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The Relationship between Financial Development and Renewable Energy Consumption in the European Union-27 Countries

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ABSTRACT

This study examines the effect of financial development on renewable energy consumption for 27 European Union member countries from an asymmetric causality perspective. Panel cointegration and asymmetric causality tests were applied using panel data for the period 2000-2023. The findings show that there is a long-term cointegration relationship between the variables. In addition, the results of the asymmetric Granger causality analysis reveal that financial development has an asymmetric effect on renewable energy consumption. It was determined that positive financial shocks are the Granger cause of positive shocks in renewable energy consumption. However, no significant causality relationship was found between negative financial shocks and negative shocks in renewable energy consumption. These results show that renewable energy consumption increases in periods when financial development increases, but financial contractions do not have a significant effect on this consumption. The findings of the study reveal that integrating financial development with sustainable energy policies can encourage long-term renewable energy investments and support green transformation in European Union countries.

Keywords: Financial Development, Renewable Energy Consumption, Asymmetric Causality, Panel Cointegration, European Union (EU-27)
JEL Classifications: Q43, G20

1. INTRODUCTION

The global energy market is constantly evolving and increasing its importance. In recent years, renewable energy consumption has emerged as a critical element in sustainable development and combating climate change. Developed countries are developing policies aimed at minimizing carbon emissions by reducing their dependence on fossil fuels and increasing their investments in renewable energy sources (Syzdykova et al., 2021). In this context, the impact of financial development on renewable energy consumption is at the center of academic and political discussions. Financial development can facilitate the financing of renewable energy projects by providing effective allocation of financial resources that encourage investment in the energy sector. In addition, the development of financial systems can encourage actors in the energy sector to focus on long-term projects and contribute to the spread of clean energy technologies. However, there is no clear consensus in the literature on whether the impact of financial development on renewable energy consumption is symmetrical or not and through which mechanisms this impact occurs. Therefore, it is of great importance to examine the impact of financial development on renewable energy consumption from an asymmetric perspective.

This study aims to analyze the relationship between financial development and renewable energy consumption in developed countries using the asymmetric panel data method. While traditional panel data models generally assume that the relationship between variables is symmetric, the asymmetric panel data method allows determining the different effects of positive and negative financial development shocks on renewable energy consumption. In this way, it is aimed to provide valuable inferences for policy makers to better understand the structural dynamics of financial markets. In this context, the main contributions of the study can be summarized as follows:

- To examine the relationship between financial development and renewable energy consumption in developed countries in detail,
- To determine whether the effect of financial development on renewable energy consumption differs under positive and negative shocks using the asymmetric panel data method,
- To provide recommendations that will guide policy makers and investors in light of the findings obtained.

In the following sections of the study, a literature review will be presented in the second section, the data set and methodology will be discussed in detail in the third section, the analysis results will be shared in the fourth section, and finally, the study will be concluded by presenting policy recommendations in light of the findings obtained in the fifth section.

2. LITERATURE REVIEW

The relationship between financial development and energy consumption is complex and varies significantly across economic contexts. Research shows that while financial development can increase energy consumption in certain regions, it can also have negative effects in others, particularly in emerging economies. This multifaceted interaction is explored in several studies that highlight the need for specific financial policies.

In their study, Alshagri et al. (2024) found that financial development positively affects renewable energy consumption in developed economies, while it negatively affects consumption in developing and emerging economies. The effect is stronger in developed economies with higher levels of financial development, as opposed to low financial development in emerging markets.

According to Mishra and Deb (2024), financial development positively affects energy consumption in the Asia-Pacific region, as it shows that advanced financial infrastructure supports increased energy use. This relationship highlights the co-dependency between financial development and energy consumption, which contributes to overall economic growth.

Makun et al. (2024) argue that while financial development worsens environmental sustainability, renewable energy consumption improves it. The authors also emphasize the need for significant financial sector reforms and investment in renewable energy infrastructure to enhance environmental sustainability in Pacific Island economies.

According to Akbulut (2024), financial development significantly affects energy consumption in developing countries and has a significant threshold effect. Specifically, the author finds that when the financial institution development index exceeds 0.356, the forces driving increased emissions due to energy consumption weaken.

Abdelhamid et al. (2023) found a nonlinear, inverted U-shaped relationship between financial development and energy consumption in Argentina. This indicates bidirectional causality between the two variables, and financial development significantly predicts economic growth and affects energy demand.

Usman et al. (2023) In their study, financial development positively affects energy consumption, and a 1-unit increase in financial development leads to a 3.07% increase in energy consumption. This relationship emphasizes the important role of financial sectors in facilitating effective investments that drive energy demand.

Nguyen et al. (2023) found a one-way causality relationship from financial development to total energy consumption in middle-income countries, and emphasized that energy consumption increases as financial systems develop, and the interdependence of economic growth, financial development, and energy use.

Minh and Ngoc (2022) found direct and spillover effects of financial development and energy consumption on economic growth in 11 Asian countries. They found that financial development benefits both host and neighboring countries, and that increased energy consumption negatively affects economic growth.

Liu et al. (2024) found that financial development affects energy consumption by encouraging the use of clean energy and preventing the consumption of non-clean energy. The authors found that the effect varies with energy consumption levels, with stronger effects on clean energy as consumption increases, especially after changes in green credit policy.

Farman et al. (2024) in their study examined the relationship between energy consumption, financial development, and environmental degradation across SAARC countries. The results indicate that higher energy use and financial growth contribute to environmental deterioration, while sustainable financial practices can mitigate negative ecological impacts. Their findings emphasize the need for green financial policies to balance economic and environmental goals in the region.

Chunyu et al. (2021) focused on developing European and Central Asian economies and found that financial development initially increases carbon dioxide emissions and energy consumption, but the square term reduces emissions, supporting the inverted U-shaped hypothesis regarding energy consumption and environmental impact.

Ahmed et al. (2022) examined the effect of financial development on energy consumption in various countries, emphasizing that factors such as foreign direct investment, economic growth, and urbanization play important roles in shaping this relationship in both developed and developing economies.

Aslan et al. (2021) investigated the relationship between financial development and energy consumption in their study, and found that financial development affects energy consumption differently in G7 economies compared to emerging markets. The authors also highlighted the varying effects on energy efficiency and consumption patterns in these economies.

According to Ma and Fu (2020), while financial development positively affects energy consumption in developing countries, its effect is negligible in developed countries. In general, financial development cannot limit the increases in global energy consumption, which requires a balance between financial sector growth and energy consumption in developing countries.

Janpolat et al. (2021) emphasize that financial development positively affects energy consumption in developing countries, does not define this effect in developed countries, and emphasizes a changing relationship based on economic situation and financial market maturity.

Horky and Fidrmuc (2024) find that developed capital markets positively affect renewable energy initiatives, while traditional financial institutions tend to favor carbon-intensive energy production. This dichotomy highlights the need for enhanced regulatory support to align financial development with renewable energy consumption.

Sun et al. (2023) argue that financial development in developed economies positively affects renewable energy consumption primarily through the development of financial institutions that increase access, depth, and efficiency, facilitating investments in renewable energy projects and technologies.

Gök (2023) argues that financial development increases renewable energy by providing investors with more reliable, efficient, and less costly funds, which in turn increases investment in renewable energy projects, thus directly linking financial resources to increasing renewable energy consumption in developed economies.

Wang et al. (2023) found that financial development significantly affects renewable energy consumption, especially in high-income countries, through improved access to capital and investment opportunities that facilitate the installation and use of renewable energy sources and thus encourage their consumption. Saygın and İskenderoğlu (2022) found that financial development positively affects renewable energy consumption in developed countries, especially through banking variables. However, stock market variables show a negative relationship, indicating that banking systems are more effective in encouraging renewable energy use.

3. DATA AND METHODS

This study examines the relationship between financial development and renewable energy consumption for EU27 countries (Austria, Belgium, Bulgaria, Croatia, Republic of Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain and Sweden). Annual data covers the period 2000-2023. The data in question is collected from the databases of international institutions. From these data, financial development (*FD*) is obtained from the International Monetary Fund database, and renewable energy consumption (*REC*) is obtained from the International Energy Agency database.

In the analysis part of the study, the stationarity of the series was tested before the panel cointegration test. For this purpose, Levin, Lin and Chu (LLC, 2002), Im, Pesaran and Shin (IPS, 2003), Fisher-ADF (1999) and Fisher-PP (1999) tests were applied to the series. The long-term relationship between the series was examined with the hidden panel cointegration method introduced to the literature by Hatemi-J (2018). Then, the causality relationship between the series was examined and the causality relationship between the series and their shocks was tried to be revealed with the asymmetric panel causality test.

3.1. Hidden Panel Cointegration Test (Hatemi-J, 2018)

This test was suggested by Hatemi-J (2018). It is based on the Panel Kao cointegration test. After Hatemi-J (2018) separates the series into positive and negative components, he applies the test suggested by Kao (1999). In order to perform cointegration analysis, the series must be stationary of the first degree. He completes the test process under the null hypothesis that there is no cointegration relationship. The following equations are given for two first degree integrated variables:

$$y_{i,t} = y_{i,t-1} + e_{i1,t} = y_{i,0} + \sum_{j=1}^{t} e_{i1,j}, i = 1,2,\ldots,m \quad (1)$$

$$x_{i,t} = x_{i,t-1} + e_{i2,t} = x_{i,0} + \sum_{j=1}^{t} e_{i2,j}, i = 1,2,\ldots,m \quad (2)$$

Here *m* denotes the cross-sectional dimension and *e* is the disturbance term assumed as a white noise process. The positive and negative shocks for each panel variable are as follows:

$$e^{+}_{i1,t} = Max(e_{i1,t}, 0)$$

$$e^{+}_{i2,t} = Max(e_{i2,t}, 0)$$

$$e^{-}_{i1,t} = Min(e_{i1,t}, 0)$$

$$e^{-}_{i2,t} = Min(e_{i2,t}, 0)$$

Using these results, the following expressions can be obtained:

$$y^{+}_{i,t} = y^{+}_{i,0} + e^{+}_{i1,t} = y_{i,0} + \sum\nolimits_{j=1}^{t} e^{+}_{i1,j} \quad (3)$$

$$x^{+}_{i,t} = x^{+}_{i,0} + e^{+}_{i2,t} = x_{i,0} + \sum\nolimits_{j=1}^{t} e^{+}_{i2,j} \quad (4)$$

$$y^{-}_{i,t} = y^{-}_{i,0} + e^{-}_{i1,t} = y_{i,0} + \sum\nolimits_{j=1}^{t} e^{-}_{i1,j} \quad (5)$$

$$x^{-}_{i,t} = x^{-}_{i,0} + e^{-}_{i2,t} = x_{i,0} + \sum\nolimits_{j=1}^{t} e^{-}_{i2,j} \quad (6)$$

where two panel cointegration equations for positive and negative components are given as follows:

$$y_{i,t}^{+} = \alpha_i^{+} + \beta_i^{+} x_{i,t}^{+} + e_{i,t}^{+} \quad (7)$$

$$y_{i,t}^{-} = \alpha_i^{-} + \beta_i^{+} x_{i,t}^{+} + e_{i,t}^{-} \quad (8)$$

If e_{it}^{+} and e_{it}^{-} are stationary in equations (7) and (8), respectively, then positive and negative cumulative shocks are cointegrated. Then, whether the e_{it}^{+} and e_{it}^{-} shocks are stationary is tested with the extended Dickey Fuller (ADF) test. The panel ADF test equation for equation (7) is as follows:

$$e_{i,t}^{+} = \rho^{+} e_{i,t-1}^{+} + \sum_{l=1}^{k} \gamma_i^{+} \Delta e_{i1,t-1}^{+} + w_{i,t}^{+} \quad (9)$$

The appropriate lag order l can be determined by minimizing an information criterion. Testing the null hypothesis $\rho^{+} = 0$ determines whether there is cointegration among the positive components. The following test statistic can be used to test the null hypothesis of Kao panel cointegration:

$$ADF = \frac{t_\rho + \sqrt{6}x \dfrac{\sigma_v}{2\sigma_{0v}}}{\sqrt{\dfrac{\sigma_{0v}^2}{2\sigma_v^2} + \dfrac{3\sigma_v^2}{10\sigma_{0v}^2}}} \quad (10)$$

Here t_{p+} is the t statistic of the parameter $\rho\rho^{+}$ in equation (7). σ_υ^2 and $\sigma_{0\upsilon}^2$ represent the variance and long-term variance, respectively. Also, equation (10) has a standard normal distribution. The long-term variance-covariance matrix is given by the kernel estimation approach as follows:

$$© = \begin{bmatrix} \sigma_{e_1^+}^2 & \sigma_{e_1^+,e_2^+}^2 \\ \sigma_{e_1^+,e_2^+}^2 & \sigma_{e_2^+}^2 \end{bmatrix} = \frac{1}{m}\sum_{i=1}^{m} \begin{bmatrix} \dfrac{1}{T}\sum_{i=1}^{T} u_{it}u_{it}^{'} + \dfrac{1}{T}\sum_{i=1}^{T} \mathcal{K}(\tau / b) \\ \sum_{t=\tau+1}^{T} \left(u_{it}u_{it-\tau}^{'} + u_{it-\tau}u_{it}^{'} \right) \end{bmatrix}$$

Here K is the kernel function and b is the bandwidth. The same testing process can be continued for negative components. Also, the cointegration process is the same from positive components to negative components or from negative components to positive components (Hatemi-J, 2018).

3.2. Asymmetric Causality

In the literature, there are many methods to test Granger (1969) causality in a panel data methodology. However, these tests do not allow for asymmetric causal effects and therefore do not take into account the effects of positive and negative shocks. Macroeconomic variables tend to respond more to negative changes than to positive ones. Therefore, it is important to consider potential asymmetric effects when applying causality tests (Hatemi-J et al., 2014). In this section, the causality relationship between positive and negative shocks for equations (3), (4), (5) and (6) is tested using the p lagged vector autoregressive (VAR) model. If positive shocks are denoted as $y^{+} = (y_{1,t}^{+}, y_{2,t}^{+})$, the VAR (p) model is written as follows:

$$y^{+} = \delta + A_1 y_{t-1}^{+} + A_2 y_{t-2}^{+} + \ldots A_p y_{t-p}^{+} + e_t^{+} \quad (11)$$

or in its widest form

$$\begin{bmatrix} y_{1,t}^{+} \\ y_{2,t}^{+} \end{bmatrix} = \begin{bmatrix} \delta_{1t} \\ \delta_{2t} \end{bmatrix} + \begin{bmatrix} \beta_{11} & \beta_{12} \\ \beta_{21} & \beta_{22} \end{bmatrix} \begin{bmatrix} y_{1t-1} \\ y_{2,t-1}^{+} \end{bmatrix} + \begin{bmatrix} e_{1,t}^{+} \\ e_{2,t}^{+} \end{bmatrix} \quad (12)$$

The null hypothesis of the test is established as $y_{i2,t}^{+}$ is not the cause of $y_{i1,t}^{+}$ and the coefficient $\beta_{i2,r}$ is calculated with the Wald test statistic (Hatemi-J, 2012). The process is the same for negative components.

4. RESULTS

In this study, while examining the relationship between financial development and renewable energy consumption for EU27 countries, it was first investigated whether each variable in the panel contained a unit root. For this purpose, the stationarity test of the series LLC, IPS, Fisher-ADF and Fisher-PP tests were applied. The results are presented in Tables 1 and 2.

According to these results, it is seen that the series have a unit root structure in both themselves and in the level values of their positive and negative shocks. However, after taking the difference, the series become stationary. In short, the series are integrated of the first degree, that is, I(1).

Since each variable in the panel is integrated of the first degree, the cointegration relationship between the series is investigated with the test suggested by Hatemi-J (2018). According to the cointegration analysis test results presented in Table 3, while there is no cointegration relationship in the standard cases of the series, there is a panel cointegration relationship between the components.

The results of the Granger causality analysis (Table 4) show that the effect of financial development on renewable energy

Table 1: Panel unit root test results

Deterministic components	Variables	LLC	IPS	Fisher-ADF	Fisher-PP
Intercept	*FD*	−0.646 (0.283)	3.467 (0.867)	13.403 (0.884)	11.282 (0.887)
	REC	−0.681 (0.246)	2.233 (0.797)	16.266 (0.880)	41.334 (0.181)
Intercept andTrend	*FD*	−0.427 (0.336)	0.0737 (0.633)	33.683 (0.483)	16.8618 (0.860)
	REC	−0.168 (0.433)	1.243 (0.773)	26.464 (0.864)	13.846 (0.888)
Intercept	Δ*FD*	−13.132 (0.000)*	−13.601 (0.000)*	239.040 (0.000)*	375.796 (0.000)*
	Δ*REC*	−11.490 (0.000)*	−11.079 (0.000)*	188.647 (0.000)*	241.403 (0.000)*
Intercept andTrend	Δ*FD*	−11.875 (0.000)*	−11.796 (0.000)*	191.601 (0.000)*	439.109 (0.000)*
	Δ*REC*	−10.260 (0.000)*	−9.703 (0.000)*	153.703 (0.000)*	236.399 (0.000)*

*indicates 1% significance level. Values in parentheses are the probability values of the series

Table 2: Panel unit root test results of shocks of variables

Deterministic components	Variables	LLC	IPS	Fisher-ADF	Fisher-PP
Intercept	FD^{+}	−0.416 (0.476)	5.476 (0.885)	9.101 (0.997)	11.170 (0.999)
	REC^{+}	0.699 (0.758)	7.083 (0.814)	3.977 (0.987)	4.073 (0.996)
Intercept andTrend	FD^{+}	−1.422 (0.094)	−0.427 (0.335)	39.915 (0.224)	22.701 (0.894)
	REC^{+}	−1.541 (0.064)	−0.806 (0.210)	42.445 (0.152)	14.408 (0.994)
Intercept	FD^{-}	0.878 (0.810)	5.251 (0.906)	9.060 (0.997)	9.936 (0.997)
	REC^{-}	2.544 (0.994)	5.284 (0.873)	4.399 (0.988)	2.980 (0.998)
Intercept and Trend	FD^{-}	1.240 (0.890)	0.381 (0.648	27.349 (0.741)	26.561 (0.814)
	REC^{-}	0.599 (0.725)	1.137 (0.872)	21.941 (0.771)	16.333 (0.985)
Intercept	ΔFD^{+}	−13.502 (0.000)*	−15.865 (0.000)*	245.378 (0.000)*	366.707 (0.000)*
	ΔREC^{+}	−9.142 (0.000)*	−10.654 (0.000)*	177.856 (0.000)*	197.517 (0.000)*
Intercept and Trend	ΔFD^{+}	−12.425 (0.000)*	−12.559 (0.000)*	177.757 (0.000)*	603.660 (0.000)*
	ΔREC^{+}	−7.725 (0.000)*	−8.926 (0.000)*	141.204 (0.000)*	167.905 (0.000)*
Intercept	ΔFD^{-}	−10.578 (0.000)*	−12.454 (0.000)*	215.228 (0.000)*	399.396 (0.000)*
	ΔREC^{-}	−12.125 (0.000)*	−12.552 (0.000)*	211.436 (0.000)*	329.931 (0.000)*
Intercept and Trend	ΔFD^{-}	−9.175 (0.000)*	−10.559 (0.000)*	163.157 (0.000)*	399.432 (0.000)*
	ΔREC^{-}	−11.774 (0.000)*	−10.486 (0.000)*	163.772 (0.000)*	291.211 (0.000)*

*indicates 1% significance level. Values in parentheses are the probability values of the series

Table 3: Hidden panel cointegration test results

Variables	$H_0{:}I\,(1),\,,\,H_1{:}I\,(0)$
(FD, REC)	−1.244 (0.107)
(FD^{+}, REC^{+})	−2.285 (0.011)**
(FD^{-}, REC^{-})	−3.281 (0.005)***
(FD^{-}, REC^{+})	−2.908 (0.001)***
(FD^{+}, REC^{-})	−2.839 (0.002)***

*** and ** indicate significance at 1% and 5% levels, respectively. Values in parentheses are probability values

Table 4: Symmetric and asymmetric panel causality test results

Direction of causality	Statistic
$FD \nrightarrow REC$	1.615 (0.7036)
$REC \nrightarrow FD$	1.908 (0.1098)
$FD^{+} \nrightarrow REC^{+}$	0.935 (0.0007)***
$REC^{+} \nrightarrow FD^{+}$	0.246 (0.0300)**
$FD^{-} \nrightarrow REC^{-}$	1.530 (0.8763)
$REC^{-} \nrightarrow FD^{-}$	1.955 (0.1479)

*** and ** indicate significance at 1% and 5% levels, respectively. Values in parentheses are probability values. X↛Y: Variable X is not the Granger cause of variable Y

consumption is asymmetric. According to the findings, positive shocks in the financial development variable were determined to be the Granger cause of positive shocks in renewable energy consumption. This situation reveals that in periods when financial development increases, demand for or investments in renewable energy also increase, thus there is a causal link between financial development and renewable energy consumption. However, the fact that no causal relationship was determined between negative shocks shows that renewable energy consumption is not affected in the same direction when financial development declines. This result suggests that financial contractions do not have a reducing effect on renewable energy use or that this relationship is shaped by different dynamics. Possible explanations may include factors such as renewable energy investments being long-term and state-supported, having a more resilient structure against financial fluctuations, or being strategically prioritized compared to traditional energy sources.

5. CONCLUSION

This study analyzed the impact of financial development on renewable energy consumption for 27 member countries of the European Union using panel cointegration and asymmetric causality tests. The findings revealed the existence of a long-term cointegration relationship between financial development and renewable energy consumption. In addition, asymmetric Granger causality analysis showed that positive shocks in financial development were the Granger cause of positive shocks in renewable energy consumption. However, no significant causality relationship was found between negative financial shocks and negative shocks in renewable energy consumption. These findings show that renewable energy investments and consumption were encouraged during periods of increasing financial development, but financial contractions did not negatively affect this area. These results show that the support mechanisms provided by financial development to the renewable energy sector are more effective, especially during growth periods. Increased access to financial resources can accelerate the growth of the sector by facilitating the financing of renewable energy projects. However, the fact that negative financial shocks did not have a significant effect on renewable energy consumption shows that this sector has a certain resilience capacity. This suggests that renewable energy investments are supported by long-term planning and can be protected from financial fluctuations by government incentives, subsidies or regulatory policies. Some policy recommendations based on the results of the study are given below:

- Strengthening financial incentives: The study results reveal the effect of financial development on increasing renewable energy consumption. In this context, European Union countries can encourage more resources to be allocated to renewable energy investments by developing mechanisms that support financial development.
- Comprehensive green financing policies: In order to facilitate access to financing for renewable energy projects, financial instruments such as green bonds, sustainable banking practices and low-interest loans should be expanded
- Resilient policies against negative financial shocks: In order to prevent financial fluctuations from harming the renewable

energy sector, long-term state support and subsidies should be maintained in a stable manner
- Conducting more comprehensive research: Future studies should examine in more detail why the asymmetric causality relationship is not significant for negative financial shocks. In particular, it would be useful to conduct additional analyses considering different macroeconomic variables, institutional structures and policy factors.

In conclusion, this study provides important implications for policy makers by revealing the asymmetric impact of financial development on renewable energy consumption. European Union countries should integrate their financial systems more strongly with renewable energy investments to achieve sustainable development goals.

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