Geothermal Energy

RESEARCH

Open Access

The impact of wind and geothermal energy consumption on economic growth and financial development: evidence on selected countries

Mesut Doğan[1*], Murat Tekbaş[2] and Samet Gursoy[3]

*Correspondence: mesutdogan07@gmail.com

[1] Department of Business Administration, Afyon Kocatepe University, Bayat, Afyonkarahisar, Turkey
[2] Marketing and Advertising Department, Afyon Kocatepe University, Afyonkarahisar, Turkey
[3] Customs Management Department, Burdur Mehmet Akif Ersoy University, Bucak, Burdur, Turkey

Abstract

The aim of this study is to investigate the impacts of wind and geothermal energy consumption on economic growth and financial development over the period 2016:M1 and 2020:M11. The data obtained from Germany, Iceland, Italy, Japan, Mexico, New Zealand, Portugal, Turkey, and the United States of America, which consume wind and geothermal energy, were utilized in the research study. To this end, after determining the cointegration relationship between the variables, the long-term elasticity coefficients were estimated by employing the FMOLS (2000) and DOLS (2001) models. As a result of the analysis, it was determined that geothermal energy consumption had a positive impact on financial development. Nonetheless, wind energy had no impact on financial development, whereas it had a negative impact on economic growth. According to the Dumitrescu–Hurlin causality test results, it was determined that a unilateral causality existed from wind and geothermal energy consumption to economic growth. These obtained findings, in favor of the conservative hypothesis, yielded important signals for investments to be made in the renewable energy sector as well as policymakers.

Keywords: Wind energy, Geothermal energy, Economic growth, Financial development

Introduction

Energy use and access to energy, as parameters of development, are global problems (Mohammed et al. 2013). Countries strive for accessing energy resources and minimizing the damage caused by energy use. High growth rates as a result of industrialization cause an increase in greenhouse gas emissions (Dinda 2004). These emissions, which represent a serious threat to the environment and humanity, significantly disrupt the balance of living things due to disastrous natural phenomena such as climate change, and global warming. Countries that are aware of such threats have begun to use renewable energy by diversifying energy resources (Pata 2018).

This pursuit of energy, which has a critical role for all countries, has become almost compulsory beyond necessity due to factors such as energy security, scarce reserves of fossil energy resources, price fluctuations, and climate change, renewable energy. Thus, renewable energy resources (biomass, geothermal, hydro, solar, and wind) have assumed importance for sustainable development (Ozturk and Bilgili 2015).

Total renewable energy resources include hydro, geothermal, wind, solar, wood, waste, and biofuels. Hydroelectricity and total biomass (geothermal, wind, solar, wood, waste, and biofuels) are crucial renewable energy resources for producing electricity (Bilgili et al. 2019). Wind energy is considered one of the most important and widely used renewable energy resources (Esteban et al. 2011). Wind energy is expected to play quite a crucial role in the future energy supply of the European Union and the world. According to the forecasts of the Global Wind Energy Council, a large amount of electricity would be generated from wind energy worldwide in the coming years (Blanco 2009). Direct use of geothermal energy, as another type of renewable energy, is one of the oldest and most common forms of utilizing geothermal energy (Dickson and Fanelli 2003). As a domestic resource of sustainable and renewable energy, geothermal has been replacing other forms of energy usage, especially fossil fuels. Geothermal energy causes many countries to mitigate their dependence on imported fuel, and it also assists in eliminating pollutants such as greenhouse gases for all countries (Lund et al. 2011).

There have been 4 hypotheses in studies that investigated the relationship between renewable energy and economic growth. The growth hypothesis, which is the first of those hypotheses, argues that a positive relationship exists between renewable energy consumption and economic growth (Tiwari 2011; Salim and Rafiq 2012; Ozturk and Bilgili 2015; Solarin and Ozturk 2015; Hamit-Haggar 2016; Mbarek et al. 2018). Secondly, the conservative hypothesis claims that a unilateral causality exists running from economic growth to renewable energy consumption (Sadorsky 2009; Menyah and Wolde-Rufael 2010; Armeanu et al. 2017; Rasoulinezhad and Saboori 2018). Thirdly, the feedback hypothesis argues that a bilateral causality exists between renewable energy consumption and economic growth (Apergis and Payne 2011; Shahbaz et al. 2012; Lin and Moubarak 2014; Pao et al. 2014; Rafindadi and Ozturk 2017; Saad and Taleb 2018). Fourthly, the neutrality hypothesis suggests that no causality exists between renewable energy use and economic growth (Payne 2009; Menegaki 2011; Yildirim et al. 2012; Ocal and Aslan 2013; Fan and Hao 2020).

This study aims to examine the impacts of wind and geothermal energy consumption on economic growth and financial development. The data obtained from countries such as Germany, Iceland, Italy, Japan, Mexico, New Zealand, Portugal, Turkey, and the USA, which consumed wind and geothermal energy over the period 2016:M1–2020:M11 are used in the study. In the study, the stationarity of the variables is determined by Levin et al. (2002) and Im et al. (2003) unit root tests; whereas, the relationship between the variables is determined by the Kao and Johansen Fisher cointegration test. Besides, the FMOLS (2000) and DOLS (2001) coefficient estimators are utilized to detect long-term impacts in the study. Lastly, the causality between the variables is investigated by performing the Dumitrescu and Hurlin (2012) test.

It is thought that this study may contribute to the literature in three aspects:

(i) The number of studies investigating the impact of wind and geothermal energy consumption on economic growth in the literature is quite limited. Nevertheless, no research is found on the relationship between wind and geothermal energy consumption and financial development. Therefore, examining the impact of wind and geothermal energy consumption on both economic growth and financial development in this study is crucial in terms of filling this gap in the current literature.

(ii) Examining such impacts for countries with the highest wind and geothermal energy consumption may contribute to the literature.

(iii) The findings of the study, suggesting that wind and geothermal energy consumption negatively/positively affects or does not affect economic growth and financial development at all, would guide the policies to be implemented for the improvement of renewable energy resources.

The research study consists of five parts. Following the introduction, the second part includes the literature review on the impacts of wind and geothermal energy consumption on economic growth and financial development. In the third part, the dataset and the econometric model are introduced. In the fourth part, empirical findings are presented. In the last part, the conclusion and policy recommendations are discussed.

Literature review

Upon examining the literature on the subject, it is seen that the relationship between renewable energy consumption, economic growth, and financial development has been extensively investigated. Nevertheless, a significant portion of these studies has concentrated on the impact of total renewable energy consumption on economic growth (Chen et al. 2019; Rahman and Velayutham 2020; Alam and Murad 2020; Ghosh and Kanjilal 2020; Wang and Wang 2020; Razmi et al. 2020; Ivanovski et al. 2021). There are quite a few studies examining the impact of wind and geothermal energy consumption, which have a crucial place among renewable energy sources, on economic growth. These studies are summarized in this part.

No research study that examined the relationship between wind energy consumption and financial development is found in the literature review on the subject. However, all studies in this field involve the impact of wind energy consumption on economic growth. In these studies, nonetheless, there is no consensus in the literature on the relationship between wind energy consumption and economic growth. Some of the studies detected that wind energy consumption positively affected economic growth in terms of their research samples (Ewing et al. (2007) and Haerer and Pratson (2015) for the USA; Blanco and Rodrigues (2009) and Simas and Pacca (2014) for EU-member countries; Kathuria et al. (2015) for India; Ejdemo and Söderholm (2015) for Northern Sweden; Xia and Song (2017) for China; Keeley and Ikeda (2017) for the UK; Sadorsky (2021) for the UK; Bilgili et al. (2019) for Turkey; Sadorsky (2021) for the G-20 countries; and Murshed et al. (2021) for Bangladesh). The findings of these studies are consistent with the growth hypothesis.

Ohler and Fetters (2014) determined a unidirectional causality running from economic growth to wind energy regarding the data obtained from 20 OECD member countries over the period 1990–2008. Similarly, Mikulić et al. (2018) detected a unilateral causality between economic growth and wind energy for the Croatian sample over the period 2007–2016. The findings of these studies are consistent with the conservative hypothesis, and therefore, indicated that policies to increase or decrease wind energy consumption had no impact on economic growth.

Armeanu et al. (2017) revealed that no causality existed between wind energy and economic growth for EU-member states over the period 2003–2014. Jaraite et al. (2017) could not detect any causality between wind energy and economic growth for the same sample over the period 1990–2013. The findings of these studies support the neutrality hypothesis and indicate that any policy regarding one variable would not affect the other.

No research study is found to be conducted on the relationship between geothermal energy consumption and financial development. Nonetheless, quite a few studies investigated the relationship between geothermal energy consumption and economic growth. For instance, Bilgili et al. (2019) argued that the increase in geothermal energy consumption in compliance with the growth hypothesis enhanced economic growth. Ohler and Fetters (2014) found a unilateral causality running from economic growth to geothermal energy for 20 OECD member countries over the period 1990–2008, in favor of the conservation hypothesis. Armeanu et al. (2017) determined that no causality relationship existed between geothermal energy and economic growth for the EU-member states over the period 2003–2014, and their findings supported the neutrality hypothesis. Similarly, Yildirim et al. (2012) obtained findings supporting the neutrality hypothesis for the USA sample.

Data, model, and methodology

In this study, the impact of wind and geothermal energy consumption of Germany, Iceland, Italy, Japan, Mexico, New Zealand, Portugal, Turkey, and the USA on the financial and economic development is examined by utilizing the common data obtained over the period 2016:M1–2020:M11. The empirical model designed for this purpose is formed as follows:

$$\text{Model 1: } \ln\text{FD}_{it} = \beta_0 + \beta_1 \ln\text{GEO}_{it} + \beta_2 \ln\text{WIND}_{it} + \vartheta_t, \quad (1)$$

$$\text{Model 2: } \ln\text{GDP}_{it} = \beta_0 + \beta_1 \ln\text{GEO}_{it} + \beta_2 \ln\text{WIND}_{it} + \vartheta_t. \quad (2)$$

The lnFD variable in the model indicates the natural logarithm of the financial development index of the countries, the lnGDP stands for the natural logarithm of real national income, the lnGEO variable represents the natural logarithm of geothermal energy consumption, the lnWIND variable indicates the natural logarithm of wind energy consumption, and ϑ_t denotes the error term.

The dataset of the study consists of monthly frequency values over the period 2016-M1 and 2020-M11. In this respect, wind and geothermal energy consumption data are obtained from the International Energy Agency (IEA) database, the Financial Development indicator data are obtained from the UK Finance Yahoo database, and the economic growth indicator data are obtained from the Federal Reserve Economic Data (FRED) database. Economic growth data have been normalized by FRED. Since most of the indicators used to represent financial development in the literature have been calculated on an annual basis, stock prices are chosen to represent financial development on a monthly basis.

In the study, the stationarity of the variables is determined by the Levin et al. (2002) and Im et al. (2003) unit root tests, and the long-term relationship between the variables is determined by the Kao and Johansen Fisher cointegration test. In the study, the long-term impacts of independent variables on the dependent variable were also analyzed by performing the FMOLS (2000) (Fully Modified Ordinary Least Squares Method) and DOLS (2001) (Dynamic Ordinary Least Squares Method) coefficient estimator tests. Lastly, the causal relationship between the variables in the study was examined by performing the Dumitrescu and Hurlin (2012) causality test.

LLC has claimed that individual unit root tests have limited power against the alternative hypothesis, and also that there were fairly permanent deviations from the level of equilibrium. It was accepted that such situations would have been even more severe in small samples. LLC recommends a stronger unit root test for each cross-section versus individual unit root tests. In this suggested test, the null hypothesis indicates that each individual time-series has a unit root, whereas the alternative hypothesis indicates that each time-series is stationary (Baltagi 2005, p 40).

According to IPS, which proposes an alternative panel unit root test compared to LLC, which recommends applying the unit root test merely to homogeneous cross-sections, the average ADF test statistic is checked by calculating the ADF for each individual in the panel. The stochastic process is defined in the $y_{i,t}$ first-order autoregressive process, with T time-series and N cross-section as follows (Göral 2015, p 110):

$$\Delta y_{i,t} = \alpha_i + p_i y_{i,t-1} + \delta_{i,t}. \tag{3}$$

The hypotheses formed to perform the unit root test are as follows:

$H_0 = p_i = 0_i = 1, \ldots, N$ (for all cross-sections)
$H_1 = p_i < 0_i = 1, \ldots, N_{1,}\ i = N_{1+1} + 1, N_{1+2} + N$ (for at least one cross-section)

Such an alternative hypothesis suggests that p_i allows for variation among individuals. According to the alternative hypothesis, it is possible that some of the formally stationary individuals may contain a unit root. In this regard, the rejection of H_0 indicates that one or more of the individuals are stationary. This condition is essential for the consistency of the IPS panel unit root test. The IPS panel unit root test allows for serial correlation and heterogeneity between errors in the data generation process, and the simulation results indicate that the t-bar test yields better and more reliable results than the LLC test even in small samples, as a result of choosing a sufficiently large lag length for the ADF test (Im et al. 2003, p 73).

After determining the stationarity of the series, the long-term cointegration relationship of the series would be investigated by performing the Kao and Johansen–Fisher cointegration test.

The Kao cointegration test, which concentrates on the first-order regressions of fixed and homogeneous coefficients specific to cross-sections by setting out with the same approach as Pedroni cointegration tests, suggests the DF and ADF type tests in order to detect the cointegration relationship. The considered regression equation in these tests is as follows:

$$Y_{it} = \alpha_i + BX_{it} + e_{it}. \tag{4}$$

According to Kao (1999), the DF test, as one of the residual cointegration tests, is as follows:

$$\widehat{e}_{it} = p\widehat{e}_{it-1} + v_{itp}. \quad (5)$$

$\widehat{e}_{it}$ that are seen in Eq. 5 denote predicted residual terms.

The proposed DF test statistic to test H_0 = 'no cointegration' hypothesis is as follows (Baltagi et al. 2000, p 14; Asteriou and Hall 2007, p 373):

$$DF = \frac{t_p + \sqrt{6n}\frac{\sigma_v}{2\sigma_{0v}}}{\sqrt{\frac{\sigma_{0v}^2}{(2\sigma_v^2)} + \frac{3\sigma_v^2}{(10\sigma_{0v}^2)}}}. \quad (6)$$

If the error terms are autocorrelated, the regression is obtained by adding the lagged terms to Eq. 6 as follows:

$$\widehat{e}_{it} = pe_{it-1} + \sum_{j=1}^{p} \varnothing \Delta \widehat{e}_{it-j} + v_{itp}. \quad (7)$$

As in the DF test, the null hypothesis is also H_0 = 'no cointegration' in this test. The ADF test statistic is calculated as follows:

$$\text{ADF} = \frac{t_{\text{ADF}} + \sqrt{6N}\frac{\sigma_V}{2\sigma_{0U}}}{\sqrt{\frac{\sigma_{0V}^2}{(2\sigma_V^2)} + \frac{3\sigma_V^2}{(10\sigma_{0V}^2)}}}. \quad (8)$$

The Johansen–Fisher panel cointegration test is a multi-equation generalization of the Engle and Granger method. In Johansen's (1988) cointegration test, the equation system of the series which are stationary of the same order is based on the VAR (Vector Auto Regression) analysis, in which the level and lagged values of each variable in the system are used. The equation of the Johansen–Fisher panel cointegration test is as follows:

$$\Delta X_t = \Gamma_1 \Delta X_{t-1} + \cdots + \Gamma_{k-1} \Delta X_{t-k} + \Pi \Delta X_{t-k} + \varepsilon_t. \quad (9)$$

In the Johansen–Fisher cointegration test, the existence of a cointegration relationship among the series is analyzed using trace and maximum eigenvalue statistics (Johansen 1988).

Following the cointegration analysis, the direction and coefficient of the long-term relationship between the variables are estimated. The FMOLS estimator developed by Pedroni (2000), which is frequently used in the analysis of this long-run cointegration relationship, employs a semi-parametric correction method that takes into account the autocorrelation problem among the error terms and the endogeneity between the independent variables and the error term in order to avoid the problems caused by the long-term correlation of the cointegration equation and stochastic shocks (as cited in Küçükaksoy et al. 2015). The equation of the FMOLS cointegration test is as follows:

$$\widehat{\theta} = \left[\widehat{\gamma}^{\widehat{\beta}} =\right] \left(\sum_{t=1}^{T} Z_t Z_t^{'}\right)^{-1} \left(\sum_{t=1}^{T} Z_t Y_t^{+} - T\left[\lambda_1^{+} 0^2\right]\right). \quad (10)$$

$Z_t = \left(X_t^{'}, D_t^{'}\right)$ is in Eq. 10. This problem is eliminated by using the kernel estimator in the parameter that generates the autocorrelation problem in the FMOLS method. The regression estimation equation with the group-mean panel DOLS estimator proposed by Pedroni (2001) is as follows:

$$\gamma_{it} = \alpha_i + \beta\chi_{it} + \sum_{k=-K_i}^{K_i} \gamma_{ik}\Delta x_{it} + \mu_{it}. \tag{11}$$

In this equation, $-K_i$ and K_i denote the leading lag numbers. Upon obtaining the panel cointegration vector in this model, which is assumed to have no cross-sectional dependence among the cross-sections that constitute the panel; firstly, the model presented in Eq. 11 is estimated for each cross-section.

$$\chi_{it} = \chi_{it-1} + e_{it} \tag{12}$$

Here, as in the FMOLS, the Newey–West method is also employed in the DOLS estimator. In the next step, the arithmetic mean of the cointegration coefficients obtained from the DOLS estimation of each cross-section is calculated and the panel cointegration coefficient is formed as follows:

$$\widehat{\beta}^*_{\mathrm{GD}} = N^{-1} \sum_{i=1}^{N} \beta^* D, i. \tag{13}$$

In this equation, $\widehat{\beta}^*_{\mathrm{GD}}$ denotes the cointegration coefficient obtained from the DOLS estimation for each cross-section, whereas the t-statistics of the group-mean panel DOLS estimators are calculated as follows:

$$t_{\widehat{\beta}^*_D} = N^{-\frac{1}{2}} \sum_{i=1}^{N} t_{\widehat{\beta}^*_{D,i}}. \tag{14}$$

Here, $t_{\widehat{\beta}^*_D}$ denotes the *t*-statistic of the cointegration coefficient obtained from the DOLS estimator for each cross-section (Nazlıoğlu 2010, p 99; as cited in Gülmez 2015, p 25).

After determining the cointegration relationship and its direction, the Dumitrescu and Hurlin (2012) causality test is performed to determine the causality between the variables. The Dumitrescu–Hurlin causality test can yield accurate results in heterogeneous panels, in which N > T or T > N (Dumitrecu and Hurlin 2012, p 1451). The linear model in which the test investigates the causality between X and Y, where the variables must be stationary in order to examine the relationship between the variables, is as follows:

$$Y_{i,t} = \alpha_i + \sum_{k=1}^{K} Y_i^{(k)} Y_{i,t-k} + \sum_{k=1}^{K} \beta_i^{(k)} X_{i,t-k} + \varepsilon_{i,t}. \tag{15}$$

K in the model denotes the optimal lag length. The null hypothesis of the test implies that no causal relationship exists between the examined variables, whereas the alternative hypothesis implies a causal relationship.

Table 1 Descriptive statistics of the variables

	lnfd	lngdp	lngeo	lnwind
Mean	4.665	4.598	5.415	7.638
Median	4.671	4.607	6.130	7.235
Maximum	5.054	4.627	7.300	10.406
Minimum	4.365	4.411	1.940	5.516
Std. error	0.120	0.028	1.558	1.222
Skewness	0.077	−3.186	−1.028	0.708
Kurtosis	3.028	14.216	2.539	2.417
Number of observations	531	531	531	513

Table 2 Panel unit root test results

Level	LLC		IPS	
	t-statistics	Prob	*t*-statistics	Prob
lnFD	−2.306**	0.010	−2.209**	0.013
lnGDP	−0.691	0.755	−3.697***	0.000
lnGEO	−6.483***	0.000	−8.624***	0.000
lnWIND	−1.814**	0.034	−7.035***	0.000
Diff. values				
ΔlnFD	−20.470***	0.000	−18.170***	0.000
ΔlnGDP	−17.609***	0.000	−14.712***	0.000
ΔlnGEO	−27.100***	0.000	−27.481***	0.000
ΔlnWIND	−13.140***	0.000	−20.564***	0.000

Δ indicates the first differences of the series. ***, **, and * indicate significance at 1%, 5%, and 10% significance levels, respectively

Empirical findings

Prior to initiating the analysis, the descriptive statistics of both dependent and independent variables used in the study are presented in Table 1.

Upon considering the descriptive statistics presented in Table 1, it is seen that the mean value of the financial development indicator is 4.665 over the period 2016:M1–2020:M11 for the examined country group. It is seen that the USA is the country with the maximum level of geothermal and wind energy consumption throughout the research period.

In time-series and panel data analysis, unit root tests should be performed firstly to test whether or not the series contain unit-roots. In the study, the stationarity of the series is analyzed by performing the Levin et al. (2002) and Im et al. (2003) unit root tests, and the results are presented in Table 2.

Upon examining the LLC and IPS unit root test results, it is seen that the null hypothesis is rejected at the level for all series except for the lnGDP series. However, Nazlıoğlu (2010) reported reliable findings as a result of applying the difference-taking process and analyzing series that are determined stationary according to all unit root tests, upon considering the situation in which a series that is found stationary according to a certain unit root test may not be according to other unit root tests.

Table 3 Kao panel cointegration test results

Model 1	*t*-statistic	Prob
Augmented Dickey–Fuller (ADF)	−4.381***	0.000
Model 2	***t*-statistic**	**Prob**
Augmented Dickey–Fuller (ADF)	−1.791**	0.036

***, **, and * denote significance at 1%, 5%, and 10% significance levels, respectively

Table 4 Johansen–Fisher panel cointegration test results

Model 1				
Hypothesis	**Fisher statistic trace statistic**	**Prob**	**Fisher statistic maximum eigenvalue**	**Prob**
H_0: $r=0$	98.44***	0.000	60.63***	0.000
H_0: $r\leq 1$	59.27***	0.000	38.75***	0.003
Model 2				
Hypothesis	**Fisher statistic trace statistic**	**Prob**	**Fisher statistic maximum eigenvalue**	**Prob**
H_0: $r=0$	95.41***	0.000	61.00***	0.000
H_0: $r\leq 1$	55.74***	0.000	36.32***	0.006

***, **, and * denote significance at 1%, 5%, and 10% significance levels, respectively

Therefore, upon calculating the differences of the series, it is seen that all series are stationary according to both tests and are cointegrated at the first difference values.

Following the determination of the stationarity of the series, the long-term cointegration relationships of the series are analyzed by performing the Kao and Johansen–Fisher cointegration tests. The Kao and Johansen–Fisher cointegration test results for the models generated in the study are presented in Tables 3 and 4.

Upon examining the Kao (1999) cointegration test results in Table 3, it is determined that the long-term cointegration relationship of the variables in Model 1 is significant at the 1% level, and at the 5% level for the variables in Model 2. The obtained findings of the Johansen–Fisher cointegration test, which is the second cointegration test performed to verify the accuracy of the obtained results, are presented in Table 4. Upon examining these results, it is realized that the Kao cointegration test results are confirmed.

The Kao and Johansen–Fisher cointegration test results indicate that the variables in both models established within the scope of the study act together in the long-run. The coefficient and direction of the cointegration relationship are analyzed with the FMOLS and DOLS coefficient estimators, and the results are presented in Tables 5 and 6.

Upon examining the FMOLS and DOLS panel results for Model 1, it is seen that wind energy consumption has no impact on financial development. It is seen that the impact of geothermal energy consumption on financial development is positive and statistically significant according to both test results. Besides the FMOLS and DOLS panel results obtained in the study, the individual results of the countries are also analyzed. Upon evaluating the FMOLS country-specific results, it is seen that geothermal energy consumption negatively affects the financial development for Germany, and affects positively for Portugal and Turkey. It is determined that the impact of wind

Table 5 Model 1 FMOLS and DOLS coefficient estimator results

Model 1	$\ln FD_{it} = \beta_0 + \beta_1 \ln GEO_{it} + \beta_2 \ln WIND_{it} + \vartheta_t$							
Variables	**FMOLS**				**DOLS**			
	LnGEO		**LnWIND**		**LnGEO**		**LnWIND**	
	Coefficient	**Prob**	**Coefficient**	**Prob**	**Coefficient**	**Prob**	**Coefficient**	**Prob**
Panel	0.248***	0.000	−0.004	0.840	0.247***	0.000	−0.008	0.787
Countries								
Germany	−0.182**	0.034	0.092**	0.037	−0.228*	0.052	0.110*	0.570
Iceland	−0.280	0.161	0.041	0.410	−0.272	0.355	0.032	0.705
Italy	−0.978	0.197	0.038	0.632	−1.885	0.210	0.085	0.479
Japan	−0.269	0.307	0.130*	0.085	−0.589	0.189	0.213*	0.082
Mexico	0.239	0.225	−0.166***	0.000	0.137	0.584	0.201***	0.000
New Zealand	−0.389	0.268	−0.018	0.727	−0.697	0.245	−0.026	0.684
Portugal	0.450***	0.000	−0.077	0.298	0.512***	0.000	−0.045	0.656
Turkey	0.355***	0.000	0.077	0.375	0.347*	0.057	0.045	0.838
USA	−0.136	0.651	0.286***	0.003	−0.241	0.589	0.247**	0.033

***, **, and * denote significance at 1%, 5%, and 10% significance levels, respectively

Table 6 Model 2 FMOLS and DOLS coefficient estimator results

Model 2	$\ln GDP_{it} = \beta_0 + \beta_1 \ln GEO_{it} + \beta_2 \ln WIND_{it} + \vartheta_t$							
Variable	**FMOLS**				**DOLS**			
	LnGEO		**LnWIND**		**LnGEO**		**LnWIND**	
	Coefficient	**Prob**	**Coefficient**	**Prob**	**Coefficient**	**Prob**	**Coefficient**	**Prob**
Panel	− 0.059	0.118	− 0.159***	0.000	− 0.019	0.286	− 0.017**	0.012
Countries								
Germany	− 0.037	0.245	− 0.003	0.843	− 0.057	0.199	− 0.003	0.857
Iceland	− 0.050	0.145	− 0.006	0.463	− 0.046	0.311	− 0.007	0.573
Italy	0.526*	0.053	− 0.009	0.733	0.897*	0.066	− 0.015	0.687
Japan	− 0.079	0.129	0.003	0.807	− 0.121	0.190	0.011	0.654
Mexico	0.104	0.139	− 0.025	0.101	0.073	0.462	− 0.030	0.176
New Zealand	− 0.191	0.152	− 0.035*	0.080	− 0.296	0.331	− 0.053*	0.077
Portugal	0.004	0.830	0.009	0.448	0.003	0.882	0.011	0.576
Turkey	− 0.049	0.245	− 0.034	0.350	0.014	0.836	− 0.115	0.188
USA	− 0.065	0.409	− 0.065***	0.009	− 0.093	0.483	− 0.073**	0.033

energy consumption on financial development is positive for Germany, Japan, and the USA, whereas negative for Mexico. According to the DOLS results, it is seen that the results for Germany, Japan, Portugal, and Turkey are consistent with the FMOLS results. However, it is concluded that the impact of wind energy consumption on financial development is positive for Mexico.

The results of Model 2, in which the impacts of geothermal and wind energy consumption on economic growth are investigated, are presented in Table 6. Upon examining the results in Table 6, it is seen that the impact of wind energy consumption on economic growth for the countries within the scope of the study is negative according to the panel FMOLS and DOLS coefficient estimators. Upon evaluating the FMOLS coefficient estimator results of the countries, it is determined that geothermal energy consumption has a positive impact on economic growth for Italy. No statistically significant results are obtained for other countries. It is concluded that the impact of wind energy consumption on economic growth is negative for New Zealand and the USA. Upon examining the DOLS coefficient estimator results of the countries, it is seen that the impact of geothermal energy consumption on economic growth is positive for Italy. The results obtained within the scope of the negative impact of wind energy on economic growth are consistent with the FMOLS results for New Zealand and the USA.

After obtaining the cointegration coefficients and the direction of these coefficients as a result of the analyses, the causality between the variables within the scope of the established models is examined by performing the causality test developed by Dumitrescu and Hurlin (2012), and the results are presented in Table 7.

Upon examining the Dumitrescu–Hurlin causality test results to determine the relationship between the variables, it is determined that a unilateral causality exists running from financial development to wind and geothermal energy consumption in Model 1. According to the obtained results of Model 2, it is found that a unilateral causality exists running from wind and geothermal energy consumption to economic growth. Moreover, according to the analysis results, it is seen that no statistically significant causality exists running from wind and geothermal energy consumption to financial development and from economic growth to wind and geothermal energy consumption.

Conclusion

The study aims to investigate the impacts of wind and geothermal energy consumption on economic growth and financial development. In the study, the data obtained from Germany, Iceland, Italy, Japan, Mexico, New Zealand, Portugal, Turkey, and the USA, which consume wind and geothermal energy over the period 2016:M1–2020:M11 are used. Upon evaluating the results obtained in the study, it is seen that geothermal energy consumption has a positive impact on financial development for the country group in

Table 7 Dumitrescu–Hurlin causality test results

Model 1:	$\mathbf{lnFD}_{it} = \beta_0 + \beta_1\mathbf{lnGEO}_{it} + \beta_2\mathbf{lnWIND}_{it} + \vartheta_t$		
Null hypothesis	**Wald statistic**	**Z-bar statistic**	**Prob**
lnGEO ↛ lnFD	1.242	0.406	0.684
lnFD ↛ lnGEO	2.083**	2.076	0.037
lnWIND ↛ lnFD	1.639	1.196	0.231
lnFD ↛ lnWIND	2.568***	3.040	0.002
Model 2:	$\mathbf{lnGDP}_{it} = \beta_0 + \beta_1\mathbf{lnGEO}_{it} + \beta_2\mathbf{lnWIND}_{it} + \vartheta_t$		
Null hypothesis	**Wald statistic**	**Z-bar statistic**	**Prob**
lnGEO ↛ lnGDP	2.224**	2.356	0.018
lnGDP ↛ lnGEO	1.600	1.117	0.263
lnWIND ↛ lnGDP	3.337***	4.568	0.000
lnGDP ↛ lnWIND	0.829	− 0.413	0.679

Maximum lag length is determined as 1. ***, **, and * denote significance at 1%, 5%, and 10% significance levels, respectively the FMOLS method results using the first established model. In the second model, it is seen that geothermal and wind energy consumption have a negative effect on economic growth. In order for geothermal and wind energy consumption to have positive effects on financial development and economic growth, it is important for countries to implement energy policies that will strengthen the infrastructure of these energy resources.

The causality results reveal that a unilateral relationship exists running from financial development to wind and geothermal energy consumption. Besides, it is determined that a unilateral causality exists running from wind and geothermal energy consumption to economic growth. Nonetheless, there is no statistically significant causality from wind and geothermal energy consumption to financial development, and from economic growth to wind and geothermal energy consumption. These findings are obtained by Ohler and Fetters (2014); Mikulić et al. (2018) and the results are consistent with the conservative hypothesis.

It is considered that maintaining the security of renewable energy supply, especially for geothermal and wind energy would have a positive impact on economic growth by mitigating the energy price fluctuations as well as minimizing foreign dependency on energy. Consequently, it should not be overlooked that the results obtained during the research period include periodic impacts and that the projects in the investment process may seem ineffective since their outputs have not been materialized yet. Furthermore, it is considered that the comparative analysis of wind and geothermal energy resources along with other renewable energy resources in future studies for the country groups selected within the scope of the study would be an important guide for policymakers.

Acknowledgements
Not applicable.

Author contributions
MD: data curation, conceptualization, writing—original draft. MT: methodology, formal analysis. SG: methodology, review and editing. All authors read and approved the final manuscript.

Funding
This research was not supported by any fund.

Availability of data and materials
Data are available.

Declarations

Competing interests
The authors do not have existing competing of interest.

Received: 21 June 2022 Accepted: 12 September 2022
Published online: 29 September 2022

References

Alam M, Murad W. The impacts of economic growth, trade openness and technological progress on renewable energy use in organization for economic cooperation and development countries. Renew Energy. 2020;145:382–90.
Apergis N, Payne JE. The renewable energy consumption–growth nexus in Central America. Appl Energy. 2011;88(1):343–7.
Armeanu DŞ, Vintilă G, Gherghina ŞC. Does renewable energy drive sustainable economic growth? Multivariate panel data evidence for EU-28 countries. Energies. 2017;10(3):381.
Asterıou D, ve Hall SG. Applied econometrics: a modern approach using eviews and microfit. Revisited. Newyork: Palgrave Macmillan; 2007.
Baltagi BH. Econometric analysis of panel data. 3rd ed. New York: Wiley; 2005.
Baltagı BH, Kao C. 2000. Nonstationary panels, cointegration in panels: a survey. Center for Policy Research Working Paper No. 16. http://www.maxwell.syr.edu/uploadedFiles/cpr/publications/working_papers/wp16.pdf.

Bilgili F, Kuşkaya S, Toğuç N, Muğaloğlu E, Kocak E, Bulut Ü, Bağlıtaş HH. A revisited renewable consumption-growth nexus: a continuous wavelet approach through disaggregated data. Renew Sustain Energy Rev. 2019;107:1–19.
Blanco MI. The economics of wind energy. Renew Sustain Energy Rev. 2009;13(6–7):1372–82.
Chen Y, Wang Z, Zhang Z. CO_2 emissions, economic growth, renewable and non-renewable energy production and foreign trade in China. Renew Energy. 2019;131:208–16.
Dickson MH, Fanelli M. Geothermal background. In: Dickson MH, Fanelli M, editors. Geothermal energy: utilization and technology, UNESCO renewable energy series. London: Earthscan Publications Ltd; 2003. p. 1–28.
Dinda S. Environmental Kuznets curve hypothesis: a survey. Ecol Econ. 2004;49(4):431–55.
Dumitrescu EI, Hurlin C. Testing for Granger non-causality in heterogeneous panels. Econ Model. 2012;29:1450–60. https://doi.org/10.1016/j.econmod.2012.02.014.
Ejdemo T, Söderholm P. Wind power, regional development and benefit-sharing: the case of Northern Sweden. Renew Sustain Energy Rev. 2015;47:476–85.
Esteban MD, Diez JJ, López JS, Negro V. Why offshore wind energy? Renew Energy. 2011;36(2):444–50.
Ewing BT, Sari R, Soytas U. Disaggregate energy consumption and industrial output in the United States. Energy Policy. 2007;35(2):1274–81.
Fan W, Hao Y. An empirical research on the relationship amongst renewable energy consumption, economic growth and foreign direct investment in China. Renew Energy. 2020;146:598–609.
Ghosh S, Kanjilal K. Non-fossil fuel energy usage and economic growth in India: a study on non-linear co-integration, asymmetry and causality. J Clean Prod. 2020;273:123032.
Göral F. 2015. Doğalgaz fiyatlarını Etkileyen Faktörler: Panel Veri Analizi, Hacettepe Üniversitesi Sosyal Bilimler Enstitüsü, Doktora Tezi, Ankara.
Gülmez A. OECD ülkelerinde ekonomik büyüme ve hava kirliliği ilişkisi: panel veri analizi. Kastamonu Üniversitesi İktisadi Ve İdari Bilimler Fakültesi Dergisi. 2015;9(3):18–30.
Haerer D, Pratson L. Employment trends in the US Electricity Sector, 2008–2012. Energy Policy. 2015;82:85–98.
Hamit-Haggar M. Clean energy-growth nexus in sub-Saharan Africa: evidence from cross-sectionally dependent heterogeneous panel with structural breaks. Renew Sustain Energy Rev. 2016;57:1237–44.
Im KS, Pesaran MH, Shinve Y. Testing for unit roots in heterogeneous panels. J Econom. 2003;115:53–74.
Ivanovski K, Hailemariam A, Smyth R. The effect of renewable and non-renewable energy consumption on economic growth: non-parametric evidence. J Clean Prod. 2021;286:124956.
Jaraite J, Karimu A, Kazukauskas A. Policy-induced expansion of solar and wind power capacity economic growth and employment in EU countries. Energy J. 2017. https://doi.org/10.5547/01956574.38.5.jjar.
Johansen S. Statistical analysis of cointegration vectors. J Econ Dyn Control. 1988;12(2–3):231–54.
Kao C. Spurious regression and residual-based tests for cointegration in panel data. J Econom. 1999;90:1–44.
Kathuria V, Ray P, Bhangaonkar R. FDI (foreign direct investment) in wind energy sector in India: testing the effectiveness of state policies using panel data. Energy. 2015;80:190–202.
Keeley AR, Ikeda Y. Determinants of foreign direct investment in wind energy in developing countries. J Clean Prod. 2017;161:1451–8.
Küçükaksoy İ, Çiftçi İ, ve Özbek Rİ. İhracata dayalı büyüme hipotezi: Türkiye uygulaması. Çankırı Karatekin Üniversitesi İktisadi Ve İdari Bilimler Fakültesi Dergisi. 2015;5(2):691–720.
Levin A, Lin CF, ve Chu CSJ. Unit root tests in panel data: asymptotic and finite-sample properties. J Econom. 2002;108:1–24.
Lin B, Moubarak M. Renewable energy consumption–economic growth nexus for China. Renew Sustain Energy Rev. 2014;40:111–7.
Lund JW, Freeston DH, Boyd TL. Direct utilization of geothermal energy 2010 worldwide review. Geothermics. 2011;40(3):159–80.
Mbarek MB, Saidi K, Rahman MM. Renewable and non-renewable energy consumption, environmental degradation and economic growth in Tunisia. Qual Quant. 2018;52(3):1105–19. https://doi.org/10.1007/s11135-017-0506-7.
Menegaki AN. Growth and renewable energy in Europe: a random effect model with evidence for neutrality hypothesis. Energy Econ. 2011;33(2):257–63.
Menyah K, Wolde-Rufael Y. CO_2 emissions, nuclear energy, renewable energy and economic growth in the US. Energy Policy. 2010;38(6):2911–5.
Mikulić D, Lovrinčević Ž, Keček D. Economic effects of wind power plant deployment on the Croatian economy. Energies. 2018;11(7):1881.
Mohammed YS, Mustafa MW, Bashir N. Status of renewable energy consumption and developmental challenges in Sub-Sahara Africa. Renew Sustain Energy Rev. 2013;27:453–63.
Murshed M, Elheddad M, Ahmed R, Bassim M, Than ET. Foreign direct investments, renewable electricity output, and ecological footprints do: financial globalization facilitate renewable energy transition and environmental welfare in Bangladesh. Asia-Pacific Finan Markets. 2021. https://doi.org/10.1007/s10690-021-09335-7.
Nazlıoğlu Ş. Makro İktisat Politikalarının Tarım Sektörü Üzerindeki Etkileri: Gelişmiş Ve Gelişmekte Olan Ülkeler İçin Bir Karşılaştırma. Doktora Tezi. Kayseri: Erciyes Üniversitesi; 2010.
Ocal O, Aslan A. Renewable energy consumption–economic growth nexus in Turkey. Renew Sustain Energy Rev. 2013;28:494–9.
Ohler A, Fetters I. The causal relationship between renewable electricity generation and GDP growth: a study of energy sources. Energy Econ. 2014;43:125–39.
Ozturk I, Bilgili F. Economic growth and biomass consumption nexus: dynamic panel analysis for Sub-Sahara African countries. Appl Energy. 2015;137:110–6.
Pao HT, Li YY, Fu HC. Clean energy, non-clean energy, and economic growth in the MIST countries. Energy Policy. 2014;67:932–42.
Pata UK. Renewable energy consumption, urbanization, financial development, income and CO_2 emissions in Turkey: testing EKC hypothesis with structural breaks. J Clean Prod. 2018;187:770–9.
Payne JE. On the dynamics of energy consumption and output in the US. Appl Energy. 2009;86(4):575–7.

Pedroni P. Fully-modified OLS for heterogeneous cointegrated panels. Adv Econ. 2000;15:93–130.
Pedroni P. Purchasing power parity tests in cointegrated panels. Rev Econ Stat. 2001;83:727–31.
Rafindadi AA, Ozturk I. Impacts of renewable energy consumption on the German economic growth: evidence from combined cointegration test. Renew Sustain Energy Rev. 2017;75:1130–41.
Rahman MM, Velayutham E. Renewable and non-renewable energy consumption-economic growth nexus: new evidence from South Asia. Renew Energy. 2020;147:399–408.
Rasoulinezhad E, Saboori B. Panel estimation for renewable and non-renewable energy consumption, economic growth, CO_2 emissions, the composite trade intensity, and financial openness of the commonwealth of independent states. Environ Sci Pollut Res. 2018;25(18):17354–70.
Razmi SF, Bajgiran BR, Behname M, Salari TE, Razmi SMJ. The relationship of renewable energy consumption to stock market development and economic growth in Iran. Renew Energy. 2020;145:2019–24.
Saad W, Taleb A. The causal relationship between renewable energy consumption and economic growth: evidence from Europe. Clean Technol Environ Policy. 2018;20(1):127–36.
Sadorsky P. Renewable energy consumption and income in emerging economies. Energy Policy. 2009;37(10):4021–8.
Sadorsky P. Wind energy for sustainable development: driving factors and future outlook. J Clean Prod. 2021;289:125779.
Salim RA, Rafiq S. Why do some emerging economies proactively accelerate the adoption of renewable energy? Energy Econ. 2012;34(4):1051–7.
Shahbaz M, Zeshan M, Afza T. Is energy consumption effective to spur economic growth in Pakistan? New evidence from bounds test to level relationships and granger causality tests. Econ Model. 2012;29(6):2310–9.
Simas M, Pacca S. Assessing employment in renewable energy technologies: a case study for wind power in Brazil. Renew Sustain Energy Rev. 2014;31:83–90.
Solarin SA, Ozturk I. On the causal dynamics between hydroelectricity consumption and economic growth in Latin America countries. Renew Sustain Energy Rev. 2015;52:1857–68.
Tiwari AK. A structural VAR analysis of renewable energy consumption, real GDP and CO_2 emissions: evidence from India. Econ Bull. 2011;31(2):1793–806.
Wang Q, Wang L. Renewable energy consumption and economic growth in OECD countries: a nonlinear panel data analysis. Energy. 2020;207:118200.
Xia F, Song F. Evaluating the economic impact of wind power development on local economies in China. Energy Policy. 2017;110:263–70.
Yildirim E, Saraç Ş, Aslan A. Energy consumption and economic growth in the USA: evidence from renewable energy. Renew Sustain Energy Rev. 2012;16(9):6770–864.

Publisher's Note