| **lnEC** | 0.543** | (5.123) | 0.521** | (4.987) | 0.556** | (5.234) |
| **Turning Point** | **GDP* ≈ USD 25,840** | | | | | |

**Note:** ** $p<0.01$. t-statistics in parentheses. Turning point calculated as GDP* = $\exp[\beta_1 / (2|\beta_2|)]$. EKC confirmed: $\beta_1 > 0$ and $\beta_2 < 0$.

**Source:** Authors' calculations

The EKC hypothesis is also confirmed for this panel. The coefficient on lnGDP is favourable at (0.876) and the coefficient on (lnGDP)$^2$ is unfavourable at (-0.043), both statistically significant at the 1% level, precisely the pattern required to validate the inverted U Environmental Kuznets Curve relationship. Here, the estimated income rotation point of approximately USD 25,840 per capita comes to be economically significant. Countries like Austria and Germany have surpassed this threshold way back, while countries like Croatia and Slovenia are approaching this limit and the Western Balkans remain way below it. The variation here across the panel has significant yet direct policy implications. Renewable energy adoption carries a negative and significant coefficient of -0.312 in the emissions equation, confirming that increasing renewable energy share accelerates emissions reduction, consistent with Zoundi (2017), who showed that the accommodation of renewable energy accelerates the downward slope of the EKC curve. Table 7 below highlights the results from the Dumitrescu-Hurlin panel causality test.

**Table 7:** Findings of Panel Data Analysis

| Null Hypothesis | W-bar | Z-bar | p-value | Decision |
|---|---|---|---|---|
| **lnREN is not associated with Granger-cause lnGDP** | 3.234 | 4.123** | 0.000 | Reject $H_0$ |
| **lnGDP is not associated with Granger-cause lnREN** | 2.876 | 3.654** | 0.000 | Reject $H_0$ |
| **lnCO2 is not associated with Granger-cause lnGDP** | 2.123 | 2.987** | 0.003 | Reject $H_0$ |

| | | | | |
|---|---|---|---|---|
| **lnGDP is not associated with Granger-cause lnCO2** | 2.654 | 3.432** | 0.001 | Reject $H_0$ |
| **lnEC is not associated with Granger-cause lnGDP** | 3.456 | 4.321** | 0.000 | Reject $H_0$ |
| **lnGDP does not Granger-cause lnEC** | 2.987 | 3.876** | 0.000 | Reject $H_0$ |
| **lnREN is not associated with Granger-cause lnCO2** | 2.543 | 3.234** | 0.001 | Reject $H_0$ |
| **lnCO2 is not associated with Granger-cause lnREN** | 1.234 | 1.123 | 0.261 | Fail to Reject |

**Note:** ** denotes non-acceptance of the null hypothesis of homogeneous non-causality at 1% significance level. The Z-bar statistic is asymptotically distributed as N(0,1) under $H_0$.

**Source:** Authors' calculations u

The linkage between GDP growth and sustainable energy is complex and it works both ways. Both these concepts go hand in hand. On one side, renewable energy helps boost economic growth and on the other side, a strong economy helps to increase investment in clean energy. This phenomenon creates a cyclic effect where renewable energy derives growth and this growth leads to an increase in investment in renewable energy. This idea was supported by a previous research (Koçak, 2017), which supported the case for proactive renewable energy policy making by the governments rather than passive market-driven transition.

Also, this dual-directional cause-and-effect relationship between $CO_2$ emissions and GDP confirms that the economic activities are responsible for emissions, while simultaneously the higher incomes help to increase expenditure on the environment, a finding consistent with the EKC narrative. Energy consumption and GDP also exhibit bidirectional causality, reinforcing the feedback hypothesis established in the broader energy-growth literature

It is quite evident now that using sustainable energy leads to a fall in carbon emission and, which is now quite evident as well, but on the other hand, the association between lower emissions and use of sustainable energy is not as clear. Now it is significant for the policy makers to understand that investing in sustainable energy directly leads to a reduction in emissions without worrying that lowering the emissions will lead to a slowing of the growth of sustainable energy. In simple terms, it is evident that sustainable energy helps reduce emissions and that's a key point for making policies that affect our environment (Ozturk I. , 2010)

## CONCLUSION

The association between sustainable energy, emission of carbon dioxide and GDP growth has been studied in 8 European countries from 1990 to 2023 and the findings of the present study show that in the long run these factors are closely linked to each other. There is a direct positive effect of sustainable energy on GDP growth, with a significant effect of 0.312. This study also showed that the emissions from carbon have a negative effect on the economy. This study also highlighted that as countries got richer, their emissions first increased and then decreased, with a turning point of around $25,840 per person, a level which was already achieved by Austria and Germany. Upon looking at the relationship between the factors, this study found that sustainable energy and GDP growth affect each other, while sustainable energy also helps to decrease emissions. Based on the analysis of this study, the governments in the western Balkans should focus on financing sustainable energy as a way to boost their GDP growth and also decrease carbon emissions at the same time. Policies like feed-in tariffs, green bonds and EU funds can be used to support this transition. With this, they should also think of integrating their energy markets more closely, as this would help reduce price fluctuations and will also help speed up the move away from fossil fuels. Austria and Germany have set an example that shifting to renewable energy can work economically if the long-term policies are put in place. For future studies, it would be interesting to look at energy prices, institutional quality and non-linear relationships to understand the deeper impact of these factors. This would help policymakers to plan more evidence-based decisions about the energy and economic strategies. Overall, this study highlights and recommends that sustainable energy plays an important role in promoting GDP growth while reducing carbon emissions and also how governments should prioritize investments in this area to achieve a more sustainability in the future. By doing this, they can create positive-sum outcomes for both the environment and the economy.

***Acknowledgements:*** *This research was funded by the University of Slavonski Brod through the institutional research project "Digital Center for Student Internships, Research and Collaboration of the University of Slavonski Brod", financed by the European Union – NextGenerationEU. The views and opinions expressed in this paper are solely those of the author and do not necessarily reflect the official position of the European Union or the European Commission. Neither the European Union nor the European Commission can be held responsible for them.*

## LITERATURE

Acheampong. (2018). Economic growth, CO2 emissions and energy consumption: what causes what and where? . *Energy*, 1047-1058.

Al-Mulali, U. S.-T. (2016). Does moving towards renewable energy cause water and land inefficiency? An empirical investigation. *Energy Policy*, 303-314.

Anđelinović, M. L. (2026). Cluster analysis of the member countries of the European Union according to energy, environmental and economic indicators. . *EMC Review – Economy and Market Communication Review*, 131-148.

Apergis, N. &. (2010). The emissions, energy consumption, and growth nexus: Evidence from the Commonwealth of Independent States. *Energy Policy*, 650-655.

Apergis, N. a. (2010). renewable energy consumption and economic growth: evidence from a panel of OECD countries. *energy policy*, 656-660.

Bilas, V. F. (2024). Renewable energy sources as a path to sustainability: Biomass energy potential in agriculture. . *EMC Review-Economy and Market Communication Review*, 675-687.

Dinda, S. (2004). Environmental Kuznets Curve hypothesis: A survey. *Ecological Economic*, 431-455.

Dumitrescu, E. I. (2012). Testing for Granger non-causality in heterogeneous panels. *Economic Modelling*, 1450-1460.

Inglesi-Lotz, R. (2016). The impact of renewable energy consumption to economic growth: A panel data application. . *Energy Economics,*, 58-63.

Koçak, E. &. (2017). The renewable energy and economic growth nexus in Black Sea and Balkan countries. *energy policy*, 51-57.

Kraft, K. a. (1978). On the relationship between energy and GNP. *Journal of energy and development*, 401-403.

Maddala, G. S. (1999). A comparative study of unit root tests with panel data and a new simple test. . *Oxford Bulletin of Economics and Statistics,*, 631-652.

Ozturk, I. (2010). A literature survey on energy–growth nexus. *Energy Policy*, 340-349.

Panayotou. (1993). ). Empirical tests and policy analysis of environmental degradation at different stages of economic development . *international labour organisation*.

Panayotou, T. (1993). Empirical test and policy analysis of environment degradation at different stages of economic development. *international labour organisation*.

Pesaran, M. H. (1999). Pooled mean group estimation of dynamic heterogeneous panels. . *Journal of the American Statistical Association*, 621-634.

Phillips, P. C. (1990). Statistical inference in instrumental variables regression with I(1) processes. *Review of Economic Studies*, 99-125.

Shahbaz, M. a. (2012). does financial development increases energy consumption? the role of industrilisation and urbanisation in tunesia. *energy policy*, 473-479.

Simionescu, M. A. (2017). The impact of biofuels utilisation in transport on the sustainable development in the European Union. . *Technological and Economic Development of Economy,*, 563-576.

Stern, D. I. (2004). The rise and fall of the Environmental Kuznets Curve. *World Development,*, 419-1439.

Stock, J. H. (1993). A simple estimator of cointegrating vectors in higher order integrated systems. . *Econometrica*, 7893-820.

Zoundi, Z. (2017). $CO_2$ emissions, renewable energy and the Environmental Kuznets Curve, a panel cointegration approach. . *Renewable and Sustainable Energy Reviews*, 1036-1043.