RESEARCH ARTICLE

The contribution of the anthropogenic impact of biomass utilization on ecological degradation: revisiting the G7 economies

Bright Akwasi Gyamfi[1] · Steve Yaw Sarpong[1] · Murad A. Bein[1]

Abstract

The debate on ecological matters that relate to the biomass emissions nexus has gained prominence and different scholars have suggested various forms of policy directions to tackle the menace. This study seeks to contribute to this subject by examining the impact of biomass energy use on carbon dioxide pollution in the G7 economies context. Thus, to this end, we employed energy usage and GDP measured as economic growth which adds factors that can influence pollution for annual time-frequency between1995 and 2016 for the case of G7 economies. The present study adds to the extant literature by the adoption of the novel econometric techniques such as the panel cross-section augment ARDL and common correlated estimate mean group (CCEMG) to evaluate the impact of biomass energy on pollutants. The empirical results from all the techniques show that biomass energy consumption significantly and negatively correlates to CO_2 emissions meaning that it helps to reduce pollution in the long run. On the other hand, there is a significant positive relationship between energy use and pollutants implying that the primary energy use is not favorable for environmental sustainability over the sampled period. Finally, the results proved that GDP increases CO_2 emissions in the long run with respect to the G7 context. Thus, validating the growth-induced pollution hypothesis in G7 blocs. On causality relationship, we observe a unidirectional causal relationship between these variables: biomass and pollutants, pollutants and output, biomass and output, biomass and energy use, and output and energy use. While there was a bidirectional causality between energy use and pollutant, these results suggest policy implication for the G7 countries which indicates that stakeholders should give much attention to technological know-how and energy mix particularly biomass energy which is environmentally friendly as well as more paradigm shift to renewables.

Keywords Biomass energy usage · Real GDP · Energy use · CO2 pollution · G7 economies

Introduction

Data from British Petroleum (BP 2018) shows that carbon dioxide (CO_2) in the orbit around the earth has risen from 19,809 to 33,431 million tonnes, the maximum rate which

✉ Bright Akwasi Gyamfi
brightgyamfi1987@gmail.com

Steve Yaw Sarpong
stevesarp414@gmail.com

Murad A. Bein
muradabdurahmanb@gmail.com

[1] Faculty of Economics and Administrative Sciences, Cyprus International University, North Cyprus, Via Mersin 10, Nicosia, Turkey

has been reported within the last years, raising threats to individual and other living species' well-being (Wang et al. 2019). Integrated Pollution Prevention and Control (IPPC 2014) states that CO_2 levels generate higher than 60% of gas in the atmosphere (GHG) pollution and are responsible for environmental transition and environmental degradation (Sarkodie et al. 2019). Increasing ecological and well-being issues are globally discussed in the studies dealing with energy use that contributes to CO_2 pollution, especially through fossil fuel reserves as a source of power (Danish Zhang et al. 2017). Regulation of global warming and air degradation has now been an emotive subject (Danish and Wang 2019). The requirement for renewable power has risen as a consequence of rising greenhouse pollutants. The development and use of sustainable energy options such as bioenergy as well as other alternatives seem to be the most powerful methods for resolving the ecological issues (Owusu and Asumadu-Sarkodie 2016). Biomass power utilization in addition to construction

will form the basis of renewable power infrastructure by shifting the trajectory of power generation and using sources that will successfully lead to massive progress and environmentalism (Mao et al. 2018).

Danish and Wang (2019) identified biomass power as an essential component for sustainability and that it has a significant role in the discourse on climate policies as well as economic growth initiatives all over the globe. According to the World Development Index (World Bank 2012), the G7 States consumed 36.6% of the world's actual power supply and emit 33.7% of the world's overall CO_2 pollution on aggregate across the span 2000 to 2008. To find answers to this problem, the adoption of biomass energy has been described by Danish and Wang as the best way to go. Bildirici and Ozaksoy (Bildirici and Ozaksoy 2017; Bildirici and Özaksoy 2018) clarified that biomass production is classified under three types: woody or compact biomass is developed in agriculture-manufacturing crops in addition to wetlands, built-up trees, scrubland trees, and farm trees; non-woody biomass is created in yield wastes such as grass, leaves and plant stems, and manufactured wastes such as wood chips, bagasse, seeds, and husks; and agricultural garbage such as food rough. Different varieties of biomass can be used explicitly or implicitly for the generation of heat and energy by way of distribution fuel and additives. Over hundreds of years, humans have been using biomass fuels, including burning wood for food or heating. Biomass power intake comprises primary utilization, such as fermentation for heat, cooking, and manufacturing operations (conventional intake) and explicit usage by turning biomass to supplementary power (Bildirici 2014). The earth needs an enormous quantity of resources to sustain socioeconomic expansion (Herbert and Krishnan 2016; Kirikkaleli et al. 2020; Etokakpan et al. 2020; Adedoyin et al. 2020a, b, c). Besides, bioenergy seems to have the ability to tackle ecological challenges such as greenhouse gases, environmental degradation, ozone contamination, and toxic rainfall by decreasing CO_2 gases as well as other polluting greenhouse gases (Bilgili et al. 2017). Furthermore, fact from www.usatoday.com reveals that the G7 nations (i.e., the USA, the UK, Japan, Italy, Germany, France, and Canada) are all within the top twenty-five states with the highest CO_2 pollution in the globe. The USA was the 2nd most generated CO_2 pollution nation with 5269.3 million metric tons; Japan the 4th with 1205.1 million metric tons; 6th was German, with 799.4 million metric tons of CO_2 output; 10th was Canada, with 572.8 million metric tons; the UK, with 386.3 million metric tons and 17th metric tons on the list; France was 18th, with 356.3 million metric tons; and Italy was 19th with 355.45 million metric tons of CO_2 releases per year.

Ozturk and Acaravci (2009) on the other hand pointed out that several nations since the 1990s have been able to reduce their greenhouse gas pollution but these changes have stayed as a localized trend. This is because, from a worldwide viewpoint, overall concentrations of carbon dioxide and greenhouse gasses produced have risen. From the examination of BP Statistical Review of World Energy (2017), eleven countries had the highest decreases in CO_2 pollution in the past decade (2007 to 2016), with the USA once again leading the world. The US reduction was nearly 800 million tons of CO_2 pollution since 2007, it was almost 5 times more than the second-ranked nation (UK) and marginally smaller than the remaining 10 nations combined which the list is as follows: USA, UK, Italy, Ukraine, Spain, Japan, Russian Federation, France, Germany, Canada, and Greece. From the list, it proves that all members from the G7 countries are part of countries over the last decade that has been able to reduce the production of CO_2 (Fig. 1).

As a consequence, the G7 nations have a significant role to play in meeting the objectives of the Paris memorandum of understanding. Biomass power may help to address the ecological catastrophe, particularly ecological destruction and resource destruction, which limits the sustainable economic growth of human civilization. It is therefore the main purpose of the study to identify if truly biomass power utilization will eventually reduce CO_2 pollution within the G7 states, thus understanding the short-term and long-term elasticity and also the causal relationship between biomass power use and sustainable development. The outcome will, therefore, be important in deciding effective energy policies for the G7 nations.

The growing demand for renewable resources exists because of growing air pollution (Dong et al. 2018). The requirement for the environment and green protection can be provided by biomass energy (Dogan and Inglesi-Lotz 2017), while findings of the analysis on its economic development connection and CO_2 emissions remain unclear (Adewuyi and Awodumi 2017). Bilgili et al. (2016), instantly, found that biomass power reduces CO_2 emissions, but Solarin et al. (2018) proposed that biomass power behaves like fossil fuels when CO_2 emissions are created. Shahbaz et al. (2019) claimed that electricity from biomass speeds up CO_2 emissions, whereas Shahbaz et al. (2017) reported in another analysis that energy consumption from biomass decreases pollution. Dogan and Inglesi-Lotz (2017) emphasized that electricity from biomass tends to minimize CO_2 emissions. Although little was addressed regarding biomass energy in environmental degradation in the literature, these results are unclear as to whether the use of biomass energy decreases CO_2 emissions.

The existing studies on ecology-emissions have failed to address the issue of biomass energy consumption in the economic development agenda without considering the impact on carbon dioxide emissions. The existing studies are scanty and have relied on outdated data for inferences and policy directions. This study employs more recent data as compared with most of the existing studies. For instance, Shahbaz et al. (2019) used data from 1980 to 2014; Danish and Wang (2019) also utilized data from 1992 to 2013, and

Fig. 1 Countries with the largest reduction of CO_2 pollution
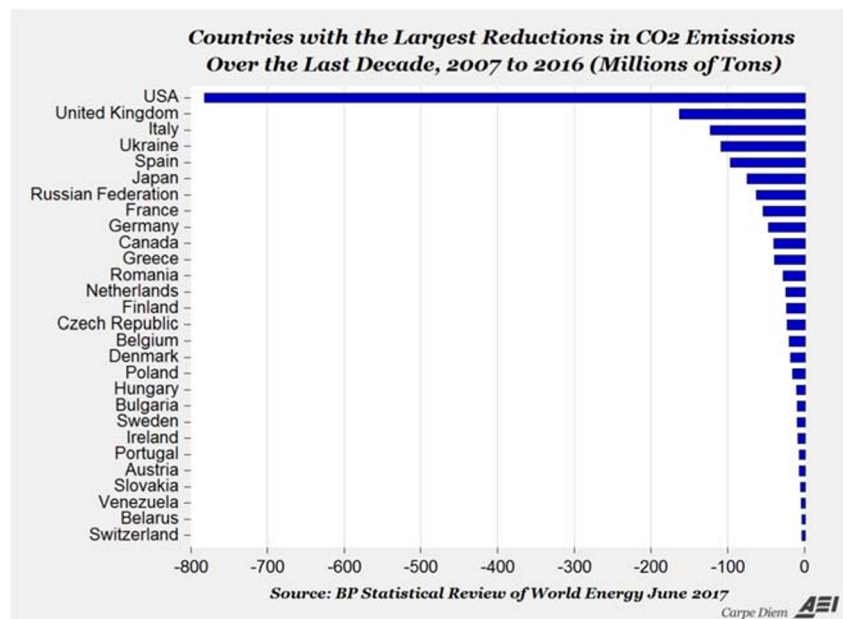
Sun et al. (2016) relying on data from 1996 to 2013. Also, several of the existing studies did pay much attention to household usage of biomass energy rather than looking at the holistic perspective of biomass energy use in order to allow the study to provide more generalized conclusions. In the sense of energy economics, this analysis can be described as supplementary to earlier studies. Nevertheless, in some ways, it breaks from the current literature on energy-environmental economics. Secondly, the study contributes to the literature in terms of method by the adoption of second-generation estimation approach (i.e., Westerlund co-integration test, cross-section augment ARDL (CS-ARDL), and common correlated effects mean group estimates (CCEMG) to investigate the relationship between biomass, real gross domestic product (GDP), and energy use on environmental degradation in the G7 context. We employed the Pesaran (2015) LM test, Pesaran (2007) CD test, and Breusch and Pagan (1980) cross-section dependence techniques to assess the cross-section dependency of the panel. Furthermore, the Pesaran (2007) panel unit root test was utilized to establish the characteristics of the variables due to the presence of the second-generation cross-section dependency; the Westerlund (2007) co-integration was employed to examine the long-run equilibrium among the variables. In order to estimate the long- and short-run relationship of the variables, the cross-sectional augmented ARDL (CS-ARDL) was utilized. The robustness of the estimations was checked by applying the common correlated effect mean group (CCEMG) technique. Our findings established that there is a long-run relationship between the variables under study. Ultimately, this paper, therefore, seeks to bridge this gap by employing a more recent data set to study the impact of biomass energy consumption on CO_2 emissions in the G7 countries for the duration 1995 to 2016. Given the

aforementioned contribution in method and scope for the case of G7, which have received less documentation, this study seeks to serve as a policy guide to the investigated blocs and other regions alike.

The remainder of this study is structured as follows: a literature summary is provided in the second part of the analysis. Econometric methods and information are presented in the third sector. The fourth sector focuses on analytical observations, while the last section contains conclusions and policies form the policymaker's implementation.

Review of related literature

This documentation has illustrated the function of bioenergy production in lowering pollutant production, growing power stability, industrial progress at the detriment of biodiversity, intense water use, deforestation, growing power costs, and potential declines in foodstuff availability (Burg et al. 2018; He et al. 2018; Shao and Rao 2018). Bioenergy, especially compost in addition to biomass, is a clean power source which brings environmental policies into consideration (Baležentis et al. 2019). The discourse discussed both the good or bad involvement of biomass power in ecological emissions. For example, Katircioglu (2015) evaluated the relation among biomass power and carbon dioxide exposure within Turkey utilizing the ARDL process, indicating the biomass power prevents contamination. Bilgili (2012) noticed that biomass production is helping to reduce pollutant emissions in the USA. In a certain analysis, Bilgili et al. (2016) had to use a wavelet consistency method to show that biomass power decreases CO_2 pollution within the USA. Shahbaz et al. (2017) implied comparable conclusions for the US economy by

means of the autoregressive distributive lag (ARDL) bounding experiment process. Dogan et al. (2017) examined the correlation regarding biomass power and carbon dioxide production in biomass-overwhelming states and identified the significant involvement of biomass power in lowering pollutants. Baležentis et al. (2019) reported that biomass power lowers emissions rather than so many green power sources. Shahbaz et al. (2019) examined the contribution of biomass power to the relation among foreign direct investment as well as CO_2 concentrations throughout the Middle East and in North Africa by means of the generalized moment method (GMM) technique and established a significant effect of biomass power on pollutants prevention. Danish and Wang (2019) investigated the energy use and pollutant impacts of biomass in BRICS countries by using the GMM model within the period of 1992 to 2013. The findings demonstrate that the use of biomass power is a sustainable source of power to mitigate carbon emissions. The report also found a consensus for N-shaped income and emission ties and concluded that free trade is the only driving factor for BRICS emissions. Ulucak (2020a, b) on the other hand examined the connection regarding biomass energy and actual income in China with CO_2 pollutions. The findings indicate a negative association regarding China's energy use in the form of biomass and CO_2, indicating that biomass use is beneficial in mitigating pollution. Furthermore, biomass output lowers pollutants and may be the perfect substitute for fossil fuels. Moreover, the impact of wood biomass intake on carbon pollution was studied for the span 1990–2017 by Sulaiman et al. (2020) in 27 countries of the European Union (EU). The findings demonstrate that CO_2 pollution declines with a rise in wood biomass power intake using panel dynamics of ordinary least squares (DOLS). As fossil fuels, per capita GDP and global globalization raise CO_2 emissions. The result suggested that the power use of wood biomass in manufacturing applications could significantly minimize CO_2 emissions in the EU Member States. Again, the Gao and Zhang (2020) study examined a group of 13 Asian developing countries in terms of relationships between carbon dioxide emissions, the use of biomass, industrial development, and urbanization. The panel co-integration experiments indicate that CO_2 pollution, biomass power use, socioeconomic development, and urbanization have long-term equilibrium. The results of the FMOLS estimate show that the total utilization of biomass power cannot decrease CO_2 emissions. The outcomes of panel causality evaluations have shown that there has been a short-term, one-way, causal effect that varies from GDP to biomass intake and from GDP to urbanization to CO_2 emissions. With regard to long-term relationships, the results suggest that one-way causality varies mainly from CO_2, biomass usage, and urbanization to GDP, suggesting that actual GDP could assume a pivotal component in the adaptation phase, as the mechanism shifts away from the long-term balance. However, by finding

the impact of energy use for human production from biomass on BRICS nations between 1990 and 2015, Wang et al. (2020a, b) wished to add to established literature. Their findings show that biomass energy consumption increases human evolution in the BRICS as well as the two parameters have a bidirectional causality. The findings could provide decision-makers with a recommendation to encourage the use of biomass resources. Kim et al. (2020) explored the causal link regarding total biomass power utilization, carbon output of CO_2, and GDP in the USA for the period of January 1973–December 2016. This analysis also looks at the nature of the Kuznets environmental hypothesis (EKC). The findings showed that a unidirectional, conventional causal link occurs between gross biomass power intake and GDP and overall carbon CO_2 emissions. This statement indicates that the use of biomass is one direction in which greenhouse emissions are minimized and regulated in the US. In comparison, the inverted U-shaped EKC theory is satisfactory in the case of the United States. The findings of this study suggest that energy policies will promote an increase in the production of biomass to reduce increased CO_2 emissions. Utilizing a revolutionary quantitative methodology, energetic ARDL, Sarkodie et al. (2019) evaluated the effect of biomass power on pollutant mitigation by foodstuff as well as the development of the country in a multivariate context and concluded that biomass power lowers greenhouse gas leakage.

Some few investigations did not approve the beneficial influence of biomass power on pollutants avoidance (Mahmood et al. 2019; Shahbaz et al. 2019; Solarin et al. 2018 as well as Ahmed et al. 2016) and claim that biomass power partakes had a negligible influence on CO_2 production. Around the very period, certain external variables in CO_2 pollution, including foreign exchange and FDI, had already been mentioned in the documentation in order to prevent requirement prejudice. Ren et al. (2014) claimed in cooperation worldwide commerce and foreign direct investment within the Chinese manufacturing industry have exacerbated ecological efficiency, although Al-Mulali et al. (2015) observed worldwide commerce greatly decreases carbon dioxide pollution throughout Europe. Liobikien and Butkus (2018) observed the same outcome on behalf of a team made up of 147 nations. However, Chang (2015) hypothesized free import and export would raise carbon dioxide emits. Zhang and Zhang (2018) noticed that the money system had a negative effect on CO_2 greenhouse gases in China. Hille et al. (2019) prediction finding has been that foreign direct investment decreases carbon dioxide production; however, in a sample of many areas, Shahbaz et al. (2015) recorded the detrimental effect of foreign direct investment with carbon dioxide greenhouse gases, supporting the toxicity theory that the existence of FDI is the contaminant.

Some studies have found that as biomass energy consumption goes down, it shows that economic growth has increased

meaning that economic development is a good indication that biomass energy use will be discouraged (Victor and Victor 2002). In some cases, the increased utilization of energy leads to a reduction in utilities especially in the household levels. For instance, Foster et al. (2000) reported that households reduced their total energy use through other means where energy consumption could provide efficacious results. A lot of the emerging economies have however proven to have lower gross domestic products per capita and these countries depend mostly on energy sources that are not clean as compared with their counterparts in the developed economies such as the G7 (IEA 2016). Since the EKC theory talks about the relationship between economic growth and clean environment, most of the studies that have been done on developed countries have proven to support this theory (Shahbaz et al. 2019). For instance, Cetin (2018) findings show that developing economies do not confirm the EKC hypothesis; however, the advanced economics support it. Again, the long-term elasticity effects of per capita income can impact CO_2 emissions in advanced and developing economies.

Such experiments are among the only credible studies on the relation between biomass power and CO_2 production, and their results are uncertain. None of the experiments listed in the analysis of the G7 nations used the cross-sectional augmented ARDL (CS-ARDL) and common correlated effect mean group (CCEMG) techniques to estimate the long- and short-run relationship of biomass power utilization and pollutants. Furthermore, a more novel and effective second-generation cross-section dependency techniques such as the Pesaran (2007) CD test, Pesaran (2015) LM test, and Breusch and Pagan (1980) have been applied.

Data and method

Exposures made by the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) which directs to the significance of clean and efficient energy use at all levels and for countries to understand that the central wellspring of CO_2 pollution exudes from the use of energy and various structures for the production of energy in comparison with activities from agricultural production, transport benefits, the utilization of land, and the related activities (IPCC 2016). It depends on these revelations that the G7 has given a lot of consideration to all policies coordinated at creating frameworks and quality institutional structures that will be competent to recognize, forestall, and control bottlenecks in the environmental administration (Sarpong and Bein 2020: Gyamfi et al. 2020).

To additionally extend the action for Europe's advancement in all perspectives including the environment, a comprehensive walk towards a supportable environment has been created courtesy the Paris COP21 as a major aspect of the region's motivation for agenda 2063 during the G7's highest meeting in 2015. These provisions order all part states to follow the rules and work inside the standard working strategies for sustainable power source and productive and compelling vitality administration structures for environmental supportability. Lastly, as part of the environmental cleanliness movement, during the ministerial meeting, Canada pledged to divert over 75% of its plastic wastes that are coming from government activities by the year 2030. Again, the countries with the G7 have committed themselves to spend over 100 billion US dollars every year by 2020 ending on a clean environment as well as take steps to eliminate inefficient fossil fuel grants. These countries have also ratified the EU Directive 2009/406/EC to be included in the regional countries' quest to tackle issues of climate change head-on. Member countries have put themselves to the resolutions that came from the 14th and 24th sessions of the conference of the countries serving on the Kyoto Protocol (CMP) and Paris Agreement (CMA 1-3 and COP21) as well as the Katowice Climate Change Conference of Parties (COP 24). All these are stringent efforts to institute frameworks that will contribute to fight pollution and ensure clean energy sources for use.

Data

This paper examined the impact of biomass energy consumption on CO_2 emissions in the G7 countries utilizing the most recent available data from 1995 to 2016. We based on the recent work of Shahbaz et al. (2019), Danish and Wang (2019), and Sun et al. (2016) for selecting our variables for this analysis which is biomass power utilization, energy use, real GDP, and CO_2 emissions. The data for biomass energy was obtained from the Global Material Flow database while CO_2 pollution, energy use, and real GDP were sourced from the World Bank's World Development Indicators (World Bank 2019). CO_2 was peroxided for pollutants and is defined as the emissions that are coming from fossil fuel burnings as well as cement manufacturing and carbon dioxide production when solids, liquids, gas fuels, and the flaring gas. It is also calculated in metric tons per capita. Biomass energy is the energy source that is emanating from the use of biomass and wastes measured in kilowatts per hour. Energy use is a proxy for primary energy which represents the final fuel usage that is domestically produced and those imported for use. It is measured in kilograms of oil equivalent per capita. The real GDP is the peroxided for economic growth or output and measured as the constant 2010 $US. This variable has been touted as the best indicator of economic growth by many scholars (Batuo et al. 2018; Akbar et al. 2020a, b). All the variables were converted into their natural logarithms in order to allow interpretation of the results to be in elasticity terms.

Method

We based our study on the cross-section augment group autoregressive distributive lag (ARDL) model proposed by Pesaran and Shin (1998) to estimate the impact of the independent variables on the dependent variable. This technique was adopted because the ARDL approach is plausible for this study since our sample data is not large but contained a small sample size. It is able to generate all together long-run and short-run equilibrium relationships and also error corrections for the bound estimations at the same time. It was appropriate to use this method for this study since it is applicable for the estimation of long-run relationships with respect to panels that are dynamic with heterogeneity in nature and that the dependency of the cross sections is associated with errors. Again, compared with the traditional ARDL, the CS-DL technique provide a standardized form of estimation which means that unlike the ARDL method, the CS-DL is able to strongly identify models that are not specified appropriated and also mistakes and items that are serially correlated. According to the Monte Carlo simulations reported by Chudik et al. (2016), this approach is suitable in cases where the T is not too huge. Considering the T for this paper is not huge and therefore qualifies to rely on the CS-DL methodology to achieve its objectives. In situations where the variables have properties of mixed order of integration at I (0) or [I (1)], this approach is mostly suitable to determine the co-integration. Estimations were basically done using four approaches. Following Wang et al. (2020a, b), we employed the CIPS propounded by Pesaran (2007) and IPS (Im et al. 2003) to determine the unit root so that approximations of the variables will not result into unauthentic regressions. Secondly, the possibility of a long-run equilibrium relationship was established through the Westerlund (2007) co-integration test considering the presence of cross dependence. After this test, it was established that the variables were cointegrated and so long-run relationships exist and so we utilized the cross-section augment ARDL (CS-ARDL) technique to estimate long- and short-run relationships. Then, sensitivity analysis of the long-run equilibrium relationship was undertaken by applying the common correlated effects mean group estimates (CCEMG) proposed by Pesaran (2006). This technique was preferable because it deals with issues

concerning endogeneity, its robustness to the heterogeneous slope, cross-sectional dependency issues, and data that are not stationary. This technique is advantageous since it could be calculated with the help of the least squares applicable to auxiliary estimations where the independent variables are given a boost with the help of the cross-sectional means of the dependent variables and the specified independent variable. In this technique, the asymptotic spreading of the attributes becomes evident in the model of Pesaran (2006). Another advantage of applying the CCEMG is the fact that this study uses a small sample size albeit the heterogeneous and dynamic characteristics of the dataset. The figures for the N and T are all small in this study which makes this trait of the CCEMG technique adequate for this study. The heterogeneous causality test was also deployed to ascertain the causal relationship between the variables. It was important to use this technique in order to find the direction of the causal relationship between the variables considering the heterogeneity of the variables. The causality test offers efficient and consistent estimates even in the presence of a mixed order of integration among variables. In Dumitrescu and Hurlin (2012), the methodology is appropriate when stationarity is gained at the level for the study variables and that the estimations are done employing the autoregressive vector (VAR) which is good for unrestricted estimations for double variables. The technique helped to identify different types of relationships between heterogeneous variables that include homogeneity of non-causality, homogenous causality, and heterogeneity in causality. Again, the heterogeneous non-causality attribute helps to show the direction of causality and that the information criterion of Akaike, Bayesian, and Hannan-Quinn was checked by employing the preferable number of lags to be used in estimation.

Model specification

We relied on the following model for our regression to establish the impact of biomass energy on CO_2 emissions. The general equations of the model are given below:

$$lnCO_2 = f(lnBEMC, lnEU, lnGDP) \tag{1}$$

$$lnCO_2 = \rho_0 + \rho_1 lnBEMC_{it} + \rho_2 lnEU_{it} + \rho_3 lnGDP_{it} + \gamma_i + \tau_t + \varepsilon_{it} \tag{2}$$

∂_i and σ_t stand for the effects that specific countries present as well as the precise period properties associated with the

variables respectively. The error term is represented by ε_{it}. The term β is the parameters to be estimated in the

equation.where lnCO$_2$ stands for the log of carbon dioxide pollution; lnBEMC is the log of biomass energy consumption; lnEU$_{it}$ indicates log of energy use; lnGDP$_{it}$ stands for the log of gross domestic products which is a proxy for economic growth. y_i and y_t are the respective specific country effects and the precise time period characteristics that are related to the variables. ε_{it} stands for the unobserved variables in the model, thus the error term. The coefficients to be estimated are denoted by ρ.

Empirical results

In determining the impact of biomass energy consumption on CO$_2$ emissions in the G7 countries, we initially established correlations between the variables for the study. The correlation matrix results from Table 1 show a significant positive association between biomass energy consumption and emissions. It also proves that energy use has a positive and significant association with CO$_2$ emissions and biomass energy and GDP. Again, biomass energy consumption is significantly and positively correlated with GDP and energy usage. The outcome of the correlation matrix generally proves that biomass energy consumption is a good energy source in fighting pollution emanating from carbon dioxide.

Descriptive statistics

Results from Table 2 show the descriptive statistics of the G7 countries with respect to the variables under study. The mean emissions that are produced from carbon dioxide on annual basis are 13.59 metric tons per the population; biomass energy consumption average is 17.50 metric tons per capita annually; on the average energy use for the countries under review is 8.40 kg of oil equivalent per capita on an annual basis. The average growth per year for the G7 countries for this study was 10.62%. The results also show that the highest CO$_2$ emissions per year for the countries used for this study were 15.57 metric tons, biomass energy was 19.27 metric tons, and

Table 1 Correlation matrix

Variables	LNCO$_2$	LNBEMC	LNGDP	LNEU
LNCO$_2$	1.			
LNBEMC	0.3618***	1		
LNGDP	0.5585***	0.3687***	1	
LNEU	0.5326***	0.7260***	0.5362***	1

Source: Authors' computations

∗0.01 significance level

∗∗0.05 significance level

∗∗∗0.10 significance level

Table 2 Descriptive statistics

	LnCO$_2$	LnBEMC	LnGDP	LnEU
Mean	13.5958	17.4916	10.6157	8.4126
Median	13.2034	17.8785	10.6170	8.2970
Maximum	15.5716	19.2777	10.8692	9.0426
Minimum	12.6224	14.7051	10.3313	7.7892
Std. Dev.	0.87546	1.14911	0.12050	0.3678
Skewness	1.3252	− 0.2690	0.0346	0.5758
Kurtosis	3.5442	2.0869	2.2786	1.9405
Jarque-Bera	46.9775	7.2068	3.3696	15.712
Probability	0.0000	0.0272	0.1855	0.0004
Sum	2093.756	2693.709	1634.824	1295.537
Sum Sq. Dev.	117.2651	202.0294	2.221670	20.70250
Observations	154	154	154	154

Source: Authors' computations

energy usage was at a maximum of 9.04 kg of oil equivalent. The highest growth rate is 10.62% per year for the countries under review. Again, the minimum pollutants per year for the countries were 12.62 metric tons per capita, consumption of biomass per year is 14.70 metric tons, and the same for energy use is 7.78 kg of oil equivalent per capita every year. Lastly, Table 2 depicts that the least growth rate per year for the G7 countries is 10.33%.

Cross-sectional dependency test

Ignoring the issue of the cross-section dependency test renders the findings and conclusion unreliable. Paying attention to present studies in the environment-energy economic nexus (Ahmad and Zhao 2018; Danish and Wang 2019), the Pesaran (2015) LM test, Pesaran (2007) CD test, and the Breusch and Pagan (1980) Lagrangian multiplier techniques were adopted to establish the cross dependence between economies. Matters concerning cross-section dependence become problems in which there are certain determinants that are not observed locally and globally and that integrate and occur within the energy and environmental spheres. In the same way, the heterogeneous nature of economies and the structural dynamics alongside locations also raises alarm for cross-sectional dependence. This approach was also utilized to serve as a guide in employing the appropriate technique for unit root test. Results in Table 3 show that from the Pesaran (2015) LM, Pesaran (2007) CD, and the Breusch and Pagan (1980) dependency tests, the independence of cross sections is supported by the null hypothesis.

Unit root test results

Because the results proved that the panel statistics were cross dependent, the unit root test of the second generation was

Table 3 Cross-sectional dependency test results

	Pesaran (2007) CD Test	Pesaran (2015) LM Test	Breusch-Pagan LM
$LnCO_2 = f(LnBEMC, LnGDP, LnEU)$	2.095**	− 2.517**	225.5297**
p value	(0.0362)	(0.012)	(0.023)

Source: Authors' computations

∗∗0.05 significance level

plausible to overly refuse to accept the null hypothesis. It was thereby important to implement a unit root test so that this issue of cross-section dependency could be addressed. Then, the IPS and CIPS techniques which are innovative and efficient tactics in dealing with heterogeneity and cross-section dependency were employed to determine the unit root. This approach was also necessary to find out the probable integration of the variables for the study. These approaches were appropriate because they are able to identify heterogeneity and cross-sectional dependency among the panels since it is regarded as a very important or significant methodology for the determination of unit root in the generation of the second order in a panel study. The general form for CIPS is given below as:

$$\Delta CA_{i,t} = \Phi_i + \Phi_i Z_{i,t-1} + \Phi_i CA_{\overline{it-1}} + \sum_{1=0}^{p} \Phi il \Delta CA_{t-1}$$
$$+ \sum_{i=0}^{p} \Phi il \Delta CA_{i,t1} + \mu_{it} \qquad (3)$$

where $CA_{\overline{it-1}}$ and $\Delta CA_{i,t1}$ represent cross-section average. The CIPS statistic is also given below as:

$$CIPS_{2007} = N^{-1} \sum_{i=0}^{n} CDFi \qquad (4)$$

Whereas CDF is a cross-sectional augmented Dickey and Fuller (1981) (CADF) given in Eq. (4).

Such approaches were favored to give us the opportunity to address the question of weak-strength generated in a pseudo-stationary set of data and to leverage from the extra knowledge given in the test results by a combined cross-sectional time series for strength. The results provided in Table 3 show that the variables have integration in the order I (1), thus the identical sequence. It really is an indicator of the non-stationarity of the parameters at the point, but at first, difference stationery implies that the difference, for example, CO_2, is found to be stationary at [I (1)] under the heterogeneity variance framework. As per Table 4 below, the unit root test shows that all the variables were not stationary at level, but they were stationary at first difference meaning that the variables were fit for analysis and that the results could be used for policy decisions.

Co-integration test results

Findings from the cross-section dependence estimations and unit root test necessitated the utilization of the second-generation co-integration propounded by Westerlund (2007). This second-generation technique is capable of detecting the co-integration of data which is panel time series even in the existence of cross-dependence issues and found that there is no presence of co-integration as specified by the null hypothesis. Results from Table 4 prove that no co-integration according to the null hypothesis should be rejected. This means that there is a long-run association between the independent variables, biomass, energy use and GPD, and the dependent variable CO_2. It implies that the variables are associated with CO_2

Table 4 Unit root

Variables	IPS (Im et al. 2003)				CIPS (Pesaran 2007)			
	Intercept		Intercept and trend		Intercept		Intercept and trend	
	Levels	1st Diff	Levels	1st Diff	Levels	1st Diff	Levels	1st Diff
$LnCO_2$	− 1.705	− 5.908***	− 2.787	− 5.753***	− 2.558	− 5.134***	− 3.515	− 5.103***
LnBEMC	− 2.306	− 4.470***	− 2.352	− 4.836***	− 3.647	− 4.869***	− 3.546	− 4.896***
LnGDP	− 1.935	− 3.376***	− 1.965	− 3.652***	− 1.568	− 2.655***	− 1.395	− 2.871*
LnEU	− 1.263	− 5.161***	− 2.790	− 4.839***	− 2.630	− 5.645***	− 4.287	− 5.655***

Source: Authors' computations

∗0.10 significance level

∗∗0.05 significance level

∗∗∗0.01 significance level

Table 5 Westerlund co-integration test

Dependent/models	Group statistics		Panel statistics	
	Gt	Ga	Pt	Pa
$LnCO_2 = f$ (LnBEMC, LnGDP, LnEU)	− 4.458***	− 13.754***	− 15.734***	− 14.342***

Source: Authors' computations
***0.01 significance level

at a 1% significant level and there is a long-run effect on pollutants (Table 5).

Long-run and short-run relationship

The test results for the cross-section augment ARDL (CS-ARDL) estimation are presented in Table 6 below. The equation for CS-ARDL is provided as:

$$\Delta CO_{2i,t} = \pi_i + \sum_{i=0}^{p} \pi_{il} \Delta CO_{2i,t-1} + \sum_{i=0}^{p} \pi_{il} AEV_{i,t-1}$$
$$+ \sum_{i=0}^{p} \pi_{il} Z_{i,t-1} + \mu_{it} \qquad (5)$$

The averages for cross-sections are denoted by $Z_t = (\Delta CO_{2,t}, AEV_t)$, where AEV_t represents the independent variables in the form of biomass, GDP, and energy use.

The results prove that there is a robust negative long-run relationship between biomass energy consumption and

Table 6 Cross-section augment ARDL (CS-ARDL)

Variables	Coefficient	STD. error	t-statistic
Long-run equations			
LnBEMC	− 0.1123***	0.0311	− 3.6146
LnGDP	0.5063***	0.0250	20.262
LnEU	0.8281***	0.0359	23.080
Short-run equation			
COINTEQ01	− 0.2067*	0.4054	− 2.5269
D (LnCO₂ (− 1))	0.2846	0.4115	0.6917
D (LnCO₂ (− 2))	− 0.0290	0.1606	− 0.1808
D (LnCO₂ (− 3))	0.3140	0.1079	2.9109
D (LnBEMC)	0.0550*	0.0975	0.5642
D (LnBEMC (− 1))	0.0659	0.0949	0.6941
D (LnGDP)	0.0996	0.4365	0.2282
D (LnGDP (− 1))	0.2727	0.3730	0.7311
D (LnEU)	0.3927*	0.5357	0.0006
D (LnEU (− 1))	0.4957	0.6639	− 0.7466
Constant	3.6720*	1.8708	1.9628

Source: Authors' computations
∗0.10 significance level
∗∗0.05 significance level
∗∗∗0.01 significance level

pollutants. These results are consistent with several studies of Katircioglu (2015), Bilgili (2012), Bilgili et al. (2016), and Shahbaz et al. (2019) but in contradiction with Mahmood et al. (2019), Shahbaz et al. (2019), and Solarin et al. (2018). The results imply that a percentage change in biomass energy use results in a 0.11% reduction in pollutants. This feedback is implying that biomass energy source is favorable in terms of fighting emissions from carbon dioxide in the G7 countries. Besides, energy usage was found to be positively and significantly related to the emission of carbon dioxide in the long run. The findings are supported by Katircioglu (2015). This means that when there is a percentage change in energy usage, it causes a 0.82% increase in pollutants. The results imply that energy usage in G7 countries is not being managed in a way that will help in fighting the reduction of pollution that is caused by carbon dioxide. Meaning that energy use in the region leads to increased levels of CO_2 production. Results from Table 6 also prove that there is a robust positive long-run relationship between GDP and carbon dioxide emissions in the countries under review. The results are inconsistent with Ulucak (2020a, b). Studying the Chinese energy/economy, the study concluded that there is a negative significant long-run relationship between output and pollutants. This current study results imply that a 1% change in output results into a 0.50% increase in pollutants, which implies in the long run, as output increases, pollutant also increases.

Our results for the error correction with regard to the coefficient proved negatively robust. This could be interpreted that any disturbance in the long-run equilibrium between the variables under consideration will be amended at a swiftness of 20.67% annually. Table 6 also reveals that in the short-run biomass energy usage and energy use, both have a significant positive relationship with pollutants. The results show that in the short-run, a 1% change in biomass and energy usage results in a 0.06% and 0.39% increase in carbon dioxide pollution respectively. On the other hand, output has an insignificant negative relationship with pollutants in the short run as a 1% change in output leads to a 0.09% decrease in pollutants.

Robustness test

After estimating the long-run equilibrium relationship using the CS-ARDL approach, we resorted to a more recent technique of estimating long-run relationships to check the

sensitivity of our results. The CCEMG method was employed and the results were not different from those provided by the CS-ARDL. This method was preferred for long-run coefficients while in cross-section, dependence exists between the panels. Estimation results as per Table 7 prove that biomass energy consumption has a negative and significant long-run relationship with pollutants; thus, in the long run, a percentage change in biomass energy usage decreases pollutants by 0.19%. The outcome affirms with several studies such as Katircioglu (2015); Bilgili (2012); Bilgili et al. (2016); and Shahbaz et al. (2019). It again shows that biomass energy is significant in fighting pollution from pollutant emissions. Energy use also has a significant and positive relationship with pollutants in the long run. It also affirms the findings of Katircioglu (2015). Furthermore, output was found to have a strong positive relationship with CO_2 emissions in the long-run relationship indicating that a 1% change in GDP leads to a 0.03% increase in pollutants significantly. The outcome does not confirm the finding of Ulucak (2020a, b), analyzing the Chinese energy/economy which concluded that there is a negative significant long-run relationship between output and pollutants.

Causality test results

Correlation is not necessarily causality and so we sought to determine the causality directional relationship between the variables for the study. The results from Table 8 show that there is a unidirectional causality relationship running from pollutants to output and biomass energy consumption, from biomass energy consumption to GDP and to energy use and from GDP to energy use. Again, there is a bidirectional causality relationship between pollutants and energy use. The causality in the long-run relationship between renewable energy sources such as biomass energy and pollutants is in line with findings by Sadorsky (2009) in respect of 18 developing countries; Apergis and Payne (2010a) study of 20 OECD economies; and Apergis and Payne (2010b) study of six economies within

Table 7 Common correlated effects mean group estimates (CCEMG)

Variables	Coefficient	STD. error	t-statistic
LnBEMC	− 0.1944***	0.08595	− 2.5120
LnGDP	0.03777**	0.09132	3.0262
LnEU	0.002107**	0.00407	28.0180
Wald test	45.55***		

Source: Authors' computations

∗0.10 significance level

∗∗0.05 significance level

∗∗∗0.01 significance level

Table 8 Heterogeneous causality test

Null hypothesis	Zbar Stat	p value
LnBEMC ≠ LnCO$_2$	2.2734**	0.0230
LnCO$_2$ ≠ LnBEMC	− 1.1601	0.2460
LnGDP ≠ LnCO$_2$	2.5430**	0.0110
LnCO$_2$ ≠ LnGDP	1.0969	0.2727
LnEU ≠ LnCO$_2$	2.7954***	0.0052
LnCO$_2$ ≠ LnEU	7.3863***	2.E-13
LnGDP ≠ LnBEMC	0.96548	0.3343
LnBEMC ≠ LnGDP	3.74057***	0.0002
LnEU ≠ LnBEMC	− 1.4043	0.1602
LnBEMC ≠ LnEU	5.1097***	3.E-07
LnEU ≠ LnGDP	0.5688	0.5695
LnGDP ≠ LnEU	7.3513***	2.E-13

Source: Authors' computations

∗0.01 significance level

∗∗0.05 significance level

∗∗∗0.10 significance level

Central America. Considering the findings of this study, there is a need for the countries of the G7 to continuously invest in research and development to find a further refined technological means of improving biomass energy consumption to help in fighting for the reduction of carbon dioxide for a clean environment. It is very important to note that the results also show that pollution from CO_2 causes energy usage, thus as there is high pollution, it means that energy usage is not encouraging and that it does not improve clean environment.

Discussion

This study scientifically investigates the impact of biomass energy consumption on CO_2 pollution in G7 countries from the period 1995–2016 using the most recent data set. In analyzing the relationships, we employed numerous dynamic panel methodologies which took into consideration the heterogeneous nature of the variables under study. Globally, pollutants have been a very challenging issue confronting many countries and governments, and stakeholders as a whole have tried very hard to find solutions associated with several problems that are presented by the use of energy in all sectors of the economies. Given this reason, it is important to undertake empirical studies to have a full understanding of the dynamics of this phenomenon, thus CO_2 emission in order to find the appropriate steps to implement in addressing the matter. Understanding this, we resorted to examining the environmental impact of the use of biomass energy source. We also included certain important economic indicators such as GDP and energy use to evaluate the impact on pollutants. The general results from the study indicated that biomass energy

consumption is significantly and negatively related to CO_2 emissions akin (Bilgili 2012; Bilgili et al. 2016; Shahbaz et al. 2019). These results mean that biomass energy use is a clean energy source that is capable of contributing to the reduction of carbon dioxide production into the atmosphere. Reliance on the biomass energy source is a better energy source to help in reducing pollution in the G7 countries. The results go to suggest that renewable energy source such as biomass is serving these economies better in fighting the reduction of pollution as a result of CO_2. On the other hand, energy usage was established by this study to have a positive and statistically significant relationship with pollutants. This outcome implies that energy usage in the G7 economies is not good or does not favor in reducing pollution but rather increases it. Energy use in these economies should be reconsidered once again if the region needs to fight against pollution of the environment as a result of energy use. A second look at the technological and energy mix of the economy should be given much attention as it is not contributing positively to the fight against a poor environment. Furthermore, economic growth within the countries under review is not a catalyst for fighting emissions levels as it contributes to increasing pollution of carbon dioxide. This study fails to validate the environmental Kuznets curve (EKC) theory as in the long-run economic growth in these economies does not help to reduce CO_2 emissions. Besides, Ulucak (2020a, b) confirmed that output has a positive relationship between pollutants and that it does not necessarily mean that when an economy grows its economy, it presupposes that the country will have a clean environment or will be free from carbon dioxide production. Moreover, from the heterogeneous causality test, it was observed that a unidirectional causality relationship between pollutants and output, between energy usage and pollutants, and between biomass energy consumption and energy use.

One important point to take cognizance here is that even though biomass energy can lead to a reduction of carbon releases, its efficacy is highly dependent on how efficient the technology of generating energy is and also the quantities of fossil fuels utilized for the biomass manufacture. We could therefore infer here that there is some level of the positive role of the technologies used for biomass production in the G7 countries and that increased biomass energy invention may reduce these countries' fossil fuel dependency and find answers to the environmental challenges associated with fossil energy within the energy mix.

Conclusion and implications of policies

This study empirically examined the impact of biomass energy consumption on CO_2 pollution in the G7 countries for the period 1995–2016. The paper applied the cross-section augment ARDL and common correlated mean group estimates to examine the hypothesized claims. The study concludes that in the G7 economies, biomass energy consumption is a good source of the energy mix, which is favorable in helping to reduce pollution coming from carbon dioxide. It is worthy to note here therefore that broadening the renewable energy source and paying much attention to a renewable energy source like biomass energy stands to benefit these countries (Bilgili et al. 2017). The increased heights of carbon dioxide productions are validated with the ever-existing cycle of pollutions that comes from the traditional sources of energy (Owusu and Asumadu-Sarkodie 2016). Perhaps these stands have been given much more credence by this study inferring from the positive shocks shown by biomass energy as a renewable energy source on carbon dioxide emissions. Existing literature has proven that biomass energy is a clean energy source which has the tendency of helping the decarbonization agenda by the International Energy Agency (IEA).

The use of energy in the region is found to be a bad source for the fight against pollution. This is because the results of a positive relationship between energy usage and pollution are a clear indication that the total energy consumption of the countries is not influencing the economy enough to help in the reduction of pollution. The implication of these findings stands to prove that the primary energy before transformation to other end-use fuels is not a good source of energy that will help in the clean environment agenda. Since this source of energy is purely based on local production without any energy exported to other countries for ships and air travels, it is incumbent on stakeholders to have the proper structures that will introduce and arrest infractions in the technological knowhow to protect the environment. Without these steps taken to ensure environmental protection, the achievement of the sustainable development goal (SDG-7) 7 for agenda 2030 would be not be achieved. Considering the relationship between biomass energy and economic growth, it could be clearly realized that expanding this section of the energy source would be encouraging for economic growth and development as the natural resources would be put into good use such as producing electrical energy for use.

As a take home for stakeholders, there should be a multilateral agreement between the countries to ensure the promotion of renewable energy and efficient energy consumption source in the G7 economies. In all these, cooperation at regional levels is very crucial. It is incumbent on governments to ensure that a congenial atmosphere is created for both public and private sector investments in clean energy source such as biomass, wind, or solar. Knowledge sharing in terms of technological advancements and other related critical projects undertaken by regional bodies should be paramount for countries to take advantage of creativity and innovations. Governments must also create the opportunity for easy access to renewable

energy project financing as specified in the Paris COP21 agreement to encourage partners in investing in the renewable energy production sector. Tax holidays are good financing mechanisms that will whip up the interest of investors in the private sector to engage in renewable energy production which will in the end have a ripple effect on final consumption. Lastly, we join the debate for policy-makers to ensure the establishment of a market, whereby renewable energy could be traded and certificates issued plus the operation of a standardized clean energy portfolio which is capable of creating more space within the renewable energy subdivision.

Availability of data The data for this study will be available upon a reasonable request.

Authors' contributions Bright Akwasi Gyamfi: investigation, methodology, writing-original draft, software, conceptualization

Steve Yaw Sarpong: formal analysis, investigation, writing-original draft, writing-review and editing

Murad A. Bein: supervision, validation

Compliance with ethical standards

Ethical approval   Not applicable.

Consent to participate   Not applicable.

Consent to publish   Not applicable.

Conflict of interest   The authors declare that they have no conflict of interest.

References

Adedoyin FF, Gumede MI, Bekun FV, Etokakpan MU, Balsalobre-lorente D (2020a) Modelling coal rent, economic growth and CO2 emissions: does regulatory quality matter in BRICS economies? Sci Total Environ 710:136284

Adedoyin F, Abubakar I, Bekun FV, Sarkodie SA (2020b) Generation of energy and environmental-economic growth consequences: is there any difference across transition economies? Energy Rep 6:1418–1427

Adedoyin FF, Alola AA, Bekun FV (2020c) An assessment of environmental sustainability corridor: the role of economic expansion and research and development in EU countries. Sci Total Environ 713:136726

Adewuyi AO, Awodumi OB (2017) Biomass energy consumption, economic growth and carbon emissions: fresh evidence from West Africa using a simultaneous equation model. Energy 119:453–471. https://doi.org/10.1016/j.energy.2016.12.059

Ahmad M, Zhao ZY (2018) Empirics on linkages among industrialization, urbanization, energy consumption, CO2 emissions and economic growth: a heterogeneous panel study of China. Environ Sci Pollut Res 25(30):30617–30632

Ahmed K, Pylsy P, Kurnitski J (2016) Hourly consumption profiles of domestic hot water for different occupant groups in dwellings. Solar Energy 137:516–530

Akbar U, Popp J, Khan H, Khan MA, Oláh J (2020a) Energy efficiency in transportation along with the belt and road countries. Energies 13(10):2607

Akbar U, Li QL, Akmal MA, Shakib M, Iqbal W (2020b) Nexus between agro-ecological efficiency and carbon emission transfer: evidence from China. Environ Sci Pollut Res 1–13

Al-Mulali U, Ozturk I, Lean HH (2015) The influence of economic growth, urbanization, trade openness, financial development, and renewable energy on pollution in Europe. Nat Hazards 79(1):621–644

Apergis N, Payne JE (2010a) Renewable energy consumption and economic growth: evidence from a panel of OECD countries. Energy policy 38(1):656–660

Apergis N, Payne JE (2010b) The renewable energy consumption-growth nexus in Central America. Appl Energy 88(1):343–347

Baležentis T, Streimikiene D, Zhang T, Liobikiene G (2019) The role of bioenergy in greenhouse gas emission reduction in EU countries: an environmental Kuznets curve modelling. Resour Conserv Recycl 142:225–231. https://doi.org/10.1016/j.resconrec.2018.12.019

Batuo M, Mlambo K, Asongu S (2018) Linkages between financial development, financial instability, financial liberalisation and economic growth in Africa. Res Int Bus Financ 45:168–179. https://doi.org/10.1016/j.ribaf.2017.07.148

Bildirici ME (2014) Relationship between biomass energy and economic growth in transition countries: panel ARDL approach. GCB Bioenergy 6:717–726. https://doi.org/10.1111/gcbb.12092

Bildirici M, Ozaksoy F (2017) The relationship between woody biomass consumption and economic growth: nonlinear ARDL and causality. J For Econ 27:60–69. https://doi.org/10.1016/j.jfe.2017.01.002

Bildirici M, Özaksoy F (2018) An analysis of biomass consumption and economic growth in transition countries. Econ Res Istraživanja 31:386–405. https://doi.org/10.1080/1331677X.2018.1427610

Bilgili F (2012) The impact of biomass consumption on CO 2 emissions: cointegration analyses with regime shifts. Renew Sust Energ Rev 16:5349–5354. https://doi.org/10.1016/j.rser.2012.04.021

Bilgili F, Öztürk İ, Koçak E, Bulut Ü, Pamuk Y, Muğaloğlu E, Bağlıtaş HH (2016) The influence of biomass energy consumption on CO2 emissions: a wavelet coherence approach. Environ. Sci. Pollut. Res 23:19043–19061. https://doi.org/10.1007/s11356-016-7094-2

Bilgili F, Koçak E, Bulut Ü, Kuşkaya S (2017) Can biomass energy be an efficient policy tool for sustainable development? Renew Sust Energ Rev 71:830–845. https://doi.org/10.1016/j.rser.2016.12.109

BP (2018). BP Statistical Review of World Energy 1–56. (http://www.bp.com/en/global/corporate/energy-economics/statistical-reviewof-worldenergy/downloads.html)

BP Statistical Review of World Energy (2017) https://www.connaissancedesenergies.org/sites/default/files/pdf-actualites/bp-statistical-review-ofworld-energy-2017-full-report.pdf

Breusch TS, Pagan AR (1980) The Lagrange multiplier test and its applications to model specification in econometrics. Rev Econ Stud 47:239e53. https://doi.org/10.2307/2297111

Burg V, Bowman G, Haubensak M, Baier U, Thees O (2018) Valorization of an untapped resource: energy and greenhouse gas emissions benefits of converting manure to biogas through anaerobic digestion. Resour Conserv Recycl 136:53–62. https://doi.org/10.1016/j.resconrec.2018.04.004

Cetin MA (2018) Investigating the environmental Kuznets curve and the role of green energy: emerging and developed markets. International Journal of Green Energy 15(1):37–44

Chudik A, Mohaddes K, Pesaran MH, Raissi M (2016) Long-run effects in large heterogeneous panel data models with cross-sectionally correlated errors. Emerald Group Publishing Limited

Danish, Wang Z (2019) Does biomass energy consumption help to control environmental pollution? Evidence from BRICS countries. Sci. Total Environ 670:1075–1083. https://doi.org/10.1016/j.scitotenv.2019.03.268

Danish Zhang B, Wang Z, Wang B (2017) Energy production, economic growth and CO2 emission: evidence from Pakistan. Nat Hazards 90: 27–50. https://doi.org/10.1007/s11069-017-3031-z

Dickey DA, Fuller WA (1981) Likelihood ratio statistics for autoregressive time series with a unit root. Econometrica: Journal of the Econometric Society 49:1057–1072

Dogan E, Inglesi-Lotz R (2017) Analyzing the effects of real income and biomass energy consumption on carbon dioxide (CO2) emissions: empirical evidence from the panel of biomass-consuming countries. Energy 138:721–727. https://doi.org/10.1016/j.energy.2017.07.136

Dogan E, Inglesi-Lotz R, Inglesi Lotz R, Inglesi-Lotz R, Inglesi Lotz R, Inglesi-Lotz R (2017) Analyzing the effects of real income and biomass energy consumption on carbon dioxide (CO2) emissions: empirical evidence from the panel of biomass-consuming countries. Energy 138:721–727. https://doi.org/10.1016/j.energy.2017.07.136

Dong K, Sun R, Dong X (2018) CO2 emissions, natural gas and renewables, economic growth: assessing the evidence from China. Sci Total Environ 640–641:293–302. https://doi.org/10.1016/j.scitotenv.2018.05.322

Dumitrescu EI, Hurlin C (2012) Testing for Granger non-causality in heterogeneous panels. Econ Model 29(4):1450–1460. https://doi.org/10.1016/j.econmod.2012.02.014

Etokakpan MU, Adedoyin F, Vedat Y, Bekun FV (2020) Does globalization in Turkey induce increased energy consumption: insights into its environmental pros and cons. Environ Sci Pollut Res 27:26125–26140

Foster V, Tre JP, Wodon Q (2000) Energy consumption and income: an inverted U- at the household level? The World Bank

Gao J, Zhang L (2020) Does biomass energy consumption mitigate CO2 emissions? The role of economic growth and urbanization: evidence from developing Asia. Journal of the Asia Pacific Economy:1–20. https://doi.org/10.1080/13547860.2020.1717902

Gyamfi BA, Bein AM, Bekun VF (2020) Investigating the nexus between hydroelectricity energy, renewable energy, non-renewable energy consumption on output: evidence from E7 countries. Environ Sci Pollut Res 27:25327–25339. https://doi.org/10.1007/s11356-020-08909-8

He LY, Hou B, Liao H (2018) Rural energy policy in China: achievements, challenges and ways forward during the 40-year rural reform. China Agric Econ Rev 10:224–240. https://doi.org/10.1108/CAER-10-2017-0190

Herbert GJ, Krishnan AU (2016) Quantifying environmental performance of biomass energy. Renew Sust Energ Rev 59:292–308

Hille E, Shahbaz M, Moosa I (2019) The impact of FDI on regional air pollution in the Republic of Korea: a way ahead to achieve the green growth strategy? Energy Econ 81:308–326. https://doi.org/10.1016/j.eneco.2019.04.004

https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&uact=8&ved=0ahUKEwir9dnAr6_XAhXhz4MKHV15BwUQFggmMAA&url=https%3A%2F%2Fwww.bp.com%2Fcontent%2Fdam%2Fbp%2Fen%2Fcorporate%2Fpdf%2Fenergy-economics%2Fstatistical-review-2017%2Fbp-statistical-review-of-world-energy-2017-full-report.pdf&usg=AOvVaw2aMOLmDMZIBQpaw8FDDumY. (Accessed on 13/4/2020)

IEA (2016) International Energy Agency Bioenergy Countries' Report Bioenergy policies and status of implementation. http://www.ieabioenergy.com/wp-content/uploads/2016/09/IEABioenergy-Countries-Report-23.09.2016-1.pdf

Im KS, Pesaran MH, Shin Y (2003) Testing for unit roots in heterogeneous panels. J Econom 115(1):53–74

IPCC (2016) IPCC report graphics. Retrieved from. https://www.ipcc.ch/report/graphics/index.php?t=Assessment%20Reports&r=AR5%20-%20Synthesis%20Report&f=SPM

IPPC (2014) Synthesis report. Contribution of working groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Geneva, Switzerland. https://doi.org/10.1046/j.1365-2559.2002.1340a.x

Katircioglu ST (2015) The impact of biomass consumption on CO2 emissions an empirical investigation from Turkey. Int. J. Clim. Chang. Strateg. Manag. Artic. Inf 7:348–358. https://doi.org/10.1108/IJCCSM-06-2014-0077

Kim G, Choi SK, Seok JH (2020) Does biomass energy consumption reduce total energy CO2 emissions in the US? J Policy Model 42:953–967

Kirikkaleli D, Adedoyin FF, Bekun FV (2020) Nuclear energy consumption and economic growth in the UK: evidence from wavelet coherence approach. J Public Affairs e2130

Liobikien G, Butkus M (2018) Scale, composition, and technique effects through which the economic growth, foreign direct investment, urbanization, and trade affect greenhouse gas emissions. Renew Energy 132:1310–1322. https://doi.org/10.1016/j.renene.2018.09.032

Mahmood N, Wang Z, Yasmin N, Manzoor W, Rahman A (2019) How to bend down the environmental Kuznets curve: the significance of biomass energy. Environ Sci Pollut Res 26:21598–21608. https://doi.org/10.1007/s11356-019-05442-1

Mao G, Huang N, Chen L, Wang H (2018) Research on biomass energy and environment from the past to the future: a bibliometric analysis. Sci Total Environ 635:1081–1090. https://doi.org/10.1016/j.scitotenv.2018.04.173

Owusu PA, Asumadu-Sarkodie S (2016) A review of renewable energy sources, sustainability issues and climate change mitigation. Cogent Eng 3:1–14. https://doi.org/10.1080/23311916.2016.1167990

Ozturk I, Acaravci A (2009) On the causality between tourism growth and economic growth: empirical evidence from Turkey. Transylvanian Review of Administrative Sciences 5(25):73–81

Pesaran MH (2006) Estimation and inference in large heterogeneous panels with a multifactor error structure. Econometrica 74(4):967–1012

Pesaran MH (2007) A simple panel unit root test in the presence of cross-section dependence. J Appl Econ 22(2):265–312

Pesaran MH (2015) Testing weak cross-sectional dependence in large panels. Econom Rev 34(6–10):1089–1117

Pesaran MH, Shin Y (1998) An autoregressive distributed-lag modelling approach to cointegration analysis. Econom Soc Monogr 31:371–413

Ren S, Yuan B, Ma X, Chen X (2014) International trade, FDI (foreign direct investment) and embodied CO2 emissions: a case study of China's industrial sectors. China Econ Rev 28:123–134. https://doi.org/10.1016/j.chieco.2014.01.003

Sadorsky P (2009) Renewable energy consumption and income in emerging economies. Energy policy 37(10):4021–4028

Sarkodie SA, Strezov V, Weldekidan H, Asamoah EF, Owusu PA, Doyi INY (2019) Environmental sustainability assessment using dynamic autoregressive-distributed lag simulations — nexus between greenhouses gas emissions, biomass energy, food and economic growth. Sci Total Environ 668:318–332. https://doi.org/10.1016/j.scitotenv.2019.02.432

Sarpong SY, Bein MA (2020) The relationship between good governance and CO2 emissions in oil-and non-oil-producing countries: a dynamic panel study of sub-Saharan Africa. Environ Sci Pollut Res Int 27:21986–22003

Shahbaz M, Nasreen S, Abbas F, Anis O (2015) Does foreign direct investment impede environmental quality in high-, middle-, and low-income countries? Energy Econ 51:275–287. https://doi.org/10.1016/j.eneco.2015.06.014

Shahbaz M, Solarin SA, Hammoudeh S, Shahzad SJH, Adebola S, Hammoudeh S, Jawad S, Shahzad H (2017) Bounds testing approach to analyzing the environment Kuznets curve hypothesis with structural beaks: the role of biomass energy consumption in the

United States. Energy Econ 68:548–565. https://doi.org/10.1016/j.eneco.2017.10.004

Shahbaz M, Balsalobre D, Shahzad SJH (2019) The influencing factors of CO2 emissions and the role of biomass energy consumption: statistical experience from G-7 countries. Environ Model Assess 24(2):143–161. https://doi.org/10.1007/s10666-018-9620-8

Shao Q, Rao L (2018) The rebound effect of dematerialization and decoupling: a case of energy efficiency. Chinese J Popul Resour Environ 16:299–313. https://doi.org/10.1080/10042857.2018.1544755

Solarin SA, Al-Mulali U, Gan GGG, Shahbaz M, Goh G, Gan GGG, Shahbaz M (2018) The impact of biomass energy consumption on pollution: evidence from 80 developed and developing countries. Environ Sci Pollut Res 1–17:22641–22657. https://doi.org/10.1007/s11356-018-2392-5

Sulaiman C, Abdul-Rahim AS, Ofozor CA (2020) Does wood biomass energy use reduce CO2 emissions in European Union member countries? Evidence from 27 members. J Clean Prod 253:119996

Sun J, Peng H, Chen J, Wang X, Wei MLW, Mellouki A (2016) An estimation of CO2 emission via agricultural crop residue open field burning in China from 1996 to 2013. J Clean Prod 112:2625–2631

Udi J, Bekun FV, Adedoyin FF (2020) Modeling the nexus between coal consumption, FDI inflow and economic expansion: does industrialization matter in South Africa? Environ Sci Pollut Res 1–12

Ulucak R (2020a) Linking biomass energy and CO2 emissions in China using dynamic autoregressive-distributed lag simulations. J Clean Prod 250:119533

Ulucak R (2020b) Linking biomass energy and CO2 emissions in China using dynamic autoregressive-distributed lag simulations. J Clean Prod 250:119533

Victor NM, Victor DG (2002) Macro patterns in the use of traditional biomass fuels, working paper. Program on Energy and Sustainable Development, Stanford

Wang Z, Huang W, Chen Z (2019) The peak of CO2 emissions in China: a new approach using survival models. Energy Econ 81:1099–1108. https://doi.org/10.1016/j.eneco.2019.05.027

Wang L, Vo XV, Shahbaz M, Ak A (2020a) Globalization and carbon emissions: is there any role of agriculture value-added, financial development, and natural resource rent in the aftermath of COP21? J Environ Manag 268:110712

Wang Z, Bui Q, Zhang B (2020b) The relationship between biomass energy consumption and human development: empirical evidence from BRICS countries. Energy 194:116906

Westerlund J (2007) Testing for error correction in panel data. Oxf Bull Econ Stat 69(6):709–748

World Bank (2012). World Dev. Indic. (https://databank.worldbank.org/home.aspx)

World Bank (2019). World Bank. World Dev. Indic. (https://databank.worldbank.org/home.aspx)

Zhang Y, Zhang S (2018) The impacts of GDP, trade structure, exchange rate and FDI inflows on China's carbon emissions. Energy Policy 120:347–353. https://doi.org/10.1016/j.enpol.2018.05.056