THE CORRELATION BETWEEN RENEVABLE ENERGY CONSUMPTION AND CO2 EMISSIONS IN WESTERN BALKAN COUNTRIES

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Abstract: Transitioning to renewable energy is a crucial strategy to reduce CO2 emissions. By replacing fossil fuels with renewables, countries can alleviate the effects of climate change, improve air quality, and move toward sustainable development goals. Thus, this research article analyses the correlation between CO_2 emissions and renewable energy consumption in the Western Balkans, a region facing with pronounced confronts regarding economic development and environmental sustainability. Using panel data regression analysis over the period 2002-2022, through the static and dynamic models, it has been examined the extent to which renewable energy contributes to reducing carbon emissions. The results indicate a statistically significant inverse relationship between renewable energy consumption and CO_2 emissions, pointing out the importance of investment on renewable energy as a key driver of decarbonization of the region. However, the findings also reveal substantial variability in renewable energy adoption across countries, influenced by economic structures as well as investment in green technologies. Thus, there is a need for consistent and coordinated regional strategies to enhance renewable energy capacity and improve energy efficiency.
Keywords: Renewable energy, CO2 emissions, Energy efficiency, Sustainability, Western Balkan

1. INTRODUCTION

The relationship between renewable energy and CO_2 emissions has gained significant research attention due to its role in addressing global climate change. Renewable energy sources such as wind, solar, and hydropower are imperative of the time in reducing CO_2 emissions, as they generate energy with minimal greenhouse gas output compared to fossil fuels. Empirical studies consistently prove a negative correlation between renewable energy consumption and CO_2 emissions (Moutinho and Robaina, 2016; Olabi and Abdelkareem, 2022; Zuhal and Göcen, 2024; Sadiku and Madzova 2024). The most recent study by Attanayake et al. (2024) for 138 countries over 27 years showed that increased renewable energy adoption significantly lowers CO_2 levels, particularly in countries with strong policy frameworks.

In some countries, the transition to renewables is particularly impactful. Research indicates that renewable energy adoption, combined with quality governance and sustainable economic development strategies, helps reduce emissions while addressing resource needs as well as spurring the economic development (Maradin, Cerović and Mjeda, 2017). Similarly, studies for the European Union focus renewable energy's long-term effectiveness in reducing emissions, despite the varying frequency of adoption. These findings emphasize the global importance of renewable energy for achieving sustainability targets. While challenges such as high initial investments and technological barriers remain, declining costs and improved accessibility are accelerating the shift towards cleaner energy systems.

The Western Balkan countries face similar challenges in the transition to renewable energy. This region depends on coal for electricity, like Kosovo, Bosnia and Herzegovina, and Serbia generating 60–95% of their electricity from coal (Bechev, 2023). However, renewable energy sources such as hydropower, solar, and wind are increasingly part of the energy mix, although their share remains low compared to coal in most of the countries, except for Albania, which relies almost entirely on hydropower for electricity generation. Albania leads with 37.3% of its energy from renewables, mostly hydropower, while other countries like Serbia and North Macedonia are gradually incorporating solar and wind projects. Efforts to align with the European Green Deal standards have seen some progress, such as Montenegro introducing a carbon-pricing scheme. However, slow implementation and heavy dependence on coal continue to remain the main problem. The solar and wind potential in the region is substantial and underutilized, with a capacity of 94.4 GW estimated across the Western Balkans under optimal scenarios (Fejzič et al. 2024; Frey, 2024; Bechev, 2023).

The transition to renewables in the Western Balkans also has implications for decarbonization. For example, increasing the use of solar energy may shift hydropower operations toward balancing roles instead of baseload supply, reflecting a broader reconfiguration of the energy mix. Still, the challenge remains substantial due to political, economic, and infrastructural constraints (Fejzič et al. 2024). Therefore, this research article examines the

correlation between CO_2 emissions and renewable energy consumption for this set of countries employing an empirical investigation and using econometric models for panel data.

2. METHODOLOGY AND DATA

This study investigates the correlation between renewable energy consumption and CO2 emissions in Western Balkan (WB) countries using panel data analysis for the period 2002–2022. To address the research objectives, both static and dynamic panel models are used. In order to account for the endogeneity and dynamic nature of the variables the system GMM model will be performed besides the fixed effects (FE) and random effects (RE).

2.1 Model Specification

The static panel model is specified as follows:

$$CO2_{it} = \Psi RE_{it} + \Phi X_{it} + \alpha_i + \varepsilon_{it}$$

Where $CO2_{it}$ represents the dependent variable (CO2 emissions) for country i at time t. RE_{it} is the independent variable of interest (renewable energy) for country i at time t. Ψ is the coefficient of interest, representing the marginal effects of renewable energy on CO2 emissions. X_{it} is a vector of control variables, including GDP per capita growth, exports, fixed capital, and two institutional variables, such as corruption and government effectiveness. α_i represent the country-specific fixed effects. ε_{it} is the error term, representing unobserved factors affecting the dependent variable.

Fixed effects (FE) and random effects (RE) estimators are employed, considering the Hausman test to determine the appropriate model. Robust standard errors are used to address heteroskedasticity and serial correlation.

For the dynamic analysis, it has been used a Generalized Method of Moments (GMM) approach to estimate the following model:

$$CO2_{it} = \gamma CO2_{i,t-1} + \Psi RE_{it} + \Phi X_{it} + \eta_i + v_{it}$$

Where $CO2_{i,t-1}$is the lagged dependent variable, capturing the persistence of CO2 emissions. η_i represents unobserved country-specific effects, and v_{it} is the idiosyncratic error term.

The system GMM estimator, developed by Arellano and Bover (1995) and Blundell and Bond (1998), is applied to address potential endogeneity and ensure consistency of the estimators. Instrument validity is checked using the Hansen test for overidentifying restrictions and the Arellano-Bond test for serial correlation in residuals.

2.2 Data Sources and description of variables

The data for all used variables, such as CO2 emissions, renewable energy consumption, and other control variables are sourced from the World Bank's World Development Indicators (WDI). The dataset includes 5 WB countries (Albania, Bosnia & Herzegovina, Montenegro, North Macedonia and Serbia, whereas Kosovo is excluded from the sample due to lack of data for most of years in the time spin 2002-2022), ensuring sufficient cross-sectional and temporal variation for robust analysis. Table 1 provides details of variables, containing the abbreviations and their definitions.

Table 1. Variables' description

Variable Abbreviation	Definition of variables
CO2	CO2 emissions (metric tons per capita)
RE	Renewable energy consumption (% of total final energy consumption)
GDPCG	Real GDP per capita growth
EXP	Exports of goods and services (% of GDP)
GFCF	Gross fixed capital formation (% of GDP)
CORR	Control of Corruption: Percentile Rank
GVEF	Government Effectiveness: Percentile Rank

Source: Author's research

3. EMPIRICAL RESULTS

The initial analysis includes descriptive statistics for the key variables across Western Balkan countries during the study period. The average CO2 emissions is 4.24 metric tons per capita, with substantial variability between countries. The share of renewable energy in total energy consumption ranged from 14.03 to 49.34 percent of total energy consumption, reflecting differences in energy infrastructure and policy frameworks across the region. Control variables such as GDP per capita growth, exports, capital formation and institutional variables also exhibit notable variation, highlighting the diversity of economic and institutional characteristics within the sample (see Table 2).

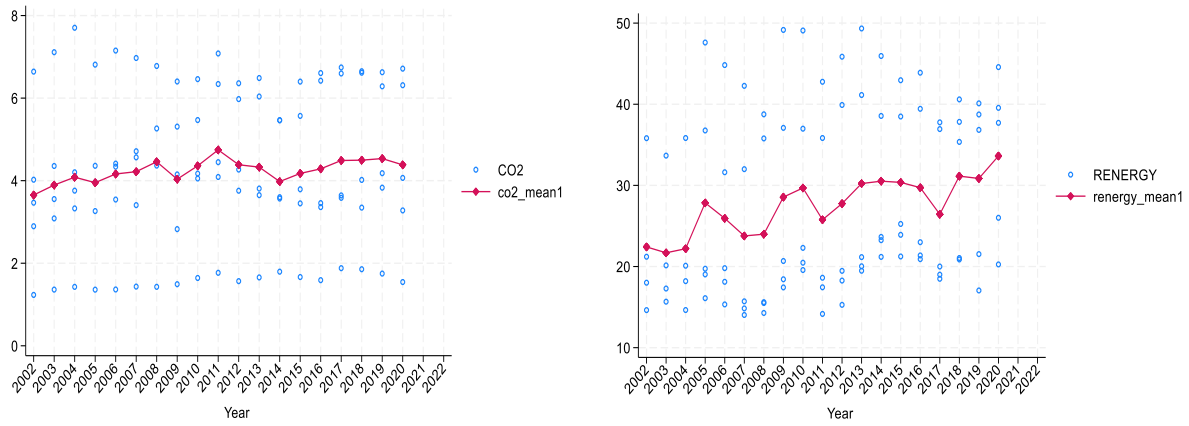
Table 2: Descriptive Statistics

Variable	Observations	Mean	St.Deviation	Min	Max
CO2	102	4.243383	1.824402	1.233002	7.704823
RE	98	27.67707	10.98618	14.03	49.34
GDPCG	105	3.610976	3.576361	-15.20847	13.42593
EXP	105	36.87555	11.19543	19.12601	74.89457
GFCF	103	23.60351	5.306707	13.29887	39.21585
CORR	105	41.61639	9.384465	22.75132	56.39811
GVEF	102	45.36889	12.2465	11.89189	64.42308

Source: Author's calculations

In Figure 1 below are displayed the trends of means of CO2 emissions and renewable energy over years of WB countries. Each point in the line represents the averages of variables of WB countries in the panel for each year. In this case it can be observed a slightly decreasing trend in the mean of CO2 emissions in the last two years and an increasing trend for renewable energy.

Figure 1. CO2 emissions and Renewable Energy of Western Balkan countries.

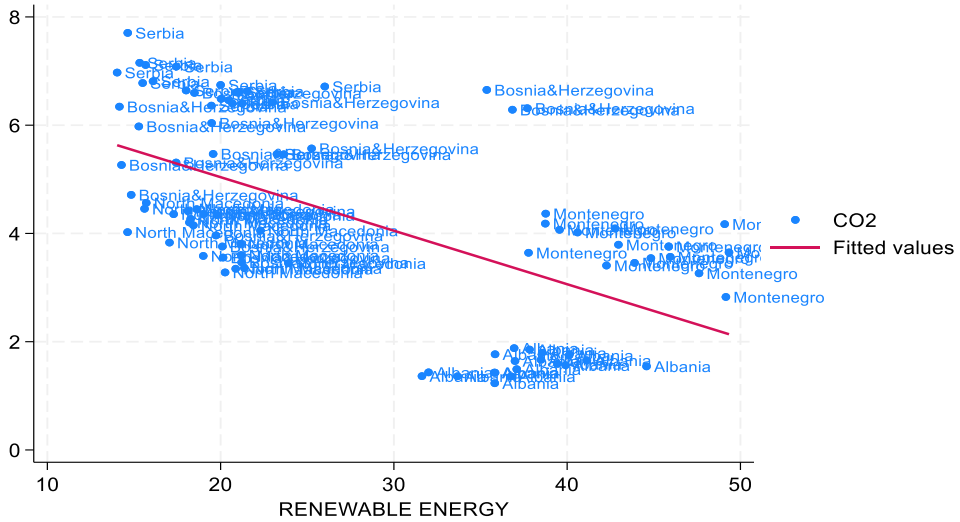


Source: Author's calculations

The results from both static and dynamic panel regression models are presented in Table 3. The fixed effects (FE) and random effects (RE) models were first estimated and afterwards, the Hausman test is performed, which results suggest that the RE model is suitable for this sample of data. Thus, the coefficient for renewable energy consumption in the random effects model (RE) suggests that higher renewable energy adoption is associated with reduced CO2 emissions. The coefficient is with negative sign and highly statistically significant. The negative correlation among them can additionally be observed from the OLS fitted line (see Figure 2). The GDP per capita growth is positively correlated with emissions, but its coefficient is not statistically significant doubting the environmental Kuznets curve hypothesis. Also, based on the results of random effects, exports do not significantly affect CO2 emissions, reflecting that the nature of the exports may determine their environmental impact. Regarding other control variables such as investment in capital, measured by gross fixed capital formation (GFCF), has a highly significant negative effect on CO_2 emissions. This finding suggests that investments in infrastructure, machinery, and technology likely contribute to more energy-efficient production processes, thereby reducing

emissions. It also indicates the potential role of sustainable investments in determining a greener economy. Corruption has a statistically significant and positive effect on CO_2 emissions. A higher level of corruption is associated with increased emissions. This could be due to weak enforcement of environmental regulations. Corrupt practices often lead to environmental degradation as businesses and industries may avoid environmental regulations for their gains. Government effectiveness has a statistically significant negative effect on CO_2 emissions, implying that better regulatory frameworks, and efficient public policies play an important role in reducing environmental pollution.

Figure 2. Correlation between renewable energy and CO2 emissions



Source: Author's calculations

Table 3. Panel regression results

Variables	Random Effects	Fixed Effects	System GMM
RE	-0.0484691 *** (0.000)	-0.0113056** (0.0242)	-0.0895893** (0.053)
CO2t-1	-	-	0.9205983*** (0.000)
GDPCG	0.0567789 (0.136)	0.0063553 (0.749)	0.0792137 (0.281)
EXP	0.0107072 (0.483)	0.0035387 (0.526)	0.2089316 (0.168)
GFCF	-0.1841079*** (0.000)	-0.0261456** (0.032)	-0.2177029** (0.024)
CORR	0 .0420073 (0.005)	-0.0218165* (0.053)	0.026599** (0.032)
GVEF	-0.0383047*** (0.007)	0.0129915* (0.064)	-0.1510415 (0.054)
Constant	9.448704 (0.057)	6.586 (0.094)	4.936412 (0.118)
Hausman test	chi2(5) =3.77 Prob>chi2 = 0.180	-	-
Heteroscedasticity Test	Chi2(78)=1.979 Prob>chi2 = 0.121	-	-

Serial correlation Wooldridge test	Prob>F = 0.462	-	-
Arellano-Bond test for AR(1)	-	-	Pr > z = 0.049
Arellano-Bond test for AR(2)	-	-	Pr > z = 0.153
Sargan test	-	-	Prob > chi2 = 0.057
Hansen test	-	-	Prob > chi2 = 0.366

*** indicates statistical significance at the 1% level and ** indicates statistical significance at the 5% level.
Source: Author's calculations

Dynamic panel model estimates using the system GMM approach are also shown in Table 3. The lagged dependent variable $CO2_{i,t-1}$ is positive and significant, indicating persistence in CO2 emissions over time. The coefficient for renewable energy consumption remains negative but statistically significant at 5% level, reaffirming the importance of renewable energy in mitigating emissions. Regarding other variables statistical significance have only shown the gross fixed capital formation and corruption which are with the same signs as in the static models, while GDP per capita growth and exports are found to be again statistically insignificant. Unlike static models where the coefficient of government effectiveness was statistically significant, in the system GMM, it doesn't significantly affect the CO2 emissions. The result of Hansen test confirms the validity of the instruments (p-value = 0.366), and the Arellano-Bond test shows no evidence of second-order serial correlation (p-value = 0.153) which assure the consistency and efficiency of the results.

4. CONCLUSSION

This study examined the relationship between renewable energy consumption and CO2 emissions in Western Balkan (WB) countries using static and dynamic panel data models. The findings provide strong evidence that increasing the share of renewable energy consumption contributes significantly to reducing CO2 emissions in the region, pointing out the powerful role of renewable energy in achieving sustainable development objectives. The persistence of emissions suggests the need for long-term strategies and consistent policy efforts to decarbonize the energy sector. Control variables further highlight the correlation between investments in fixed capital, corruption, government effectiveness and environmental consequences. The results align with existing literature on the emissions-reducing potential of renewable energy and offer insights for policymakers in this region to balance economic growth with environmental sustainability. Thus, governments should prioritize investments in renewable energy infrastructure, strengthen regulatory frameworks to support clean energy transitions, and more important implement the regulations of environment protection. Additionally, fostering regional cooperation in renewable energy projects could enhance resource efficiency and accelerate progress toward achieving sustainable development goals.

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