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Institutional Quality, Foreign Direct Investment, and Renewable Energy Production: Evidence from Eastern European Countries Using a Panel VAR Model

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ABSTRACT

Renewable energy is crucial for mitigating climate change, stabilizing energy prices, and preventing energy crises; however, governance quality and foreign direct investment (FDI) in promoting clean energy development are often overlooked. Renewable energy production depends on political decisions and capital, technology, and expertise provided through FDI. This paper examines how institutional quality and FDI inflows affect renewable energy production. We analyze data from 1996 to 2022 across 12 Eastern European countries with growing economies and potential for renewable energy development. Our findings reveal that these countries cannot meet the institutional quality standards and FDI inflows required for renewable energy development.

Keywords: Eastern Europe, FDI, Institutional Quality, Renewable Energy Production, VAR
JEL Classifications: C33, Q42, Q48, O52

1. INTRODUCTION

Increasing environmental pollution, the adverse effects of climate change, depleting fossil fuels, and the impact of international tensions on energy prices and supply have intensified the global search for alternative energy sources. In response, many countries are prioritizing the replacement of fossil fuels with renewable energy (RE), which has become an economic priority worldwide. RE is expected to significantly reduce carbon dioxide (CO_2) emissions and meet about two-thirds of the world's energy needs by 2050 (Gielen et al., 2019).

Given the international challenges and impact of nonrenewable resource consumption on the energy market and environment, researchers have increasingly focused on the energy sector. Many economic studies concentrated on conventional energy sources and CO_2 emissions (Islam et al., 2021; Bakhsh et al., 2021; Teng et al., 2021; Sarkodie and Strezov, 2019; Sariannidis et al., 2013; Asiedu and Lien, 2011). Research on RE consumption has grown recently (Appiah-Otoo et al., 2023; Rahman and Sultana, 2022; Oluoch and Susaeta, 2021; Nyiwul, 2017; Wu and Broadstock, 2015; Sebri and Ben-Salha, 2014); however, studies focused on RE production remain sparse and scattered (Pan et al., 2022; Murshed et al., 2021; Sahlian et al., 2021; Bamati and Raoofi, 2020). Given the rising global demand for RE, the focus must shift toward understanding the production and investment in RE and the factors influencing it. Analyzing these factors is essential for policymakers to develop effective RE-development strategies to meet demand and enhance production. Research has identified macroeconomic and environmental variables as significant influencers of RE production, including urbanization, economic growth, CO_2 emissions, trade openness, financial development, and energy prices (Lin and Okoye, 2023; Cui et al., 2022; Acheampong et al., 2021; Rintamaki et al., 2017; Al-Mulali et al., 2015; Ohler and Fetters, 2014).

Governance quality and investment are vital in advancing RE programs. Apergis and Pinar (2021) and Uzar (2020) highlighted that RE development is likelier in nations with lower political instability, strong adherence to the rule of law, effective governance, and minimal corruption. Political stability, corruption control, and democratic structures are crucial elements that support the expansion of RE technologies (Fankhauser et al., 2015; Pfeiffer and Mulder, 2013). Additionally, RE financing can come from external sources, such as foreign direct investment (FDI), remittances, and international aid (Fotio et al., 2022). Investments in clean energy to sustain the environment and expand the RE sector have been increasingly emphasized, and some multinational corporations suggest that attracting FDI can support the growth of RE industries (Dossou et al., 2023). Saba and Biyase (2022) argued that governments should direct FDI toward RE development to achieve energy security goals. Multinational enterprises facilitate technology and knowledge transfer; thus, nations should incentivize international investors to promote FDI in RE while limiting environmentally harmful investments competing with RE sources. Governance quality is crucial for attracting FDI, as strong institutions can channel more investment (Raza et al., 2021). Sou and Vinnicombe (2023) noted that effective governance enhances property rights protection, encouraging FDI; thus, high-quality governance is essential for attracting FDI, which can significantly boost RE production (Dossou et al., 2023; Belaïd et al., 2021). Understanding the joint impact of governance quality and FDI on RE advancement is crucial; however, how these factors affect RE production remains underexplored.

This study aims to address the existing gap by investigating how institutional quality (IQ) and FDI inflows affect RE production in 12 Eastern European countries: Bulgaria, Croatia, Czech Republic, Estonia, Hungary, Latvia, Lithuania, North Macedonia, Poland, Romania, Slovakia, and Slovenia. The analysis utilizes a panel vector autoregression (VAR) model with annual data from 1996 to 2022. Regarding economic performance, these Eastern European nations have improved significantly with varying governance conditions (Boltho, 2020). These countries are also emerging as growing economies[1] in Europe, and the region has substantial potential for RE production, such as solar and wind, which can attract additional foreign investment.

This paper details our methodology and research focus, specifically examining the impacts of governance quality, FDI, and their interaction on RE development. Furthermore, we provide policy recommendations and explore implications for selected countries. To our knowledge, this study is the first to build an equation for RE production to substantially evaluate the role of IQ on the relationship between FDI and RE production in the European region. The paper is structured as follows. Section 2 presents the theoretical framework and literature review, highlighting articles with similar methodologies. Section 3 focuses on the data and methodology. Section 4 discusses the results, and Section 5 presents the conclusion and policy recommendations.

1 https://www.ft.com/content/b7e2c18b-e1c9-452d-b9d6-13db4d28fb89

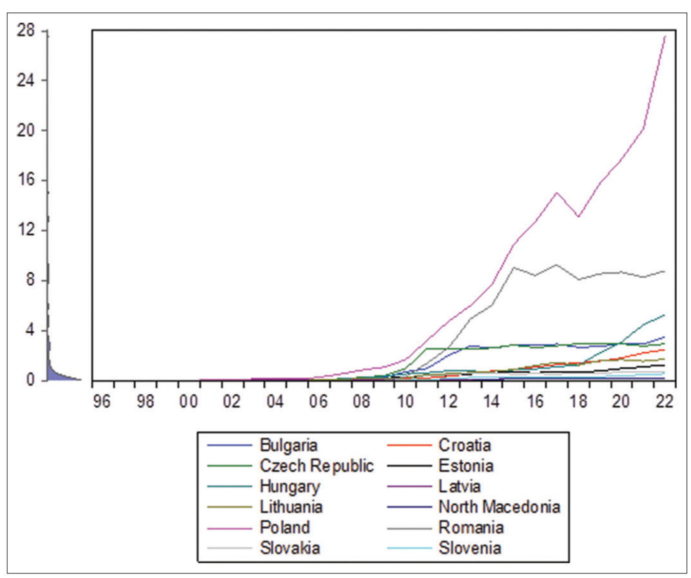
2. THEORETICAL BACKGROUND

Energy is vital for human survival, life, and progress. For example, electricity is the most prominently utilized energy source to produce national outputs, and countries have traditionally relied on indigenous primary fossil fuel supplies for electricity-generation purposes. Furthermore, some nations overwhelmingly depend on imported fossil fuels to generate electricity (Murshed and Tanha, 2021); however, the high price of fossil fuels, security and political threats, exhaustion risk of fossil fuels, global warming, and climate change have prompted the global pursuit of alternative energy sources. Exploring potential means to reduce global reliance on fossil fuels is essential for harmony between economic development and environmental progress.

Several countries have taken serious actions to tackle the issue of fossil fuels in connection with global warming and climate change, following the Glasgow Climate Pact of 2022, the Paris Agreement of 2015, and the Kyoto Protocol of 1997. One measure is to replace fossil fuels as steadily as possible with RE utilization, which aligns with the net zero goals. Regarding net zero scenarios, RE is expected to increase globally, from 28% in 2021 to 61% in 2030 and 88% in 2050 (IEA[2], 2022). Szetela et al. (2022), Saidi and Omri (2020), and Gielen et al. (2019) concluded that promoting RE could help reduce CO_2 emissions. Figure 1 shows that RE production in Eastern European countries has increased since 2008, and this expansion indicates that the countries must consistently lower their CO_2 emissions (Figure 2).

2 International Energy Agency

Figure 1: RE production in terawatt-hours (from solar and wind) by the selected countries from 1996 to 2022. Source: Authors' edition in Eviews 10+



RE development can be an important catalyst for improving the quality of the environment; hence, the literature often highlights increases in RE supply and demand as an important tool for reducing CO_2 emissions, improving the quality of the environment, ensuring energy security, and achieving sustainable growth (Olanrewaju et al., 2019).

Deploying RE is considered an important strategy for improving environmental quality; therefore, comprehensively analyzing RE determinants can help policymakers promote this type of energy. However, focusing solely on economic and environmental factors and disregarding the impact of political or institutional measures when evaluating RE generation leads to notable shortcomings, as the attitude toward RE productivity is primarily political (Cadoret and Padovano, 2016). Moreover, while RE sources like solar and wind power offer long-term environmental benefits, their initial setup costs can be higher than traditional fossil fuels. This cost barrier often necessitates supportive policies and IQ to encourage RE adoption and development (Mehrara et al., 2015).

IQ expresses the behavior and performance of governments in political and economic dimensions. According to the political and economic indicators that state the quality of governance, this research uses the term IQ, defined as (1) The procedure by which officials are chosen, overseen, and replaced; (2) The ability of the government to create and carry out sensible policies; and (3) The state's and the people's regard for institutions that control their social and economic relations. Thus, the quality of governance is determined by how this exercise of power affects citizens' quality of life (Kaufmann et al., 2003). Governance involves the comprehensive management of a state's resources through institutions, representing a complex concept of authority. Assessing governance quality hinges on how this authority affects the citizens' quality of life (Huther and Shah, 2003).

Countries are drafting regulatory and strategic plans for energy markets to increase the tendency to RE. For instance, motivations to promote RE have become the dominant elements in the European Union's climate and energy policy (Strunz et al., 2016). Though it is not satisfactory, Figure 3 shows an upward trend in the selected countries for IQ, followed by the policies of the European Union.

Policymakers can use the effects of financial development and high-quality governance more effectively by enacting laws and policies that gradually strengthen the expansion of low-cost RE technologies against conventional energy sources. This situation can ease the availability of funds and public funds, enabling firms to invest in RE projects and deploy low-cost RE technologies (Belaïd et al., 2021).

Investment is the engine of the energy transition. The Organization for Economic Cooperation and Development[3] (OECD) defines FDI as a category of cross-border investment in which a resident investor establishes a lasting interest in and significant influence over an enterprise in another economy. An investor from one economy owning 10% or more of the voting power in an enterprise in another economy is evidence of such a relationship. This connection is key to international economic integration and creates stable and long-lasting links between economies. Furthermore, FDI is an important channel for transferring technology between countries; it promotes international trade through access to foreign markets and can be an important vehicle for economic development.

Energy transformation requires massive investment, especially in efficiency, research and development, and infrastructure. When considering only renewable power production, global yearly investment needs will surpass 1 trillion US dollars (USD) by 2030. With 430 billion USD in annual financial obligations reported for 2021, a gap of more than half a trillion dollars may exist (UNCTAD, 2023). Figure 4 depicts a true picture of the previous

3 https://www.oecd-ilibrary.org/finance-and-investment/foreign-direct-investment-fdi/indicator-group/english_9a523b18-en

Figure 2: CO_2 emissions in million tons by the selected countries from 1996 to 2022. Source: Authors' edition in Eviews 10+

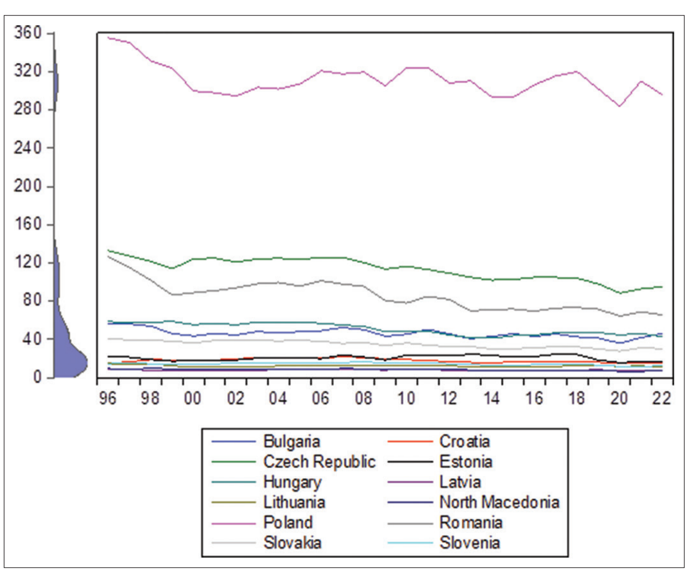


Figure 3: IQ trend of the selected countries from 1996 to 2022. Source: Authors' edition in Eviews 10+

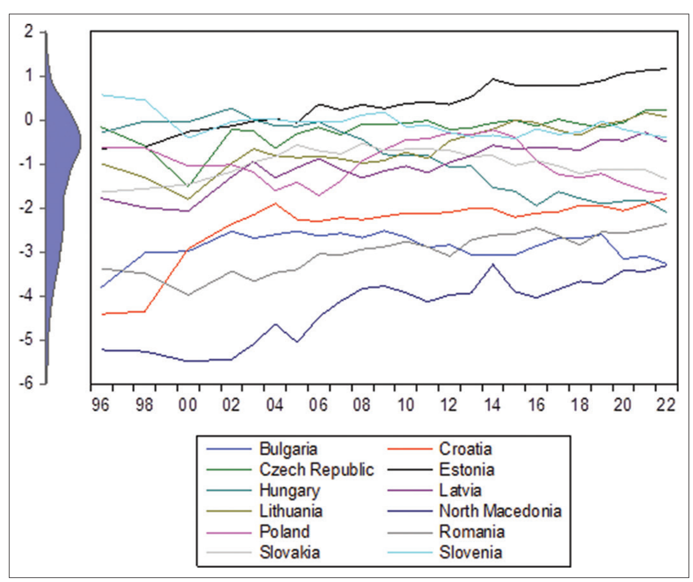
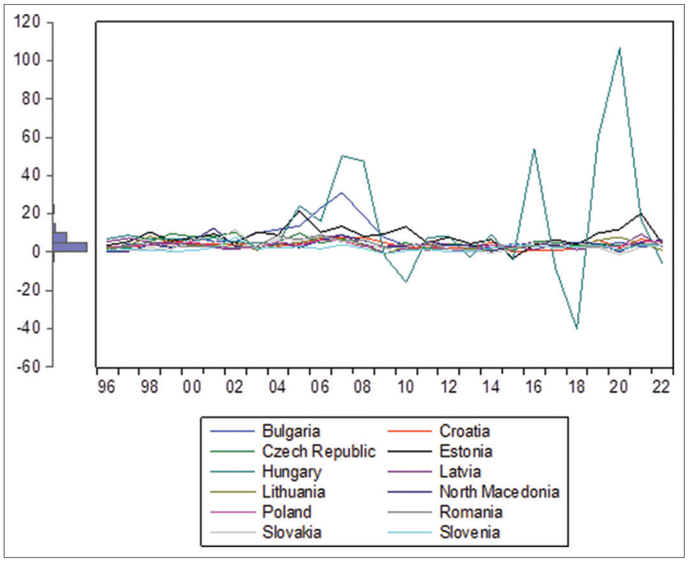


Figure 4: FDI inflows (% of GDP) of the selected countries from 1996 to 2022. Source: Authors' edition in Eviews 10+



statement, as most selected countries have very low FDI inflows (except Hungary).

Financial limitations frequently hinder nations from making the necessary shift to RE, thus alleviating environmental challenges (Murshed et al., 2021). Furthermore, the high cost of RE investments and the longer return times of these compared with non-RE investments negatively affect investment-related risk and skepticism. Regarding this matter, FDI inflows can significantly affect RE development (Ergun et al., 2019); they are essential for developing the energy sector, as they are related to transferring capital, technology, and expertise from the home countries to the host ones (Abe et al., 2017).

2.1. Literature Review

Lin and Okoye (2023) examined the effects of financial development and governance on RE generation; they applied panel vector autoregressive (VAR) testing in 35 high-income countries between 1996 and 2020. The results showed that financial development is positively associated with the level of RE, indicating that financial development favorably affected the level of RE production. The results of this financial development of RE show the potential for growing the RE sector by providing capital for green projects. Governance has an important impact on the production of RE. Since effective governments can be more practical in giving greater importance to RE, it can significantly impact the production of RE. In the same direction, Belaïd et al. (2021) used a panel quantile framework, revealing that governance quality had a positive and statistically significant impact on RE production in nine selected Middle East and North Africa countries from 1984 to 2014. Their findings also showed that financial development has a positive, statistically significant effect on RE production. In contrast, Pan et al. (2022) revealed that governance quality had a negative and statistically significant impact on RE development in 42 African countries from 1996 to 2020; their work was based on the panel-corrected standard errors estimation technique. Their results show that governance quality in most African countries largely promotes non-RE. Furthermore, Saba and Biyase (2022) investigated a panel of 35 European countries from 2000–2018, applying the system general method of moments. Their results show that accountability and the control of corruption and voice have a statistically significant and positive impact on renewable electricity development. In contrast, political stability and the absence of violence/terrorism had a statistically significant negative impact on renewable electricity development. The research by Acheampong et al. (2021) used annual data and the generalized method of moments–panel vector autoregression. They examined the dynamic relationships between institutions, RE, CO_2 emissions, and economic growth for 45 sub-Saharan African countries from 1960 to 2017, determining that economic growth had a negligible effect on institutions. Moreover, their results revealed that institutions had a negligible positive effect on RE and were not supportive enough to foster RE growth in sub-Saharan Africa; hence, the need to transition toward RE does not affect institutional reform in sub-Saharan Africa. Finally, Shahzad et al. (2021) utilized the fully modified ordinary least square technique to examine the impact of the stringent environmental policies index and the performance of institutions on RE production in 29 developed countries from 1994 to 2018. They showed that environmental regulation supports RE production and indicated that features such as bureaucratic decision-making tend to reduce RE generation.

Dossou et al. (2023) applied the panel-corrected standard errors to investigate the relationship between FDI and RE production. They used an estimation approach to demonstrate that FDI significantly and positively impacted RE generation in 37 sub-Saharan African economies from 1996 to 2020. Similarly, Murshed et al. (2021) focused on the dynamic associations between FDI inflows and RE output shares in Bangladesh between 1972 and 2015. They evaluated the direct and indirect impacts of such FDI inflows on the nation's environmental sustainability. The results from their autoregressive distributed lag technique and causality test implied a unidirectional causality from FDI inflows to RE output shares in the long run, suggesting that FDIs can enhance RE output shares. Correspondingly, Ahmed et al. (2019) used autoregressive distributed lag technique to examine China's long-run and short-run interactions between FDI, CO_2 emissions, and RE generation from 1991 to 2017. Their empirical results revealed that both FDI inflows and CO_2 emissions increased RE generation. The intensity of long-run impacts remained much stronger than that of short-run ones. Any addition to RE generation in response to the rise in CO_2 emissions is derived from policy response, which may prompt policymakers and governors to promote renewables to attain the curtailment goals of CO_2 emissions. Conversely, Kilicarslan (2019) evaluated the relationship between FDI inflows and RE production in Brazil, Russia, India, China, South Africa (BRICS countries), and Turkey from 1996 to 2015 using autoregressive distributed lag. Their results demonstrated the long-run negative impacts of FDIs on RE production in each country's target structure of FDI; however, FDIs did not significantly impact RE production in the short-run. Thus, FDIs do not appear to be directed toward the RE sector.

Enhancing regulatory quality and the rule of law seems vital for drawing FDI into the RE industry, which could foster economic expansion, diminish unemployment rates, narrow income disparities, and alleviate poverty (Pan et al., 2022). According to Kilicarslan (2019), policymakers should identify correspondent motive policies to concentrate FDI from non-RE sources to the RE sector and attract investments.

2.2. Model Specification

Following the literature and previously mentioned studies investigating RE drivers, this research examines the relationship between RE production, IQ, FDI, and other control variables. The following model was considered to estimate:

$$\Delta lnREPs\text{-}w,i,t = Constant+\beta_1\ \Delta lnIQ_{i,t}+\beta_2\ \Delta lnFD_{i,t}+\beta_3\ \Delta lnIQ_{i,t}*\Delta lnFDI_{i,t}+\beta_4\ \Delta lnTOi,t+\beta_5\ \Delta lnGDP_{i,t}+\beta_6\ \Delta lnFI_{i,t}+\beta_7\ \Delta lnCO_{2i,t}+\varepsilon_{i,t} \quad (1)$$

Where "*i*" is the country and "t" is the time; β_x (x = 1,..., 7) represents the elasticity parameters to be estimated, and ε measures the error term. $REP_{s\text{-}w}$ is RE production from solar and wind sources, while IQ and FDI are institutional quality and foreign direct investment respectively. IQ*FDI is the interaction between IQ and FDI to investigate the effect of IQ on FDI-RE production nexus. Furthermore, TO, GDP (gross domestic product), FI, and CO_2 represent trade openness, economic growth, financial institutions index, and CO_2 emissions, respectively, which are used to elude variable omission bias. All variables are converted into their natural logarithms to facilitate estimating.

Based on our specified model, we predict the following outcomes. (1) Policy initiatives by the European Union can positively influence IQ to enhance the RE sector in the selected Eastern European countries ($\beta_1 > 0$). (2) FDI inflows can increase RE production by bringing capital, expertise, and technology ($\beta_2 > 0$). (3) This improved IQ can attract FDI inflows toward RE production ($\beta_3 > 0$). Additionally, RE growth can be enhanced by the inflow of technological expertise derived from TO ($\beta_4 > 0$) and higher per capita GDP can boost RE production ($\beta_5 > 0$). RE development can support the growth of financial sector; however, the current improvement in IQ will not necessarily translate into stronger financial sectors in these countries ($\beta_6 > 0$). Finally, RE expansion will reduce CO_2 emissions in the selected Eastern European countries ($\beta_7 > 0$).

3. RESEARCH METHODOLOGY

3.1. Data and Description of the Variables

We use panel data from 1996 to 2022 to empirically analyze 12 Eastern European countries: Bulgaria, Croatia, Czech Republic, Estonia, Hungary, Latvia, Lithuania, North Macedonia, Poland, Romania, Slovakia, and Slovenia. This approach allows us to validate the proposed theoretical model (equation 1) as those parts of Europe show their economic performance and have the potential for utilizing solar and wind for RE generation.

Data for the variables are from the Energy Institute, the World Bank's World Development Indicators, the World Governance Indicators, and the International Monetary Fund. Table 1 presents details for the variables used in this analysis. The panel data is unbalanced due to missing data for specific periods and countries, which was analyzed using the panel vector autoregression (VAR) model. Notably, the data show no unit-root characteristics. Furthermore, the mean and standard deviation of the data remain consistent, supporting the stability condition of the VAR model, as shown in Table 2.

3.1.1. Dependent variable

Renewable Energy Production: This study uses the amount of electricity generated from solar and wind sources, measured in terawatt-hours, to indicate RE production. This approach aligns with the methodologies in previous research (Dossou et al., 2023; Saba and Biyase, 2022; Pan et al., 2022; Murshed et al., 2021; Shahzad et al., 2021; Acheampong et al., 2021; Kilicarslan, 2019).

3.1.2. Explanatory variables

Institutional quality: Building on Lin and Okoye (2023), Dessous et al. (2023), Saba and Biyase (2022), Pan et al. (2022), Rahman and Sultana (2022), Mahmood et al. (2021), and Acheampong et al. (2021), we utilize six governance indicators to demonstrate governance quality. These indicators include political stability and absence of violence, voice and accountability, government effectiveness, regulatory quality, rule of law, and control of corruption. Governance performance is assessed from approximately −2.5 (indicating weak governance) to 2.5 (indicating strong governance). In this study, IQ is represented by these six governance indicators, calculated using principal component analysis (PCA). The application of PCA preserves the data's uniqueness and mitigates multicollinearity among the variables (Acheampong et al., 2021).

Foreign Direct Investment: Based on Dossou et al. (2023), Shaari et al. (2022), Saba and Biyase (2022), Pan et al. (2022), Belaïd et al. (2021), Zhang et al. (2021), and Kilicarslan (2019), this study uses FDI net inflows (% of GDP). This metric represents the total amount of FDI entering a country as a percentage of its GDP.

Table 1: Data sources

Name of the variables	Sources
Renewable Energy Production from Solar and Wind ($REP_{S\text{-}W,\ i,\ t}$)	Energy Institute Database[4]
Institutional Quality ($IQ_{i,\ t}$)	World Governance Indicators[5]
Foreign Direct Investment ($FDI_{i,\ t}$)	World Development Indicators[6]
Trade Openness ($TO_{i,\ t}$)	World Development Indicators[7]
Economic Growth ($GDP_{i,\ t}$)	World Development Indicators[8]
Financial Institutions Index ($FI_{i,\ t}$)	International Monetary Fund[9]
Carbon Dioxide (CO_2) Emissions ($CO_{2,\ i,\ t}$)	Energy Institute Database[10]

Source: Authors' elaborations

4 https://www.energyinst.org/statistical-review
5 https://www.worldbank.org/en/publication/worldwide-governance-indicators
6 https://data.worldbank.org/indicator/BX.KLT.DINV.WD.GD.ZS
7 https://data.worldbank.org/indicator/NE.TRD.GNFS.ZS
8 https://data. worldbank.org/indicator/NY.GDP.PCAP.CD
9 https://data.imf.org/?sk=f8032e80-b36c-43b1-ac26-493c5b1cd33b
10 https://www.energyinst.org/statistical-review

Table 2: Descriptive statistics and unit-root tests

Statistic	$REP_{S-W, i, t}$	$IQ_{i, t}$	$FDI_{i, t}$	$IQ_{i, t}*FDI_{i, t}$	$TO_{i, t}$	$GDP_{i, t}$	$FI_{i, t}$	$CO_{2, i, t}$
Mean	0.0423	0.0128	−0.1073	0.0922	3.2978	748.7862	−0.0029	−0.3403
Median	0.0020	0.0227	0.1088	0.0063	2.4210	753.4527	−0.0001	−0.0243
Maximum	5.0000	0.6523	100.1176	164.9318	27.0181	4390.0820	0.1775	26.3431
Minimum	−4.3370	−0.6206	−89.1719	−185.6886	−31.9961	−4135.215	−0.2178	−18.2234
Std. Dev.	0.6882	0.1976	12.4448	21.5420	9.2026	1499.0780	0.0346	4.4554
Skewness	1.1527	−0.0764	0.5277	−0.8043	−0.2464	−0.3955	−0.9188	0.0882
Kurtosis	31.7944	3.6224	35.9105	45.9969	4.3482	3.7856	12.6371	13.0879
Jarque-Bera	8344.29	4.1072	10842.16	18513.24	20.6061	12.4279	962.50	1017.96
Probability	0.0000	0.0083	0.0000	0.0000	0.0000	0.0020	0.0000	0.0000
Unit-root test: Levin, Lin and Chu t*	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Observations	240	240	240	240	240	240	240	240

Source: Authors' Edition in Eviews 10+

3.1.3. Control variables

Trade openness: Trade openness measures the combined value of a nation's exports and imports relative to its GDP. Higher TO is believed to enhance the inflow of essential technological knowledge and other inputs for generating electricity from RE sources (Murshed et al., 2021; Zhang et al., 2021; Qamruzzaman and Jianguo, 2020; Omri and Nguyen, 2014).

Economic growth: Per capita gross domestic product, calculated by dividing the total GDP by the midyear population, is a key indicator of economic growth and is commonly used in the analysis of production. This metric is presented in current US dollars. An increase in economic growth is anticipated to boost RE production, making economic growth a crucial element in the shift toward RE sources (Lin and Okoye, 2023; Shahzad et al., 2021; Murshed et al., 2021; Ahmed et al., 2019).

Financial institutions index: FI assesses nations based on the breadth, accessibility, and efficiency of their financial institutions. This study uses the index to measure financial development (ranging from approximately 0, indicating weak, to 1, indicating strong). Recent research indicates that financial development significantly influences investment in the RE sector (Lahiani et al., 2021; Anton and Nucu, 2020), and RE growth can be supported by the dynamism of the financial sector (Samour et al., 2022; Mukhtarov et al., 2020).

CO_2 emissions: Carbon dioxide (CO_2) emissions are produced by oil, gas, and coal combustion for energy purposes and are measured in millions of tons. The influence of CO_2 on climate change is well established, highlighting the importance of RE deployment in mitigating its environmental impact. Saba and Biyase (2022), Belaïd et al. (2021), Murshed et al. (2021), and Ahmed et al. (2019) have acknowledged the significant correlation between CO_2 emissions and RE solutions.

3.2. Method

VAR models capture the dynamic relationships within the data by imposing specific constraints. These models facilitate the construction of impulse response analysis or policy counterfactuals that include relevant external shocks. The panel VAR model extends the traditional VAR model by treating all variables as endogenous and interdependent while incorporating a cross-sectional dimension (Canova and Ciccarelli, 2013). Additionally, this model effectively evaluates spillovers from unique interdependencies among countries, markets, and sectors (Jouida, 2018). The panel VAR model also helps to identify shocks within endogenous variables by considering both dynamic and static perspectives; it moves beyond a set of predetermined or exogenous variables and includes a cross-sectional dimension (Somosi et al., 2024). A set of N time series variables, represented as $y_t = (y_{1t},\ldots, y_{kt})$," can be modeled using a basic VAR model (equation 2). In this model, y_t is an $(Nx1)$ vector of the variables, and F_i is an (NxN) matrix containing autoregression coefficients. Furthermore, $\varepsilon_t = (u_{1t},.u_{Kt})'$ is an $(Nx1)$ vector of unobserved error terms that follow a Gaussian distribution with $\varepsilon_t \sim \left(0, E\left(u_t, u_t'\right)\right)$. The covariance matrix, $\varepsilon_t \sim \left(0, E\left(u_t, u_t'\right)\right)$, is positive definite. To determine the optimal lag length in the VAR model, we use criteria like the Schwarz (Bayesian) information criterion (SC), Akaike information criterion (AIC), and Hannan–Quinn information criterion (HQ). These criteria help in assessing the model's stability and asymptotic normality. Finally, we test whether the modulus values are <1, ensuring that the model's explanations are invertible and consistent with infinite-order vector moving averages (Lütkepohl, 2005).

$$y_t = A_1 y_{t-1} + \cdots + A_p y_{t-p}) + \varepsilon_t \tag{2}$$

When formulating equation 2, different parameter constraints can be examined. Short-term constraints might be overlooked to clarify the distribution of shocks in Cholesky decomposition; in contrast, long-term constraints can be clarified by the shocks described in the Blanchard–Quah approach. We first familiarize ourselves with the structural representation of the VAR model in a simplified form (equation 3). This model includes a time lag (ρ) and three variables with structural coefficients A and A^s:

$$y_t = A_1^s y_{t-1} + \ldots + A_p^s y_{t-p} + Bu_t \text{, where } \varepsilon_t = A^{-1}Bu_t \text{ and } S = A^{-1}B \tag{3}$$

We assume that specific coefficients are zero. The variable u_{1t} immediately affects all other variables simultaneously, while u_{2t} only impacts variables 1 and 2 simultaneously. Similarly, u_{3t} affects only the third variable, as dictated by Cholesky's restriction (equation 4). The extended restriction model by Blanchard and Quah (1989) posits that a shock's impact is evaluated by examining the specific row in the F-matrix that corresponds to the affected

Table 3: Structure of the F-matrix containing the long-term effects

Variables	Shocks							
	$REP_{S\text{-}W, i, t}$	$IQ_{i, t}$	$FDI_{i, t}$	$IQ_{i, t}*FDI_{i, t}$	$TO_{i, t}$	$GDP_{i, t}$	$FI_{i, t}$	$CO_{2, i, t}$
$REP_{S\text{-}W, i, t}$	f_{11}	0	0	0	0	0	0	0
$IQ_{i, t}$	f_{21}	f_{22}	0	0	0	0	0	0
$FDI_{i, t}$	f_{31}	f_{32}	f_{33}	0	0	0	0	0
$IQ_{i, t}*FDI_{i, t}$	f_{41}	f_{42}	f_{43}	f_{44}	0	0	0	0
$TO_{i, t}$	f_{51}	f_{52}	f_{53}	f_{54}	f_{55}	0	0	0
$GDP_{i, t}$	f_{61}	f_{62}	f_{63}	f_{64}	f_{65}	f_{66}	0	0
$FI_{i, t}$	f_{71}	f_{72}	f_{73}	f_{74}	f_{75}	f_{76}	f_{77}	0
$CO_{2, i, t}$	f_{81}	f_{82}	f_{83}	f_{84}	f_{85}	f_{86}	f_{87}	f_{88}

Source: Authors' edition in Eviews 10+

variable. We assume that the overall impact of the shock over time is minimal; ψ, which represents the long-term multiplier (F = ψS), is used in the formulation (equation 5).

$$\varepsilon_t = Su_t = \begin{vmatrix} s_{11} & 0 & 0 \\ s_{21} & s_{22} & 0 \\ s_{31} & s_{32} & s_{33} \end{vmatrix} \begin{vmatrix} u_{1t} \\ u_{2t} \\ u_{3t} \end{vmatrix} \tag{4}$$

$$(1—A_1—\ldots A_p)^{-1}\,\varepsilon_t = \psi_{\varepsilon t} = F_{ut} \text{ and } F = \begin{vmatrix} f_{11} & 0 & 0 \\ f_{21} & f_{22} & 0 \\ f_{31} & f_{32} & f_{33} \end{vmatrix}, \text{ while}$$

$$S = \begin{vmatrix} s_{11} & s_{12} & s_{13} \\ s_{21} & s_{22} & s_{23} \\ s_{31} & s_{32} & s_{33} \end{vmatrix} \tag{5}$$

In EViews 10+, constructing the F-matrix, representing long-term relationships, depends on the order in which variables are entered into the VAR model. This setup assumes that a shock influences each variable sequentially, with the last variable being affected only by its own shock. The F-matrix (Table 3) is developed following the theoretical framework discussed in the paper.

This study uses the Johansen test for cointegration to identify stable and enduring connections among the variables. Failure to establish such a relationship with this test does not definitively prove its absence; it merely suggests that a relationship may not exist (Dinh, 2019). The impulse response analysis is crucial in econometric studies, especially within the VAR model context. Here, the functions represent the effect of a unit shock on a specific variable in the model; the shock originates from variable *i* and impacts variable *j*, holding all else constant. Additionally, variance decomposition over a specified time horizon breaks down the prediction error variance. This process distinguishes between short- and long-term effects of specific variables, showing the percentage of uncertainty in variable i^{th} attributed to the shock from variable j^{th} after period h (Dinh, 2020).

4. EMPIRICAL RESULTS AND DISCUSSION

This study's model determined the lag length by employing the "lag order selection criteria," with lags restricted to 0-2 to ensure stability. The AIC (Appendix 1) guided the model selection, which identified an optimal lag of 2 (with an AIC value of 41.80878*, the lowest in the table); the panel VAR displayed no statistical errors at this stage. Notably, we found no inverse roots of the characteristic polynomial outside the unit circle, confirming that all moduli were <1; thus, the stability condition of the VAR model was met (Table 4). The cointegration analysis (Appendix 1) demonstrated the statistical significance of the independent variables at a 5% significance level. Over the long-term, the independent variables significantly impacted the dependent variable. This conclusion is based on the observation that all the trace statistic and Max-Eigen statistic values exceeded their respective critical values (Dinh, 2019).

Table 4: Roots of characteristics polynomials

Root	Modulus
−0.115953−0.937569i	0.944712
−0.115953+0.937569i	0.944712
−0.616641−0.428501i	0.750905
−0.616641+0.428501i	0.750905
0.226746−0.559102i	0.603332
0.226746+0.559102i	0.603332
0.019020−0.569275i	0.569592
0.019020+0.569275i	0.569592
−0.150779−0.488497i	0.511238
−0.150779+0.488497i	0.511238
−0.313157−0.381726i	0.493743
−0.313157+0.381726i	0.493743
0.109175−0.400591i	0.415202
0.109175+0.400591i	0.415202
−0.271405	0.271405
0.128665	0.128665

Source: Authors' edition in Eviews 10+

Impulse responses identify cross-sectional dependence in a VAR model and pose a challenge; the findings rely on the impacts of individual variable shocks on RE sources, such as solar and wind production, rather than focusing on the model's coefficients, as is common in many econometric approaches. Nonetheless, the residuals show significant homogeneity, as demonstrated in Appendix 2. These responses illustrate the effect of each variable's stimulus on RE production over time, along with 95% confidence intervals (±2 standard errors) (Figure 5).

The dependent variable, RE production, was initially examined to determine the trend at the starting period, revealing a positive trend. The subsequent impulse responses of the remaining variables, specifically IQ and FDI, and the joint effect of IQ*FDI, showed a minimal positive impact. This outcome indicates that the governments of the selected Eastern European countries can still enhance their IQ to attract more FDI, which could boost RE production; however, these countries currently face challenges in supporting the increased generation of solar and wind power instead of conventional fossil-fuel-based energy.

The impulse responses of other control variables, such as trade openness (TO) and per capita GDP, were also positive, though not significantly. This outcome suggests that the countries studied have not achieved sufficient IQ for substantial RE production. Consequently, economic growth alone cannot rapidly accelerate RE production to meet the net-zero targets by 2050. Additionally, the FI index had a negative impact, indicating that the current trends in IQ and FDI cannot effectively support the financial sector's role in supporting increased RE deployment. CO_2 emissions also had a negative relationship, suggesting that increased RE deployment will gradually reduce carbon emissions. This finding is consistent with our theoretical model.

Finally, we must analyze the variance decomposition, which identifies the proportion of fluctuations in a time series that can be attributed to specific variables over a given time horizon; it also dissects the forecast error variance for that period (Dinh, 2020). Table 5 shows that the variance decomposition analysis reveals that the production of RE (solar and wind) in the selected Eastern European countries is significantly influenced (~66%) by the main factors. In contrast, IQ, FDI, and the joint effect of IQ and FDI account for approximately 6%, 7%, and 3%, respectively, indicating a marginal impact. Furthermore, control variables such as TO, GDP, CO_2, and FI exhibit peripheral effects of approximately 5%, 3%, 7%, and 1%, respectively. These results support our initial hypothesis regarding the relationship between IQ and FDI and their joint impact on RE deployment in the 12 Eastern European countries.

5. CONCLUSION AND POLICY RECOMMENDATION

Disruptive human activities often create environmental imbalances, leading to extreme weather conditions, such as intense heat. Civilian actions exacerbate these imbalances. Additionally, people face unpredictable fluctuations in essential daily resources due to factors like oil and gas embargoes and frequent conflicts, such as the Russia–Ukraine and Israel–Palestine wars. Consequently, the global landscape is changing rapidly, and the energy sector dynamics are evolving; thus, there is a strong

Figure 5: Accumulated impulse response functions of RE production for solar and wind to model variables in the long run. Source: Authors' edition in Eviews 10+

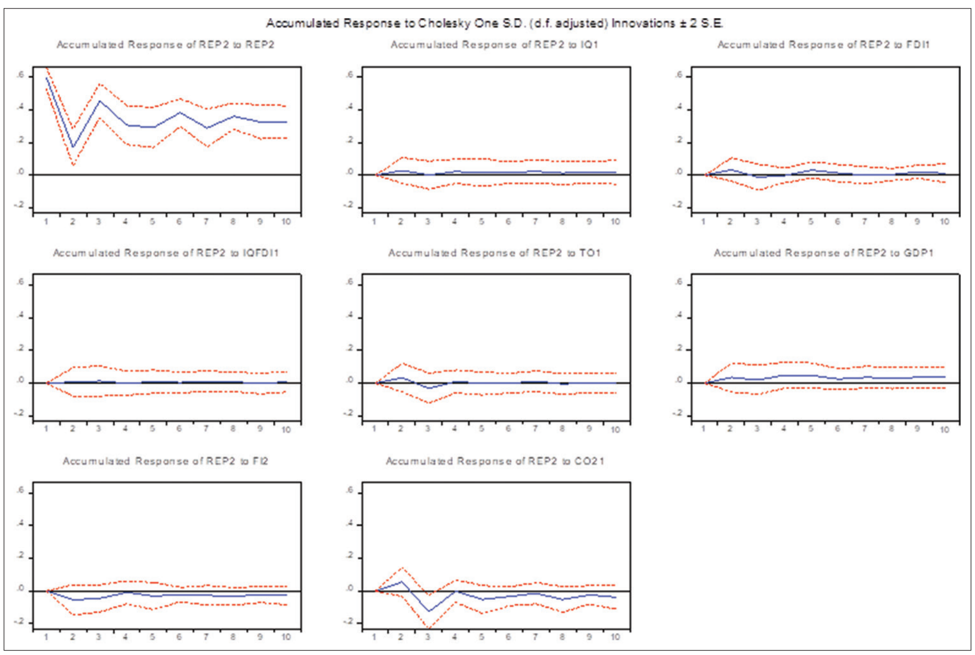


Table 5: Variance decomposition of $REP_{S-W, i, t}$ on VAR factors

Period	$REP_{S-W, i, t}$	$IQ_{i, t}$	$FDI_{i, t}$	$IQ_{i, t}*FDI_{i, t}$	$TO_{i, t}$	$GDP_{i, t}$	$FI_{i, t}$	$CO_{2, i, t}$
1	80.00000	4.00000	4.00000	2.00000	2.00000	0.00000	0.00000	4.00000
2	78.08533	5.15937	4.22146	2.00797	3.20329	1.21923	0.52891	6.57445
3	72.30567	6.25059	5.51289	3.01041	4.78534	1.21231	0.44422	7.47857
4	69.87748	6.30510	5.49969	3.03353	4.97267	2.31814	0.60229	7.39110
5	66.32237	6.31014	5.64589	3.04634	5.98699	2.31695	0.66841	7.70293
6	63.29349	7.30604	7.68198	5.04905	5.97433	4.37453	0.66979	7.65080
7	59.31789	7.30904	7.69595	4.05593	6.97887	4.38267	0.66301	7.59663
8	59.16889	7.32092	8.69162	4.05677	7.00295	4.38002	0.66159	7.71725
9	59.02737	7.32351	8.72616	5.07047	7.00617	5.37981	0.67150	7.79501
10	58.97724	8.32337	8.73727	5.08379	7.00603	5.37963	1.67392	8.81876

Source: Authors' edition in Eviews 10+

push for RE production, which would improve environmental quality and help countries become more self-reliant by utilizing their energy resources.

This research uses a panel VAR model to investigate the impact of IQ, FDI, and their joint effect on RE production in 12 Eastern European countries from 1996 to 2022. In this model, RE production is the dependent variable, allowing the examination of the impulse responsiveness of the relevant variables.

The impulse responsiveness of IQ and FDI shows a marginal effect, including their joint impact. Individual countries should adopt tailored policy measures to enhance RE deployment to support the European Green Deal. Political support, effective governance, and reduction of corruption in the energy sector are crucial for ensuring sustainable and low-cost energy. Enhanced institutional effectiveness can attract more FDI to the RE sector by reassuring investors about their returns. Furthermore, the VAR model reveals only a marginal response to the joint effect of IQ and FDI. Therefore, dynamic policy regulations, such as setting time-bound energy-mix targets and implementing robust and centralized supervision, may benefit the concerned countries.

This research indicates a minimal response from one of the control variables, specifically financial institutions. Furthermore, organizations dedicated solely to supporting the expansion of RE projects are scarce. Tanvir Alam and Somosi (2023) found that higher discount rates impact the levelized cost of electricity. This shortage of financial institutions and lack of fair competition may result in higher rates. The government should create policies to establish financial institutions that exclusively support RE projects with lower discount rates. A portion of shares in the RE projects could be offered to investors to ensure these lower rates. Alternatively, public-private partnerships could be viable for developing RE projects.

Energy policy requires consistency. Many developing and impoverished nations remain energy-poor due to inconsistent policies and high corruption levels in the energy sector. If corruption is not eradicated, foreign investors will be unwilling to invest in the RE sector, and corruption will continue to inflate the per-unit cost of energy production. Market-based mechanisms, such as RE auction schemes, are becoming increasingly popular for producing large amounts of RE at low costs, and many European countries are adopting this approach; however, appropriate governance support, tailored auction design features, and adequate liquidity by FDI are necessary for these schemes to be effective. Specific regional characteristics, such as access to natural resources, weather conditions, access to technology and capital, and governance characteristics distinguish Eastern European countries from Asian and South American countries. Therefore, in this research, the focus was on Eastern European economies. It is hoped that by examining the hypotheses in this study in other regions, the researchers will provide the possibility to compare the results

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APPENDICES

Appendix 1: VAR optimum lag selection criteria

Lag	LogL	LR	FPE	AIC	SC	HQ
0	−4673.448	NA	9.24E+08	43.34674	43.47175*	43.39724
1	−4556.106	224.905	5.64E+08	42.85284	43.97793	43.30738
2	−4379.349	325.6920*	1.99e+08*	41.80878*	43.93396	42.66736*

Johansen co-integration test

Unrestricted cointegration rank test (Trace)				
Hypothesized		Trace	0.05	
No. of CE (s)	Eigenvalue	Statistic	Critical Value	Prob.**
None*	0.563149	748.8023	159.5297	0.0000
At most 1*	0.500341	579.8572	125.6154	0.0001
At most 2	0.437864	438.3158	95.75366	0.0001
At most 3*	0.363515	320.8094	69.81889	0.0001
At most 4*	0.33208	228.6432	47.85613	0.0001
At most 5*	0.273598	146.3114	29.79707	0.0001
At most 6*	0.193025	81.10241	15.49471	0.0000
At most 7*	0.167314	37.35207	3.841466	0.0000
Unrestricted Cointegration Rank Test (Maximum Eigenvalue)				
Hypothesized		**Max-Eigen**	**0.05**	
No. of CE (s)	**Eigenvalue**	**Statistic**	**Critical Value**	**Prob.****
None*	0.563149	168.9452	52.36261	0.0000
At most 1*	0.500341	141.5414	46.23142	0.0000
At most 2*	0.437864	117.5063	40.07757	0.0000
At most 3*	0.363515	92.16619	33.87687	0.0000
At most 4*	0.33208	82.33183	27.58434	0.0000
At most 5*	0.273598	65.209	21.13162	0.0000
At most 6*	0.193025	43.75034	14.2646	0.0000
At most 7*	0.167314	37.35207	3.841466	0.0000

Trace test indicates 8 cointegrating eqn (s) at the 0.05 level. *Denotes rejection of the hypothesis at the 0.05 level. **MacKinnon-Haug-Michelis (1999) P values

Max-eigenvalue test indicates 8 cointegrating eqn (s) at the 0.05 level. *Denotes rejection of the hypothesis at the 0.05 level. **MacKinnon-Haug-Michelis (1999) P values

Appendix 2: VAR model residuals