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MODELING THE RENEWABLE ENERGY CONSUMPTION IN WESTERN BALKAN COUNTRIES

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Abstract

This study helps us understand how renewable energy consumption is affected by foreign direct investment (FDI), trade openness, labor force participation, gross fixed capital formation (GFCF), and CO_2 emissions per capita in Western Balkan countries, focusing on Bosnia and Herzegovina, Serbia, Montenegro, Albania, and North Macedonia. The study employs panel data models to examine the connection between renewable energy consumption and explanatory variables from 2005 to 2023. This research uses a Random Effects model, and the results revealed that only CO_2 emissions have a statistically significant negative impact on renewable energy consumption ($p \approx 0.00006$), while FDI, trade openness, labor force participation, and GFCF are not statistically significant. Analysis is done using R and EViews software programs. The article contributes to existing literature *by exploring how CO_2 emissions, foreign direct investment, trade openness, labor force participation, and gross fixed capital formation affect renewable energy use in the Western Balkans.*

Keywords: CO_2 emissions, renewable energy (RE), renewable energy consumption (REC), Economic growth (EG), Western Balkans

INTRODUCTION

Nations worldwide have positioned the adoption of RE sources at the forefront of their development agendas because they need sustainable solutions to power their growing economies while handling environmental and financial problems (IRENA, 2021). The Western Balkans face both immediate necessity and policy complexity toward RE transition as they have historically relied on fossil fuels (Young & Macura, 2023). The understanding of RE adoption drivers becomes vital for countries during their economic restructuring and EU integration process because it forms the basis for successful development strategies.

The research focuses on economic and environmental factors which drive RE use within the Western Balkans from 2005 to 2023. The research centers on the analysis of five independent variables including foreign direct investment (FDI), trade openness, labor force participation, gross fixed capital formation (GFCF), and CO_2 emissions per capita as a non-renewable energy proxy. In line with previous research, the chosen variables demonstrate both theoretical and empirical significance according to Environmental Kuznets Curve (EKC), Porter Hypothesis and Green Job Transition Framework.

Researchers evaluate whether the economic elements of capital investment and labor participation together with trade and FDI either support or obstruct the transition to RE in the region. The environmental sector analyzes how CO_2 emissions impact the market demand for sustainable energy resources. Previous research demonstrates conflicting results regarding the impact of FDI and trade on RE development because their effects depend on the existing institutional and regulatory environment.

This study employs a range of econometric methods and tests, including descriptive statistics, Kendall's and Spearman's correlation, the Jarque-Bera test for normality, poolability test, Breusch-Pagan LM and Pesaran CD tests for cross-sectional dependence, Wooldridge test for serial correlation, Augmented Dickey-Fuller test for stationarity, Panel Granger Causality test, Hausman test for model selection, Lagrange Multiplier test for individual and time effects, and both Random Effects and FMOLS models for panel regression analysis.

The goal of this research is to investigate how economic and environmental factors affect REC in the Western Balkans. The main focus is on analyzing dependent (renewable energy consumption) and independent variables (FDI, trade openness, labor force participation, GFCF, and CO_2 emissions per capita) by employing panel econometric methods to assess whether these independent variables have a statistically significant impact on REC.

Despite significant research on the factors influencing RE adoption in established and growing economies, the Western Balkans are overlooked. Prior research frequently fails to account for these nations' specific structural, institutional, and transitional challenges. This study offers insights into better understanding of the factors shaping energy policies in countries that are in the process of joining the European Union.

LITERATURE REVIEW:

This research on the subject investigates the considerable impact of Foreign direct investment (FDI), trade (% of GDP), labor force participation, CO2 emissions per metric tons, and gross fixed capital formation (GFCF) on REC. This study follows the mainstream of econometric analysis, which focuses on understanding the relationship between REC and key economic and environmental variables. Given the Western Balkans' growing importance as a region undergoing energy transition and the global push toward sustainable energy sources, this research aims to explore how these factors influence the adoption and consumption of RE in the region.

FDI vs Renewable Energy Consumption

The impact of economic and environmental factors on REC has been the main topic of research in sustainable development studies. Many economists have researched the impact of these variables in different regions by focusing on theories such as Environmental Kuznets Curve (EKC) and the Porter Hypothesis. For example, the EKC proposes an inverted U-shaped relationship between economic development, as measured by Foreign Direct Investment (FDI), and environmental quality, implying that increased FDI initially causes negative impacts on the environment but eventually favors RE adoption as economies mature. One of the economists that have tested the EKC is Kang et al. (2021), and he found evidence that suggests a strong and negative relationship between Foreign Direct Investment (FDI) and RE usage in South Asian countries, suggesting that an increase in FDI correlates with a decrease in RE use. Similarly, the empirical findings of Tan & Uprasen (2022) reveal that FDI can lead to less use of RE if environmental rules are too weak, but when the regulations are stronger, FDI helps increase RE use. This means that good environmental policies are important for making sure

FDI supports clean energy. Samour et al. (2022) found empirical evidence that FDI can significantly increase REC in the UAE. According to Huang, Ahmad, and Ali (2022) foreign direct investment (FDI) and the quality of governance positively influence REC, indicating that when countries improve their governance and attract more FDI, they tend to use more RE sources. Kiliçarslan (2019) examined the impact of Foreign Direct Investment (FDI) on RE production in BRICS nations and Turkey from 2007 to 2015 using a Panel ARDL approach. The findings show that when there is more foreign direct investment (FDI), RE production actually goes down. This suggests that more foreign investment doesn't always help grow the RE sector.

Trade vs Renewable Energy Consumption

Similarly, the Porter Hypothesis proposes that trade (% of GDP) may boost innovation and RE usage by providing competitive advantages through extreme environmental rules. According to Vural (2021) the empirical research shows that trade has a positive and statistically significant effect on RE production per capita. This shows that as trade activity grows, so does RE production per individual. Han et al. (2022) found that trade leads to more use of non-renewable energy at all levels, but only partly increases RE use. This means trade is more connected to non-renewable energy, while its impact on RE is not as strong. Aïssa, Jebli, and Youssef (2014) found that trade doesn't affect RE use in the short term. Even in the long term, they didn't find any link from trade to RE, suggesting that trade has little to no influence on how much RE is used. On the other hand, the findings of Bonsu and Wang (2022) shows that a 1% increase in trade openness leads to a 0.5395% rise in per capita energy consumption across countries. As countries become more connected to the world through globalization, their economies grow. To keep up with this growth and higher demand, they need more energy production and industries. So, when countries open more to global trade, their energy use usually increases a lot. The causality analysis conducted by Bayar, Sasmaz, and Ozkaya (2021) indicated that globalization had an impact on RE development in Estonia, Latvia, and Slovenia.

Labor Force Participation vs Renewable Energy Consumption

Furthermore, the Green Job Transition Framework highlights the need of labor force engagement in promoting RE by matching workforce skills to green economy demands. Polcyn et al. (2021) stated that the total labor force is inversely related to REC. Findings that Kushawaha and Kharwar (2024) conducted suggest that higher labor force participation decreases fossil fuel usage and promotes RE adoption. According to Zhao and Luo (2017) the number of people employed plays an important role in helping RE grow. More jobs can support the RE sector by increasing the demand for green technologies and providing a skilled workforce. The results published in article by Irfany et al. (2024) showed that the involvement of young people aged 15 to 24 in the workforce also has a big impact on energy use. So, when there are more young people working, energy usage is likely to increase alongside higher investment and workforce engagement. Additionally, Wahyudi and Palupi (2023) revealed that the labor force participation rate variable had a negative but statistically negligible effect on consumption of energy.

GFCF vs Renewable Energy Consumption

In addition to these theories, Gross Fixed Capital Formation (GFCF) has been linked to RE development through its association with infrastructure investment and technological advancement. The capital accumulation theory suggests that higher GFCF enhances the ability of economies to finance and adopt RE projects. The study of (Qamruzzaman, 2024) highlights a significant relationship between gross capital formation (GCF) and REC. It demonstrates that domestic capital creation positively impacts the adoption and integration of RE technologies. According to Polcyn et al. (2021) gross capital formation is negatively associated with REC, suggesting that increased investment in physical assets tends to coincide with a decrease in the use of RE sources. The study by Tan, Qamruzzaman, and Karim (2023) highlights that gross capital formation (GCF) plays a crucial role in ensuring energy sustainability in Belt and Road Initiative (BRI) countries. Analysis of Irfany et al. (2024) reveals that Gross Fixed Capital Formation (GFCF) has a significant impact on energy consumption in OIC countries. This suggests that increased investment in GFCF can lead to higher energy consumption, as it often involves the development of infrastructure and projects that require substantial energy resources.

CO_2 emissions per metric ton vs Renewable Energy Consumption

Past studies show that CO_2 emissions are important when looking at economic growth and the environment. The Environmental Kuznets Curve (EKC) explains how economic growth can first harm the environment but later lead to using cleaner energy. Polcyn et al. (2022) found that as RE use goes up, CO_2 emissions per person also increase. This might happen because of the mix of energy sources during a transition to cleaner energy. Farhani (2013) found that in the MENA region, CO_2 emissions is one of the main variables that affect RE use. Omri and Nguyen (2014) showed that higher CO_2 emissions and more trade openness help increase REC.

Numerous studies have researched the relationship between economic and environmental factors and REC, and most of them are focused on developed countries with strong economies. However, the Western Balkans remain overlooked. This is the research gap, especially considering these nations' specific structural, institutional, and transitional challenges. According to EKC, environmental degradation first increases with EG but later decreases as investment and policy support advance to cleaner technologies. This concept considers FDI and CO_2 emissions as indicators of economic and environmental transformation. The Porter Hypothesis suggests that environmental regulations can affect innovation and efficiency, which is meaningful for the impact of trade openness on REC. The importance of the labor market in the green economy is emphasized by the Green Job Transition Framework which provides the basis for analyzing the impact of labor force participation on REC. Finally, the Capital Accumulation Theory points out the importance of GFCF for the adoption of clean technologies. By combining these theories, this study provides insight into the drivers of RE use in the Western Balkans and a basis for future recommendations to policymakers, especially in the context of directing investments and institutional strategies towards a sustainable energy transition in the Western Balkan countries.

RESEARCH QUESTIONS AND HYPOTHESIS

Based on the reviewed literature, this study poses key research questions and hypotheses that seek to determine the significance of the impact of economic and environmental factors on REC in the Western Balkan countries.

H_1: Economic indicators such as FDI, trade, labor force participation, and GFCF have a statistically significant effect on REC in the Western Balkans.

Research Question 1:

Do key economic indicators foreign direct investment (FDI), trade openness, labor force participation, and gross fixed capital formation have a significant impact on REC in the Western Balkans?

H_2: CO_2 emissions per capita have a statistically significant impact on REC in the Western Balkans.

Research Question 2:

Does the level of CO_2 emissions per capita, as a proxy for non-renewable energy use, influence REC in the Western Balkans?

RESEARCH METHODOLOGY

Research Design

This study investigates the relationship between economic and environmental factors and REC in the Western Balkan countries during the period 2005–2023. The research is based on a quantitative approach using secondary panel data collected from publicly available sources, primarily the World Bank.

Key variables include foreign direct investment (FDI), trade openness, labor force participation, gross fixed capital formation (GFCF), and CO_2 emissions per capita. The selection of variables is based on existing literature and theoretical frameworks such as the Porter Hypothesis, Environmental Kuznets Curve (EKC), and Energy Transition Theory.

The study applies panel data econometric techniques to test whether these selected variables significantly affect REC. The empirical design is structured to answer the defined research questions and test corresponding hypotheses.

Identifying variables of interest

Consistent with the variables identified in the literature, this study examines variables like REC, foreign direct investment (FDI), trade, labor force participation, gross fixed capital formation, and CO2 emissions with a purpose to better understand REC in Bosnia and Herzegovina, Serbia, Montenegro, Albania, and North Macedonia. This research delves into the period from 2005-2023. The data for this study was sourced from publicly available and reliable repositories, primarily the World Data Bank.

Methods and tests

Following the methodological approaches used in similar studies, several statistical methods and tests were employed to ensure robust and valid results. Descriptive statistics were first used to summarize the distribution, variability, and shape of each variable, including measures such as mean, standard deviation, skewness, kurtosis, and range. A poolability test was conducted to assess whether a pooled OLS model is appropriate across all entities; the high p-value indicated that model coefficients are stable throughout the sample.

To evaluate relationships between variables, both Kendall's tau and Spearman's rho correlation analyses were used. These non-parametric tests confirmed key associations, particularly the inverse relationship between CO_2 emissions and REC. The Jarque-Bera test was applied to test for normality of residuals.

The presence of cross-sectional dependence was tested using the Breusch-Pagan LM and Pesaran CD tests. Both showed statistically significant results, indicating that the assumption of independent entities in the panel dataset does not hold. Autocorrelation was assessed using the Wooldridge test, which confirmed serial correlation in the panel structure.

Stationarity of the variables was examined using the Augmented Dickey-Fuller (ADF) test. All variables were found to be stationary, satisfying a key requirement for panel data analysis. The Panel Granger Causality Test was used to determine whether past values of explanatory variables help predict the dependent variable across panel data units.

To determine the most appropriate panel data model, the Hausman test was applied. It showed that the random effects model is more consistent and appropriate than the fixed effects model. Additionally, the Lagrange Multiplier (LM) test for two-way effects confirmed the presence of significant individual and time-specific effects, supporting the use of random effects over pooled OLS.

The random effects model itself showed that CO_2 emissions have a significant negative impact on REC, while other variables such as FDI, trade, labor force participation, and GFCF were not statistically significant. For a more robust estimation, the Fully Modified Ordinary Least Squares (FMOLS) method was also applied, correcting for serial correlation and endogeneity. This model further confirmed the significance of CO_2 emissions, with other predictors remaining insignificant. Overall, combination of these methods ensures the validity and reliability of the findings.

Model empirical

The regression model to analyze the relationship between REC (Y) and the independent variables (FDI, trade, labor force participation rate, CO_2 emissions, and GFCF) is specified as:

$drenewableenergyconsumption_{it} = \alpha + \beta 1LnFDI_{it} + \beta_2 LnTrade_{it} + \beta_3 LaborForce_{it} + \beta_4 dCO_{2it} + \beta 5LnGFCF_{it} + u_{it}$

Where:

- $drenewableenergyconsumption_{it}$: First difference of REC (as a percentage of total energy consumption) for country i at time t.
- $LnFDI_{it}$: Logarithmic form of Foreign Direct Investment (as a percentage of GDP) for country i at time t.
- $LnTrade_{it}$: Logarithmic form of Trade (percentage of GDP) for country country i at time t.
- $LaborForce_{it}$: Labor force participation rate for country i at time t.
- dCO_{2it}: First difference of CO_2 emissions (in metric tons per capita) for country i at time t.
- $LnGFCF_{it}$: Logarithmic form of Gross Fixed Capital Formation (as a percentage of GDP) for country i at time t.
- u_{it}: Error term

RESULTS

Descriptive statistics provide insights into variable distribution and variability (Bhandari, 2020). The dependent variable *drenewableenergyconsumption* shows high variability (SD = 3.44), with a right-skewed, heavy-tailed distribution (skewness = 1.19, kurtosis = 8.22) and values ranging from -7.28 to 16.90, indicating significant fluctuations. dCO_2 has a modest positive trend (mean = 0.035), near-symmetric distribution (skewness = -0.07), and moderate variability (SD = 0.42), with values from -1.46 to 1.25. *Labor force participation* shows considerable variability (SD = 4.27), is slightly left-skewed (skewness = -0.36), and ranges from 43.41 to 60.32. *Lnfdi* exhibits moderate dispersion (SD = 0.85), strong left skew (skewness = -1.80), and extreme kurtosis (kurtosis = 10.86), with values from -2.78 to 3.62. *Lngfcf* shows a stable trend with low variance (SD = 0.17), near-symmetric distribution (skewness = 0.57), and slight leptokurtosis (kurtosis = 4.04). *Lntrade* has minimal variability (SD = 0.21), is nearly symmetric (skewness = 0.27), and slightly platykurtic (kurtosis = 2.61), with values between 4.09 and 5.11.

Figure 1 Descriptive Statistics

	Drenewableenergy consumption	dCO2	Labor.force. participation	Lnfdi	Lngfcf	Lntrade
Mean	0.288405	0.034831	52.72943	1.733754	3.146875	4.557545
Median	0.4	0.017899	53.618	1.835368	3.139863	4.570225
Maximum	16.9	1.250664	60.319	3.618255	3.669081	5.112875
Minimum	-7.282506	-1.457272	43.407	-2.776722	2.764519	4.086324
Std. Dev.	3.438201	0.419363	4.272143	0.851141	0.173664	0.205376
Skewness	1.187733	-0.070769	-0.359093	-1.796343	0.569887	0.270957
Kurtosis	8.217409	5.50215	2.324539	10.8627	4.0345	2.610266
Jarque-Bera	123.2407	23.55296	3.645141	280.2357	8.884781	1.67086
Probability	0	0.000008	0.16161	0	0.011768	0.433688
Sum	25.95649	3.134762	4745.649	156.0379	283.2188	410.1791
Sum Sq. Dev.	1052.089	15.65201	1624.357	64.47532	2.684163	3.753945
Observations	90	90	90	90	90	90

The poolability test checks whether it is appropriate to use the same regression coefficients for all individuals in a panel dataset. Under the null hypothesis (H_0), the model assumes uniform coefficients across individuals, indicating that pooled OLS is stable; the alternative hypothesis (H_1) suggests that the coefficients differ, implying instability and the need for a more flexible model. Because of high p value of 0.7266 and F-statistic of 0.77925 we can conclude that coefficients of the model are stable across the sample.

Figure 2 Poolability Test

F statistic
Data: drenewableenergyconsumption ~ Lnfdi + Lntrade + labor.force.participation + dCO2 + Lngfcf
F = 0.77925; df1 = 20; df2 = 60; p-value = 0.7266
"alternative hypothesis: unstability"

Significant relationships between the variables are presented by correlation analysis. DCO_2 and drenewableenergyconsumption show moderate negative relationship (–0.303), indicating that increases in RE usage correlate with decreases in carbon emissions. Relationships with LaborForceRate (0.005) and Lngfcf (-0.021) are insignificant, whereas weak negative associations are also observed with Lnfdi (-0.139) and Lntrade (-0.104).

Figure 3 Kendall's Correlation

	Drenewableenergy consumption	Lnfdi	Lntrade	LaborForceRate	Lngfcf	dCO2
Drenewableenergy consumption	1	-0.139565	-0.104486	0.0050119	-0.02129	-0.303435
Lnfdi	-0.139565	1	-0.024219	0.12436	0.1920099	0.0931358
Lntrade	-0.104486	-0.024219	1	0.1038387	-0.074157	0.0117353
LaborForceRate	0.0050119	0.12436	0.1038387	1	0.229241	-0.1238606
Lngfcf	-0.02129	0.1920099	-0.074157	0.229241	1	0.0082397
dCO2	-0.303435	0.0931358	0.0117353	-0.1238606	0.0082397	1

These results are supported by Spearman's correlations, which indicate a stronger inverse relationship between dCO_2 and REC (–0.441). Lnfdi (-0.204) and Lntrade (-0.161) also show negative but weaker correlations. LaborForceRate and Lngfcf have a moderately positive relationship (0.351), while LaborForceRate and dCO_2 have a slight negative relationship (–0.186). There is not a significant relationship between Lngfcf and dCO_2, as the result is negligible (0.005).

Figure 4 Spearman's Correlation

	Drenewableenergy consumption	Lnfdi	Lntrade	LaborForceRate	Lngfcf	dCO2
Drenewableenergy consumption	1	-0.203781	-0.161192	0.0204095	-0.0260819	-0.4412107
Lnfdi	-0.203781	1	-0.034761	0.1933909	0.2520395	0.1406676
Lntrade	-0.161192	-0.034761	1	0.0905463	-0.1345104	0.0190394
LaborForceRate	0.0204095	0.1933909	0.0905463	1	0.3507937	-0.1855381
Lngfcf	-0.026081	0.2520395	-0.13451	0.3507937	1	0.0049307
dCO2	-0.441211	0.1406676	0.0190394	-0.1855381	0.0049307	1

The Jarque-Bera test is a statistical test used to assess whether the residuals of a model follow a normal distribution, based on skewness and kurtosis (Jarque & Anil K. Bera, 1980). The test statistics are 221.63 with a probability value of 0.000000, which indicates that the residuals are not distributed normally, which will be taken into consideration in the analysis.

Figure 5: Jarque-Bera test

Series: Standardized Residuals	
Observations: 90	
Mean	0.013637
Median	0.157781
Maximum	16.25067
Minimum	-8.598868
Std. Dev.	3.111176
Skewness	1.196604
Kurtosis	10.30567
Jaraque-Bera	221.6259
Probability	0.000000

The Breusch-Pagan LM test is commonly used to detect the presence of cross-sectional dependence in panel data by examining the correlation of residuals across entities Breusch and Pagan (1980). Since Breusch-Pagan LM test and Pesaran CD tests yield statistically significant p-values (0.01166 and 0.00066 respectively), we reject the null hypothesis and conclude that cross-sectional dependence is present in the panel dataset.

Figure 6: *Breusch-Pagan LM test*

Breusch-Pagan LM test for cross-sectional dependence in panels
Data: drenewableenergyconsumption ~ Lnfdi + Lntrade + labor.force.participation + dCO2 + Lngfcf
Chisq=22.761; df=10, p-value = 0.01166
"alternative hypothesis: cross-sectional dependence"

The Wooldridge test is a reliable method for checking whether autocorrelation exists in panel data model, and since p-value is less than 0.05, we cannot reject H_0, and this confirms the presence of serial correlation in the panel data. Later models and tests account for this issue, so the overall analysis stays valid.

Augmented Dickey-Fuller (ADF) test was used to evaluate the stationarity of a variable in a time-dependent dataset. Sine p-values are equal to 0.01, the null hypothesis is rejected and the ADF test findings show that the variables are stationary.

Figure 7: *Augmented Dickey – Fuller Test*

„Augmented Dickey – Fuller Test – Panel Unit Root Testing (drenewableenergyconsumption)“
Data: pdata_clean
Dickey – Fuller = -4.8398; Lag order = 2; p-value = 0.01
“alternative hypothesis: stationary”
„Augmented Dickey – Fuller Test – Panel Unit Root Testing (Lnfdi)“
Data: pdata_Lnfdi
Dickey – Fuller = -4.2068; Lag order = 2; p-value = 0.01
“alternative hypothesis: stationary”
„Augmented Dickey – Fuller Test – Panel Unit Root Testing (Lntrade)“
Data: pdata_Lntrade
Dickey – Fuller = -9.7129; Lag order = 2; p-value = 0.01
“alternative hypothesis: stationary”
„Augmented Dickey – Fuller Test – Panel Unit Root Testing (Labor.force.participation)“
Data: pdata_ Labor.force.participation
Dickey – Fuller = -9.2817; Lag order = 2; p-value = 0.01
“alternative hypothesis: stationary”
„Augmented Dickey – Fuller Test – Panel Unit Root Testing (Lngfcf)“
Data: pdata_ Labor.force.participation
Dickey – Fuller = -4.5774; Lag order = 2; p-value = 0.01
“alternative hypothesis: stationary”
„Augmented Dickey – Fuller Test – Panel Unit Root Testing (dCO2)“
Data: pdata_ Labor.force.participation
Dickey – Fuller = -4.7184; Lag order = 4; p-value = 0.01
“alternative hypothesis: stationary”

The Panel Granger Causality Test (PGCT), proposed by Dumitrescu and Hurlin (2012), assesses whether past values of explanatory variables help predict the dependent variable across panel data units. In the given results, all p-values are greater than 0.05, so we fail to reject the null hypothesis—indicating no evidence of Granger causality between the tested variables and REC.

The Hausman test was used to determine the effectiveness of the random effects (or fixed effects) model is compared to that of the fixed effects (or random effects) model. Since the test result shows that p-value is equal to 0.9986, which is far greater than conventional significance level 0.05, we fail to reject H_0 hypothesis. This means that Random Effects Model is consistent and more suitable for this model.

Figure 8: *Hausman Test*

Hausman Test
Data: drenewableenergyconsumption ~ Lnfdi + Lntrade + labor.force.participation + dCO2 + Lngfcf
Chisq = 0.23907; df = 5; p-value = 0.9986
“alternative hypothesis: one model is inconsistent”

The Lagrange Multiplier (LM) Test for two-way effects, developed by Gouriéroux, Holly, and Monfort (1981), is used in panel data analysis to detect unobserved individual and time-specific effects. It helps determine whether a pooled OLS model is appropriate or if a panel model that accounts for these effects is needed. The Lagrange Multiplier test (p = 0.0012) indicates significant individual and time effects, supporting the use of a random effects model over pooled OLS.

The primary model used for this research is the Random Effects model, validated through diagnostic tests. The random effects model shows that CO_2 emissions have a significant negative impact on REC (p ≈ 0.00006), while other variables like FDI, trade, labor force, and GFCF are not significant. Most variation comes from within-entity differences.

The findings also reveal that the model's idiosyncratic component, part of the model capturing changes within each country over time, has a value of 9.944 and a standard deviation of 3.153. On the other hand, the part of the model that captures differences between individual countries has a value of zero, which means that there isn't much variation caused by country-specific factors.

The model explains 19.6% of the variation and is overall statistically significant (p = 0.001).

Table 9. Random Effects model in R

One way effects Random Effect Model					
Call: plm(formula = drenewableenergyconsumption ~ LnFDI + LnTrade + labor_participation + LnGFCF + dCO2, data=pdata, model = ”random”)					
“Balanced Panel”: n = 5, T = 18, N = 90					
Effects:					
	Var	“std.dev”	share		
Idiosyncratic	9.944	3.153	1		
Individual	0.000	0.000	0		
Residuals:					
Min = -8.585637 1st Qu = -1.561085 Median = -0.059965 3rd Qu = 1.612884 Max = 16.104212					
Coefficients:					
	Estimate	“Std.Error”	“t-value”	“Pr(>abs.z)”	
Intercept	12.731850	10.220584	1.2457	0.2129	
Lnfdi	-0.401305	0.411804	-0.9745	0.3298	
Lntrade	-1-872519	1.655925	-1.1308	0.2581	
LaborForceRate	-0.054953	0.082719	-0.0317	0.9747	
Lngfcf	-0.064170	2.025762	-0.0317	0.9747	
dCO2	-3.272855	0.819324	-3.9946	6.481e-05***	
“Total sum of squares”		1052.1	“Residual Sum of Squares”		845.86
“R^2”	0.19602	“Adj. R^2”	0.14816	Chisq	20.4802 on 5 Df
P-value:	0.0010152				

The FMOLS results show that *dCO_2* is the only statistically significant variable (p = 0.000), with a coefficient of –3.145, indicating that a 1% increase in emissions leads to a 3.145% decrease in REC, holding other factors constant. Other variables (*LaborForceRate*, *Lnfdi*, *Lngfcf*, *Lntrade*) are not statistically significant despite some positive or negative coefficients. The model explains 21.73% of the variation (adjusted R^2 = 0.2173), and accounts for serial correlation and endogeneity using a long-run variance of 5.2740.

DISCUSSION

This research highlights key factors that impact REC in Western Balkan countries. Five variables were analyzed: foreign direct investment (FDI), trade openness, labor force participation, gross fixed capital formation (GFCF), and CO_2 emissions per capita. Among these, only CO_2 emissions showed a statistically significant effect on REC.

The random effects model indicates a negative relationship between CO_2 emissions and renewable energy use, meaning that higher emissions are associated with a lower share of renewables in the energy mix. This implies that the transition to greener energy sources may be limited by structural and policy barriers. Additionally, these findings align with the Environmental Kuznets Curve (EKC) theory, which proposes that environmental degradation worsens during early EG but improves as cleaner technologies are adopted. However, this transition toward sustainability may still be incomplete in the Western Balkans.

In contrast, economic indicators such as FDI, trade openness, labor participation, and GFCF did not exhibit statistically significant effects. This suggests that the mere presence of capital flows or trade activities does not guarantee progress in RE deployment, possibly due to institutional weaknesses, lack of policy enforcement, or insufficient alignment between investment and green infrastructure. The findings corroborate previous literature suggesting that the impact of FDI and trade on renewables depends heavily on the regulatory and institutional context.

The model also shows that most of the variation in REC comes from within-country changes over time, rather than differences between countries. The research indicates that internal national policies together with institutional reforms and temporary economic disruptions including the COVID-19 outbreak, and energy price changes have a greater impact than fundamental differences between countries. The sample demonstrates that these countries experience equivalent fundamental economic and institutional factors which influence their RE transition.

The FMOLS model confirms the direction and significance of the CO_2 variable, reinforcing the conclusion that environmental degradation has a tangible suppressive effect on

RE growth. Other variables remained statistically insignificant, reinforcing the notion that economic activity alone—without environmental stringency and targeted green policies—may be insufficient to drive REC.

CONCLUSION

This study analyzes how foreign direct investment (FDI), trade openness, labor force participation, gross fixed capital formation (GFCF), and CO_2 emissions per capita influence REC in five Western Balkan nations from 2005 to 2023. Using a panel dataset and employing random effects and FMOLS models, the analysis reveals that only CO_2 emissions have a statistically significant negative influence on REC. In contrast, FDI, trade, labor participation, and capital formation show no statistically meaningful impact. These results underscore the persistent reliance on non-renewable energy sources and suggest that rising emissions may inhibit the development and integration of RE in the region.

Although this study sheds important light on the factors influencing renewable energy consumption (REC) in the Western Balkans, it is important to recognize certain limitations. The analysis is limited to five countries within this specific region, which narrows the applicability of the results to broader, global contexts. The distinct economic, political, and energy sector characteristics of these countries may differ significantly from those in more developed or diversified energy systems, thereby constraining the external validity of the findings.

Moreover, while the study incorporates key economic and environmental indicators, such as foreign direct investment, trade openness, labor force participation, gross fixed capital formation, and CO_2 emissions, it does not address institutional or regulatory elements that could play a crucial role in shaping renewable energy outcomes. Variables like the quality of environmental governance, institutional capacity, regulatory stability, and policy incentives for renewable energy were not examined, which may have limited the depth of the analysis.

Western Balkan nations should prioritize lowering CO_2 emissions to mitigate their negative impact on REC. This might be accomplished by improving environmental policies, implementing incentives and grants for RE projects, and adjusting energy infrastructure in order to promote the establishment of clean technology. Furthermore, investing in public awareness campaigns and education about the need of renewable energy, as well as enhancing institutional support, could result in the more stable and efficient implementation of energy reform.

Future research could benefit from incorporating these institutional and political dimensions, including the impact of environmental legislation, administrative efficiency, and political stability. Such additions would enrich the understanding of REC determinants and help explain country-specific differences in energy transitions. Further, extending the research to a larger sample of countries, either within Southeast Europe or globally, and increasing the time span could enhance comparative insights and reflect long-term trends, especially in light of recent shifts in EU climate and energy policies.

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