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Research Article

The Impact of Geopolitical Risk and Financial Development Dynamics on Wind Power

Jeopolitik Risk ve Finansal Gelişme Dinamiklerinin Rüzgar Enerjisi Üzerindeki Etkisi

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Abstract

Environmental disasters resulting from global warming and current geopolitical events inevitably affect both the energy and economic strategies of countries. Consequently, factors such as energy independence and low costs are further fueling the transition to sustainable and renewable energy. Today, the trend toward wind energy, one of the renewable energy sources, is increasing due to factors such as lower cost, ease of use, abundance, and inexhaustibility. In this context, this study examines the relationship between FD and GPR and wind energy for the countries with the highest wind energy production: China, the USA, Germany, the UK, India, Spain, France, Canada, and Sweden. The study covers the period 2001-2021. Necessary priori tests are performed to peruse the long-term cohesion of the variables in the model. Westerlund and Edgerton (2008) panel cointegration test is enforced. The panel cointegration test results indicate that the variables move together in the long term. Long-term coefficient estimates were subsequently performed, finding that FD has a surprisingly negative impact on wind energy production in China, the US, India, and Sweden. In France, the impact is notably positive. GPR has a positive impact on wind energy in Sweden but a negative impact in China and France.

Keywords: *Wind power, Renewable Energy, Financial Development, Geopolitical Risk, Panel Cointegration Test*

Öz

Küresel ısınmanın ve güncel jeopolitik olayların sonucu oluşan çevre felaketleri, ülkelerin hem enerji hem de ekonomik stratejilerini kaçınılmaz olarak etkilemektedir. Sonuç olarak, enerji bağımsızlığı ve düşük maliyetler gibi faktörler sürdürülebilir ve yenilenebilir enerjiye geçişi daha da körüklemektedir. Günümüzde, bir yenilenebilir enerji kaynağı olan rüzgar enerjisine yönelim, daha düşük maliyet, kullanım kolaylığı, bol miktarda bulunması ve tükenmez olması gibi faktörler nedeniyle giderek artmaktadır. Bu bağlamda, bu çalışmada, en yüksek rüzgar enerjisi üretimine sahip ülkeler olan Çin, ABD, Almanya, İngiltere, Hindistan, İspanya, Fransa, Kanada ve İsveç için finansal gelişme ve jeopolitik riskin rüzgar enerjisi ile arasındaki ilişki incelenmiştir. Çalışma 2001-2021 dönemini kapsamaktadır. Modeldeki değişkenlerin uzun vadeli uyumunu incelemek için gerekli önsel testler yapılmıştır. Westerlund ve Edgerton (WE) (2008) panel eşbütünleşme testi uygulanmıştır. Panel eşbütünleşme testi sonuçları, değişkenlerin uzun vadede birlikte hareket ettiğini göstermektedir. Daha sonra uzun vadeli katsayı tahminleri yapılmış ve finansal gelişmenin Çin, ABD, Hindistan ve İsveç'te rüzgar enerjisi üretimi üzerinde şaşırtıcı derecede olumsuz bir etkiye sahip olduğu bulunmuştur. Fransa'da bu etki dikkate değer ölçüde olumludur. Jeopolitik riskin İsveç'te rüzgar enerjisini olumlu etkilediği görülürken, Çin ve Fransa'da olumsuz etki yaratmaktadır.

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1. INTRODUCTION

With a rising demand for global energy, the demand for renewable energy has also increased at this rate due to its contribution to a clean environment. Sources such as wind, solar hydro, geothermal, wood are just some of the renewable energy sources. Wind power (WP) is the most widespread and rapidly developing renewable energy source. Wind, found freely and abundantly in nature, is also a clean energy source, making it the most preferred alternative energy source. The value given to wind power, which is among the renewable energy sources, is rising due to reasons such as low cost, easy accessibility, renewable and sustainability. Wind has been used for many different purposes since the past, such as grinding wheat, raising low-level water to a higher level or moving sailing ships. The first mill has been built in Scotland to generate electricity from wind in 1887 (The Renewable Energy Hub, 2024). In addition, the 1973 oil crisis has paved the way for the establishment of the IEA, prompting countries to turn to energy technology to reduce their dependence on foreign energy sources (European Parliament, 2023). Especially recently, with the reality of increasingly deteriorating climate change, the transition of nations to clean energy sources such as wind power has accelerated even more instead of fossil fuels that cause pollution and climate change. WP is one of the most economical and clean ways of generating electricity.

Wind is a power that will never end as long as the world continues to turn. In other words, wind is created by the sun, the atmosphere and the physical structure of the world. Wind power refers to electricity generated by using the power of the wind, unlike other methods such as burning fossil fuels or solar panels. Wind power is clean because it does not pollute the environment like fossil fuels. In addition, considering that wind will never run out, it is the most easily accessible, renewable and sustainable resource. It is affordable. It is easy to make various adjustments in size to achieve optimum power. Wind power is generated by wind turbines, which start with the wind turning the blades and then turning a generator through a series of gears, which in turn produces electricity.

The literature reports that many factors, such as economic, financial, technical, and GPRs, have significant impacts on renewable energy production. We believe that geopolitical risk (GPR) and financial development (FD) have an impact on wind power (WP), one of the renewable energy sources, and we would like to examine the connection between them in our study.

Geopolitical concerns and crises arising in countries, such as competition over traditional non-renewable energy sources and the protection of international strategic transit routes, further fuel interest in renewable energy. The energy crisis following the war between Russia and Ukraine has caused inflation, significantly increasing natural gas prices. Of course, this war is not the first of its kind, and the continuation of past conflicts has brought new geopolitical concerns to the forefront in the Middle East, where energy production is highly concentrated. Historical energy crises, coupled with technological innovation and change, have fuelled the accelerated deployment of clean energy. Today's electric vehicles, windmills, renewable energy sources, heat pumps, solar panels, and increasingly efficient appliances are among the most significant indicators of this transformation. This stored clean energy ensures the use of electricity at all times. Consequently, energy, finance, economics, industry, and climate policy are working together globally to advance renewable energy resources. This, in turn, is driving significant innovation at every stage of the energy sector, including financing, production and consumption, and technology (Öğütçü, 2024). For instance, China, the almost exclusive supplier of the materials needed for offshore wind turbine deployment, has raised concerns about the supply of this material in other countries. Furthermore, this raw material is needed not only for wind turbines but also for technologies such as electric vehicle engines, electronics, and robotics, creating global competition among countries. This, in turn, increases countries' dependence on China (Carrara et. al., 2025). Furthermore, China's high investment in wind power, which is among its clean energy resource targets, is strategically significant, both reducing China's dependence on imported oil and elevating it to the next level in the clean energy sector.

Regarding the effect of FD on renewable energy production, a well-functioning financial sector strengthens the economy by offering a variety of financial products, thus encouraging stronger renewable energy investments. A developed financial sector is also crucial for financing better technological investments for the adoption of renewable energy. A country's FD can be achieved through improved markets and increased diversity and access to financial instruments. FD transforms savings into more effective investment tools, enabling these funds to be invested in productive sectors. Increased FD, in turn, increases the country's economic development. Energy plays a significant role in the development of a country's economy. While energy may initially appear to have a high cost, reducing this cost and ensuring its sustainability depends on renewable energy sources. Financing, directing investors to these investments, and the amount and method of investment are of great importance in investments in clean energy sources, e.g. wind, geothermal and solar energy. Issues such as environmental pollution, environmental quality, climate change, energy independence of countries, GPRs, energy security, and sustainability have increasingly emphasized the importance of renewable energy sources, making it even more crucial to accelerate their deployment. This is precisely why investment in clean energy is increasing. The EU is taking significant steps and is concluding agreements on clean energy and its sustainability. These agreements aim to reduce carbon emissions, neutralize climate change, and utilize clean products and clean technology. With the investments already made and to be made, they aim to transition completely to clean energy and reduce greenhouse gas emissions to very low levels.

For this reason, the importance of FD and GPR variables on wind power production has led to this study. This study is conducted for the countries with the highest WP generation between 2001-2021. These countries are China, US, Germany, UK, India, Spain, France, Canada and Sweden. The reason for choosing top countries with the highest WP generation is to reveal the impact of GPR and FD on the wind power. Additionally, wind power is preferred among renewable energy sources because it holds the largest share and fastest pace of development among renewable energy technologies globally.

The construction of the study is as follows: Next part consists of a literature review related to our research topic. The third part then develops the data and the model to be investigated. The econometric method and empirical results necessary to test the model are put forwarded in the fourth section, and final section encloses the conclusions and necessary policy recommendations.

2. LITERATURE REVIEW

With the increasing number of geopolitical events today, GPR has become a significant factor affecting countries both economically and socially. Given the importance of this topic, researchers are contributing to the literature with various studies on GPR. While studies examining the impact of GPR on renewable energy are recent, there are still no consistent conclusions regarding the direction of the link between two variables. Some studies suggest that GPR have a positive impact on renewable energy sources (Hille, 2023), while others suggest a negative one (Wang et. al., 2024). Meanwhile, some studies could not indicate a significant relationship. While some argue that GPR, a country's excessive energy dependence on a foreign country, threatens its energy security and supports the development of clean energy resources due to the necessity of independence to maintain this security, others argue that GPR increases uncertainty in markets, reduces the expected returns of firms investing in clean energy, and leads to increased transaction costs.

Lee and Lee (2024) have created a dataset of 30 provinces in China to investigate the impact of GPR on renewable energy. It is observed that the results are not the same for every province; for instance, GPR has a negative impact on clean energy in the west part compared to the east and central parts of China. Furthermore, they have found that GPR weakens clean energy use in regions with weaker economies. This suggests that the path to green energy is through stronger financial functioning and technological innovation. Zhao et al. (2023) have investigated the interaction between GPR and renewable energy demand in 20 OECD countries between 1970 and 2019 and have concluded that GPR reduces the demand for clean energy while jeopardizing policies to mitigate climate change. Conversely, economic globalization and rising per capita income have a positive impact on clean energy. Increasing carbon emissions degrade environmental quality and hinder clean energy demand. In light of all these, GPR are believed to deter demand for renewable energy, and policymakers are advised to focus on geopolitical harmony. Sweidan (2021) has examined whether GPR affected the US's renewable energy deployment over the period 1973-2020. Using the ARDL method, the author finds that US renewable energy deployment is significantly and positively affected by GPR. Another study examining the impact of GPR on renewable energy consumption is by Cai and Wu (2021). Using a Bayesian vector autoregressive model, this study finds that GPRs increase with different time horizons and specific geopolitical events, positively affecting renewable energy consumption.

This study examines wind power, a kind of clean energy sources, and examines the impact of GPR on wind power. In this context, some wind power studies, which are limited in the literature, are listed below.

Li et al. (2025) have examined the impacts of hydroelectric, nuclear, solar, wind, and geothermal energy on CO2 emissions and economic growth for 24 countries over the period 2005-2020. The authors have concluded that each type of energy consumption has a positive impact on economic development. Moreover, hydroelectric and nuclear energy have resulted in higher emissions, while wind, solar, and geothermal energy are found to reduce emissions. Furthermore, the significant impact of international geopolitics on energy and socioeconomic development, the political exploitation of oil and gas resources by some resource-rich countries, and the need to develop energy strategies that enhance security in a complex geopolitical landscape amidst increasing global GPR are taken into account, and GPR is selected as the threshold. In other words, the path to carbon-free economic growth lies through solar and wind power.

The escalation of geopolitical events and climate change has led He et al. (2025) to analyse the impact of GPR on the renewable energy transition. This study, covering the period 2000-2021, has examined 41 countries. The results indicate that increasing GPR gains speed the transition to renewable energy. Additionally, the analyses have revealed that other variables thought to influence the renewable energy transition are technological innovation, oil rents, and openness. It is concluded that GPR is more influential in the transfer to clean energy in countries that are both ecologically disadvantaged and more dependent on other countries for their energy.

A sound renewable energy transition strategy in Europe both mitigates climate change and protects countries from geopolitical complexities. Furthermore, the role of capital markets has been perused, and the effect of risk-tolerant investments and a strong capital market has been found to accelerate this transition. This is particularly true for WP. However, it also extends to solar energy, which requires substantial investment. The impact of the clean energy transition is not only mitigating climate change; it also significantly impacts the reduction of GPR and increased energy security (Horky and Martin, 2024). Zhao et al. (2024) have investigated the link between five renewable energy sub-sector markets—bioclean fuels, solar, wind, full-cell, and geothermal indices—and the GPR and economic uncertainty index. Using daily data from March 30, 2012, to April 1, 2022, the research has found a non-negative relationship during the COVID-19 time, while a more mitigating effect is observed during the Russia-Ukraine war. The conclusion is that robust renewable energy systems can be a shield against political uncertainty.

Su et al. (2021) have investigated the link between GPR and renewable energy for the period 2000–2020. The study has revealed a bi-directional causal relationship between these variables. In this context, GPR has a significant impact on renewable energy due to factors such as rare metal competition, energy security that encourages the transition to renewable energy, and trade disputes. Inversely, renewable energy has a significant impact on GPR because of the factors such as growing fossil fuel prices, economic growth, and technological innovation. Besides, renewable energy contributes to international peace by adapting to innovations in international politics and can subsequently mitigate the effects of GPR.

The study also explores the impact and contributions of FD on wind power. Although the studies directly examining the connection between wind power and FD are limited, a literature, including renewable energy studies, is as follows.

A clean energy transfer can only be supported by superior technologies, which raises a need for high financial resources. In order to prevent environmental pollution, more renewable energy sources need to be adopted, so this requires financing to green projects. However, both geopolitical and economic situations of countries make it difficult to analyse by differentiating the impact of FD on clean energy sources. Considering the high risk-high gain duo, FD converts a driving force for clean energy and increases clean energy consumption (Habiba and Xinbang, 2023; Wang et al., 2020). On the other hand, investments in bad and non -valuable projects are shackled to the development of renewable energy by wasting money (Wei and Wu, 2023). Osmani and Salari (2025) have examined the impact of financial and technological development on clean energy resources (wind, sun, electricity and total energy) in the period of 1990-2022 for 23 European countries and have concluded that financial market development has positive effects on wind and solar energy. It has also been revealed that the positive effects of FD on clean energy (Bilal and Shaheen, 2024; Jayabal, 2024; Esen et. al., 2024) as well as negative effects (Ziolo et al., 2024).

Zeren and Gürsoy (2022) have examined 26 OECD countries for the period January 2016 to November 2020 to peruse the effects of financial markets on wind power. Panel cointegration and panel causality tests have revealed a positive relationship between wind power and FD but a negative relationship with economic growth. Furthermore, a causal relationship running from both FD and economic growth to wind power is demonstrated. Another study discussed in this context belongs to Doğan et al. (2022). Doğan et al. (2022) would like to examine the effects of economic growth and FD on geothermal and wind energies, including January-2016 and November-2020 periods, through the panel data set of Germany, Iceland, Italy, Japan, Mexico, New Zealand, Portugal, Turkey and the United States. While there is no connection between FD of wind power, it is found that there is a non-negative interaction with geothermal energy. At the same time, there is a negative link between wind power and economic growth.

Increasing the problems experienced in the power plants and demand for clean energy has pushed researchers to investigate whether FD and economic growth has an effect on clean energy. This research is conducted in South Africa and covers the 1990-2021 period. In the light of the findings, it has been sighted that both FD and economic growth have an increasing effect on clean energy consumption (Ngcobo and De Wet, 2024). Between 1994 and 2015, a study of how FD affects renewable energy consumption for 34 emerging countries is included in the literature (Shahbaz et al., 2021). According to the examination results, it has been disclosed that FD increases renewable energy consumption, in other words, FD has the power to support clean energy. However, it has been found that economic growth has a negative impact on renewable energy. In a study conducted for the period of 1997-2017, the effects of FD and economic growth on renewable energy are examined and FD and economic growth affect clean energy consumption negatively and positively, respectively (Wang et al., 2021).

One of the most important constraints on energy development in China is FD, which has led to the conduct of this study. Therefore, the impact of FD on the renewable energy of China is considered as a time series work through the data obtained from the 1992-2013 period to examine. The results have provided important insights for the authors into the significant and positive contribution of FD to clean energy (Ji and Zhang, 2019).

Based on the information provided by the literature, the importance of FD and GPR variables in wind energy production, a renewable energy source, is significant. This study is conducted for the countries with the highest wind energy production (China, USA, Germany, UK, India, Spain, France, Canada, and Sweden). The selected group of countries effectively demonstrates the effect of GPR and FD on wind energy and makes a significant contribution to the literature. Furthermore, wind energy is chosen for this study because it has the largest share and the fastest growth rate among renewable energy technologies globally. This study, which examines the effect of GPR and FD on wind energy production, distinguishes from other studies in the literature due to its use of current econometric techniques, the uniqueness of the selected group of countries, and especially its focus on wind energy, which has the largest share.

3. DATA AND MODEL

The excessive use of non-renewable energy resources on the one hand and the increasing global energy demand on the other hand pose challenges in terms of energy security and cause environmental degradation. Global economic costs arising from environmental pollution reveal the importance of further increasing renewable energy production. It can be said that wind power generation, one of the renewable energy sources, is quite valuable in terms of its low cost, easy accessibility and sustainability. When FD is considered in terms of costs and financial risk, the effect of FD on wind power production is quite important and encouraging. Wind power is not only used for clean environmental effects, but has also become important for nations in terms of strengthening international relations and ensuring both political and economic independence. That is, the transition to wind power plays a strategic role not only for decreasing climate change, but also for global trade, diplomatic relations and trust between countries.

For this reason, the importance of FD and GPR variables on wind power production has led to this study. This study is conducted for the countries with the highest WP generation between 2001-2021. These countries are China, US, Germany, UK, India, Spain, France, Canada and Sweden (https://worldpopulationreview.com). The reason for choosing top countries with the highest WP generation is to reveal the impact of GPR and FD on the wind power.

The dependent variable is wind power production and the data is collected from the website of Our World in Data. The independent variables are GPR and FD, has been obtained from the Economic Policy Uncertainty and International Monetary Fund databank, respectively. Since wind power generation and FD data have an annual frequency, the GPR index values calculated on a monthly basis are converted to annual data by taking the averages of the monthly-data sets over the twelve-month period (Wang et al., 2023; Ding et al., 2023; Daştan, 2024; Yuen and Yuen, 2024).

Table 1: Variable Definitions

Variables	Definitions	Sources
Wind Power (WP)	Wind power production	Our World in Data
Geopolitical Risk (GPR)	Geopolitical risk index	Economic Policy Uncertainty Index, https://www.matteoiacoviello.com/gpr.htm
Financial Development (FD)	Financial development index	International Monetary Fund

To test this predicted relationship, the model is established as follows:

$$lnWP_{it} = \beta_0 + \beta_1 GPR_{it} + \beta_2 lnFD_{it} + \varepsilon_{it} \quad (1)$$

Here, while i denotes the countries, t denotes the time. ε_{it} is the error term. Moreover, $\beta_0, \beta_1, and\ \beta_2$ are the coefficients of constant, GPR, and FD, respectively. Only WP is used in its natural logarithmic form.

Table 2 indicates us the descriptive statistics.

Table 2: Descriptive Statistics

Variables	Mean	Maximum	Minimum	Std. Dev.	VIF
LNWP	2.863934	6.476972	-2.302585	1.717839	
GPR	0.615980	4.349712	0.024163	0.770583	1.13
FD	0.752048	0.955775	0.354008	0.155780	1.13

There are 189 observations (21 years and 9 countries) in total. Since the calculated VIF values are not bigger than five, there is no-multicollinearity problem. The WP variable has reached a maximum of 6.476, a minimum of -2.302, and an average of 2.863. On the other hand, the GPR variable has a max value of 4.349, a min value of 0.024, and an average of 0.615. Finally, the FD variable has a maximum of 0.955, a minimum of 0.354, and an average of 0.752. The standard deviations of the WP, GPR, and FD variables are found to be 1.717, 0.770, and 0.155, respectively.

4. ECONOMETRIC METHODOLOGY AND EMPIRICAL RESULTS

4.1. Priori tests

In panel data analysis, first of all, it is necessary to start the research with preliminary tests such as cross-sectional dependence (CSD) of variables and heterogeneity of slope. After analysing the CSD of model and variables with CD_{LM1} (Breusch and Pagan 1980), CD_{LM2} and Pesaran CD tests (Pesaran 2004), slope heterogeneity test which belongs to Pesaran and Yamagata (2008) is tested. Then, whether the variables have unit root and then cointegration relationship of panel model is investigated. Finally, long-term coefficients are estimated.

The first test to determine whether CSD exists is the test in Eq. (2) has put forward by Breusch and Pagan (1980):

$$CD = T\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\hat{\rho}_{ij}^2 \quad (2)$$

Here, $\hat{\rho}_{ij}$ displays the correlation between errors calculated from Eq. (1). The test statistic below has been suggested by Pesaran (2004) due to the calculated test statistic in Eq. (2) might yield deviant results in large samples:

$$CD_{LM1} = \sqrt{\frac{1}{N(N-1)}}\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\left(T\hat{\rho}_{ij}^2 - 1\right) \quad (3)$$

With some adjustments made to Eq. (2), CSD has become testable for large samples. Besides, if time (T) is smaller than observation (N), the following test statistic is obtained as a result of the adjustments made by Pesaran (2004):

$$CD_{LM2} = \sqrt{\frac{2T}{N(N-1)}}\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\hat{\rho}_{ij}^2 \quad (4)$$

The hypothesis valid for all three tests above is as follows:

H_0: there is no cross − sectional dependency

H_1: there is cross − sectional dependency

Then, the two Delta test statistics put forward by Pesaran and Yamagata (2008) to test homogeneity of the slope coefficient of the model are as follows:

$$\hat{\Delta} = \sqrt{N}\left(\frac{N^{-1}\tilde{S}-k}{\sqrt{2k}}\right) \quad (5)$$

$$\hat{\Delta}_{adj} = \sqrt{N}\left(\frac{N^{-1}\tilde{S}-E(\tilde{z}_{\hat{i}\hat{t}})}{\sqrt{var(\tilde{z}_{\hat{i}\hat{t}})}}\right) \quad (6)$$

Here, $E(\tilde{z}_{\hat{i}\hat{t}}) = k$, $var(\tilde{z}_{\hat{i}\hat{t}}) = \frac{2k(T-k-1)}{T+1}$ and $\tilde{S}$ is the changed statistics of Swamy (1980). The null hypothesis argues for both tests above is as the slope coefficients are homogeneous.

In light of the above information, CSD and slope homogeneity have been first perused in order to determine whether the units in the panel are equally affected by the shocks in the series and to determine the homogeneity of the slopes between the units. To do this, the CD of Breusch and Pagan (1980), CD_{LM1} of Pesaran (2004) and CD_{LM2} of Pesaran (2008) are utilized. According to the obtained CD and CD_{LM1} test results shown in Table 3, CSD is present in all variables in the model. This points out that CSD is weak for FD and strong for other variables according to the CD_{LM2} test. In the slope homogeneity test, delta analysis of Pesaran and Yamagata (2008) is operated. The findings have revealed the existence of heterogeneity in both test statistics.

Table 3: Cross-sectional Dependency and Slope Homogeneity Test Results

Variables	CD	CD_{LM1}	CD_{LM2}
LNWP	710.7475* (0.0000)	79.51975* (0.0000)	26.65174* (0.0000)
GPR	203.7619* (0.0000)	19.77093* (0.0000)	10.90723* (0.0000)
FD	143.5218* (0.0000)	12.67157* (0.0000)	1.410796 (0.1583)
Panel	707.7114* (0.0000)	79.16195* (0.0000)	26.59520* (0.0000)

Slope Homogeneity	Statistics
$\hat{\Delta}$	14.111* (0.0000)
$\hat{\Delta}_{adj}$	15.601* (0.0000)

Note: * denotes 1% significance level.

4.2. Panel Stationary Test

The Fourier panel KPSS test is a stationarity test proposed by Nazlıoğlu and Karul (2017). It is a panel adaptation of the Fourier KPSS test, developed by Becker et al. (2006), which takes account of structural shifts and cross-sectional dependence and is modeled as a gradual/smooth process due to the Fourier approach. In this test, proposed using the Fourier approach, it is not necessary to know the dates, numbers, or modes of breaks, as structural breaks are captured using frequency components (Nazlıoğlu and Karul, 2017). Unlike other tests, the null hypothesis supports stationarity. Heterogeneity is allowed among cross-sections in the panel.

It has a test procedure based upon the time-series stationarity test built up by Becker (2006), where structural shifts are modeled with the Fourier approach, and also the panel stationarity test with cross-sectional dependence explained by the common factor structure, put forward by Hadri & Kurozumi (2011, 2012). The data output process of the FPKPSS test is as follows:

$$y_{it} = \alpha_i(t) + r_{it} + \lambda_i F_t + \varepsilon_{it} \quad (7)$$

$$r_{it} = r_{it-1} + u_{it} \quad (8)$$

Here, $i = 1, \dots, N$ and $t = 1, \dots, T$ denote the cross-section and time dimension, respectively. r_{it} is a stochastic term where $r_{i0} = 0$ for t=0 and for all i. F_t and λ_i are an unobservable common factor and factor load, respectively. ε_{it} and u_{it} are independent and identically distributed. Eq. (7) is a time dependent function with a deterministic component $\alpha_i(t)$ stated as follows:

$$\alpha_i(t) = a_i + \gamma_{1i} sin\left(\frac{2\pi kt}{T}\right) + \gamma_{2i} cos\left(\frac{2\pi kt}{T}\right) \quad (9)$$

Here, γ_{1i} indicates the amplitude of the changes, while γ_{2i} indicates the displacement of the changes. Eq. (9) calculates the time-varying intersection term, using the nonzero values of γ_{1i} and γ_{2i} to detect gradual changes in intersection. Furthermore, fluctuation of the slope of both intercept and time trend is allowed by FPKPSS test. A Fourier expansion has been improved by Jones and Enders (2014) to approach the non-linear trend function either with structural-breaks or another form of non-linearity as follows:

$$\alpha_i(t) = a_i + b_i t + \gamma_{1i} sin\left(\frac{2\pi kt}{T}\right) + \gamma_{2i} cos\left(\frac{2\pi kt}{T}\right) \quad (10)$$

The KPSS procedure introduced by Becker et. al. (2006) is as follows which is able to estimate country-specific statistics with k:

$$\eta_i(k) = \frac{1}{T^2} \sum_{t=1}^{T} \frac{\tilde{S}_{it}(k)^2}{\tilde{\sigma}_{\varepsilon i}^2} \quad (11)$$

where, $\tilde{S}_{it}(k) = \sum_{j=1}^{T} \tilde{\varepsilon}_{ij}$ and $\tilde{\sigma}_{\varepsilon i}^2$ is the estimation of the long-run variance of ε_{it}. The panel statistics $FP(k)$ where individual statistics are averaged and developed by Nazlıoğlu and Karul (2017), is as follows:

$$FP(k) = \frac{1}{N} \sum_{i=1}^{N} \eta_i(k) \quad (12)$$

The final test statistics for panel stationary test $FP(k)$ which converges to the standard normal-distribution is as follows:

$$FZ(k) = FPKPSS = \sqrt{N}\left(\frac{FP(k) - \xi(k)}{\zeta(k)}\right) \backsim N(0,1)$$

where $\xi(k)$ and $\zeta(k)$ are the mean and the variance.

Table 4: FPKPSS Stationary Test Results

Variables	Level (I(0))	First differences (I(1))
LNWP	7.059 (8.382e-013)*	0.5552 (0.2894)
GPR	7.509 (2.975e-014)*	1.194 (0.1162)
FD	6.612 (1.899e-011)*	0.4305 (0.3334)

Note: * denotes the rejection of null hypothesis at %1 significance level.

With the determination of CSD, the results displayed in Table 4 of the FPKPSS test by Nazlıoğlu and Karul (2017) reveal that the null hypothesis advocating stationarity is rejected at the level, however, their first differences are stationary, i.e., I(1).

4.3. Panel Cointegration Test

In empirical studies, the existence of a long-run connection between variables can be investigated with various cointegration methods. Among the second-generation tests that take into account cross-sectional dependence, there are tests that avoid obtaining biased results by taking structural breaks into account. Therefore, in this study, the cointegration test with structural breaks discovered by Westerlund and Edgerton (WE) (2008) has been utilized to control the three basic difficulties of panel data, namely cross-sectional dependence, autocorrelation and structural breaks.

The WE (2008) test has been composed from the LM-based unit root tests presented by Schmidt and Phillips (1992), Ahn (1993), and Amsler andLee (1995).

$$y_{it} = \alpha_i + \eta_i t + \delta_i D_{it} + x'_{it}\beta_i + (D_{it}x_{it})'\gamma_i + z_{it} \tag{13}$$

$$x_{it} = x_{it-1} + \omega_{it} \tag{14}$$

Where, $i = 1, \dots, N$ and $t = 1, \dots, T$ denote panel members and the time-period, respectively. While α_i and β_i are constant and trend coefficients term before the break, δ_i and γ_i display the change after the break. D and ω_{it} are the dummy variable and error term, respectively.

The following three equations compose the error term z_{it} which considers CSD through usage of common factors (Dobnik, 2011).

$$z_{it} = \lambda'_i + F_t + v_{it} \tag{15}$$

$$F_{jt} = \rho_j F_{jt-1} + u_{jt} \tag{16}$$

$$\phi_i(L)v_{it} = \phi_i v_{it-1} + e_{it} \tag{17}$$

Here, F_t and F_{jt} are r- dimensional common factor vector where $j = 1, \dots r$. λ_i denote a matched factor of factor loadings. $\phi_i(L)$ is defined as a numeral polynomial in the lag operator L. The following equation is the cointegration model which is robust against serial correlation:

$$\Delta\hat{S}_{it} = constant + \phi_i\hat{S}_{it-1} + \sum_{J=1}^{p_i}\phi_{ij}\Delta\hat{S}_{it-j} + error \tag{18}$$

where $\hat{S}_{it}$ is the error term. The two panel Lagrange multiplier based test statistics defined by WE (2008) are as follows:

$$LM_\phi(i) := T\hat{\phi}_i\left(\frac{\hat{\omega}_i}{\hat{\sigma}_i}\right) \tag{19}$$

$$LM_\tau(i) := \left(\frac{\hat{\phi}_i}{SE(\hat{\phi}_i)}\right) \tag{20}$$

Here, $\hat{\phi}_i$ and $\hat{\sigma}_i$ are the least square estimator and the estimated standard errors, respectively. The null hypothesis of the WE (2008) test argues that there is no cointegration.

In light of the FPKPSS stationarity test results and the above information, this part of the study focuses on investigating the long-term relationship between WP variable and explanatory variables. For this purpose, WE (2008) cointegration procedure is used. The WE (2008) test results are represented in Table 5 with the break dates. In light of these results, the alternative hypothesis that there is cointegration amidst the variables cannot be rejected. Thence, it can be finalized that there are long-run equilibrium connection amidst wind power, GPR and FD. The structural break years are examined for all three cases: no shift, level shift and regime shift.

Table 5: WE (2008) Panel Cointegration Test Results With Structural Breaks

Model	LM_τ	**p-value**	LM_φ	**p-value**
No-shift	-4.337*	0.000	-4.270*	0.000
Level-shift	-2.084**	0.019	-2.521*	0.006
Regime-shift	-2.675*	0.004	-1.683**	0.046

Countries	**No-shift**	**Level-shift**	**Regime-shift**
China	2003	2007	2007

US	2003	2007	2007
Germany	2003	2014	2002
UK	2003	2015	2019
India	2003	2005	2005
Spain	2003	2002	2003
France	2003	2005	2002
Canada	2003	2002	2002
Sweden	2003	2010	2010

Note: * and ** denote the rejection of null hypothesis at 1% and 5% significance levels, respectively.

Remainder of the study, coefficients are estimated in the panel model and country-specific by utilizing the Augmented Mean Group (AMG) estimator method proposed by Eberhardt and Teal (2010) which is a two-step process to measure unobserved common dynamic effect. The AMG estimator is acquired by averaging the coefficient at each cross-sectional unit. The AMG long-term coefficient results are exhibited in Table 6. According to obtained results, FD has a surprisingly negative impact on wind power production in China, the United States, India, and Sweden. However, in France, this impact is notably positive. While GPR positively affects wind power in Sweden, it has a negative impact in China and France.

Table 6: AMG Long-term Coefficient Estimation Results

Countries	GPR	FD
China	-0.9138768**	-5.640758*
US	0.0147407	-3.888019**
Germany	0.3624598	0.1040287
UK	0.0860138	-1.268867
India	0.1110291	-1.540028**
Spain	-1.059688	1.770242
France	-0.6966871**	4.676524**
Canada	-0.2674807	1.219804
Sweden	9.877178*	-3.733135**
Panel	0.8348544	-0.9222455

Note: * and ** denote the rejection of null hypothesis at 1% and 5% significance levels, respectively.

5. CONCLUSION AND POLICY RECOMMENDATIONS

Factors such as the oil crises of the 1970s, climate change, the pursuit of energy independence, and current international wars and their consequences have increased environmental awareness worldwide, leading countries to turn to renewable energy sources. WP, which holds the largest share and fastest pace of development among renewable energy technologies globally, stands out among other sources. Wind, abundant and freely available in nature, is also a low-cost, easily accessible, renewable, sustainable, and never-ending clean energy source. WP is one of the most economical and clean ways to generate electricity.

From the past to the present, endless wars and conflicts between countries have impacted the entire world in some way, creating geopolitical concerns and crises. Furthermore, the supply of raw materials can sometimes lead to crises among countries. For instance, China is almost the sole supplier of the materials required for wind turbine deployment, significantly increasing countries' dependence on China. These justified concerns also pressure countries to acquire their own clean energy sources.

On the other hand, the provision of necessary and sufficient financing for the acquisition of renewable energy resources and the use of this financing for appropriate investments are closely related to a country's FD. A country's FD is closely linked to its energy security and independence, which will contribute to its development. Based on this, we examined the effects of FD and GPR on wind power production in our study. We selected the nine countries with the highest WP generation, which we believed would best demonstrate this effect, as the study group. These countries are China, the US, Germany, the UK, India, Spain, France, Canada, and Sweden. The study covers the period 2001-2021.

In the model created to peruse the connection between the variables, we have first applied a priori tests to investigate whether the variables behave together in the long-term, that is, whether they are cointegrated. The results have indicated that CSD is present for all variables and the variables are heterogeneous. The FPKPSS stationarity test proposed by Nazlıoğlu and Karul (2017) has concluded that the first differences of all variables are stationary. Following the stationarity test result, a panel cointegration test is utilized, which also takes into account the structural breaks put forward by Westerlund and Edgerton (WE) (2008), to peruse the presence of a long-term connection between the variables. The results indicate a long-term equilibrium connection between wind power, GPR, and FD. The breakout dates for each country are also shown in Table 4. In the final stage of the study, coefficients are estimated using a panel model and a country-specific AMG estimator. According to obtained results, FD has been observed to have a dampening effect on wind power production in China, the US, India, and Sweden. However, in France, this impact is notably positive. The financial crisis of 2007-2008 in China and the US may explain this unexpected result. Considering that India is a developing country, the country faces a high demand for energy, which challenges the Indian economy to find the necessary financing and technological support for wind power. In France, we see that increased FD is also reflected in wind power production, thanks to appropriate financing and investments in the right technology. In this context, it is crucial that governments effectively implement incentive mechanisms for wind power. Similarly, a country's effective financial system is crucial for supporting energy production. Improving the financial system is one of the most important strategies that will also ensure the development of clean energy.

While GPR positively affects wind power in Sweden, it has a negative impact in China and France. In China and France, wind power production appears to increase as GPR decreases. This also brings with it increased costs. In Sweden, the opposite is true. This requires channels such as government, diplomacy, politicians, and organizations to avoid tension as much as possible.

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Araştırma Makalesi

The Impact of Geopolitical Risk and Financial Development Dynamics on Wind Power

Jeopolitik Risk ve Finansal Gelişme Dinamiklerinin Rüzgar Enerjisi Üzerindeki Etkisi

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Genişletilmiş Özet

Giriş

1970'lerdeki petrol krizleri, iklim değişikliği, enerji bağımsızlığı arayışı ve günümüzdeki uluslararası savaşlar ve bunların sonuçları gibi faktörler, dünya çapında çevre bilincini artırmış ve ülkeleri yenilenebilir enerji kaynaklarına yönelmeye yönlendirmiştir. Küresel olarak yenilenebilir enerji teknolojileri arasında en büyük paya ve en hızlı gelişim hızına sahip olan rüzgar enerjisi, diğer kaynaklar arasında öne çıkmaktadır. Doğada bol miktarda bulunan ve serbestçe bulunabilen rüzgar, aynı zamanda düşük maliyetli, kolay erişilebilir, yenilenebilir, sürdürülebilir ve hiç bitmeyen bir temiz enerji kaynağıdır. Rüzgar, dünya dönmeye devam ettiği sürece asla bitmeyecek bir güçtür. Başka bir deyişle, rüzgar güneş, atmosfer ve dünyanın fiziksel yapısı tarafından yaratılır. Rüzgar enerjisi, fosil yakıt yakma veya güneş panelleri gibi diğer yöntemlerin aksine, rüzgarın gücünden yararlanılarak üretilen elektriği ifade eder. Rüzgar enerjisi, fosil yakıtlar gibi çevreyi kirletmediği için temizdir. Uygun fiyatlıdır. Optimum güce ulaşmak için boyutta çeşitli ayarlamalar yapmak kolaydır. Rüzgar enerjisi, rüzgarın kanatları döndürmesiyle başlayan ve ardından bir dizi dişli aracılığıyla bir jeneratörü döndüren ve bunun da elektrik üreten rüzgar türbinleri tarafından üretilir. Geçmişten günümüze ülkeler arasındaki bitmek bilmeyen savaşlar ve çatışmalar, jeopolitik kaygılar, ülkeler arası hammadde tedariki gibi faktörler ülkelerin enerji bağımsızlığını da tehdit etmektedir. Bu haklı endişeler, ülkeleri kendi temiz enerji kaynaklarını edinmeye zorlamaktadır.

İyi işleyen bir finans sektörü, çeşitli finansal ürünler sunarak ekonomiyi güçlendirir ve böylece daha güçlü yenilenebilir enerji yatırımlarını teşvik eder. Gelişmiş bir finans sektörü, yenilenebilir enerjinin benimsenmesi için daha iyi teknolojik yatırımların finansmanı için de hayati önem taşır. Bir ülkenin finansal gelişmişliği, gelişmiş piyasalar ve finansal araçlara erişimin ve çeşitliliğin artırılmasıyla sağlanabilir. Finansal kalkınma, tasarrufları daha etkili yatırım araçlarına dönüştürerek bu fonların üretken sektörlere yatırılmasını sağlar. Artan finansal gelişme ise ülkenin ekonomik kalkınmasını artırır. Enerji, bir ülkenin ekonomisinin kalkınmasında önemli bir rol oynar. Enerji başlangıçta yüksek maliyetli gibi görünse de bu maliyeti düşürmek ve sürdürülebilirliğini sağlamak yenilenebilir enerji kaynaklarına bağlıdır. Yenilenebilir enerji kaynaklarının edinimi için gerekli ve yeterli finansmanın sağlanması ve bu finansmanın uygun yatırımlarda kullanılması bir ülkenin finansal kalkınması (FD) ile yakından ilişkilidir. Bir ülkenin finansal gelişmesi de kalkınmasına katkıda bulunacak olan enerji güvenliği ve bağımsızlığına bağlıdır. Bu nedenle çalışmada finansal gelişme ve jeopolitik riskin (GPR) rüzgar enerjisi üretimi üzerindeki etkileri incelenmiştir. Çalışma 2001-2021 dönemini kapsamaktadır. Bu araştırmanın çalışma grubu en yüksek rüzgar enerjisi üretimine sahip ülkelerden oluşmaktadır (Çin, ABD, Almanya, İngiltere, Hindistan, İspanya, Fransa, Kanada ve İsveç). Bu ülkelerin seçilme sebebi jeopolitik risk ve finansal gelişmenin rüzgar enerjisi üzerindeki etkisini ortaya koymaktır.

Yöntem ve Ampirik Bulgular

Rüzgar, dünya döndüğü müddetçe asla tükenmeyecek mükemmel bir enerji kaynağıdır. Yenilenebilir enerji kaynaklarından biri olan rüzgar enerjisi üretimi, düşük maliyeti, kolay erişilebilirliği ve sürdürülebilirliği gibi faktörler açısından ele alındığında oldukça değerli olduğu söylenebilir. Rüzgar enerjisi yalnızca temiz çevresel etkiler için kullanılmakla kalmamakta, aynı zamanda uluslararası ilişkileri güçlendirmek ve hem siyasi hem de ekonomik bağımsızlığı sağlamak açısından da uluslar için önemli hale gelmiştir. Yani rüzgar enerjisine geçiş, yalnızca iklim değişikliğinin azaltılması için değil, aynı zamanda küresel ticaret, diplomatik ilişkiler ve ülkeler arasındaki güven açısından da stratejik bir rol oynamaktadır. Bununla da kalmayıp ülkeler arası hammadde tedariki de yine bir ülkeyi başka bir ülkeye bağımlı kılmakta olup, bu ise ülkelerin enerji bağımsızlığını tehdit etmektedir. Bu durum da bizi finansal gelişme ve jeopolitik risk dinamiklerinin rüzgar enerjisi üretimi üzerindeki etkilerini incelemeye itmiştir. Çalışma 2001-2021 yılları arasını kapsamaktadır. Araştırma grubu en yüksek rüzgar enerjisi üretimine sahip ülkeler olan Çin, ABD, Almanya, İngiltere, Hindistan, İspanya, Fransa, Kanada ve İsveç için yürütülmüştür. En yüksek rüzgar enerjisi üretimine sahip ülkelerin seçilmesinin nedeni, jeopolitik risk ve finansal gelişmenin rüzgar enerjisi üzerindeki etkisini ortaya koymaktır. Ayrıca son günlerde temiz enerji kaynaklarından popüler olan rüzgar enerjisinin hem finansal gelişme hem de jeopolitik risk üzerindeki etkilerini inceleyen kısıtlı sayıda çalışma olması bu çalışmayı ortaya çıkarmıştır.

Bağımlı değişken rüzgar enerjisi üretimidir ve veriler Our World in Data web sitesinden alınmıştır. Bağımsız değişkenler GPR ve FD ise sırasıyla Ekonomik Politika Belirsizliği ve Uluslararası Para Fonu veri bankasından elde edilmiştir. Rüzgar enerjisi üretimi ve FD verileri yıllık bir frekansa sahip olduğundan, aylık olarak hesaplanan GPR endeks değerleri, on iki aylık dönem boyunca aylık veri kümelerinin ortalamaları alınarak yıllık verilere dönüştürülmüştür (Wang vd., 2023; Ding vd., 2023; Daştan, 2024; Yuen ve Yuen, 2024).

Bu öngörülen ilişkiyi test etmek için model aşağıdaki gibi kurulmuştur:

$$lnWP_{it} = \beta_0 + \beta_1 GPR_{it} + \beta_2 lnFD_{it} + \varepsilon_{it} \qquad (1)$$

Modelde yer alan değişkenlerin uzun dönemde birlikte hareket edip etmediklerini test etmek adına birtakım öncül testler ve ardından da panel eşbütünleşme testi yapılmıştır. Öncelikle değişkenlerin yatay kesit bağımlılığı (YKB) test edilmiş ve tüm değişkenlerin YKB'ye sahip olduğu sonucuna ulaşılmıştır. Ardından Pesaran ve Yamagata (2008) tarafından ortaya atılan homojenlik testi sınanarak eğim katsayılarının heterojen olduğu sonucu elde edilmiştir. Yani araştırmada sadece panel model değil aynı zamanda ülkelerin her biri tek tek incelenebilecektir. Bu sonuçlar bizi değişkenlerin birim köklü olup olmadığı hususunda araştırmaya yönlendirmektedir. Bunun için Nazlıoğlu ve Karul (2017) tarafından ortaya atılan Fourier Panel KPSS durağanlık testi kullanılmıştır. Yapılan testin sonucunda ise tüm değişkenlerin birinci farklarının durağan olduğu sonucu elde edilmiştir. Nihayetinde değişkenler arasında uzun dönemli bir ilişkinin varlığını sınamak üzere Westerlund ve Edgerton (WE) (2008) tarafından ortaya atılan yapısal kırılmalı bir panel eşbütünleşme testi uygulanmıştır. Bu panel eşbütünleşme testi sonuçlarına göre değişkenlerin eşbütünleşik olduğu diğer bir ifadeyle uzun dönemde birlikte hareket ettikleri görülmüştür. Değişkenler arasında uzun dönemli bir ilişkinin varlığı tespit edilmiştir. Aralarında uzun dönemli bir ilişkinin varlığı sonrasında değişkenlerin katsayılarını tahmin etmek adına Genişletilmiş Ortalama Grup (Augmented Mean Group) katsayı tahmincisi yöntemine başvurulmuştur. Katsayı tahmin sonuçlarını aşağıdaki şekilde sıralayabiliriz: Finansal gelişmenin rüzgar enerjisi üretimi üzerindeki etkisi Çin, ABD, Hindistan ve İsveç'te negatif iken sadece Fransa'da pozitif olduğu sonucu gözlemlenmiştir. Diğer yandan jeopolitik riskin rüzgar enerjisi üretimi üzerindeki etkisinin negatif olduğu ülkeler Çin ve Fransa iken pozitif olduğu tek bir ülke olup o da İsveç'tir. Diğer ülkeler için katsayıların anlamlı olup olmaması durumu seçilen döneme, seçilen yönteme ve çalışma grubuna bağlı olarak farklılıklar gösterebilir.

Sonuç ve Politika Önerileri

Yenilenebilir enerji kaynaklarının edinimi için gerekli ve yeterli finansmanın sağlanması ve bu finansmanın uygun yatırımlarda kullanılması bir ülkenin FD'si ile yakından ilişkilidir. Bir ülkenin FD'si de kalkınmasına katkıda bulunacak olan enerji güvenliği ve bağımsızlığına bağlıdır. Bu nedenle çalışmamızda FD ve GPR'nin rüzgar enerjisi üretimi üzerindeki etkilerini inceledik. Bu etkiyi en iyi şekilde göstereceğine inandığımız en yüksek WP üretimine sahip dokuz ülkeyi çalışma grubu olarak seçtik. Bu ülkeler Çin, ABD, Almanya, İngiltere, Hindistan, İspanya, Fransa, Kanada ve İsveç'tir. Değişkenler arasındaki uzun dönemli ilişkinin varlığı sonrasında Genişletilmiş Ortalama Grup (AMG) katsayı tahmincisi yöntemi uygulanmış ve anlamlı olan katsayılar değerlendirilmiştir.

Katsayı tahmin sonuçları bazı beklenmeyen sürpriz sonuçları da beraberinde getirmektedir. Mesela, Hindistan'ın gelişmekte olan bir ülke olduğu düşünüldüğünde, ülke yüksek bir enerji talebiyle karşı karşıyadır ve bu durum Hindistan ekonomisini rüzgar enerjisi için gerekli finansman ve teknolojik desteği bulma konusunda zorlamaktadır. Yine Çin ve ABD'de 2007-2008 de yaşanan mali kriz bu beklenmedik sonucun açıklayıcısı olabilir. Fransa'da, uygun finansman ve doğru teknolojiye yapılan yatırımlar sayesinde artan finansal gelişmenin beraberinde rüzgar enerjisi üretimine yansıdığı görülmektedir. Demek oluyor ki, hükümetlerin rüzgar enerjisi için teşvik mekanizmalarını etkili bir şekilde uygulaması hayati önem taşımaktadır. Benzer şekilde, bir ülkenin etkili finansal sistemi enerji üretimini desteklemek için oldukça önemlidir. Finansal sistemin iyileştirilmesi, temiz enerjinin gelişimini de sağlayacak en önemli stratejilerden biridir. Çin ve Fransa'da, GPR azaldıkça rüzgar enerjisi üretimi artmaktadır. Bu durum aynı zamanda artan maliyetleri de beraberinde getirmektedir. İsveç'te ise tam tersi geçerlidir. Bu durum, hükümet, diplomasi, politikacılar ve kuruluşlar gibi kanalların mümkün olduğunca gerginlikten kaçınmasını gerektirmektedir.