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Electricity Prices, Technology, Productivity, And Environmental Degradation: Implications For Financial Stability

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Abstract The limited availability of fossil fuels and the financial pressure they create for countries that do not have the resources have led countries to search for new energy sources. In particular, renewable energy sources and therefore electrical energy obtained from these sources have been proposed in the literature as an alternative to fossil fuels. Thus, this study investigates the impact of electricity prices on financial stability in European Union countries from 2010 to 2021 using Driscoll Kraay fixed effects estimation. Financial stability is measured using the bank z-score, while productivity-intensive technology, environmental quality, and economic growth are included as control variables. The findings indicate that an increase in electricity prices negatively affects the bank z-score. In contrast, productivity-intensive technology positively impacts the bank z-score. Similarly, environmental quality contributes to an increase in the bank z-score. Additionally, economic growth enhances financial stability. Considering that rising electricity prices negatively affect financial stability, policymakers should encourage companies to produce electricity from renewable sources, such as solar panels or wind turbines. This can be supported through incentives such as tax breaks or low-cost financing for firms investing in on-site renewable energy systems. In this way, electricity price fluctuations will have less impact on companies and, in turn, help protect financial stability.

Keywords Financial Stability · Electricity Prices · Productivity Intensive Technology · Bank z-score · Economic Growth

JEL Classification G33 · O33 · P18 · Q56

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Electricity Prices, Technology, Productivity, And Environmental Degradation: Implications For Financial Stability

Energy is a key factor for economic activities, and economic history has witnessed countless events demonstrating its importance for market economies. Any significant fluctuation in energy prices has the potential for disruption of market equilibrium. The report of the United Nations (1974) illustrates the adverse impact of energy crises on financial and product markets. The surge in energy prices has led to a rise in commodity prices and disruption in financial equilibrium. The study of Labandeira et al. (2017) shows that the elasticity of energy demand is very low, especially in the short term. This makes energy not only important for economies and financial markets but also a potential threat. The fact that economies are quite dependent on energy has led economies to focus on different solutions for their energy needs and energy dependency.

There have been several significant historical examples, such as the 1973 oil embargo and Russia's war on Ukraine, that demonstrate how energy prices affect economies. A sudden change in oil prices has negatively affected output growth and increased the general level of prices (Jarrett et al., 2019). Similarly, Russia's war on Ukraine has affected gas prices, which have reached record-high levels, leading to a rise in the general price level, especially in European economies (IEA, 2023). As Schwartz (1995) indicates, financial stability relies on price stability; however, unexpected price changes, especially in energy prices, can damage financial stability. This is consistent with Minsky's financial instability hypothesis, which suggests that when economies experience long periods of stability, financial institutions and investors tend to take on more risk, ultimately increasing the system's vulnerability to external shocks, such as sudden increases in energy prices (Minsky, 1992). To ensure financial stability, economies must address their dependence on energy. A common solution proposed by many scholars, such as Paramati et al. (2022) and Li and Solaymani (2021), is the adoption of technology and consequent innovation. Technological advancements can lead to the generation of renewable energy, particularly electricity, from sustainable sources (Ang et al., 2022).

Renewable energy mainly generates electricity and aims to reduce the impact of oil price shocks on economies by reducing oil dependency. The report of the European Commission Statistical Office of the European Union (2023) shows that in Europe, oil dependency is more than 90%, which has led European countries to diversify their energy sources by investing in technology to protect themselves from price and supply shocks. The report of the European Commission Statistical Office of the European Union (2024) shows that the share of renewable energy in electricity generation increases by 12.4 % in 2023, reaching 44.7 % of the total share, while oil-based electricity generation declines by 32.5 %. Considering the potential of electricity to replace oil, this rising rate reached by European Union countries can end the dependency on oil and oil-originated financial problems in the countries. While technological innovation helps reduce energy dependency, it also creates significant economic opportunities. According to the United Nations technology and innovation report (2023) , the market for technological innovation is growing so fast that it will reach $ 9.5 trillion by 2030, with European countries making one of the largest contributions. In addition, the same report indicated that technology and innovations have created tremendous jobs in Europe. For example, approximately 200.000 permanent jobs will have been created by 2030 in the electric vehicle industry. In addition, replacing oil-based energy with electricity generated from renewable sources contributes to improvements in environmental quality, which can help reduce firms' costs by lowering health-related expenditures associated with pollution-induced illnesses (Bayraktar et al., 2024).

The war between Ukraine and Russia has underscored the critical importance of energy security and source diversification, particularly the strategic role of electricity in ensuring stable supply. However, renewable energy, and therefore electricity, is seen as a solution to the energy problem, but the price shocks of electricity on financial stability have not yet been known. This study aims to investigate how fluctuations in electricity prices affect financial stability in European Union countries over the period 2010–2021, using the bank z-score as a financial stability proxy. This study fills a gap in the literature by shifting the focus from oil price shocks to electricity prices. Specifically, the study uses the bank z-score as an indicator of financial stability to assess the effects of electricity price volatility. The bank z-score reflects how financially stable a bank is by combining information about its profitability, capital adequacy, and earnings volatility. It successfully accomplishes prediction with over 75% accuracy (Chiaramonte et al., 2016). A higher z-score indicates greater stability and a lower probability of bankruptcy. Since firms rely heavily on bank financing, financial stress, such as that caused by rising electricity costs, can lead to higher default rates. These risks are transferred to banks through non-performing loans, increasing banks' credit risk and reducing their z-scores. In this way, electricity price shocks affecting firms can indirectly weaken overall financial stability. In addition, productivity-intensive technology, environmental quality, and economic growth are added as control variables to the model. Productivity-intensive technology can improve efficiency and reduce costs, environmental quality affects economic risks and regulatory pressures, and economic growth strengthens financial markets and government finances, all of which can help shape financial stability.

This study makes several contributions to the literature. First, while previous studies have primarily focused on the effects of oil price shocks on financial stability, this study specifically examines the impact of electricity prices on financial stability. Second, whereas earlier research has typically used either financial market or fiscal policy indicators to assess the impact of electricity prices, this study employs the bank z-score as a comprehensive measure of financial stability. Although prior literature has analysed the effects of financial markets on environmental quality, this study investigates the reverse relationship by examining how environmental quality influences both the financial market and public expenditures.

Following the first section, the second section provides a literature review, and then, the data, methodology, and discussion of the econometric findings are presented in the third section. In the last section, the study is completed with conclusions and policy recommendations.

Literature

The Arab–Israeli war of 1973 changed the energy prices dramatically and damaged the financial markets around the world. After the war, studies such as Gramlich (1979), Bernanke et al. (1997), Cuñado and Pérez De Gracia (2003), and Herrera et al. (2019) in the literature have accelerated and investigated the effect of oil prices on economies. When the current studies are analysed in detail, the general findings in the literature and the direction of the literature can be understood better. One of these studies, Evgenidis (2018), using a threshold vector autoregressive (VAR) model and data covering from 2000 to 2016, shows that oil price shocks have a negative effect on stock markets, which in turn leads to a greater decline in output due to increased market uncertainty in the Euro area . However, the impact of oil price shocks is not linear. It is stronger during periods of economic stress, larger in size, and varies depending on whether the shock is positive or negative. Horobet et al. (2019) investigated the relationship between oil prices and stock prices in the EU from 2010 to 2018 using the autoregressive distributed lag approach. Their results show that an increase in oil prices has a negative effect on stock prices. They argue that positive oil price shocks raise inflation risk and increase the global volatility index (VIX), which in turn negatively impacts stock prices. Both studies found that oil price shocks reduce stock prices in the EU, with Evgenidis (2018) stressing stronger effects during economic stress, whereas Horobet et al. (2019) highlighting the roles of inflation

and market volatility. Similarly, Demirer et al. (2020) investigated the impact of oil price shocks on global financial markets using a classification strategy and multifactor regression model with data from 2000 to 2018. The findings indicate that oil demand shocks have a positive effect on stock returns. Oil demand shocks raise stock returns globally by signalling economic strength, whereas supply shocks have uneven and often negative effects due to cost and inflation concerns. Alamgir and Amin (2021) concluded, based on the ARDL method, that there is a positive relationship between oil prices and stock market indices in South Asia over the period from 1997 to 2018. They state that stock markets in South Asia are not fully efficient and that governments heavily subsidise energy, which shields domestic markets from global oil price volatility. As a result, contrary to common findings in the literature, a positive relationship has been observed. Anand and Paul (2021) indicated that oil demand shocks significantly influence stock returns and volatility in India between 2003 and 2020. Demand shocks signal economic growth, boosting investor confidence and lowering risk, making them the key channel linking oil prices to stock markets. Chien et al. (2021) also examined the influence of oil price on the stock market in EU from end of December 2019 to the beginning of August 2020. The wavelet method indicates that oil prices strongly affect stock markets by driving sharp price fluctuations, contributing to increased market volatility and investor uncertainty. Magazzino et al. (2023) examined the link between the oil market and stock market in 27 European countries from May 2007 to April 2022 using a structural vector auto-regression model. Their results show that oil prices affect stock market returns, particularly in oil-importing regions like the EU, through sensitivity to oil price movements and real economic activity shocks, with this relationship intensifying during crises due to heightened uncertainty and increased market volatility. The relationship between oil prices and stock markets in European countries from March 11, 2020, to August 12, 2022, was examined by Olayungbo et al. (2024) using the autoregressive conditional heteroscedasticity test. The findings show that the stock markets in Italy and Germany exhibit a statistically significant positive correlation with oil returns. Volatility spillover driven by uncertainty and risk aversion during crises is an important channel explaining how oil price shocks affect stock markets. Their findings support the studies of Magazzino et al. (2023) and Chien et al. (2021) regarding the effect of uncertainty on financial stability.

Although not as common as oil prices, gas prices are also used as an energy price indicator in some studies. For example, Saif-Alyousfi et al. (2021) examined the impact of both oil and gas prices on bank performance from 2000 to 2017 using generalised method of moments (GMM) method. The findings indicate that price volatility has an asymmetric impact on conventional and Islamic banks, and Islamic banks are more vulnerable than conventional banks to negative gas price shocks. Energy prices directly impact banks in oil-exporting countries: higher prices boost cash flow and lending, improving bank performance. Cuestas et al. (2024) stated that gas price shocks have short-term but asymmetric effects on EU countries' real exchange rates and current accounts, with negative shocks often having a stronger impact than positive ones. Due to their high dependence on gas imports, these countries are vulnerable to external shocks. Increases in gas prices raise import costs, which can negatively affect the trade balance, currency value, and ultimately financial stability.

Economies are fragile to energy shocks because energy is a fundamental input for nearly all economic activities. Moreover, since energy is a natural resource, countries, such as many European countries, lack sufficient domestic supply and are heavily dependent on imports. Sharp changes in energy prices can disrupt production, raise costs, increase inflation, reduce consumer spending, and ultimately slow economic growth and financial stability. As a result, economies are actively seeking solutions to mitigate this vulnerability. The most commonly suggested strategies in the literature are the diversification of energy sources and improvements in energy efficiency, with a strong emphasis on renewable energy and technological innovation.

Although studies analysing the impact of technology and productivity on financial stability are not widely available in the literature, there are many studies showing their effects on macroeconomic indicators. For example, Toader et al. (2018) investigated the impact of technology on economic growth in European Union countries from 2000 to 2017. Although the effect of technology on growth varies from country to country, it is generally concluded that technology leads to economic growth. Similar findings have been reached by Bahrini and Qaffas (2019). They have found that technology leads to economic growth in the Middle East, North Africa, and Sub-Saharan Africa regions using the GMM method. In firm-level analyses, Dave et al. (2013) focused on information and technology companies in the S&P 500 index to investigate the impact of research and development on financial sustainability. The results of the study indicated that the technological performance of the companies has a positive and significant effect on financial sustainability. Xu et al. (2020) also investigated the effect of innovation on financial stability in energy companies in China from 2009 to 2018 using the Ordinary Least Squares method. The results show that in technology-intensive firms, wage incentives have a significant positive effect on the relationship between innovation investment and financial sustainability. Lee and Lee (2022) investigated the opposite relationship between productivity and financial development in China from 2006 to 2018 using heterogeneity analysis. They have stated that financial development has the power to increase productivity. As seen in the literature review, studies have mainly focused on the relationship between financial development and technology and productivity. However, this study focuses on the impact of productivity-intensive technology on financial stability using bank z-scores and government spending.

Economic growth is one of the most widely studied topics in the economics literature. Although the relationship between economic growth and many financial and macroeconomic variables has been studied extensively, the effect of financial stability on economic growth has either been overlooked in the literature or financial development indicators have been used instead of financial stability. One of these studies, the study of Emara and El Said (2021), applied the GMM methods to examine the effect of financial inclusion on economic growth in 44 emerging economies between 1990 and 2018. They stated that financial inclusion has a positive and significant effect on economic growth. Similarly, Danisman and Tarazi (2020) have reached the similar result for the period 2010 to 2017 in European economies as result of dynamic panel data estimation techniques. They have indicated that financial inclusion has a positive effect on stabilising banking industry. Ijaz et al. (2020) conducted a study on European economies about financial stability and economic growth using the GMM method. The findings indicate that financial stability has a positive effect on economic growth for the period 2001-2017. Bayar et al. (2021) used a bank stability indicator and causality test to investigate the effect of bank stability on economic growth from 1998 to 2016. The findings show that bank stability positively triggers economic growth in European Union countries. Jima and Makoni (2023) have shown the positive effect of financial inclusion and financial stability on economic growth in Sub-Saharan African economies for the period from 2000 to 2019 as a result of the application of the autoregressive distributed lag (ARDL) method. The studies in the literature have been analysed in general terms. However, our study is already aware of the effect of financial stability on economic growth and investigates whether there is an inverse relationship.

Many studies in the literature examine the relationship between economic and financial activities and environmental degradation, and the general opinion in the literature is that economic and financial activities reduce environmental quality. However, studies examining the impact of environmental degradation on financial stability are limited; therefore, close studies will be analysed. Khan and Yoon (2021) investigated the impact of financial instability and environmental degradation in 88 developing economies from 1980 to 2014 using the panel vector error correction model (P-VECM). The findings show that financial instability increases environmental degradation. Financial stability has a positive effect on environmental quality. Khan

et al. (2022) also investigated the impact of financial development on environmental sustainability in five regions, including European countries, from 2007 to 2021 using the Granger causality test. The outcomes of the study show that financial development has a positive effect on environmental quality. Zhen et al. (2023) investigated the link between financial development and environmental degradation in European countries from 1980 to 2018 using the cross-sectional ARDL method. The link between financial development and environmental degradation is negative. An increase in financial development augments environmental quality in European economies. Topalcık and Kirikkaleli (2024) investigated the effect of financial stability on environmental degradation in Turkey from 1990 to 2019 using the Fourier ARDL method. The findings show an opposite relationship between financial stability and environmental degradation.

To summarise, the war between Ukraine and Russia has led to changes in energy paths and resources in European Union countries and accelerated the electrification of energy economies. The report of the International Energy Agency (2023) stated that electricity consumption is expected to reach 25% of total energy consumption by 2030 in European Union countries. The same report has also shown that electricity consumption is projected to reach 20% of the world's total energy consumption by 2030, which is less than the European Union countries, and electrification will save 10% of the world's energy. Renewable energy and thus electricity can be a solution for energy security and dependence, but price fluctuations are a solution for financial stability. As evident from the studies in the literature, the impact of electricity prices on financial stability constitutes a gap in the literature. The major contribution of this study to the literature is filling this gap. Moreover, another contribution is to determine whether environmental quality impacts financial stability. The literature is abundant with studies showing the opposite of this relationship. The use of bank z-scores as financial stability indicators will contribute to the finance literature.

Data, Methodology, and Empirical Findings

Data and Model

This study aims to analyse the effects of energy prices on financial stability in European Union countries. Since the multifactor productivity data of 13 countries in the EU are available in the OECD Database, the study has been conducted on 13 countries: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Italy, Luxembourg, the Netherlands, Portugal, Spain, and Sweden. In addition, since the energy price variable of these countries belongs to the years 2010-2021, the study covers a period of 12 years. In order to make the panel data analysis more reliable, annual data have been converted into quarterly data to increase the time frequency and used the same method in the study of Nadeem et al. (2020) in Eviews. While bank Z-score (ZS) has been taken as a financial stability indicator, non-household electricity prices taken as energy prices are added to the model as independent variables. Non-household electricity use reflects industrial and commercial activity more directly, which is closely tied to economic performance and financial stability (Doruk, 2024). In addition, economic growth (GDP) and load capacity factor (LCF) are added to the model as control variables. Productivity-intensive technology (PAT*MFP) has been added to the model because technological innovation improves operational efficiency and productivity, which strengthens the resilience of financial institutions and firms (Sahay et al., 2020). In addition, productivity-intensive technology provides a more accurate measure of how technological change supports financial stability because it captures both the input (technology) and output (productivity), unlike single-dimension indicators. Detailed information and sources of the variables used in the study are shown in Table 1.

Table 1
Definitions and Sources of Variables

Variables	Symbol	Unit of measurement	Source
Bank Z-Scores	ZS	(Average Profit Return on Assets) (ROA) + Equity/Assets) ÷ Standard Deviation of ROA	World Bank-WDI
Electricity Price	EPR	Non-household (kWh US $)	Eurostat
Economic Growth	GDP	GDP per capita (US$)	World Bank-WDI
Load capacity factor	LCF	Biocapacity divided by ecological footprint (Global hectares per person)	Global Footprint Network Database
Productivity*Patent	PAT*MFP	Total patent applications (residents+ nonresidents) * Multifactor productivity (overall efficiency, labor and capital) 2015 = 100	WIPO Statistics Database, OECD

The econometric model used in the study is shown in Equation (1).

Model:

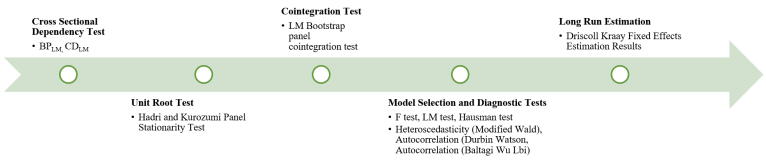
$$\mathbf{ZS_{it} = \alpha_0 + \alpha_1 lnLEPR_{it} + \alpha_2 lnPAT^{*}MFP_{it} + \alpha_3 lnLCF_{it} + \alpha_4 lnGDP_{it} + \varepsilon_{it}} \quad (1)$$

The model shows the effect of electricity prices EPR, productivity intensive technological development $PAT^{*}MFP$, economic growth GDP and load capacity factor LCF on bank z-score ZS. With this model, it is aimed to show whether electricity prices cause stability deterioration in bank z-scores. In the equations α_0 is constant parameter and $\alpha_1, \alpha_2, \alpha_3, \alpha_4$ are slope coefficients. i and t refer to the unit and time dimension and ε represents error term.

Methodology

In this section, the preliminary tests required for the use of the main econometric test and the findings of the tests are explained. Also, the findings of the main econometric test will be presented, and explanations of these findings will be made. The tests used in the study and their sequence are shown in Figure 1.

Figure 1
Flowchart of the Methodology



Testing for cross-sectional Dependence

In panel data models, due to the existence of shocks and unobservable components, it is important to determine the cross-sectional dependence between countries. If it is revealed that there is dependence between the cross-sections used in the panel, tests that consider cross-sectional dependence should be used in the analyses to be applied. The results obtained regarding the cross-sectional dependence in the series assist in determining the appropriate unit root test to be performed. For instance, when there is cross-sectional independence in the series, the first-generation unit root test can be employed, whereas when there is cross-sectional dependence, the second-generation unit root tests can be utilised. Consequently, many tests have been developed to assess cross-sectional dependence. One of these tests is the LM test

developed by Breusch and Pagan (1980). The Breusch-Pagan LM test is used in panel data analysis to test whether the data sets have cross-sectional dependence, and the Breusch and Pagan (1980) LM test is based on the sum of squares of the correlation coefficients between the sectional residuals obtained from the least squares estimation. The Breusch and Pagan (1980) LM test is a test that can be used in the case of T>N. The null hypothesis of the LM test is "there is no correlation between the residuals," and it shows χ^2 distribution for T goes to ∞ and N is constant (Pesaran, 2004: 4-5).

$$LM = T \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \hat{\rho}_{ij}^2 \sim X^2_{\frac{N(N-1)}{2}} \tag{2}$$

In general, the LM test is recommended for the case of small N and large T samples. Since the BP-LM test is not suitable for large N, Pesaran (2004) developed the CD_{LM} test that can be applied in panels with the samples consisting of large N and T. The CD_{LM} test developed by Pesaran (2004) can also be used in the case of T>N in the sample. The CD_{LM} test statistic shows an asymptotically standard distribution first for the case when T and N goes to ∞ (Pesaran, 2004: 5)

$$CD_{LM} = \sqrt{\frac{1}{N(N-1)}} \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \left(T\hat{\rho}_{ij}^2 - 1\right) \sim N(0,1) \tag{3}$$

Hadri and Kurozumi Panel Stationarity Test

In this study, the series are evaluated using the panel unit root test of Hadri and Kurozumi (2012), which is a developed version of Pesaran (2007), as proposed by Hadri and Kurozumi (2012), to check the stationarity of these series. The advantage of this test is that it considers cross-sectional dependence and allows for the presence of common factors and autocorrelation. The test follows the formula below:

$$y_{it} = z_t'\delta_i + f_i + \varepsilon_{it}\varepsilon_{it} = \varphi_{it-1} + ... + \varphi_{ip}\varepsilon_{it-p} + \nu_{it} \tag{4}$$

Where z_t' is the deterministic and for $i = 1, ..., N$ and $t = 1, ..., T$ s.

In this test the hypothesises tested are shown as

$H_0' : \varphi i(1) \neq 0 \ \forall_i$ and $H_1' : \varphi i(1) = 0$ for some i

The tests can evaluate the unit root of the panel in the case of existing cross-sectional dependence. To do this, for every i i y_{it} on $\omega_t = [\, z_t', \overline{y}_t, \overline{y}_{t-1}, ..., \overline{y}_{t-p}]$ since ε_{it} are the AR(p) process (Hadri and Kurozumi, 2012). The test statistics of Z_A^{SPC} are calculating by using the formula below:

$$Z_A^{SPC} = \frac{1}{\hat{\sigma}_{iSPC}^2 T^2} \sum_{t=1}^{T} (s_{it}^{\omega})^2 \tag{5}$$

Where $\hat{\sigma}_{iSPC}^2 = \frac{\hat{\sigma}_{Vi}^2}{\left(1-\hat{\varphi}_i\right)^2}$

Also, by adding an additional lag of y_{it} , AR(p+1) model can be estimated, and the test statistic based on this idea can be calculated using the formula below:

$$Z_A^{LA} = \frac{1}{\hat{\sigma}_{iLA}^2 T^2} \sum_{t=1}^{T} (s_{it}^{\omega})^2 \tag{6}$$

Where $\hat{\sigma}_{iLA}^2 = \frac{\hat{\sigma}_{Vi}^2}{\left(1-\hat{\varphi}_{i1}-...-\hat{\varphi}_{ip}\right)^2}$

Using these formulations, Z_A^{SPC} and Z_A^{LA} statistics are calculated for the Hadri and Kurozumi (2012) test, which considers both serial correlation and cross-sectional dependence, and the hypothesis of no unit root in the series is tested.

Panel Co-integration Test

The LM Bootstrap panel cointegration test was developed by Westerlund and Edgerton (2007) to test whether the models contain co-integration. The advantage of the test is that it allows the use of autocorrelation and heteroscedasticity in the co-integration equation under the assumption of cross-sectional dependence and eliminates the endogeneity problem using the FMOLS method. The following equation shows the calculation method of the test.

$$LM_N^+ = \frac{1}{N} T^2 \sum_{i=1}^{N} \sum_{t=1}^{N} w_i^{-2} S_{it}^2 \tag{7}$$

In the Westerlund and Edgerton (2007) panel co-integration test, the partial sums of error terms (S_{it}^2) estimated by applying the FMOLS method and the long-run variances (w_i^{-2}) aare obtained. The LM_N^+ statistic, asymptotic probability value, and bootstrap probability value are also obtained. Westerlund and Edgerton (2007) stated that the null hypothesis of the LM Bootstrap panel co-integration test shows that the series demonstrate co-integration. In the event of cross-sectional dependence, bootstrap probability values are to be considered.

Model Selection and Diagnostic Tests

In panel data analyses, there are three models in practice: the classic pooled model, the fixed-effects model, and the random-effects model. The objective of the tests for the validity of the classic model is to determine whether there is a unit and time effect. One of these tests, the F test, tests whether the data differ across units. If the null hypothesis of the F test, which is that all unit effects are equal to zero, is rejected, the classical model is not appropriate for this dataset. Therefore, if the null hypothesis is rejected because of the F test, the pooled least squares method should not be used. On the other hand, the LM test is used to test the classic model against the random-effects model. Thus, Breusch and Pagan (1980) developed the LM test with the null hypothesis that the variance of random unit effects is equal to zero. If we reject the null hypothesis in this test, it means that the classic model is not the right fit. Rejection of the null hypothesis of the LM test indicates that the model to be used in the study is not a classical model and a choice between fixed-effects model or random-effects model should be made. After the LM test findings, the Hausman (1978) test is used to choose between fixed-effects model and random-effects model. The null hypothesis of this test is that there is no correlation between unit effects and explanatory variables, and rejecting by the hypothesis implies that the fixed-effects model is consistent.

In addition, panel data analyses should be tested for the presence of heteroscedasticity and autocorrelation to avoid biased results and ensure that the findings obtained are consistent and accurate. In this study, the modified Wald test is used in the fixed-effects model to detect heteroscedasticity. In this study, the modified Wald test is used in the fixed effects model for the detection of heteroscedasticity. The null hypothesis of this test is that there is no heteroscedasticity, and its rejection indicates that there is a heteroscedasticity problem in the model.

After testing the problem of heteroscedasticity, another problem is that autocorrelation must be tested in the model, otherwise the results of the model are biased and not constant. For the detection of autocorrelation, the LBI test of Baltagi and Wu (1999) and Durbin-Watson test of Bhargava et al. (1982) have been utilised in both fixed effects and random effects models. In autocorrelation tests, the critical value is 2, and if the statistical values obtained are less than the critical value of 2, it is concluded that autocorrelation is significant (Yerdelen Tatoğlu, 2016: 220- 226).

After testing the deviations from the assumptions, it has been concluded that estimators that are robust to heteroscedasticity and autocorrelation should be used in the models. In the model based on

random effects, it is necessary to estimate random effects with robust standard errors that consider both heteroscedasticity problem and autocorrelation, and “cluster” or “robust” commands are used in the Stata package programme. Results from the model, in the random effects model, using the “cluster” command and using “robust” for all units gives the same result, and the results obtained show the random effects estimation with robust standard errors (Yerdelen Tatoğlu, 2016: 258). On the other hand, in the fixed effects model, the estimator developed by Driscoll and Kraay (1998) has been used to make robust standard error estimation. In this method developed by Driscoll and Kraay (1998), in the case of heteroscedasticity problem and autocorrelation in the model, biased results are avoided, and the fixed effects model based on robust standard errors can be estimated.

Empirical Findings

This study aims to analyse the effects of energy price movements on financial stability. While the literature examines this relationship through studies on oil prices, this study uses electricity prices as energy price data and builds a model using bank z-scores s as indicators of financial stability. In order to determine which econometric method should be used to examine the relationship in these models, a series of preliminary tests have been applied, and the results of these tests are as follows.

Table 2

Cross-sectional Dependence Test Results for Variables

Variables	BP_{LM}	CD_{LM}
ZS	501.620***	33.917***
lnEPR	531.956***	36.346***
lnPAT*MFP	427.72***	28.001***
lnLCF	533.102***	36.437***
lnGDP	973.103***	71.666***
Model	366.5***	10.71***

*** denotes the 1% significance level

The first preliminary test is the cross-sectional dependence test. The first of the preliminary tests is the cross-sectional dependence test. In this context, cross-sectional dependence of the variables has been tested with the BPLM test originated by Breusch and Pagan (1980), and CD_{LM} originated by the Pesaran (2004) test. The results of the related tests are shown in Table 2. According to the results in Table 2, the null hypotheses of both tests have been rejected. These states exist of cross-sectional dependence among the variables.

Another preliminary test is the panel unit root test. Based on these results, second-generation unit root tests can be applied to the variables. Hence, the panel unit root test of Hadri and Kurozumi (2012), which is a developed version of Pesaran (2007), as proposed by Hadri and Kurozumi (2012), has been used, and the results are shown in Table 3.

Table 3

Hadri and Kurozumi Panel Stationarity Test Results

Variables	Test	Level	1st Difference
ZS	ZA_spac	7.3348***	−3.3742
	ZA_la	11.3885***	−4.2306
lnEPR	ZA_spac	6.4758***	−3.3182
	ZA_la	20.3176***	−3.5907

Variables	Test	Level	1st Difference
lnPAT*MFP	ZA_spac	66.3641***	-2.7616
	ZA_la	109.9181***	-3.9477
lnLCF	ZA_spac	1.6554**	-3.0240
	ZA_la	10.4864***	3.5278
lnGDP	ZA_spac	13.2799***	-1.5429
	ZA_la	3.2707***	-1.9631

The test was performed according to the trended model. Max lag was taken as 5

The findings in Table 3 show that all variables are stationary at the fist difference level.

Another preliminary test applied in the study is the LM panel cointegration test. This test indicates whether each model has a co-integrated relationship eventually. The findings in Table 4 show that the null hypothesis cannot be rejected for the models. This clearly states that the series in the model have a co-integrated relationship. The findings of the panel cointegration test are demonstrated in Table 4.

Table 4

LM Panel Co-integration Results

Models	Statistics	Bootstrap Probability
Model	3.236	0.001
	1.000 bootstrap	

After concluding preliminary tests in the study, the next step is to determine the model specification for the analysis. Model specification tests have tested the models to choose the best fit model for the study. These tests are the F test, LM test, and Hausman test. The F and LM tests tested the fixed effects and random effects models against the pooled model. The test results are shown in Table 5.

Table 5

Model Specification Test Results

Test	Model
F test	522.22***
LM test	7613.33***
Hausman test	83.67***
Results	Fixed Effects Model

Based on the findings in Table 5, the F-test results indicate that the fixed-effects model is the most appropriate when comparing the pooled model. The LM test results demonstrate that the random-effects model has the optimal fit when comparing the pooled model. In this case, with the help of the Hausman test, the best appropriate model (fixed or random effects model) can be chosen for the model. The results of the test indicate that the fixed-effects model is the optimal choice.

Table 6

Model Diagnostic Test Results

Test	Model
Heteroscedasticity (Modified Wald)	1913.87***
Autocorrelation (Durbin Watson	0.089
Autocorrelation	0.210

Test	Model
(Baltagi Wu Lbi)	
Results	Driscoll Kraay Fixed Effects Estimation

For robust random model estimation, the results of heteroscedasticity and autocorrelation tests show that the model has both heteroscedasticity and autocorrelation problems. Therefore, the model to be used must be robust to these effects. Thus, Driscoll Kraay fixed effects estimation was used in the study. The diagnostic results of the model can be seen in Table 6.

After completing preliminary and diagnostic tests, estimation methods were determined for the model, and the results of the model are shown in Table 7.

Table 7

Driscoll Kraay Fixed Effects Estimation Results

Variables	Model
$\mathbf{ZS_{it} = \alpha_0 + \alpha_1 lnLEPR_{it} + \alpha_2 lnPAT*MFP_{it} + \alpha_3 lnLCF_{it} + \alpha_4 lnGDP_{it} + \varepsilon_{it}}$	
lnEPR	-36.728***
	(0.000)
lnPAT*MFP	5.442***
	(0.000)
lnLCF	11.613*
	(0.080)
lnGDP	21.876***
	(0.000)
Cons	-150.99***
	(0.000)
Sample Size	585
Number of countries	13
F Test	179.94***

All variables have a significant impact on ZS, as shown by the results of the model. The model test results show that a 1% increase in lnEPR leads to a 0.367 unit decrease in ZS. This means that one percentage increase in electricity price causes a 0.367 unit decrease in bank z-sores. Also, one percentage increase in lnPAT*MFP raises ZS by 0.054 unit. This result shows that productivity-intensive technology positively affects bank z-scores. The positive relationship between environmental quality and bank z-score has also been identified by the model. One percentage increase in lnLCF leads to a raise in ZS by 0.116 unit. Similarly, lnGDP positively affects bank z-sores. More specifically, one percentage increase in lnGDP raises ZS by 0.218 unit.

In summary, the increase in electricity prices negatively affects bank Z-score, which is a financial stability indicator. In addition, productivity-intensive technology has a positive effect on the bank z-score in the model. Similarly, environmental quality leads to an increase in bank z-score. At the same time, economic growth enhances the bank z-score.

Discussion

The study examined the effect of electricity price, technology productivity, environmental quality, and economic growth on bank z-score in European countries from 2010 to 2021. The literature on energy prices and financial stability has primarily focused on fluctuations in oil and gas prices, as economies heavily reliant on these energy sources are dependent on exporting countries and face challenges in substituting

them in the short term. For this reason, especially oil-importing countries, such as the European Union countries, have turned to electricity as an alternative energy source and have emphasised obtaining it from renewable sources (Holman and Lefort, 2024). The increase in the use of renewable electricity has been confirmed by the report of European Commission Statistical Office of the European Union (2024). We're seeing a 12.4% increase in renewable energy in electricity generation in 2023, which brings the total share up to 44.7% in the report. At the same time, oil-based electricity generation is down 32.5%. There is no doubt that this alternative energy source solution will reduce the energy dependency of countries, reduce their imports, and even improve their environmental quality. However, the extent to which electricity contributes to financial market stability, often proposed as a solution to energy dependence and related shocks, remains largely unexplored in the existing literature. The findings of the study show that changes in electricity prices have a detrimental effect on market stabilisation. More specifically, a 1% increase in electricity prices leads to a 0.367 unit decrease in the bank z-score. This effect of electricity prices on the market is similar to the effect of oil and gas prices on market stability in the literature. For example, Evgenidis (2018) has confirmed that oil price shocks have a negative effect on stock markets. Also, Saif-Alyousfi et al. (2021) and Shi and Shen (2021) determined the relationship between gas price and overall market stability. An increase in electricity prices raises companies' costs and reduces their profits, which can increase their default risk and lead to a decline in the value of banks' assets (Herman et al., 2023). Also, higher electricity prices can generate credit risk problems, especially in energy-intensive sectors (European Central Bank, 2022). In summary, a rise in electricity prices reduces investment, causing a credit crisis, increasing vulnerability, and reducing financial stabilisation. Therefore, firms can generate their own electricity, decentralised electricity generation, or on-site using renewable energy systems like solar panels or wind turbines. By producing electricity themselves, firms rely less on the grid, protect themselves from fluctuating electricity prices, reduce costs, and improve energy reliability, as indicated the report of European Commission. Directorate General for Energy. et al. (2024)

Regarding the effect of control variables on financial stability, productivity-intensive technology increases bank z-score, thus increasing financial stability. Although studies in the literature have not used the same variables, in terms of general inference, Toader et al. (2018), Bahrini and Qaffas (2019), Dave et al. (2013), Xu et al. (2020), and Lee and Lee (2022) have reached the same result. The rise in technological productivity enables financial institutions to extend loans and guarantee their repayment, thereby enhancing the bank z-score.

The literature is full of studies examining the effects of financial stability and development on the environment, but there are no studies examining the effects of environmental quality on financial stability. The results of the study show that an increase in environmental quality increases the bank z-score. Findings of the studies such as M. Khan and Yoon (2021), Khan et al. (2022), Zhen et al. (2023) and Topalcık and Kirikkaleli (2024) supported our findings in an inferential way, but not in a direct way. Environmental quality may have increased because of the promotion of green financing and sustainable lending, which may allow banks to extend more loans, thereby leading to an increase in bank z-score.

In conclusion, the study finds that rising electricity prices negatively impact financial stability, while productivity-intensive technology and improved environmental quality enhance financial stability. These results highlight the complex role of energy prices and technological and environmental factors in shaping financial market resilience in European countries.

Conclusion and Policy Recommendation

Fluctuations in energy prices pose a threat to economic stability, especially in energy-importing countries. Especially after the Arab Israeli war in 1973, the sudden volatility in oil prices increased the vulnerability

of economies and put pressure on all macroeconomic indicators. Later, the war between Ukraine and Russia has threatened the energy security of the European Union and has aimed to ensure both energy security and financial stability by increasing the shift from conventional energy sources to renewable energy sources and thus to electric energy. Although it is thought that the production of electricity from renewable sources and without dependence on external resources will lead to a reduction in vulnerability, there is a lack of studies on the European Union countries in the literature on this issue. Therefore, this study aims to analyse the impact of changes in electricity prices on financial stability in European Union countries between 2010 and 2021. Financial stabilisation is modelled with bank z-score, and energy prices, environmental quality, productivity-intensive technology, and economic growth variables are added as control variables.

The findings of the study show that an increase in electricity prices puts pressure on the bank z-score. Higher electricity prices can affect banks' return on assets by reducing business profits, as most industries are primarily dependent on energy, and by increasing loan defaults. Furthermore, higher loan defaults put banks equity in a danger position. A decline in the z-score of banks for these reasons indicates a deterioration in the economy in general, and banks are unable to perform their functions fully. Increases in productivity-intensive technology increase banks z-score. This is likely related to an increase in banks' revenues and a decrease in loan defaults. Similarly, economic growth significantly affects bank z-scores. The findings of the study also show that environmental quality leads to an increase in bank z-scores.

Approximately half of the electricity produced in Europe comes from renewable sources as an alternative to oil and gas energy to reduce energy dependence and financial stability. This may be a solution to energy dependence, but the findings of our study show that electricity prices are a threat to financial stability. Therefore, it would be appropriate and important for policymakers to seek solutions to this threat. Some policy recommendations to guide policymakers are as follows.

Policymakers should focus on increasing the share of renewable energy in electricity generation. This will reduce reliance on traditional energy sources and help insulate electricity prices from shocks in oil and gas markets. Additionally, policymakers should encourage companies to produce their own electricity from renewable sources, such as solar panels or wind turbines. This can be supported through incentives such as tax breaks or low-cost financing for firms investing in on-site renewable energy systems. In this way, decentralised electricity generation will reduce the impact of electricity price fluctuations on companies and, in turn, help protect financial stability. However, as indicated in the report of European Commission. Directorate General for Energy. et al. (2024), member states should immediately simplify permitting procedures for producers, reduce barriers to installation, make adjustments to self-consumption regulatory frameworks, and encourage the use of energy management systems.

Policymakers should identify the most energy-intensive industries and make them a priority in the energy transition. Focusing on these sectors will speed up the transition process. At the same time, mandatory energy efficiency programmes should be implemented to reduce energy consumption and lower costs in these industries.

To protect market stability until the use of renewable electricity becomes widespread, energy price stabilisation funds should be established. These funds would help cushion the impact of energy price spikes, preventing them from disrupting financial markets and the broader economy.

The short length of the data is the major limitation of this study. Future studies should use longer time periods and cover all EU countries for more robust results. Sectoral level analysis is also recommended to identify which industries are most affected by electricity price changes and how this impacts financial stability.

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