A new methodological perspective on the impact of energy consumption on economic growth: time series evidence based on the Fourier approximation for solar energy in the US

Umit Bulut[*]
Kirsehir Ahi Evran University, Turkey
ubulut@ahievran.edu.tr

Nicholas Apergis
University of Derby, UK
n.apergis@derby.ac.uk

[*] Corresponding author. Tel.: +90 386 280 4920. Fax Number: +90 386 280 4079

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1. Introduction

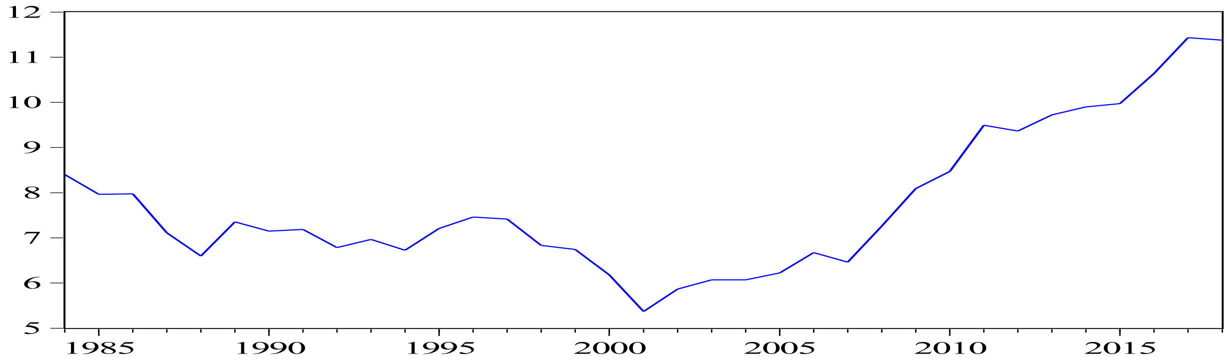
Energy is crucial for a modern economy because all economic activities require the utilization of energy (Bulut and Durusu-Ciftci 2018; Inglesi-Lotz 2018). Increases in economic activities, industrialization, and urbanization have all led to increases in energy demand in the last decades (Bilgili et al. 2016; Menegaki and Tsani 2018; Nathaniel, 2019). According to British Petroleum (2016) and World Bank (2019) data, primary energy demand in the world increased by 17.7% during the period 2005-2013, while the share of fossil sources, namely natural gas, coal, and oil, in total energy consumption was about 81% in 2013. These figures clearly show that the world substantially relies on fossil energy sources. The dependence on fossil sources, however, triggers certain environmental problems, namely climate change, global warming, and air pollution (Chindo et al. 2015; Bulut 2017; Bilgili et al. 2017a; Kocak and Sarkgunesi 2017; Aslan and Topcu 2018; Mikayilov et al. 2018; Zafar et al. 2019). Because of these serious environmental threats, policy makers have redesigned their energy and environmental policies to be able to achieve sustainable development goals (Ozcan et al. 2018). Hence, policymakers have more been interested in renewable energy that is considered as a clean and green energy source (Bilgili and Ozturk 2015; Bilgili et al. 2017b; Ali et al., 2018; Bao and Xiu 2019). Renewable energy sources are wind, solar, hydroelectric, geothermal, and biomass. Fang (2011) remarks that the public, as well as policymakers, have two major expectations from renewable energy. Firstly, renewable energy is capable of satisfying the energy necessity for sustainable economic growth, and secondly, it can significantly reduce environmental issues induced by the utilization of fossil sources.

Solar energy is one of the greatest and cleanest potential energy sources (Sahu 2015). The amount of solar rays that reach the earth's surface every hour is greater than all the energy consumed each single year (Centre for Climate Change and Energy Solutions, 2019). Solar energy has many advantages, namely emitting no greenhouse or toxic gases, improving debased land, improving water sources' quality, increasing energy independence, diversifying energy supply, providing energy security, and leading to the access of rural population to electricity in developing countries (Solangi et al. 2011). As Aman et al. (2015) denote, solar technology has two main elements, namely solar photovoltaic (PV) cells and concentrating solar power (CSP). While PV cells transform sunlight into direct current electricity, CSP technologies use mirrors or lens to concentrate the sun's rays and to convert these rays into heat, thus driving a steam turbine that generates electricity. The cost of PV cells has decreased considerably over the last years due to technological improvements and investments in the solar energy industry. While the cost of a PV cell per watt was 76.67 USD in 1977, it reduced to 0.74 USD in 2013 (Economist, 2013). This enormous decrease stimulates the employment of solar energy, as well as more investments in the solar energy technology through the feedback mechanism. Even though some toxic materials are used to produce PV cells and the high heat that the production of PV cells needs is met by burning fossil fuels, solar energy is much cleaner than fossil sources since solar panels do not emit greenhouse gas emissions as they are producing electricity (Aman et al. 2015). Due to the large potential and cleanness, 46 countries strongly promote solar energy systems today (Aman et al. 2015). The USA is one of these countries. The USA implemented production tax credit as a part of the Energy Policy Act during the period 1992-2003 for solar energy, along with other renewable energy sources (Menz 2005). The payments were 1.5 cents/kilowatt-hour, adjusted for inflation during the first ten years of this policy scheme. The most considerable policy that the US government implements regarding solar energy has been the federal solar tax credit (investment tax credit, hereafter ITC) since 1978 (Solangi et al.

2011). ITC encourages the usage of solar energy by decreasing the tax liabilities of both individuals and businesses which purchase solar energy technologies. ITC lets individuals and businesses reduce 30% of the cost of establishing a solar energy system from their taxes, and there is no upper bound for ITC. Due to these incentives, the share of renewables consumption in energy consumption and the share of solar energy consumption in total renewable energy consumption has increased in the USA.

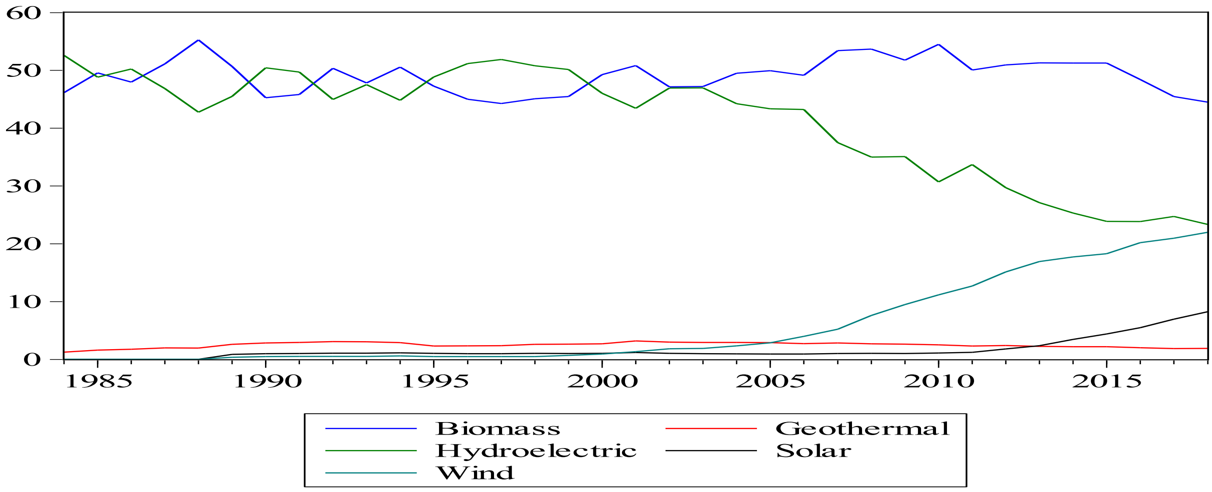
Figures 1 and 2 illustrate the share of renewable energy consumption in total energy consumption and the shares of renewable energy sources in total renewable energy consumption for the USA, respectively. As it is shown in Figure 1, after certain fluctuations during the period 1984-2007, the share of renewables consumption boosts from 2007. While this share was 6.45% in 2007, it reached 11.37% in 2018. Figure 2 presents the shares of renewable sources in total renewables consumption during 1984-2018. As it can be clearly seen, biomass energy consumption has the greatest share, with 44.5% in 2018. After biomass energy, hydroelectric power consumption has the second greatest share though the share of hydroelectric power consumption began to decrease beginning in 2003. The share of geothermal energy consumption followed a horizontal path during the observed period being only 1.88% in 2018. During the period 2007-2018, solar energy has the highest growth rate with an average of 24.3%, and thus the share of solar energy consumption increased from 1% to 8.26%. Similarly, due to high growth rates of wind energy consumption, the share of wind energy consumption was about 22% in 2018.

Fig. 1. The share of renewables consumption in total energy consumption in the USA (%)



Source: Energy Information Administration (2019, hereafter EIA)

Fig. 2. Shares of renewables in total renewables consumption for the USA (%)



Source: EIA (2019)

This paper considers the first expectation denoted by Fang (2011) for solar energy in the USA. More clearly, the paper considers the relationship between solar energy consumption and gross domestic product (GDP) in the USA, exploiting quarterly data spanning the period 1984-2018. The paper differs from similar papers in the relevant literature in some aspects and clarifies the contributions of the paper to the energy literature in the following part.

The remainder of the paper is organized as follows: Section 2 gives the empirical literature and the contributions of the paper to the existing literature. Section 3 introduces the model and data set. Section 4 presents estimation methodology while Section 5 shows the empirical findings. Section 6 concludes the paper.

2. Literature review and contribution

Since the pioneer study of Kraft and Kraft (1978), the energy consumption and economic growth nexus has been investigated extensively in the relevant literature over the last three decades (Saidi and Hammami 2015). Even though panel data studies are more popular than time series studies because of the lack of a sufficient number of observations for a single country (Tiwari et al. 2018; Tugcu 2018), some papers in the empirical literature examine the energy consumption and economic growth nexus using different time series methods[1].

When one considers the literature on the relationship between economic growth and renewable energy consumption for the US, he/she observes that the number of the studies that focus on this nexus has grown in the recent years, but is still limited. Among these papers, Ewing et al. (2007) analyze the interaction among waste, hydroelectric, solar, wood, and wind energy consumption and GDP for the period 2001-2005 through the generalized variance decomposition approach. They find that renewable energy consumption enhances GDP. Payne (2009) considers the causal relationships between total renewable energy consumption and GDP over the period 1949-2006. He yields that there is no causality between renewable energy consumption and GDP. Bowden and Payne (2010) investigate the relationship between renewable energy consumption and GDP across sectors for the period 1949-2006. Their findings document that the only causal relationship occurs from residential energy consumption to GDP. Yildirim et al. (2012) utilize data over the period 1949-2010, use causality methods, and consider the effects of total renewable, geothermal, hydro-electric, total biomass, biomass-wood-derived, and biomass-waste-derived energy consumption on GDP. They document that

[1] See e.g. Menegaki (2018) for a comprehensive analysis on the energy-economic growth nexus.

there is a causal relationship from only biomass-waste-derived energy consumption to GDP. Bilgili (2015) uses data for the period 1981-2013 and performs the wavelet coherence approach. He finds that renewables consumption increases industrial production. Aslan (2016) researches the relationship between biomass energy consumption and GDP over the period 1961-2011 by performing cointegration and causality tests. His findings illustrate that biomass energy consumption increases GDP, while there is a unidirectional causal relationship running from biomass energy consumption to GDP. Bildirici and Gokmenoglu (2017), using data over the period 1961-2013 and performing the Markow switching vector autoregressive model, find that hydropower energy consumption has positive effects on economic growth. Bilgili et al. (2017b) investigate the relationship between GDP and biomass energy consumption over the period 1982-2011 through causality methodologies. They yield that there is unidirectional causality running from biomass energy consumption to GDP. Tugcu and Topcu (2018) focus on the relationship between renewable energy consumption and economic growth over the period 1980-2014 by carrying out asymmetric cointegration and causality tests. They evidence renewables consumption positively influences growth. Troster et al. (2018) consider the relation between industrial production and renewable energy consumption during the period 1989-2016 by performing Granger-causality in a quantiles regression framework. Their findings confirm the presence of a bidirectional causal relationship between renewable energy consumption and industrial production at the lowest quantiles of the distribution and unidirectional causality from renewable energy consumption to industrial production at the higher quantiles of the distribution. Bilgili et al. (2019), using data over the period 1989-2010 and employing the continuous wavelet approach, examine the impacts of different types of renewable energy consumption on industrial production. They yield that all types of renewable energy, including solar energy consumption, have significant and positive effects on industrial production. Finally, Bulut and Inglesi-Lotz (2019) investigate the influence of renewable energy consumption on industrial production over the period 2000-2018 by performing a nonlinear cointegration test. They evidence renewable energy consumption has significant and positive effects on industrial production.

Considering the empirical literature, we can argue that the present paper makes some considerable contributions to the energy literature. First, although there exists an extending empirical literature on the renewable energy-economic growth nexus in the USA, only a few of them examine the direct and specific influences of solar energy consumption on GDP. Therefore, there appears to be a research on the relationship between solar energy consumption and GDP for the USA. This paper tries to fill this gap to some degree. Second, while investigating the influence of solar energy consumption on GDP, the paper employs the traditional Cobb-Douglas production function, which includes capital and labour as the inputs of production. In addition, the paper establishes two empirical models to consider the specific effects of total renewable energy consumption and solar energy consumption on GDP. In that sense, the paper can eliminate possible model specification errors and make a comparative analysis. Third, none of the previous papers in the literature considers structural breaks while examining the impact of renewable energy consumption on economic growth for the USA. The present paper employs some recently developed time series methods. Accordingly, it pays regard to structural breaks while estimating the empirical model. While considering the structural breaks, it takes both sharp and gradual/smooth breaks into account using the Fourier approximation. Therefore, a key strength of this paper is that it is the first paper that takes structural breaks into account for the relationship between renewable energy consumption and economic growth in the USA.

3. Model and data

Following mainstream economics that considers capital and labour as the leading determinants and inputs of GDP (Menegaki 2018), the analysis uses the Cobb-Douglas production function to examine the impact of solar energy consumption on GDP in the USA. The model used in the paper therefore incorporates solar energy consumption along with capital and labour. Besides, to make a comparative analysis, the paper sets up a second model to explore the influence of total renewables consumption on GDP. The production functions used in the empirical analysis yield:

$$Y = K^{\alpha_1} L^{\alpha_2} SEC^{\alpha_3} e^{u} \quad (1)$$

$$Y = K^{\beta_1} L^{\beta_2} REC^{\beta_3} e^{u} \quad (2)$$

where Y denotes GDP, K stands for capital, and L implies labour. Besides, SEC and REC denote solar energy and total renewables consumption, respectively. Finally, e is error term. In these empirical models, the returns to scale for independent variables are shown by α and β parameters. As the non-linear specification cannot provide consistent and unbiased results, while it cannot help policy makers to design efficient energy policies either (Shahbaz et al. 2015), this work makes use of a log-linear demonstration to explore the relationship among the variables. The log-linear forms of the functions are specified as follows:

$$\ln Y_t = \alpha_0 + \alpha_1 \ln K_t + \alpha_2 \ln L_t + \alpha_3 \ln SEC_t + u_t \quad (3)$$

$$\ln Y_t = \beta_0 + \beta_1 \ln K_t + \beta_2 \ln L_t + \beta_3 \ln REC_t + u_t \quad (4)$$

where Y defines real GDP (billions of chained 2012 USD), K denotes gross fixed capital formation (billion USD), L stands for employment rate (people aged 15-64), SEC stands for solar energy consumption (trillion Btu), and REC represents total renewables consumption (trillion Btu). Finally, u indicates error term. As data for solar energy consumption have been publicly available since 1984, the data in the paper are on a quarterly basis, spanning the period 1984:Q1-2018:Q4. Data on GDP, capital, and labour are extracted from the Federal Reserve Bank of St. Louis (2019), while energy consumption data are sourced from EIA (2019).

Table 1 Descriptive statistics and correlation matrix for the variables in the empirical models

	lnY	lnK	lnL	lnSEC	lnREC
Descriptive statistics					
Mean	9.437	6.273	4.258	2.233	7.467
Median	9.493	6.383	4.265	2.809	7.381
Maximum	9.841	6.991	4.308	5.504	7.975
Minimum	8.920	5.418	4.196	-5.477	7.123
Std. deviation	0.267	0.451	0.030	2.616	0.217
Observations	140	140	140	140	140
Correlation matrix					
lnY	1.000				
lnK	0.996	1.000			
lnL	-0.272	-0.233	1.000		
lnSEC	0.768	0.747	0.028	1.000	
lnREC	0.711	0.699	-0.562	0.549	1.000

Table 1 exhibits descriptive statistics and correlation matrix for the variables in the models. One can observe from the table that all descriptive statistics except minimum and standard deviation of lnY are greater than those of other variables. One can also notice that lnY is negatively correlated with lnL and positively correlated with other independent variables in the models. Descriptive statistics and correlation matrix present valuable information about the variables in an empirical model, but researchers should need to consider some statistical and/or econometric methodologies, such as unit root and cointegration tests, to acquire efficient and unbiased results about the influences of the independent variables on the dependent variable. Therefore, the following section of the paper presents the methodological approaches employed in the paper.

4. Methodological framework

4.1. Enders and Lee (2012) unit root test

Since the seminal work of Perron (1989) on the importance of structural breaks in unit root analysis, several unit root tests that take structural breaks into account have been produced by econometric theorists, such as Zivot and Andrews (1992), Lumsdaine and Papell (1997), Lee and Strazicich (2003), and Narayan and Popp (2010), etc. All these unit root tests regard a certain number of breaks and use dummy variables to grab alterations in intercept or in intercept and trend. Therefore, they consider only sharp breaks, implying structural breaks in variables are assumed to happen promptly. Enders and Lee (2012, hereafter EL) develop a unit root test that is able to present efficient output when (i) the number of the breaks is unknown and (ii) structural breaks in series are gradual.

E&L begin exploiting the Dickey-Fuller test including the deterministic term below:

$$y_t = \alpha(t) + \rho y_{t-1} + \gamma t + e_t \qquad (5)$$

where e_t is the stationary error term and $\alpha(t)$ denotes the deterministic function of t. The null hypothesis that indicates there exists a unit root is described as $\rho = 1$. When the form of $\alpha(t)$ is unknown, E&L use the Fourier expansion exhibited below:

$$\alpha(t) = \alpha_0 + \sum_{k=1}^{n} \alpha_k \sin(2\pi kt/T) + \sum_{k=1}^{n} \beta_k \cos(2\pi kt/T), \qquad n \leq T/2 \qquad (6)$$

where n indicates the number of frequencies involved in the approximation, k stands for a particular frequency, and T denotes the sample size.

E&L state that there is at least one Fourier frequency for the data generating process while there is a break or nonlinear trend. As the usage of many frequency components declines degrees for freedom and may lead to an overfitting problem, E&L use only a frequency k by regarding the following equation in their study:

$$\Delta y_t = \rho y_{t-1} + c_1 + c_2 t + c_3 \sin(2\pi kt/T) + c_4 \cos(2\pi kt/T) + e_t \quad (7)$$

In Equation (5), to test for the null hypothesis of the existence of a unit root described as $\rho = 0$, E&L compare the test statistic to the critical values that rely on the frequency and the sample size. When the calculated test statistic is higher than the critical values suggested by E&L, the null hypothesis of the existence a unit root can be rejected.

4.2. Tsong et al. (2016) cointegration test

One can observe throughout the econometrics literature that the previous literature on cointegration with structural breaks, such as Gregory and Hansen (1996), Hatemi-J (2008), and Maki (2012), has focused on a certain number of breaks and also analyzed only sharp breaks. Therefore, the performance of these tests are strongly related to the estimated break point and the form of the break. Following the Fourier approximation, Tsong et al. (2016) propound a relatively new cointegration test that can present efficient output regardless of the number and the form of the structural breaks, namely sharp or gradual. Another great advantage of this test is that it suggests a pretesting to examine whether the empirical model should include the Fourier component.

To produce a cointegration test that is based on the Fourier approximation, Tsong et al. (2016) first consider the following regression:

$$y_t = d_t + x_t^{'}\beta + \eta_t, \qquad \eta_t = \gamma_t + \upsilon_{1t}, \quad \gamma_t = \gamma_{t-1} + u_t, \quad x_t = x_{t-1} + \upsilon_{2t} \quad (8)$$

where u_t is the error term with zero mean and σ_u^2 variance and γ_t denotes a random walk with mean zero. In the above equation, d_t is defined as $d_t = \delta_0 + f_t$. For the model, f_t is the Fourier function described as below:

$$f_t = \alpha_k \sin\left(\frac{2k\pi t}{T}\right) + \alpha_k \cos\left(\frac{2k\pi t}{T}\right) \quad (9)$$

where k is the Fourier frequency, t denotes time trend, and T represents the number of observations. When $\sigma_u^2 = 0$, $\eta_t = \upsilon_{1t}$ is stationary, implying that there exists a cointegration relationship between y_t and x_t. Therefore, the null hypothesis of the existence of cointegration against the alternative hypothesis of no cointegration can be defined as the following:

$$H_0: \sigma_u^2 = 0 \text{ versus } H_1: \sigma_u^2 > 0 \quad (10)$$

To test for the null hypothesis of the presence of cointegration, the model can be described as the following:

$$y_t = \sum_{i=0}^{m} \delta_i t^i + \alpha_k \sin\left(\frac{2k\pi t}{T}\right) + \beta_k \cos\left(\frac{2k\pi t}{T}\right) + x_t'\beta + \upsilon_{1t} \quad (11)$$

The cointegration test statistic is exhibited as

$$CI_f^m = T^{-2}\hat{\omega}_1^{-2} \sum_{t=1}^{T} S_t^2 \quad (12)$$

where $S_t = \sum_{t=1}^{T} \hat{\upsilon}_{1t}$ indicates the partial sum of the ordinary least squares (OLS) residuals in Equation (11) while $\hat{\omega}_1^2$ denotes the estimator of the long-run variance of υ_{1t}.

Finally, Tsong et al. (2016) suggest a test to investigate whether the cointegration testing procedure should include the Fourier component. They test the null hypothesis of the absence of the Fourier component, H_0: $\alpha_k = \beta_k = 0$, against the alternative hypothesis indicating the presence of structural breaks. They utilize the following F test to test this hypothesis:

$$F^m\left(k^*\right) = \max_{k\in\{1,2,3\}} F^m(k) \quad (13)$$

where

$$F^m(k) = \frac{\left(SSE_0^m - SSE_1^m(k)\right)/2}{\frac{SSE_1^m(k)}{(T-q)}} \quad (14)$$

In Equation (14), SSE_0^m and $SSE_1^m(k)$ stand for the sum of squares residuals obtained from the estimation of Equation (11) through the dynamic OLS (DOLS) estimator, developed by Saikkonen (1991, 1992) and Stock and Watson (1993), under the null hypothesis and the alternative hypothesis, respectively. Finally, q shows the number of the parameters under the alternative hypothesis.

5. Empirical findings and discussion

The first step detects the order of integration of the variables through the E&L unit root test under the paper. The test statistic along with the optimal frequency for each variable are depicted in Table 2. As is seen, the null hypothesis of a unit root is rejected at first difference forms for all variables in the empirical models. Put differently, E&L unit root test discovers that all variables in the empirical models are integrated of order one and the Tsong et al. (2016) cointegration technique can be used to examine whether or not there exists cointegration in the empirical models.[2]

Table 2 E&L unit root test[a]

Variable[b]	Optimal frequency	Test statistic
lnY	1	-0.284
lnK	2	-1.560
lnL	1	-1.993
lnSEC	3	-2.991
lnREC	2	0.506
ΔlnY	1	-8.483[c]
ΔlnK	2	-6.525[c]
ΔlnL	1	-4.005[c]
ΔlnSEC	1	-14.962[c]
ΔlnREC	2	-7.067[c]

Notes:

[2] In addition to the E&L unit root test, we performed the unit root tests propounded by Dickey and Fuller (1981) and Phillips and Perron (1988) to check the robustness of the findings about the stationarity levels of the variables. Both tests confirm all variables are integrated of order one. The results of these unit root tests are available upon request.

[a] Critical values for 5% level are -3.81, -3.27, and -3.07 for the optimal 1, 2, and 3 frequencies.

[b] Δ is the first difference operator.

[c] Illustrates statistical significance.

Next, Table 3 demonstrates the results of the cointegration tests along with the long-run parameters of the independent variables. Accordingly, panel A of the table gives the empirical results for the model including solar energy consumption. Accordingly, as one can see in panel A1, the null hypothesis that there is no need to add the Fourier component to the empirical model can be rejected at 1% level, implying the cointegration testing procedure should depend on the Fourier approximation. Besides, the null hypothesis of cointegration can not be rejected with the optimal frequency 1, indicating there exists cointegration in the empirical model and the long-run coefficients could be estimated via the DOLS estimator. As is seen in panel A2 of the table, lnK, lnL, and lnSEC are associated with the estimations of 0.543, -0.513, and 0.009, respectively. Besides, all parameters are statistically significant. Panel B of the table presents the empirical findings for the model with total renewable energy consumption. As is seen in panel B1 of the table, the null hypothesis of the absence of the Fourier component can be rejected at 1% level, indicating the empirical model should include the Fourier component. Moreover, the null hypothesis implying the presence of cointegration can not be rejected with the optimal frequency 1, meaning there occurs cointegration in the empirical model and the long-run coefficients can be estimated through the DOLS estimator. Finally, the long-run estimates in panel B2 show that lnK, lnL, and lnREC respectively have the estimations of 0.563, -0.265, and 0.041. The parameters of lnK and lnREC are statistically significant, whereas that of lnL is statistically insignificant.

Table 3 Tsong et al. (2016) cointegration test[a]

Panel A: Cointegration test for the model including SEC			
Panel A1: Results of the cointegration test			
Optimal frequency	Min SSR	Test statistic	F-statistic
1	0.017	0.039	125.590[a]
Panel A2: DOLS results			
Variable	Coefficient	Std. error	t-statistic
lnK	0.543[a]	0.007	77.404
lnL	-0.513[a]	0.095	-5.378
lnSEC	0.009[a]	0.001	5.894
Panel B: Cointegration test for the model including REC			
Panel B1: Results of the cointegration test			
Optimal frequency	Min SSR	Test statistic	F-statistic
1	0.018	0.045	230.428[a]
Panel B2: DOLS results			
Variable	Coefficient	Std. error	t-statistic
lnK	0.563[a]	0.012	46.454
lnL	-0.265	0.199	-1.327
lnREC	0.041[b]	0.019	2.126

Notes:

[a] Illustrates 1% statistical significance.

[b] Illustrates 5% statistical significance.

The positive coefficient of capital concurs with the neoclassical growth model formulated by Solow (1956). Accordingly, following the previous literature, this paper finds that the main factor enabling the USA to have the greatest economy in the world is the rapid capital accumulation (see e.g. Acemoglu 2009). As capital is used in the production process of goods and services and thus represents the production capacity of a country (Acemoglu 2009), this finding is compatible with the conventional macroeconomic theory as well. Besides, the results for labour indicate that the US economy has a capital-intensive production structure as the coefficient of labour is negative and statistically insignificant for the first and the second empirical models, respectively. Besides, the empirical findings imply that both solar energy consumption and total renewable energy consumption are considerable determinants of economic growth for the US economy. Hence, these findings provide considerable implications for policymakers in the USA. Accordingly, the empirical findings present evidence that renewable energy including solar energy is a complementary of capital and a crucial component of economic growth for the USA (see e.g. Apergis and Payne 2009). In other words, additional volumes of renewable energy consumption will expand GDP of the USA. In addition, renewable energy-saving policies and energy supply shocks have negative influences on the growth rates of the US economy. Therefore, both economic and energy policy makers should keep in mind that renewable energy sources, including solar energy, have considerable influences on the US economic growth.

Hence, the empirical findings of this paper conform to the findings of Ewing et al. (2007), Bilgili (2015), Bildirici and Gokmenoglu (2017), Tugcu and Topcu (2018), Troster et al. (2018), Bilgili et al. (2019), Bulut and Iglesi-Lotz (2019). Additionally, the findings of the paper contradict with those of Payne (2009), Bowden and Payne (2010), and Yildirim et al. (2012).

6. Conclusion and policy implications

As nowadays, a considerable part of the world demand for energy is met by fossil energy sources, such as coal, oil, and natural gas, and this dependence on fossil energy sources generates substantial environmental problems, namely air pollution, climate change, and global warming. For this reason, governments pay close attention to renewable sources because they are considered as clean and green energy sources (Menegaki and Tsagarakis 2015). Governments expect renewable energy sources not only to reduce environmental problems, but also to satisfy energy needs for economic growth. The USA has considerably focused on renewable energy sources since the Energy Independence and Security Act of 2007. When one observes the shares of renewables in total renewable energy consumption for the USA over the recent years, he/she will observe that the growth of solar energy consumption is especially remarkable. Given that the cost of PV cells used to generate electricity from the sun has decreased considerably due to technologic improvements, the US government actively promotes production and consumption of solar energy.

This paper empirically investigated the effects of solar energy consumption and total renewables consumption on GDP for the USA, spanning the period 1984-2018 through Cobb-Douglas production functions. The paper first performed the E&L unit root test with gradual breaks and determined the order of integration of the variables. Then, the analysis performed the Tsong et al. (2016) cointegration test based on the Fourier approximation and the DOLS estimator developed by Saikkonen (1991, 1992), and Stock and Watson (1993) to decide whether or not there occurred a cointegration relationship in the empirical models and to estimate the long-run coefficients, respectively. The Tsong et al. (2016) cointegration test documented that there was a cointegration relationship among the variables in the long run, while the DOLS estimator evidenced that both solar energy and total renewables consumption had statistically significant and positive influences on GDP.

Despite the increase in the share of renewables consumption in total energy consumption in the USA, this share is still low compared with the share of fossil energy. Moreover, biomass energy, hydroelectric power, and wind energy still dominate the renewable energy sector in the

US, though the share of solar energy consumption has a tendency to increase over the last years. The empirical findings of this paper imply that both total renewable energy and solar energy consumption have positive influences on economic growth in spite of their low shares in total energy consumption and in total renewables consumption, respectively. Put differently, considering the findings of the paper, we might argue that renewable energy sources, including solar energy, played a key role in the economic activities in the USA over the period 1984-2018.

As will be remembered, the US government first announced that ITC for solar energy systems would decrease from 30% to 10% beginning from 2017. Comello and Reichelstein (2016) examined the impact of this policy on the cost of solar power and explored that the anticipated reduction in ITC would substantially increase the cost of solar power. Then, the US government gave up this sharp decrease policy and decided to make a gradual decrease as from 2020 in ITC and declared that ITC would be 10% in 2022. This paper advocates that this decrease in ITC may increase the cost of solar energy systems and make solar energy less attractive for individuals and businesses and that long-standing solar energy policies of the USA may fail in terms of economic growth. Based on its own empirical findings, this paper suggests the US government proceed to implement incentives and even be more active in solar energy markets without ignoring the impact of solar energy policies on the government budget. Within this scope, the US government can play the role performed by the Chinese government. In China, (i) all PV electric power is purchased by Power Company, (ii) the electrovalence is set up more than conventional price to promote solar energy, (iii) the central government gives grants to the industry of renewable sources, and (iv) the central government stimulates the distributed generation of renewable sources to advance the electric power serves (Solangi et al. 2011). Therefore, this paper argues that solar energy might play a major role in economic activities and remain to be a strong policy tool for sustainable economic growth if the US government becomes more active and provides more incentives toward solar energy. Hence, incentives along with these policies may (i) reduce the costs of PV cells further and (ii) make solar energy more economic and attractive. Moreover, solar energy may contribute to environmental sustainability. Put differently, solar energy does not face environmental problems mentioned previously. Policy makers expect other renewable energy types along with solar energy to reduce these problems as well. Therefore, the findings signify that debates about renewable energy should focus on both economic growth and environmental effects and that these environmental effects of renewable energy types should not be ignored by policy makers and researchers.

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