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The Effects of Macroeconomic Indicators on Renewable Energy Use: The Case of Eastern Europe

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ABSTRACT

This study examines how carbon dioxide (CO_2) emissions per capita, Gross Domestic Product (GDP) per capita, percentage of trade in GDP, inflation and foreign direct investment (FDI) data for 8 Eastern European countries (Romania, Bulgaria, Poland, Czechia, Moldova, Hungary, Slovakia, Moldova, Hungary, Slovakia and Belarus) for the period 1992-2021 affect percentage of renewable energy consumption in total energy consumption. The seemingly unrelated regression (SUR) model is the methodology employed in this investigation. According to the SUR model's results, the increase in per capita income increases the share of renewable energy consumption in all countries. However, the increase in per capita CO_2 emissions has reduced the share of renewable energy consumption. Although the impact of inflation, trade, and FDI on renewable energy consumption differs across countries, this effect is at a lower level compared to the income effect. The nations with comparatively higher rates of sustainable green growth are Poland, Moldova, and Slovakia. Hungary, Belarus, and Czechia, on the other hand, have a comparatively lesser propensity to use renewable energy.

Keywords: Growth, Inflation, Trade, Foreign direct investment, Seemingly Unrelated Regression

JEL Classification: E01, E31, C01

Makroekonomik Göstergelerin Yenilenebilir Enerji Kullanımı Üzerindeki Etkileri: Doğu Avrupa Örneği

ÖZ

Bu çalışma, 1992-2021 dönemi için 8 Doğu Avrupa ülkesi (Romanya, Bulgaristan, Polonya, Çekya, Moldova, Macaristan, Slovakya, Moldova, Macaristan, Slovakya ve Belarus) için kişi başına karbondioksit emisyonu, kişi başına Gayri Safi Yurtiçi Hasıla (GSYİH), GSYİH içindeki ticaret yüzdesi, enflasyon ve doğrudan yabancı yatırım verilerinin yenilenebilir enerji tüketiminin toplam enerji tüketimi içindeki yüzdesini nasıl etkilediğini incelemektedir. Görünüşte ilişkisiz regresyon (SUR) modeli bu araştırmada kullanılan metodolojidir. SUR modelinin sonuçlarına göre, kişi başına düşen gelirdeki artış tüm ülkelerde yenilenebilir enerji tüketiminin payını artırmaktadır. Ancak, kişi başına düşen karbon emisyonundaki artış yenilenebilir enerji tüketiminin payını azaltmıştır. Enflasyon, ticaret ve doğrudan yabancı yatırımların yenilenebilir enerji tüketimi üzerindeki etkisi ülkeler arasında farklılık gösterse de bu etki gelir etkisine kıyasla daha düşük düzeydedir. Sürdürülebilir yeşil büyüme oranları nispeten daha yüksek olan ülkeler Polonya, Moldova ve Slovakya'dır. Macaristan, Belarus ve Çekya ise yenilenebilir enerji kullanma konusunda nispeten daha az eğilime sahiptir.

Anahtar Kelimeler: Büyüme, Enflasyon, Ticaret, Doğrudan Yabancı Yatırım, Görünürde İlişkisiz Regresyon

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1. INTRODUCTION

Although climate change is primarily considered an environmental issue, economists have begun to examine its economic implications due to the growing impact of natural disasters like floods and droughts. This shift has led to the incorporation of climate change, a naturally occurring phenomenon, into the field of economics (Çakır ve diğerleri, 2024, s. 341). The primary contributor to the global climate crisis is the continuous increase in fossil fuel consumption. A fundamental measure to address this crisis is transitioning to renewable energy sources while maintaining economic growth. As global production and consumption increase, energy demand escalates. In this context, fossil fuels continue to dominate most industries worldwide. The persistent reliance on fossil fuels presents a substantial obstacle to implementing climate change measures. Therefore, transitioning to environmentally sustainable energy alternatives and advocating for this transition are essential for mitigating climate change (Görgülü, 2022). Since the Industrial Revolution, reliance on conventional energy sources, particularly fossil fuel combustion, has markedly increased global CO_2 emissions, contributing to global warming and climate change. Efficient and judicious energy use has become critical for sustainable development. The rapid increase in energy demand is depleting resources, and adverse effects of traditional energy consumption are becoming apparent. Consequently, concerns about energy security and global warming are propelling the global community towards greater reliance on renewable energy sources in the future (Zhang et al., 2024). Renewable energy is a clean, carbon-neutral form developed through innovative technologies, distinguishing it from traditional fossil fuels. It differs from fossil energy in theoretical technology, utilization cost, environmental impact and management strategies. As advancements in renewable energy technology, artificial intelligence, and novel materials continue, the industry has seen significant breakthroughs recently. Nevertheless, global energy consumption remains predominantly dependent on fossil fuels, with renewable energy comprising only a minor portion of the total (Zhang et al., 2021).

The extent to which macro variables such as GDP per capita, trade volume, FDI, and inflation support renewable energy consumption is crucial for sustainable growth. Economic growth and energy demand are interdependent. Energy resources that meet the demand for economic growth are related to a country's energy policies, technological infrastructure, and macroeconomic outlook. Investments in energy transitions are hampered by economic instability. Negative indicators can hinder the development of renewable energy projects. Although clean technologies offer several benefits, the path toward sustainability remains uncertain. A rapid transition could lower the prices of both clean technologies and conventional energy. A slower transition may raise energy prices owing to limited fossil fuels before sufficient clean energy is established. In the long term, decreasing costs of clean energy and declining fossil fuel demand are likely to drive energy prices down. International agreements address financial deficits in climate change adaptation in developing countries. Although the private sector is expected to play a significant role in renewable energy production, global organizations recognize the ongoing need for public funding, particularly for grid infrastructure and high-emission sectors. The global increase in renewable energy usage is linked to the macroeconomic stability. Trade cooperation with economies that have strict CO_2 emission rules can encourage renewable energy diffusion. Improving access to renewable technologies and supporting environmental regulations can increase the share of renewable energy in total consumption. Stringent environmental regulations facilitate ecological transitions. Public research and development funding for renewable energy technologies has played a pivotal role. Well-designed policies can align decarbonization efforts with economic stability (Cappelli and Carnazza, 2025). In contrast, a trade model based on fossil fuel imports can lead to a low share of renewable energy in total energy consumption. FDI's impact on renewable energy consumption varies depending on investment orientation, environmental policies, and local market conditions. FDI in renewable projects can increase consumption through capital accumulation and innovation, while FDI in fossil fuel-intensive sectors can reduce it. Countries' strategies to attract sustainable energy investors are influential in meeting energy demand. Both strong climate policies and broader investment drivers are necessary for an enabling renewable energy environment. Investing in renewable energy is imperative for mitigating climate change risk. FDI can significantly accelerate the transition to a carbon-neutral economy by providing essential financial and technological resources for green growth. As countries intensify efforts to diversify energy sources and enhance independence in response to geopolitical tensions, attracting FDI for environmental policy objectives has become challenging. Understanding the macroeconomic factors that facilitate FDI in the renewable energy sector is crucial (Knutsson and Flores, 2022).

In numerous Eastern European countries, coal mining and dependence on fossil fuels for industrial purposes exacerbate environmental challenges, a trend rooted in historical practices. Fossil fuel subsidies persist in the country. However, renewable energy technology costs have begun to decline as investments increase. Despite this, research indicates Eastern European nations lag other European countries in transitioning to renewable energy, primarily due to bureaucratic impediments. According to "Empowering Central and Eastern Europe 2024," although Eastern European countries are progressing in renewable energy, they have not fully realized their potential. The report highlights that even as the region advances towards renewable energy, it continues expanding gas infrastructure, particularly in cross-border transmission systems. The principal challenges confronting Eastern Europe's energy transition are inadequate investment and infrastructural deficiencies (Czyzak and Theisen, 2024). The aging infrastructure of electricity grids is likely to face challenges in adapting to intermittent power plants. In some Eastern European countries, a significant share of the population is employed in the coal industry. Instability and unpredictability in policy frameworks for renewable energy support programs are major factors limiting energy transition in Eastern Europe. Minimizing bureaucratic processes for implementing wind, hydropower, and solar energy, alongside offering technical support to enhance efficient utilization of EU funds, is crucial for addressing these challenges (Muoneke et al., 2023).

The transition to renewable energy consumption in Eastern European countries is of great importance for enhancing energy security, harmonizing with EU policies, boosting economic growth and promoting environmental sustainability. Many Eastern European countries are members of the European Union or have trade ties with the European Union. The EU's Green Deal program aims to achieve carbon neutrality by 2050 and calls on member states to change their energy policies in favor of renewable energy. The EU's Green Deal program for the expected energy transition requires specific institutional arrangements for participating countries. In order to ensure the sustainability of the investments of the institutions investing in the renewable energy sector, a stable public policy as well as dynamic research and development programs are expected from the countries in the Green Deal program (Gürdal, 2024, s. 319).

The high dependence on Russia to meet energy demand makes security of energy supply an important issue for the European Union as well. The main motivation of this study is to investigate the extent to which the transition to renewable energy consumption has been achieved in Eastern European countries. To this end, we examine how the use of renewable energy in eight Eastern European countries is affected by economic size, trade, FDI and inflation. Achieving sustainable development goals and addressing climate change require an understanding of how economic dynamics affect renewable energy use, especially at a time when Europe's energy supply security has become a top priority due to the conflict between Russia and Ukraine. This study uses the SUR model, introduced by Zellner in 1962, for evaluations. The SUR model is a framework of multiple regression equations estimated simultaneously, allowing correlation of error terms across equations. Each equation has its own dependent and independent variables, but disturbances are assumed correlated, capturing interdependencies. The SUR model is advantageous for analyzing macroeconomic factors influencing renewable energy consumption in Europe. European countries may show interdependencies in energy policies, economic conditions, and technological advancements. The SUR model accommodates correlated error terms, capturing connections that single-equation models might miss. By leveraging error correlations, the SUR model provides more efficient estimates than Ordinary Least Squares, especially when explanatory variables differ across equations (Srivastava and Dwivedi, 1979). Factors like GDP growth, energy prices, carbon regulations, and technological innovations may impact European nations variably. The SUR model considers these interdependencies. By accounting for country-level variations, it can offer accurate policy recommendations, aiding policymakers in deciding whether regional strategies should be unified or tailored. The SUR model provides a robust framework for evaluating how macroeconomic variables influence renewable energy consumption patterns in Europe, addressing interdependencies and enhancing forecasting efficiency.

2. LITERATURE

Many studies have investigated the macroeconomic determinants of renewable energy consumption in various countries. However, there are complex relationships between renewable energy consumption and macroeconomic variables. In their study on Malaysia, Yusoff et al. found that both economic growth and urbanization have a positive impact on renewable energy adoption, while FDI, trade liberalization, and CO_2 emissions can have negative effects. The study also states that domestic investment and financial development do not significantly affect renewable-energy consumption in the long run (Yusoff et al.,2023). In their study conducted in 2021, Yıldırım and Kaya found that GDP fluctuations are the strongest determinant of renewable energy use in selected OECD countries. In addition, the study states that the current account balance, economic growth, inflation, and oil prices equally affect renewable energy use (Yıldırım ve Kaya, 2021). Vyrostkova et al. concluded that a higher level of GDP per capita positively affects the renewable energy ratio in the Eurozone. Conversely, the findings of the research show that unemployment rates, financial development, and inflation adversely affect the proportion of renewable energy consumed relative to overall energy consumption (Vyrostkova et al., 2024).

The theories used to analyze how renewable energy consumption is affected by macroeconomic indicators are mostly the environmental Kuznets curve, Porter, Green Growth and Pollution Haven Hypotheses. Mahmood et al. evaluated 69 studies on the Environmental Kuznets Curve and stated that 57 of the 69 studies confirmed the Environmental Kuznets Curve hypothesis, while 12 studies did not confirm the Environmental Kuznets Curve. 64 out of 69 studies find that renewable energy consumption helps to reduce emissions, while 5 studies find that renewable energy consumption has a negligible impact on emissions. Compared to country-specific studies, panel studies report more evidence for the validity of the Environmental Kuznets Curve, while country-specific studies provide more evidence for the positive environmental impact of renewable energy consumption (Mahmood et al., 2023). In contrast, Destek and Sinha, in their study for 24 OECD countries, found a U-shaped relationship between economic growth and ecological footprint, contradicting the environmental Kuznets curve hypothesis, while still confirming that increasing renewable energy consumption reduces environmental degradation. These conflicting results indicate that the relationship between economic growth, renewable energy usage, and environmental quality is complex and may vary depending on the context and indicators utilized (Destek and Sinha, 2020).

The renewable energy sector supports the Porter Hypothesis, which proposes that rigorous environmental rules can spur innovation. According to studies, stronger environmental restrictions and early adoption of renewable energy policies promote innovation and export advantages in solar and wind energy technology (Li and Shao, 2023). Renewable energy consumption and energy efficiency have been shown to have a favorable impact on technical innovation, as evidenced by trademark and patent applications (Wen et al., 2022). Recent studies have also examined the relationship between renewable energy consumption and green economic growth for various countries. Taşkın et al. found that both renewable energy usage and trade liberalization contribute positively to environmentally sustainable economic development. Notably, the long-term influence of trade openness on green economic growth surpasses that of renewable energy consumption. Additionally, the study reveals a two-way causal link between green economic expansion and the use of renewable energy sources, lending support to the feedback hypothesis (Taşkın et al., 2020). Conversely, Alataş determined that in developing nations, the impact of consuming renewable energy on environmentally sustainable economic growth is statistically significant and unfavorable. The study's results indicate that in these countries, the utilization of renewable energy sources fails to contribute to sustainable economic development (Alataş, 2022). According to Ashfag et al., the consumption of renewable energy in G-20 nations has been substantially boosted by economic globalization and green economic growth. Nevertheless, even though highly industrialized countries have embraced renewable energy, their emission levels continue to be considerable (Ashfag, et al., 2024). Research conducted by Ghafoof et al. on OECD nations reveals a substantial inverse correlation between green growth and environmental deterioration. The study's results indicate that non-green growth exhibits a U-inverted relationship with environmental degradation, supporting the Environmental Kuznets Curve hypothesis. The research also shows that environmentally friendly technological advancements, consumption of renewable energy, environmental taxation, and human capital contribute to reducing CO_2 emissions. Conversely, FDI and trade openness are found to increase these emissions (Ghafoor et al., 2023). In studies dealing with the relationship between renewable energy, industrialization and environmental impact, Pollution Haven Hypotheses is also included. Improvements in energy efficiency can paradoxically result in increased energy usage and emissions, a phenomenon known as the "rebound effect." However, these advancements may also promote greater utilization of renewable energy sources, potentially reducing emissions per unit of output. Interestingly, technological progress that decreases emissions from fossil fuel sources might inadvertently slow down the adoption of renewable energy technologies. Overall, a boost in efficiency can lead to higher energy consumption and emissions (Bongers, 2022). A study by Mentel et al. examined how the renewable energy industry affects CO_2 emissions in Europe and Central Asia. Their findings reveal that a 10% rise in industrialization results in a 2.6% increase in CO_2 emissions. In contrast, a 10% increase in renewable energy use leads to a 2.2% reduction in CO_2 emissions. Therefore, Mentel et al. stated that renewable energy consumption can help mitigate the negative environmental consequences of industrial development (Mentel et al., 2022). According to Lange, an increase in renewable energy innovation, measured by the number of patents, leads to higher GDP, and pollution taxes play a supportive role in this innovation process. Lange also emphasized that government support for fossil fuel sectors negatively impacts renewable energy innovation (Lange, 2024).

Research conducted in Europe on renewable energy presents complex and varied findings regarding the influence of macroeconomic indicators. In a 2018 study, Marinaş et al. investigated the correlation between economic growth and renewable energy consumption, as well as their causal relationships in both the short and long term, across ten European Union member states from Central and Eastern Europe during the period 1990-2014. The short-term analysis indicates a shift towards green energy, whereas the long-term perspective is contingent upon the equilibrium of macroeconomic factors. The study's short-term findings suggest that Gross Domestic Product and Renewable Energy Consumption are independent in Romania and Bulgaria, while increased renewable energy consumption enhances economic growth in Hungary, Lithuania, and Slovenia (Marinaş et al., 2018). Similarly, Soava et al. emphasize that renewable energy consumption has a positive impact on economic growth, and the relationship is bidirectional in their study on the causal relationship between economic growth and renewable energy consumption using data from 28 European Union countries between 1995 and 2015 (Soava et al., 2018). Vyrostkova et al. conducted an analysis of the relationship between GDP per capita, unemployment, financial development, inflation, governance, and the proportion of renewable energy consumption in Eurozone countries from 2006 to 2020. The findings indicate that an increase in GDP per capita positively influences the share of renewable energy, whereas factors such as unemployment, lower levels of financial development, higher inflation, inefficient governance, and corruption adversely impact the adoption of renewable energy. This study underscores the importance of enhancing GDP per capita and addressing impediments such as unemployment and corruption to facilitate the transition towards a sustainable energy framework (Vyrostkova et al., 2024). Przychodzeń and Przychodzen seek to contribute novel empirical insights, highlighting that numerous questions persist regarding the primary economic and political determinants influencing the transition to a low-carbon economy via renewable energy production, particularly in former socialist nations. By analyzing data from 27 transition economies spanning 1990 to 2014, they ascertain that elevated economic growth, increasing unemployment, and rising government debt stimulate renewable energy production. Furthermore, the study indicates that the Kyoto Protocol significantly increased renewable energy utilization. However, this research contends that since the onset of the global financial crisis in 2007, additional public funding has become essential to bolster competition within the energy market. The reduction in market competitiveness, which is attributed to financial distress, has constrained the adoption of renewable energy sources (Przycchodzen and Przychodzen, 2020). Fedajev et al. asserted that for Central and Eastern European countries, it is imperative to enhance the electricity infrastructure alongside implementing market principles to achieve environmental objectives. They concluded that the presence of inefficient electricity infrastructure in these nations adversely affects GDP and industrial value-added growth rates (Fedajev et al., 2023). Botha et al. contend that factors such as energy dependence, natural resource rents, and greenhouse gas emissions constrain the production of renewable energy in Central and Eastern European countries. Their findings underscore the necessity of addressing economic development in conjunction with sustainable energy initiatives to facilitate the transition to a more sustainable energy framework in the region (Botha et al., 2022).

This study aims to contribute to the development of policies that promote sustainable growth and environmental protection in Eastern European countries in relation to the climate crisis and concerns regarding energy supply security. In this direction, since macroeconomic indicators are an important guideline, The next section presents the dataset and methodology of the econometric model used to assess the impact of macroeconomic factors on renewable energy consumption.

3. DATA AND METHODOLOGY

3.1. Data

This study aims to examine how selected macroeconomic variables affect the share of renewable energy consumption in total energy consumption in eight Eastern European countries (Romania, Bulgaria, Poland, Czechia, Moldova, Hungary, Slovak Republic, Romania, Poland, Czech Republic, Moldova, Hungary, Slovak Republic, and Belarus). This study analyzes the impact of renewable energy consumption, CO_2 emissions, GDP per capita, trade, inflation, and FDI on renewable energy consumption for these countries using data from to 1992-2021. Numerous factors significantly influence a nation's energy framework. CO_2 emissions are a primary contributor to climate change, necessitating their reduction as a global priority. Analyzing the relationship between CO_2 emissions and the utilization of renewable energy is essential for assessing how the transition to renewable sources can mitigate environmental impacts. Economic development, often measured by GDP per capita, influences energy consumption patterns. While higher income levels may lead to increased energy demand, they also provide the financial resources necessary to invest in renewable energy infrastructure. Openness to international trade significantly impacts the accessibility and implementation of renewable energy technologies. Countries engaged in global trade can access advanced renewable technologies and benefit from the exchange of knowledge, facilitating the integration of renewable energy into their energy portfolios. However, the influence of trade on renewable energy consumption may vary depending on the types of goods and services exchanged. Inflation can affect the cost of capital and the feasibility of investing in renewable energy projects. High inflation rates may increase financing costs, thereby hindering investments in capital-intensive renewable energy infrastructure. Conversely, stable inflation rates can create a favorable economic environment for such investments. FDI can significantly contribute to the advancement of the renewable energy sector by offering financial resources, technology, and expertise. Nonetheless, it may also enable the transference of pollution across national boundaries. Consequently, integrating FDI into models related to renewable energy consumption is crucial for comprehensive analysis. Table 1 presents recent studies on macroeconomic factors affecting renewable energy and the variables used.

Table 1: Macroeconomic indicators considered in previous studies

Study	Study Design	Variables Analyzed
(Jebli et al.,2013)	Panel cointegration analysis	CO2 emissions, renewable and non-renewable energy consumption, trade openness, Gross Domestic Product
(Saidi and Omri, 2020)	Ordinary least square and vector error correction model	Economic growth, renewable energy consumption, CO2 emissions
(Khan etal., 2020)	Static and dynamic panel data models	Renewable energy consumption, CO_2 emissions, FDI, Economic growth
(Khan et al., 2021)	Static, dynamic, and long-run estimators	Trade openness, renewable energy consumption, FDI, CO_2 emissions, tourism
(Yang et al., 2022)	Augmented Mean Group estimator	Real oil prices, trade openness, CO_2 emissions, economic growth, income inequality, renewable energy consumption
(Wencong et al., 2023)	Cross-sectional autoregressive distributed lag and panel quantile regression	FDI, economic growth, renewable energy, natural resources, economic freedom, CO2 emissions
(Wang and Zhang, 2021)	Panel data analysis	Renewable energy consumption, trade openness, industrialization, urbanization, economic growth, CO_2 emissions
(Andrei et al., 2025)	Panel data analysis	CO2 emissions, renewable energy consumption, FDI, labor force, industrial value-added, gross capital formation, economic growth

The GDP per capita variable was logarithmically transformed to ensure a normal distribution, and the model was estimated as follows: All data were obtained from the World Bank. The definitions of the selected variables are presented in Table 2.

Table 2: Description of the Selected Variables

Variable	Description	Data Sources
Renewable energy consumption (% of total final energy consumption)	The proportion of renewable sources in the total final energy usage represents the consumption of renewable energy.	World Bank
Carbon dioxide (CO2) emissions excluding LULUCF per capita (t CO2e/capita)	The measure represents yearly CO_2 emissions, one of six greenhouse gases identified in the Kyoto Protocol, from agricultural, energy, waste, and industrial sectors. These emissions are converted to CO2 equivalent values and divided by the economy's population, excluding Land Use Change Land Use and Forestry due to higher uncertainties associated with greenhouse gases fluxes from these activities.	World Bank
GDP per capita (constant 2015 US$)	The calculation of GDP per capita involves dividing the gross domestic product by the population at mid-year. The gross domestic product encompasses the total gross value added by all resident producers, with the addition of product taxes and subtraction of subsidies not in the product value. This estimation does not consider depreciation of fabricated assets or depletion and degradation of natural resources.	World Bank
Trade (% of GDP)	The combination of exported and imported goods and services, expressed as a percentage of gross domestic product, constitutes trade.	World Bank
Inflation, consumer prices (annual %)	The consumer price index, which measures inflation, represents the yearly percentage shift in the average cost of goods and services.	World Bank
Foreign direct investment, net inflows (% of GDP)	FDI involves the inflow of funds aimed at acquiring a significant management stake in a business operating outside the investor's home country. This encompasses capital contributions, profits reinvested, and both short- and long-term investments, as documented in the balance of payments records. The indicator measures the net capital inflow from international investors into the economy being reported, calculated as a proportion of GDP.	World Bank

3.2. Methodology

To reveal how CO_2 emissions, GDP per capita, trade, inflation, and FDI affects renewable energy consumption of these countries, the following model was constructed:

$$rnw_{it} = \alpha + \beta_1 cde_{it} + \beta_2 lgdp_{it} + \beta_3 trd_{it} + \beta_4 inf_{it} + \beta_5 fdi_{it} + \varepsilon \quad (1)$$

Regression analysis establishes causal relationships between multiple variables and forecasts outcomes based on these connections. In some instances, multiple models may be encountered, each with distinct relationships between the variables. While these models might seem unconnected, they can incorporate different dependent variables within a system of linear regression models and potentially have correlated error terms. These scenarios are known as SUR models. SUR models permit error correlation across equations and were initially introduced by Zellner (1962). These models are characterized by their ability to accommodate interrelated errors between equations despite appearing unrelated. The SUR model consists of a set of equations featuring multiple, multivariate formulas. Each formula represents a linear multivariate regression equation, and typically, there is no interconnection between these equations. When a variable is omitted from any equation, its influence is manifested in the error term. If this omitted variable strongly correlates with an explanatory variable in another equation, it creates or intensifies the connection between the error terms (Bulut, Balaylar, & Karımlı, 2024, s. 347).

The SUR estimator is suitable when the time dimension (T) is substantial, and the number of units (N) is less than 10. To compute the SUR, individual regression models are initially estimated for each unit of observation. Within the variance-covariance matrix, the diagonal components represent the residual variances of the separately estimated regression models for each unit, while the off-diagonal elements indicate the covariance between the residuals (Yerdelen Tatoğlu, 2020, s. 72).

The mathematical formulation of the SUR model, which considers the n regression equation system, is given below (Zellner A. , 1962).

$$y_1 = X_1 \beta_1 + \epsilon_1 \quad (1)$$

$$y_2 = X_2 \beta_2 + \epsilon_2 \quad (2)$$

$$y_n = X_n \beta_n + \epsilon_n \quad (3)$$

y_i is a vector of observations for the dependent variable. X_i is the matrix of independent variables. β_i is the vector of coefficients. ϵ_i is the vector of error terms. The properties of the error terms are: $E(\epsilon_i \epsilon_j)=\Sigma_{ij}$ for $i \neq j$, Σ is the covariance matrix of the error terms.

The SUR model is based on five fundamental assumptions. First, it posits a correlation between the error terms of the equations within the same period. Second, the model assumes that the equations maintain a constant variance. Third, it stipulates that no relationship exists between the error terms of the equations from different time periods. Fourth, the error terms are assumed to follow a normal distribution. Finally, the model presumes that the expected value of the error term for each equation equals zero. (Bulut, Balaylar, & Karımlı, 2024).

The subsequent section of the study presents the results of the SUR model analysis for eight Eastern European countries. Prior to constructing a SUR model, it is imperative to assess the correlation between error terms utilizing the Breusch-Pagan test. In the presence of a statistically significant correlation, the SUR method is deemed more appropriate. Additionally, heteroskedasticity and normality tests should be conducted to evaluate the model's robustness. If the error terms do not conform to a normal distribution, the reliability of the estimates may be compromised. The results of these tests facilitate the evaluation and interpretation of the model's appropriateness and the reliability of its forecasts.

4. RESULTS

Table 3 presents descriptive statistics for the variables for 8 Eastern European countries (Romania, Bulgaria, Poland, Czechia, Moldova, Hungary, Slovak Republic, Belarus) for the period 1992-2021.

Table 3: Descriptive statistics of the selected variables.

Variable	Abbreviation	Mean	Min.	Max.	Std. Deviation
Renewable energy consumption (% of total final energy consumption)	rnw	10.52375	1.2	26.1	6.294021
Carbon dioxide (CO2) emissions excluding LULUCF per capita (t CO2e/capita)	cde	6.826126	2.356678	13.99089	2.556431
GDP per capita (constant 2015 US$)	gdp	8460.812	1316.432	20373.88	4875.065
Trade (% of GDP)	trd	110.7784	43.55522	188.733	35.02109
Inflation, consumer prices (annual %)	inf	50.91205	-1.544797	2221.017	220.9246
Foreign direct investment, net inflows (% of GDP)	fdi	5.141498	-40.26288	106.4279	10.57202

Table 4 displays the correlation matrix for the error terms derived from the SUR model for the eight Eastern European countries. The Breusch-Pagan Lagrange Multiplier test for cross-sectional dependence shows a statistically significant correlation among the error terms of these models, indicating that the SUR model is more suitable in this scenario. An analysis of the error term correlation matrix reveals that Czechia and Slovakia exhibit the highest correlation (0.5837). A high correlation in the correlation of error terms between two countries may indicate similar economic shocks, high financial linkages, and similar political and economic arrangements between them. Slovakia has a high inverse correlation with Romania and a direct correlation with the Czech Republic. The significant correlations between the country-specific error terms render traditional regression models unsuitable for this study. Moreover, the Breusch-Pagan Lagrange multiplier test results invalidate the assumption of model independence. As a result, the SUR method is warranted, as it considers the relevant error components in the eight Eastern European nations under examination.

Table 4: Correlation matrix of the error terms for the 8 Eastern European countries

	model1	model2	model3	model4	model5	model6	model7	model8
model1	1.0000							
model2	-0.2593	1.0000						
model3	-0.3417	0.4710	1.0000					
model4	-0.3220	0.2480	0.2460	1.0000				
model5	0.0262	0.4272	0.1006	0.3851	1.0000			
model6	0.4240	0.0452	-0.1279	-0.1570	0.0401	1.0000		
model7	-0.5642	0.1016	0.3492	0.5837	-0.1101	-0.0698	1.0000	
model8	-0.0425	-0.2644	-0.2170	-0.1691	-0.3855	-0.0365	0.0749	1.0000
Breusch-Pagan test of independence: chi2(28) =62.339, Pr=0.0002								

Note: Models 1–8 mean that the SUR model was used to Romania, Bulgaria, Poland, Czechia, Moldova, Hungary, Slovak Republic and Belarus respectively.

This study utilized the variance inflation factor (VIF) test, among other techniques, to evaluate the potential multicollinearity between the independent variables. Multicollinearity can lead to biased estimation results, which is undesirable in this study. Table 5 illustrates that multicollinearity is not present among the independent variables, as both the individual VIF values and the mean VIF are well within the acceptable ranges.

Table 5: Variance Inflation Factor (VIF) Statistic Values of the Independent Variables

Independent Variable	VIF	1/VIF	Mean VIF
Carbon dioxide (CO2) emissions	1.99	0.501302	
GDP per capita	1.72	0.581105	
Trade	1.16	0.858429	1.41
Inflation	1.14	0.879761	
Foreign direct investment	1.04	0.963794	

This research employed the SUR model to investigate the determinants of renewable energy usage across eight countries in Eastern Europe. The model enables analysis at both the aggregate and individual country levels. Table-6 presents the initial results from the SUR model for each nation, with all eight Eastern European countries demonstrating statistically significant outcomes (P-value =0.0000). Furthermore, the Chi-square values for all models show statistical significance, and the R-square values for each model are strong.

Table 6: Overall Statistical Significance of the 8 Models

Model	RMSE	R^2	Chi^2	P-value
Model1	1.145088	0.9288	387.37	0.0000
Model2	1.101263	0.9599	725.67	0.0000
Model3	0.8854401	0.9200	335.84	0.0000
Model4	0.4357048	0.9883	2420.87	0.0000
Model5	2.647807	0.9185	337.41	0.0000
Model6	0.8950501	0.9623	722.69	0.0000
Model7	1.355902	0.9053	281.81	0.0000
Model8	0.4694727	0.8912	244.81	0.0000

Table 7 shows the results of the Swamy, Pesaran, and Yamagato tests, which indicate that the parameters are heterogeneously distributed. Swamy's S Test examines the homogeneity of the coefficients in a random-effects model across multiple cross-sectional units. The Pesaran and Yamagata Delta tests assess the homogeneity of the slope coefficients in large panel data models that are resistant to diverse specifications. Both tests are effective in assessing the consistency and variability of coefficients in panel data models, allowing researchers to decide whether to adopt models that account for cross-sectional heterogeneity.

Table 7: The Results of the Swamy S, Pesaran, and Yamagato Delta tests

Swamy S		Chi2(42) =2742.36	Prob>chi2=0.0000
		Delta	p-value
Pesaran, Yamagata		11.484	0.000
	adj.	13.194	0.000

The normal distribution criteria are met by the model, as evidenced by the Jacque-Bera value (4.27) being below 5 and the probability value (0.1182) exceeding 0.05. The SUR model's Estimation Results for the independent variables are shown in Table 8. All parameters are deemed significant due to the overall absolute t-values surpassing the table values (1.97). The share of renewable energy consumption in total energy consumption decreases by roughly 2.7% for every one-unit rise in CO_2 emissions, per capita. A 1% growth in GDP per capita leads to an approximate 1.8% increase in the proportion of renewable energy consumption within total energy consumption. In contrast, trade openness, inflation, and FDI have minimal impact.

Table 8: Estimation Results of the SUR model for the Independent Variables

Independent Variable	Coefficient	Standart Error	t-Statistic
Carbon dioxide (CO2) emissions	-2.7348526	0.21226514	-12.884134
GDP per capita	1.8187349	0.75481338	14.332993
Trade	-0.0241628	0.01058982	-2.2817007
Inflation	0.05936599	0.01523111	3.89767981
Foreign direct investment	-0.0782635	0.03341241	-2.3423477
_cons	-65.424656	6.60885864	-9.8995394

Table 9 presents a summary of the SUR model's estimation results for the eight Eastern European nations. In Romania, the variables of CO_2 emissions, GDP per capita, inflation, and FDI were found to be statistically significant. Among these, GDP per capita has the strongest influence on renewable energy consumption. Specifically, a 1% rise in GDP per capita led to an increase of approximately 7.7% in the proportion of renewable energy consumption relative to total energy consumption. Conversely, a single unit increase in per capita CO_2 emissions, resulted in a decrease of approximately 3.8 units in the percentage of renewable energy consumption compared to total energy consumption. Furthermore, inflation and FDI showed effects of approximately 0.02 and 0.26, respectively. In Bulgaria's case, several factors were found to be statistically significant: CO_2 emissions, GDP per capita, trade openness, and FDI. The analysis revealed that for every unit increase in per capita CO_2 emissions, the proportion of renewable energy consumption in total energy use decreased by approximately 3.42 units. Conversely, a 1% rise in GDP per capita leads to an approximate 14.7% increase in the share of renewable energy. Additionally, when the trade-to-GDP ratio increases by 1%, the percentage of renewable energy consumption increases by approximately 0.04 units. Finally, a higher percentage of FDI net inflows correlates with a decrease in the renewable energy consumption share by approximately 0.05 units. In Poland, GDP per capita and inflation emerged as statistically significant factors. A 1% increase in GDP per capita results in a 17.68% increase in renewable energy usage. Additionally, each unit increase in inflation corresponds to a 0.15 unit increase in renewable energy consumption. In Czechia, the statistically significant variables were CO_2 emissions, GDP per capita, trade volume, and FDI. A single unit increase in CO_2 emissions, per capita reduces the percentage of renewable energy in total energy consumption by approximately 1.95 units. Like Poland, a 1% growth in GDP per capita leads to a 4.98% increase in renewable energy use. Trade volume has a positive impact, with each unit increase contributing approximately 0.02 units to renewable energy consumption. Conversely, FDI had a negative effect, decreasing renewable energy usage by approximately 0.08 units per unit increase. In Moldova, several factors were statistically significant in relation to renewable energy consumption. CO_2 emissions, exhibited an inverse relationship, with a decrease of approximately 3.15 units for each unit increase in renewable energy use. Economic growth, measured by GDP per capita, had a positive impact, with a 1% increase resulting in approximately 16.5% more renewable energy consumption. Trade volume was negatively correlated with renewable energy use, decreasing it by approximately 0.21 units per unit increase. Inflation demonstrated a slight positive effect, increasing renewable energy consumption by approximately 0.12 units per unit rise.

For Hungary, three factors were found to be statistically significant. CO_2 emissions, displayed a stronger negative correlation with renewable energy consumption, decreasing by approximately 6.31 units per unit increase. Economic growth also positively influenced renewable energy use, with a 1% increase in GDP per capita leading to approximately 8.10% more consumption. Inflation showed a minor positive impact, increasing renewable energy consumption by approximately 0.17 units per unit increase. The analysis of Slovakia revealed several statistically significant factors: CO_2 emissions, GDP per capita, and FDI. For each unit increase in CO_2 emissions per capita, the proportion of renewable energy in total energy consumption decreases by approximately 1.57 units. In contrast, a 1% growth in GDP per capita correlates with a 13.53% increase in renewable energy usage. FDI negatively impacted renewable energy consumption, with each unit increase causing a decline of approximately 0.21 units.

In Belarus, the statistically significant variables are CO_2 emissions, GDP per capita, trade volume, and inflation. A one-unit increase in per capita CO_2 emissions leads to a reduction of approximately 0.82 units in the renewable energy share of total energy consumption. GDP per capita demonstrates a positive relationship, with a 1% increase resulting in an approximate 3.30-unit growth in the percentage of renewable energy consumption. Trade has a small but positive effect, as a 1 unit rise in trade's share of GDP corresponds to a 0.01 unit increase in the renewable energy consumption percentage. Inflation has a slight negative impact, with each unit increase causing a 0.002-unit decrease in the proportion of renewable energy consumption.

Table 9: Estimation Result of the SUR Model for the 8 East European Countries

Country	Dependent Variable	Independent Variable	Coefficient	Z-value	P-value
Romania	Renewable energy consumption	(CO2) emissions	-3.805822	-9.24	0.000
		GDP per capita	7.709717	4.96	0.000
		Trade	0.0402542	1.21	0.226
		Inflation	0.0235566	3.15	0.002
		Foreign direct investment	0.264815	2.94	0.003
		_cons	-35.48261	2.84	0.005
Bulgaria	Renewable energy consumption	(CO2) emissions	-3.427768	8.88	0.000
		GDP per capita	14.70535	10.83	0.000
		Trade	0.043078	2.62	0.009
		Inflation	-0.0004963	-0.53	0.595
		Foreign direct investment	-0.056538	-2.02	0.044
		_cons	-95.98724	-8.97	0.000
Poland	Renewable energy consumption	(CO2) emissions	-0.8223386	-1.52	0.128
		GDP per capita	17.68568	5.00	0.000
		Trade	-0.1077992	-1.83	0.068
		Inflation	0.152676	3.45	0.001
		Foreign direct investment	-0.1968755	-1.86	0.063
		_cons	-137.8026	-4.61	0.000
Czechia	Renewable energy consumption	(CO2) emissions	-1.95298	-21.20	0.000
		GDP per capita	4.989577	4.93	0.000
		Trade	0.026552	4.07	0.000
		Inflation	-0.0127519	-0.44	0.656
		Foreign direct investment	-0.0818318	-3.21	0.001
		_cons	-17.96584	-1.81	0.070
Moldova	Renewable energy consumption	(CO2) emissions	-3.155405	-2.55	0.011
		GDP per capita	16.51751	6.32	0.000
		Trade	-0.2121424	-5.55	0.000
		Inflation	0.1277117	2.26	0.024
		Foreign direct investment	-0.2453782	-1.22	0.224
		_cons	-80.68685	-3.70	0.000
Hungary	Renewable energy consumption	(CO2) emissions	-6.314403	-12.62	0.000
		GDP per capita	8.10176	4.75	0.000
		Trade	0.0297691	1.84	0.066
		Inflation	0.1764265	3.65	0.000
		Foreign direct investment	-0.0063712	-1.11	0.266
		_cons	-35.62869	-2.24	0.025
Slovak Republic	Renewable energy consumption	(CO2) emissions	-1.570926	-2.56	0.010
		GDP per capita	13.53737	4.57	0.000
		Trade	-0.0297122	-1.32	0.188
		Inflation	0.0098975	0.12	0.902
		Foreign direct investment	-0.2123982	-3.13	0.002
		_cons	-102.1656	-3.61	0.000
Belarus	Renewable energy consumption	(CO2) emissions	-0.8291781	-2.53	0.011
		GDP per capita	3.302915	8.94	0.000
		Trade	0.0166981	2.58	0.010
		Inflation	-0.0020922	-2.91	0.004
		Foreign direct investment	-0.0915299	-1.26	0.209
		_cons	-17.67782	-7.45	0.000

5. DISCUSSION

The study's findings unexpectedly revealed that increases in CO_2 emissions led to a decrease in the proportion of renewable energy used in overall energy consumption. This phenomenon can be attributed to a shift towards more carbon-intensive fossil fuels, such as coal, in response to energy supply security crises, such as the Russia-Ukraine conflict, and temporary spikes in CO_2 emissions. The need for short-term energy security is likely to have driven this change. For instance, Russia's curtailment of natural gas supplies may have prompted Eastern European nations to seek immediate alternatives, potentially resulting in greater fossil fuel usage and subsequent increases in CO_2 emissions levels. In essence, apprehensions about possible disruptions in energy supply chains can spark developments that favor fossil fuel use.

When the share of renewable energy consumption in the total energy consumption of the GDP per capita variable is evaluated, a reciprocal linear relationship is observed in all countries included in the model. The highest and lowest effects were observed in Poland and Belarus, respectively. The increase in renewable energy consumption as GDP per capita increases can be explained by the environmental Kuznets curve hypothesis. According to the environmental Kuznets curve hypothesis, there is an inverted U-shaped relationship between economic growth and environmental degradation. At low-income levels, priority is given to economic growth, while cheaper and more easily accessible fossil fuels are preferred. At middle-income levels, environmental policies gradually start to come into play, and at high-income levels, technological progress and stricter environmental policies lead to an increase in clean energy investments. Economic growth beyond a certain level tends to prioritize environmental sustainability and increases renewable energy usage. The environmental Kuznets curve hypothesis supports this idea, whereas Porter's hypothesis suggests that environmental regulations can boost economic growth by fostering long-term technological innovation. In the Eastern European nations studied, rising GDP per capita significantly influenced the shift toward renewable energy consumption. Despite increased CO_2 emissions due to energy supply security issues, the impact of per capita GDP growth on renewable energy use was substantially greater in the countries examined. This indicates a trend toward green growth in these nations' efforts to combat climate change. This trend is particularly pronounced in Bulgaria, Poland, Moldova and Slovakia. Notably, Moldova exhibits values like those of EU member states, despite not having joined the EU.

In the model, Bulgaria, the Czech Republic, Moldova, and Belarus show significant parameters for the trade variable, although its impact on renewable energy consumption is minimal. Moldova exhibited the strongest negative effect, with a decrease of approximately 0.21, suggesting the need to align trade policies with long-term sustainable energy strategies. Romania, Poland, Moldova, Hungary, and Belarus demonstrate significant inflation variable parameters, with Poland, Moldova, and Hungary showing relatively higher inflation effects. In these three nations, rising inflation is correlated with increased renewable energy consumption. This may be due to inflation driving up fossil fuel costs and encouraging policies that promote the adoption of cleaner energy. However, high inflation can also lead to increased interest rates, potentially making renewable energy project financing more expensive and slowing the transition to renewable energy. To address these conflicting factors, it is crucial to establish long-term energy strategies and incentive programs. The model indicates significant FDI parameters for Romania, Bulgaria, Czechia, and Slovakia. The two countries with the most substantial effects, Romania and Slovakia, show opposite trends: FDI boosts renewable energy consumption in Romania but decreases it in Slovakia.

The impact of FDI on renewable energy usage depends on various factors, including the investment target, national energy policies, and incentive schemes. Government initiatives promoting clean energy can lead to increased renewable energy consumption through FDI.

However, in countries that allow investments heavily focused on fossil fuels, such financial influxes may result in a decrease in renewable energy use. Several conditions can cause a decline in renewable energy consumption, such as when FDI is directed towards fossil fuel sectors (in line with the Pollution Haven Hypothesis), insufficient incentives for renewable energy exist, interest rates are high, and investors prioritize short-term gains. These elements can collectively reduce the utilization of renewable energy sources in the region. In contrast, renewable energy consumption can be positively affected when nations invest in sustainable power generation (Porter Hypothesis), encourage environmentally friendly innovations and technology transfer (Green Growth), and implement policies that promote renewable energy adoption. The implementation of these strategies can foster the greater adoption and use of renewable energy sources. A general assessment of the countries in the study reveals that Poland, Moldova, and Slovakia demonstrate a comparatively more favorable outlook regarding their shift towards renewable energy consumption. It is worth noting that among these countries with a more positive outlook, Moldova is currently seeking EU membership. In contrast, Hungary, Belarus, and Czechia exhibit a relatively low inclination towards renewable energy. Although Eastern European nations are making efforts to promote renewable energy adoption, their investments fall short of the global average. The proportion of renewable energy in the total energy consumption of Eastern European countries is lower than that of their Western and Northern European counterparts. Nevertheless, in recent years, Eastern European nations have witnessed substantial growth in renewable energy capacity. Notably, Poland has made considerable strides in solar energy investment, as corroborated by the empirical findings of this study. The expanding renewable energy capacity in the region indicates that this proportion is likely to continue to increase in the coming years. Although the SUR model used in this study offers significant advantages in analyzing the relationship between variables, it has some limitations. First, although the model considers the correlations between error terms, it cannot identify the possible causal relationships between variables with certainty. Although the effects of macroeconomic variables vary across countries, the effects of factors other than those identified by the model, such as policy regulations, technological advances, and social awareness of renewable energy use, can be addressed in future research to expand the scope of the study. Furthermore, it would be useful to conduct studies assessing the impact of institutional quality, energy policies, and incentive mechanisms on renewable energy consumption.

Ethic Statement Acknowledgement
This study has been prepared in accordance with the rules of scientific research and publication ethics.

Authors' Contribution
The entire study was created by the author.

Declaration of Interest
There is no conflict of interest for the authors or third parties arising from the study.

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