Renewable Energy 206 (2023) 858–871

Contents lists available at ScienceDirect

Renewable Energy

journal homepage: www.elsevier.com/locate/renene

The role of solar energy usage in environmental sustainability: Fresh evidence through time-frequency analyses

Sevda Kuşkaya [a], Faik Bilgili [b,*], Erhan Muğaloğlu [b], Kamran Khan [c], Mohammad Enamul Hoque [d], Nurhan Toguç [e]

[a] Justice Vocational College, Dept. of Law, Erciyes University, 38280, Kayseri, Turkey
[b] Faculty of Economics and Administrative Sciences, Erciyes University, 38039, Kayseri, Turkey
[c] Kashmir Institute of Economics, University of Azad Jammu & Kashmir, Muzaffarabad, Pakistan and Erciyes University FEAS, 38039, Kayseri, Turkey
[d] BRAC Business School, BRAC University, 66 Mohakhali Dhaka 1212, Bangladesh
[e] Gelisim University, Faculty of Economics, Administrative and Social Sciences, 34310, İstanbul, Turkey

ARTICLE INFO

Keywords:
Solar energy
Carbon dioxide emissions
Sustainability
Time-frequency analysis
Wavelet transform
The United States

ABSTRACT

The most important challenge for both developed and developing countries is to ensure sustainability while struggling with environmental degradation. CO_2 emissions as a proxy for environmental degradation can be considered an obstacle to sustainability. There exist several significant works in the literature on the effects of solar energy use on environmental degradation/sustainability. In this study, the effects of the use of solar energy within different time and frequency dimensions on CO_2 emissions were examined with the methodology of the continuous wavelet transform. The paper investigated the association between solar energy consumption and total energy-related CO_2 emissions in the USA through Morlet wavelet analysis, which is one of the most advanced time-frequency analysis methods for the period 1990:1–2022:6. In the wavelet coherency computations, geothermal energy consumption, hydroelectric energy consumption, industrial production, and manufacturing industry production variables were also included as control variables. Empirical findings demonstrate that solar energy consumption can have reducing effects on CO_2 emissions at lower frequencies (longer-term cycles) and sub-time periods (2014:1–2022:1) in the USA. The findings can guide the energy and environmental policies of developed and developing countries that aim to struggle with global warming and/or climate change through the increase in solar energy usage.

1. Introduction

The modern economic growth paradigm is heavily reliant on the consumption of fossil fuels that are mainly responsible for CO_2 emissions. While carbon dioxide emissions are a leading source of climate change and global warming, which have dire consequences for sustainable human survival, ecosystems, and biodiversity [1–3]. Recent spells of rapid economic growth have spurred the consumption of fossil fuels and subsequently enhanced global warming by triggering carbon emissions at a larger scale [4]. It is worth mentioning that ongoing efforts for the decarbonization of the environment are encouraging but inadequate to avoid climate disasters knocking down in near future. Thus economy-wide transformations are required to achieve zero carbon emissions in key sectors like energy, industry, agriculture, and transport; and to achieve the Paris Agreement goal of limiting the global average temperature to well below 2 °C preferably 1.5 °C [5]. Meanwhile, [6] iterated that human-induced climate change originating primarily from burning fossil fuels has already caused irreversible damage to human-wellbeing and planetary health. It has cautioned the global community about the spiking global average temperature and urged for a 45% cut in carbon emissions by 2030 to restrict it to 1.5 °C. The report further insisted on the urgent decarbonization of the global economy to avoid natural calamities such as frequent and intense droughts, freshwater shortages, tropical cyclones, heat waves, melting glaciers, mounting sea levels, ocean acidification, and declining precipitation. In short consumption of fossil fuels has many repercussions for the environment and society that are; (1) triggering carbon emissions and air pollution, (2) spiking global average temperature, (3) causing natural

* Corresponding author.
E-mail addresses: skuskaya@erciyes.edu.tr (S. Kuşkaya), fbilgili@erciyes.edu.tr (F. Bilgili), erhanmugaloglu@erciyes.edu.tr (E. Muğaloğlu), kamrankhanajk@gmail.com (K. Khan), iiuc.enam@ymail.com (M.E. Hoque), nurhantoguc@gmail.com (N. Toguç).

https://doi.org/10.1016/j.renene.2023.02.063
Received 30 November 2022; Received in revised form 25 January 2023; Accepted 14 February 2023
Available online 20 February 2023
0960-1481/

disasters, (4) food, water, energy insecurity, (5) threatening human well-being, (6) hindering sustainable growth and sustainable development, (7) accelerating natural resource depletion. Therefore, it is crucial to alter fossil fuels with renewable energy sources to protect the environment and ensure a sustainable future for humanity [7]; IERNA, 2022; [8–12].

Considering the challenge of climate change and the global emphasis on renewable energy, the first aim of this study is to examine the influence of solar energy on environmental quality in the USA. Solar energy is amongst the cleanest forms of energy having the potential of 6500 TW [13] that is capable enough to meet a substantial portion of the world's energy demand [14]. It has tremendous environmental advantages over traditional energy sources that are; (1) reducing CO_2 emission and other toxic gas emissions like SO_2, (2) mitigating natural resources depletion, (3) providing energy independence and security, (4) enhancing the quality of water resources, and (5) contributing to sustainable development [12]. Furthermore, it is an everlasting and relatively inexpensive energy source that mitigates negative externalities to the environment [7]; and the most promising alternative to carbon-intensive non-renewable energy that contributes to Sustainable Development Goals adopted by the UN in 2015 [15,16]. That is why solar energy has grabbed significant attention amongst all the other renewables; and achieved remarkable growth in recent years [17]. Renewable energy sources have gained momentum last year by manifesting 38% of the global installed capacity. In 2021, the world has added 257 Gigawatts of renewables reflecting a 9.1% increase in the stock of renewable power; and only solar power accounted for record more than half of the renewable additions that are 133GW. This progress is encouraging but not sufficient to achieve a net zero carbon future. Hence, it is crucial to enhance the share of renewables by up 40% in total energy generation in 2030 [18]. Being the world's largest energy-producing and consuming country [19], the USA has also added 13.2 Gigawatts (GW) of utility-scale solar capacity in 2021 which is a record 25% more than the 10.6 GW supplemented in 2020 [20] reflecting a significant increase in the energy transition.

Besides, the present study uses hydropower energy consumption, geothermal energy consumption, industrial production, and manufacturing industrial production as control variables. Geothermal and hydro energy consumption were found significant in increasing environmental quality in the USA [21,22]. Industrial production is at the heart of economic growth [23] however, it stimulates energy consumption that is fundamentally accountable for the deterioration of the environment [24]. Hence, the outstanding challenge for modern-day governments and policymakers is to preserve the environment without compromising economic growth. In the last couple of decades, economies with an uppermost share of the global manufacturing output witnessed spectacular economic growth coupled with environmental degradation [25–27]. Likewise, Liu and Bae [28] noted that rapid industrialization has triggered CO_2 emissions in China; the world's largest manufacturing hub. Lending support to the argument [29], highlighted that industrial sector growth is inescapably linked to the consumption of fossil fuels responsible for triggering CO_2 emissions in both SR and LR. On the contrary [24,30], claimed that industrial sector growth reduces CO_2 emissions to protect environmental quality.

This research offers various contributions to recent economic literature. (i) It is worth mentioning that numerous studies have researched the solar energy-CO_2 relationship for various countries at different points in time. Most of the studies have utilized panel data while the rest have employed traditional methodologies such as OLS, ARDL, and quantile [7]. Whereas, the current study uses the wavelet methodology to investigate the nexus between solar energy and CO_2 emissions. The wavelet approach is a contemporary estimation methodology that offers localization in time and frequency domains and allows the researchers to examine the data at different scales [31]. Therefore, the present study uses wavelet decomposition to simultaneously examine the SR and LR association between solar energy and carbon emissions. As the synchronized investigation offers a better understanding of the mentioned earlier phenomena to reach solid conclusions. (ii) Besides, the current study examines the sustainability of hydropower energy, geothermal energy, and industrial production. As hydropower and geothermal energy are among the cleanest renewable energy sources that have gained significant momentum in recent years [18]. While industrial production is at the heart of economic growth [23] and is principally accountable for carbon emissions [24]. (iii) This is a country-specific study that focuses on the USA. Because the USA is the world's largest economy [19], and is among the top solar energy consumers around the globe [7]. (iv) This study comprehensively reviews the solar energy policies implemented by the USA as well as the policies and proposals that are underway. Furthermore, it thoroughly reviews the existing literature on the solar energy-carbon emissions nexus. (v) Based on the empirical findings, the current study presents some suggestions for policymakers and governments that might be helpful to mitigate the carbon footprint.

This research includes five sections. After the introduction section, the literature review section reviews the available works regarding renewable energy use, solar energy usage, and sustainability in terms of CO_2 emissions, and growth. In the third section, the data and wavelet methodology are introduced. The empirical results are discussed in the 4th section. The last section yields conclusion and policy recommendations.

2. Literature review

The postwar neo-classical theory perceives energy as an outcome of economic activity, which neglects its possible direct impact on economic growth, because of the relatively stable energy markets and seemingly maintained energy-secure environment of the pre-oil crisis era in the 1970s [32]. However, oil supply shocks in 1973 and 1979, tensions and wars in oil-producing countries' neighborhoods during the Iraq-Iran war in the 1980s, Kuwait's invasion and Gulf war in 1991, and fast-growing environmental concerns related to climate change have altered energy as an endogenous factor in economic growth [33]. influential paper pioneers in investigating the relationship between energy and economic growth in the USA and find evidence of energy conservation, which suggests that economic growth causes energy consumption. Since then, a vast number of economic studies have been investigating the energy consumption and economic growth nexus, in the context of either aggregated or disaggregated energy measures, different periods, and various types of econometric methods for single countries, regions as well as country groups [34–42]; Ozturk et al., 2010; [3,43–48]. Nevertheless, the economic growth and energy consumption nexus literature lacks a common conclusion. Some review studies summarize these mixed results [19,49–51].

2.1. Renewable energy-growth-emission

Since fossil fuel combustion is the main source of carbon emissions, climate change mitigation policies mostly force economic agents either to substitute non-renewables for renewable energy sources or promote energy-saving technology investments [52,53]. Therefore, energy economics literature particularly on sustainable growth and renewable energy has been increasing around the substitutability among different energy sources and its inclusion into macroeconomic models, and how it might affect the countries' economic growth path [32,54]. In recent work [55], investigate the cyclical relationship between the technical progress in green and sustainable energy, and carbon emissions in G7 countries from 1990 to 2018. They show that the sustainable growth and environmental degradation nexus is counter-cyclical [19]. state that most studies investigating the relationship between renewable energy and economic growth analyze the total renewable energy consumption and employ panel cointegration and causality analysis to multi-country data. On the other hand, recent studies pay more attention to the link between disaggregated renewable energy and sustainable growth. The following selected literature includes different types of renewable energy sources in their analysis and examines how they are connected to economic growth (see Refs. [56] [biomass, geothermal, hydro] [57]; [biomass] [58]; [biomass] [59]; [hydro]; [60] [biomass, hydro, geothermal, wind, solar] [61]; [solar] [62]; [nuclear])

The rising concerns about the expected and/or unforeseen catastrophic economic damage of climate change have led to the inclusion of environmental degradation measures such as carbon emissions, land and water pollution, carbon footprint, and air quality into sustainable growth-energy consumption nexus analysis. In their panel study examining the linkage between 35 OECD member countries' economic and environmental aggregates over the period 2000 and 2014, Ozcan et al. [63] reveal that countries' economic growth and energy consumption tendencies determine their success in achieving environmental targets. Since the dynamic models including energy consumption eliminate the omitted variable problem, they provide enhancement to understanding the income and environment nexus [64–66]. According to studies investigating the relationship between energy consumption, carbon emissions, and economic growth, governments should incorporate the reduction in fossil fuel dependence as a common global policy goal to sustain economic growth and prevent environmental degradation simultaneously [67]. Renewable energy sources are most likely substitutes for fossil fuel combustion, particularly in power markets [68]. Therefore, analyzing renewable energy consumption and its direct and indirect impact on carbon emissions and economic growth become crucial concerning energy and environmental policy implementations. Using dynamic OLS and Granger causality for cointegrated series, Mulali et al. [69] find that renewable energy consumption negatively impacts CO_2 emissions in the observed global regions with a considerable renewable energy consumption to total energy consumption ratio. On the other hand, this relationship is inconclusive for regions with an insignificant renewable total energy ratio [70]. employs panel and generalized method of moments (GMM) methodology with fixed effects to assess the relationship between renewable energy consumption, growth, and CO_2 emissions in the US states between the periods 1997 and 2017. Its results validate an inverted Environmental Kuznets Curve (EKC) and verify that renewable energy consumption has a negative impact on CO_2 emissions in the US states. In addition to CO_2 emissions [71], examines the validity of the EKC hypothesis against the ecological footprint in ASEAN countries from 1991 to 2016 and confirms that EKC holds for ecological footprint. Besides, there is a considerable number of studies examining the economic growth, environmental degradation, and renewable energy consumption nexus for various country groups in addition to single-country analysis. (Please refer to Refs. [3,45,72–76]; for OECD countries, [77–79]; for EU countries, [80–83]; for developing countries, [84,85]; for the USA). They support a common result that renewable energy consumption plays an important role in CO_2 emissions reduction.

2.2. Solar energy-growth-emission

In addition to a vast literature on the renewable energy consumption, economic growth, and environmental degradation nexus, Sarı et al. [86] examine the relationship between disaggregated renewable energy variables of hydropower, solar, and wind energy consumption and macroeconomic aggregates of industrial production and employment in the US. Although they find a significant long-run causality from economic growth to all disaggregated energy variables, the sign of impact turns out to be negative for solar energy. Besides, contrary to other energy variables, solar energy consumption is reversely connected to employment. In a recent panel estimation study by Refs. [87–89] for G-7 countries from 1995 to 2018, the relationship between solar energy consumption and economic growth validates the EKC hypothesis. On the other hand [90], show that there is a weak long-run relationship between solar energy consumption and economic growth over the period 1990 and 2008 in 20 OECD countries, while Grio and Soares [91] suggest that solar energy consumption positively affects the economic growth in 18 EU countries. Literature that studies the relationship between economic growth and solar energy consumption provides mixed estimation results for different countries and country groups.

Recent studies, which examine the solar energy consumption and CO_2 emissions nexus in the US, show that solar energy consumption reduces environmental degradation, ecological footprint, and CO_2 emissions [7,92–94]. Contrary to their single-country findings [92], conclude that there is no significant panel causal relationship between CO_2 emissions and solar energy consumption, while [87,88] find evidence that solar energy consumption reduces CO_2 emissions in G-7 countries. In addition to econometric techniques, energy system engineering methods of life cycle assessment (LCA) and parametric modeling also state that solar energy consumption reduces CO_2 emissions since it effectively replaces fossil fuel combustion in the power sector [95,96]. Besides Li et al. [97] examines the importance of solar energy as well as rigid environmental policy in achieving environmental sustainability in OECD countries from 2001 to 2018 by considering cross-sectional dependency. They verify that solar energy consumption lowers the ecological footprint of most OECD countries. In their review study [98], investigate the role of solar energy especially photovoltaic and thermal technologies to maintain sustainable development. They state that solar energy consumption significantly reduces carbon emissions as well as air pollution as a medium of fossil fuel substitute, thus it is a prospective tool for achieving global sustainable development goals in the energy sector [87–89]. include various renewable energy technologies in a data envelopment analysis to measure their relative importance to achieve a more green and sustainable economy in Pakistan. They rank solar energy as the second most important renewable technology just after wind energy to diminish the use of fossil energy. Analogously Ghenai et al., 2020 propose solar PV following wind and fuel cells technologies to maintain sustainable energy development by performing a multi-criteria decision-making model to evaluate the realization of various renewable energy technologies including solar photovoltaic cells in major indicators of resource, economic, social technology, and environmental sustainability. Table 1 presents an extensive summary of the literature that examines the relationship between solar energy consumption, economic growth, and environmental measures.

2.3. Solar energy policy

The volume and scheduling of solar energy power generation investment decisions are very much responsive to the federal energy policy enforcement in the USA [107]. Main energy policy implementations are investment tax credits (ITC) and production tax credits (PTC), which are first introduced to the public for renewable energy technologies in 1992. These energy policy-related tax incentives have an important role during the decision-making process in energy projects as well as in the scenario analysis of energy policy and research centers' projections for future renewable energy generation trends. For instance Ref. [108], predicts total solar photovoltaic (PV) net generation of 1.2 billion, 1.0 billion, and 1.4 billion megawatt-hours in 2050 regarding alternative tax credits cases of business as usual, extended, and sunset cases, respectively. Table 2, below, summarizes the solar energy policy

Table 1
Recent studies on solar energy consumption (SEC), environmental degradation, and economic growth.

Authors	Country/Region (Period)	Methodology	Main findings
[86]	The USA (2001:1–2005:6)	ARDL	In the LR, there is a significant negative relationship between SEC and economic growth. (Growth → SEC)
[90]	20 OECD (1990–2008)	Panel error correction and co-integration	In the LR, weak relationship between SEC and GDP. (Growth→SEC)
[91]	18 EU countries (2000–2012)	Panel estimation with fixed effects	SEC positively affects GDP. CO_2 emissions positively affect GDP. SEC has a higher positive impact than the aggregated renewable energy consumption
[19]	The USA (1989:1–2016:11)	Wavelet coherence, Phase difference	In both SR and LR, SEC positively affects industrial production.
[99]	China (1990–2007)	VAR-based cointegration, VECM	SEC and CO_2 emissions are negatively related. Technical progress in solar energy diminishes CO_2 emissions.
[92]	G-7 countries, (1990–2004)	AMG, Panel bootstrap causality	There is no significant (panel) relationship between SEC and CO_2. Mixed results for single-country cases. SEC reduces CO_2 in the USA.
[95]	Technical report Alexandria, Egypt	Parametric model on photovoltaic cell position	PV electricity generation prevents CO2 emissions associated with grid electricity.
[100]	13 electricity markets in the US, (Hourly data in 2016)	Linear model	Decreasing the cost of wind and solar energy installment technology isn't alone sufficient to satisfy CO_2 emissions abatement targets.
[101]	China, India, the USA (1983–2017)	Machine learning, Causal direction from Dependency	Wind and SEC combination is an effective substitute for coal consumption, thus reducing CO_2 emissions. (CO_2→SEC, in India)
[93]	10 most SEC countries: China, the USA, Japan, Germany, India, Italy, Australia, Vietnam, South Korea, and Spain. (1991–2018)	Quantile on Quantile for each country.	SEC reduces CO_2 emissions in the USA and other countries except for Spain and India
[25]	World aggregated data, (1990–2020)	ARDL bounds test	In both LR and SR, SEC reduces global CO_2 emissions.
[102]	8 most SEC countries: China, the USA, Japan, Germany, Italy, Australia, South Korea, and Spain. (1990:Q1 – 2017:Q4)	Quantile on Quantile, Quantile-based Granger causality	SEC decreases human ecological footprint at lower quantiles, however, it isn't sufficient at higher quantiles.
[103]	Saudi Arabia (2010:1–2018:12)	VECM	SEC reduces CO_2 emissions. It supports achieving SDGs by limiting polluting industries.
[104]	China (1990–2018)	Quantile ARDL	In the LR, SEC and CO_2 emissions are negatively related at higher quantiles.
[96]	Technical report	Life cycle assessment (LCA)	Solar energy generation has a significant CO_2 emission reduction impact, but its production requires more technical progress.
[94]	The USA (1981:1–2020:1)	Wavelet coherence Phase differences	Residential SEC mitigates CO_2 emissions in 1–2 years cycles.
[105]	35 countries from diverse income groups (2005–2018)	CCEMG, AMG, and FMOLS	In the LR, SEC reduces CO_2 emissions.
[7]	10 most SEC countries: China, the USA, Japan, Germany, India, Italy, Australia, the UK, South Korea, and Spain. (1991–2018)	Quantile on Quantile for each country.	SEC reduces CO_2 emissions in the USA and other countries except for France. The overall SEC and CO_2 nexus are stronger at higher quantiles of CO_2.
Karlılar and Emir [106]	India (1995–2018)	Fourier ARDL cointegration, FMOLS	SEC is negatively related to ecological footprint. Wind and Solar energies are alternatives to coal-fired energy.
[87–89]	G-7 countries, (1995–2018)	Panel estimation, cross-sectional dependence, panel co-integration	SEC reduces CO_2 emissions. EKC is validated.

Table 2
Summary of the USA's solar energy-related policy implementations [109].

Year	Status	Act	Policy implementations and their goals
1978	Ended	Solar Photovoltaic Energy Research, Development, and Demonstration Act	Re-establishment of research and development programs for solar PV energy systems.
1978	Ended (Extended in 1980)	Energy Tax Act of 1978	Up to 30% ITC, Residential tax credit for solar energy investments 10% PTC, first time introduced a business energy tax credit at
1986	Ended (Extended till 1992)	Tax Reform Act of 1986	10% PTC, extended for 2 years
1992	In force (Extended last time in 2015)	Federal Business Investment Tax Credit (ITC)	30% of ITC is available through 2019, ramping down to 26% in 2020 and 22% in 2021. 10% of ITC is permanent in 2022 and beyond.
1999	Ended	Energy for the New Millennium: National Photovoltaics Program Plan	Fund for research and development of silicon materials, thin film, and other innovative concepts that progress in solar PV.
2006	Ended (Integrated into 2009 Solar energy tech. program)	Solar America	Funds for research and development in solar cell manufacturing Support for electricity market integration of solar power generation Reducing the cost of solar power to be regularly available at less than 10 cents/kWh by 2015
2008	In force	Advanced Solar PV development: Solar America Initiative	Fund for university-leading projects Maintain a competitive price in the markets between 5 and 10 cents/kWh by 2015
2009	In force	American Recovery and Reinvestment Act: Appropriations for Clean Energy	Extra fund of $80 billion to support clean energy R&D projects, smart grids, and previous programs.
2015	In force	Renew300 Federal Renewable Energy Target	The goal of reaching 300 MW of renewable energy through onsite and community-scale renewable energy installations at federally assisted housing by 2020. Solar PV is at the center of this initiative.
2021	In force	Funding for thin film technologies for solar PV	Fund for advancing solar PV technology to lower the price of solar energy by 60%, from 4.6 cents in 2021 to 2 cents in 2030.
2021	In force	Consolidated Appropriations Act	26% ITC extended till 2023, gradual reduction to 22% in 2024 and 10% in 2025

implementations listed in the US legislation.

According to Ref. [111]'s Annual Energy Outlook 2022, the renewable share in electricity generation will expand from 21% in 2020 to 44% in 2050 and solar energy will account for more than half of total renewable energy generation in 2050. On the other hand [112], has projected that the renewable share in electricity generation will rise to 42% in 2050. These differentials in energy consumption projections occur mainly because of energy policy adjustments and updates. For instance, the Consolidated Appropriations Act of 2021, updates the ITC rate for solar energy generation to remain at 26% till 2023, and to be at %10 in 2025, however Federal Business Investment Tax Credit (ITC) Act of 1992 had intended to be fixed at 10% in 2022.

The USA solar energy policy provides a permanent tax credit for solar energy power generation investments at 10% by the Federal Business Investment Tax Credit (ITC) Act of 1992 while the production tax credit for wind energy power generation phases out in 2024. Therefore, solar power generation is projected to be responsible for 80% of the increase in renewable energy electricity by 2050 [112]. After ITC and PTC, energy policy implementations supporting the USA renewable energy generation are the funds that advance solar energy generation technologies. These funds aim to lower solar energy's initial investment costs to maintain more competitive prices in power markets.

Table 3
The definition of variables.

Variables	Abbreviation	Unit	Data Source
Solar energy usage	Solar	Trillion Btu	[20]
Total energy-related CO_2 emission	CO_2	Million Metric Tons of Carbon Dioxide	[20]
Geothermal energy usage	Geo	Trillion Btu	[20]
Hydroelectric power usage	Hydro	Trillion Btu	[20]
Industrial production index	IP	Index	[110]
Manufacturing industrial production index	MANIP	Index	[110]

3. Data and methodology

3.1. Data

In this paper, the nexus between monthly solar energy consumption (Solar) and total energy-related CO_2 emissions (CO_2) in the USA economy is investigated by Morlet wavelet analysis for the period 1990:1–2022:6. Geothermal energy consumption (Geo), hydroelectric power consumption (Hydro), industrial production index (IP), and manufacturing industrial production index (MANIP) variables are included as control variables in the analysis (see Table 3).

The main descriptive statistics of the variables used in the analysis are presented in Table 4. All variables have positive mean values. Among the renewable energy sources, the Hydro variable has the highest mean value. The variables with the highest volatility according to their standard deviation (Std. Dev.) values are Hydro, Solar, and CO_2 emissions, respectively (see also Fig. 1). The variables with negative and positive kurtosis values indicate that the series does not follow a normal distribution. Considering the positive and negative values of skewness values, it is observed that there is an asymmetry in the series.

3.2. Methodology

Wavelets are one of the most effective tools used in the construction of functional spaces in recent years [114]. Function $W(t)$, which is known as a mother wavelet and $W(t)$ localized in both space and frequency domains, is used to form a family of wavelets [21,22,115]. The continuous version of the wavelet transform conducted in different fields such as economics, finance, medicine, and engineering provides the opportunity to create a time-frequency representation of a signal by offering a very good time and frequency localization [116]. The continuous wavelet transform provides a method for monitoring and analyzing characteristics of signals that are dependent on time and scale [117]. At the same time, the continuous wavelet transform partitions the spatial series into continuous scales and locations by interpolating between them. Also, it preserves all the information in the original data series, thereby giving us the possibility of gaining insight into the original data [118,119]. The continuous wavelet transform gives the wavelet coefficients as the output [120].

Table 4
Descriptive statistics.

Descriptive statistics	Hydro	Geo	Solar	CO_2	IP	IPMAN
Mean	230,375	15,673	24,580	453,504	89,275	88,882
Std. Dev.	45,415	1915	37,173	42,182	13,067	14,318
Kurtosis	−0,322	1027	4709	0,051	−0,394	−0,291
Skewness	0,462	−0,818	2245	0,084	−0,954	−1032
Min	145,715	8603	2935	305,074	60,438	56,660
Max	357,387	19,182	199,707	560,770	104,258	106,474
N	390	390	390	390	390	390

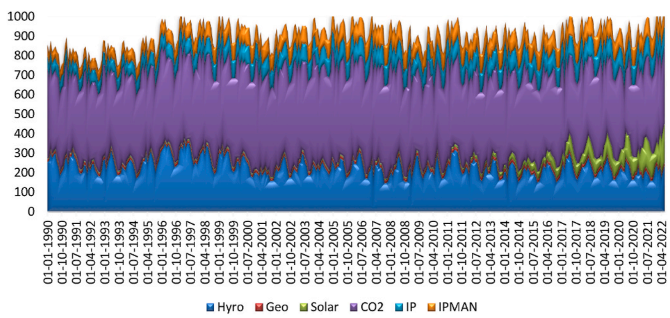

Fig. 1. Trends of variables from 1990:1 to 2022:6.

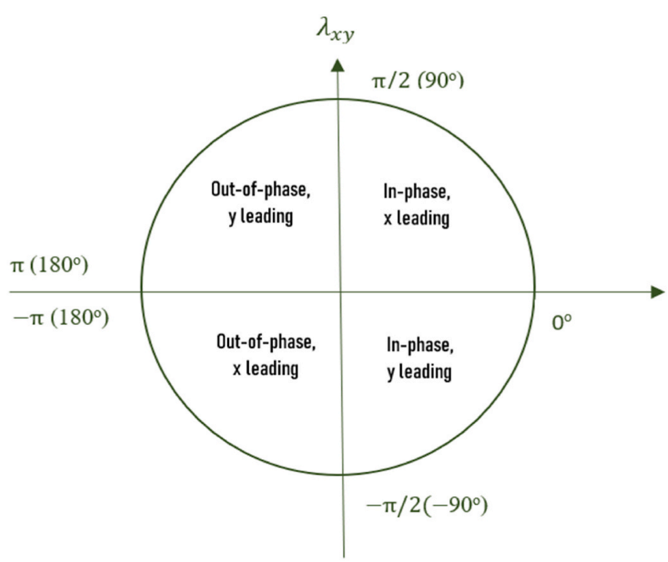

Fig. 2. Phase difference circle.
Source: [113].

Basically, the wavelet function $W_{(a,b)}(t)$ is commonly defined as follows;

$$W_{\varphi}^{x}(a,b)(t)=\frac{1}{\sqrt{a}}\int_{-\infty}^{\infty}x(t)\varphi^{*}\left(\frac{t-b}{a}\right)d_{t} \tag{1}$$

In Eq. (1) the asterisk (*) represents complex conjugation, and, φ^* stands for conjugated mother wavelet. The term $\frac{1}{\sqrt{a}}$ is used to conserve the norm. The parameter a (scaled) checks the width of the wavelet and represents the position of the wavelet in the frequency domain. This parameter ensures to compresses or to expands the wavelet to catch cycles or trends in different frequencies, as well. The term b is the location parameter that checks the location of the wavelet and indicates the position of the wavelet in the time domain.

The Morlet wavelet transform employed in the analysis of the study is a typical formalization of the continuous wavelet transform technique [121]. The Morlet wavelet transform presented by Morlet et al. [122] has both imaginary and real parts, thus providing the advantage of performing both phase and amplitude analysis simultaneously. The wavelet function $W_{(t)}$ for Morlet can be expressed as in Eq (2).

$$W_{w}(t)=\pi^{-\frac{1}{4}}e^{iw_{0}\eta}e^{\frac{-\eta^{2}}{2}} \tag{2}$$

In Eq. (2), η is dimensionless time and w_0 is dimensionless frequency. Choosing $w_0 = 6.0$, the wavelet scale simplifies the interpretation of the wavelet analysis. This value is approximately equal to the Fourier period (Congraria and Soares, 2011; [123].

To diagnose the interaction between two-time series, wavelet coherence needs to be defined. Therefore, first of all, the cross-wavelet transform and the cross-wavelet power should be explained explicitly [124]. The cross wavelet transform of two time series of $x(t)$ and $y(t)$ can be formulated as follows:

$$W_{xy}(a,b)=W_{x}(a,b)W_{y}^{*}(a,b) \tag{3}$$

where $W_x(a,b)$ and $W_y(a,b)$ are continuous wavelet transforms of $x(t)$ and $y(t)$, respectively. The cross-wavelet power reveals the areas in the time-frequency space where the time series show a high common power. It represents the local covariance between the time series at each scale [125]. The cross-wavelet power can be computed using the cross-wavelet transform as $|\Im_{xy}(a,b)|$:

$$\Im_{xy}(a,b)=\left(\frac{\mathbb{S}(W_{xy}(a,b))}{\sqrt{\mathbb{S}(W_{x}(a,b))\mathbb{S}(W_{y}(a,b))}}\right) \tag{4}$$

where $\Im_{xy}$ stands for the correlation, and parameter a ranges from "strong consistency" to "zero coherency" in both the time and frequency domains. The $\mathbb{S}$ represents the smoothing parameter. The phase difference analysis detects the phase correlations between components (e.g., the correlation direction and lead or lag relations). The phase difference

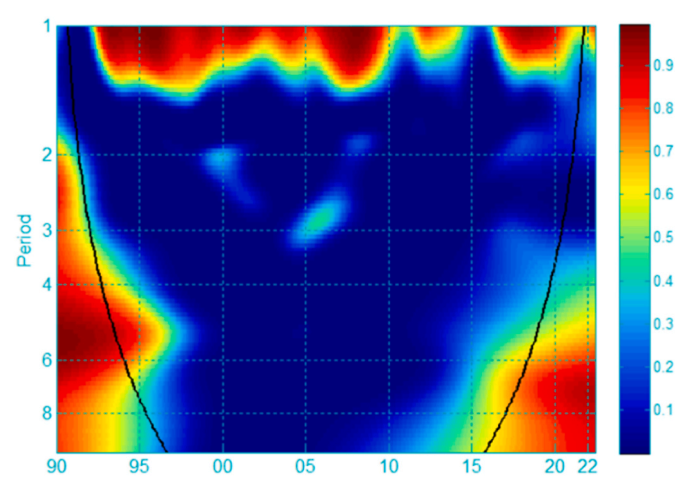

Fig. 3. Wavelet coherence (Solar, CO_2)
(The thick black curves show the cone of influences considering the border distortions).

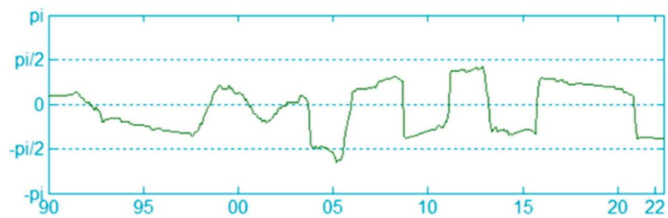

Fig. 4. 1–4 Frequency band.

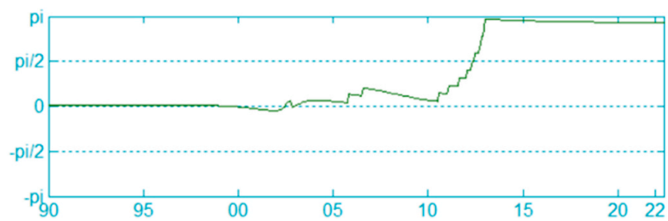

Fig. 5. 5–8 Frequency band.

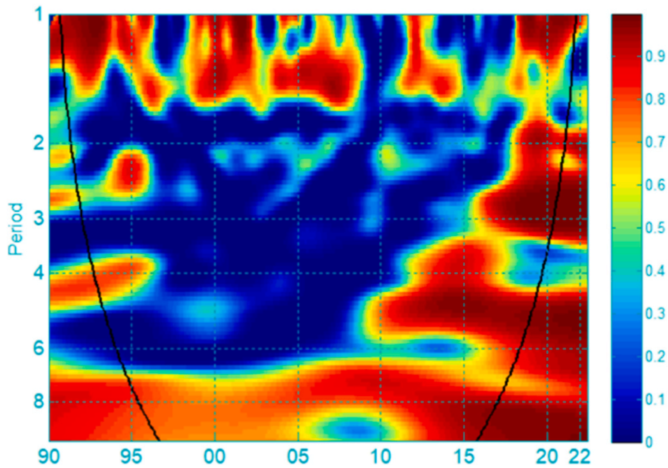

Fig. 6. Partial wavelet coherence (Solar, CO_2||Geo, Hydro, IP)
(The thick black curves show the cone of influences considering the border distortions).

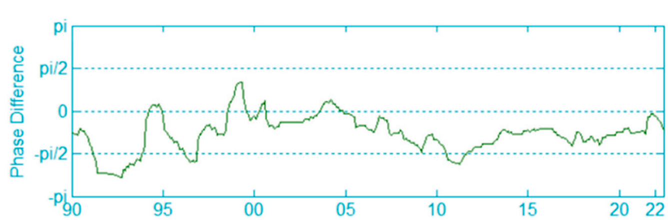

Fig. 7. 1–4 Frequency band.

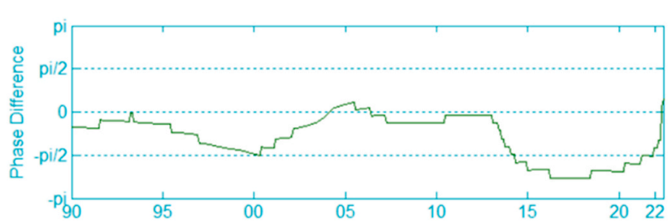

Fig. 8. 5–8 Frequency band.

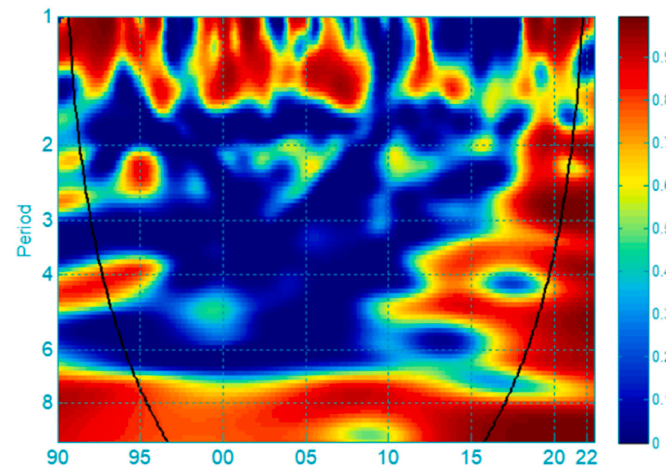

Fig. 9. Partial wavelet coherence (Solar, CO_2||Geo, Hydro, MANIP)
(The thick black curves show the cone of influences considering the border distortions).

(with$\lambda_{x,y} \in [-\pi, \pi]$) among time series $x(t)$ and $y(t)$ can be described as given in Eq. (5).

$$\lambda_{xy} = arctan\left(\frac{\mathbb{I}\{\mathbb{S}(\mathbb{W}_{xy}(a,b))\}}{\mathbb{R}\{\mathbb{S}(\mathbb{W}_{xy}(a,b))\}}\right) \quad (5)$$

where $\mathbb{I}(\lambda_{xy})$ and $\mathbb{R}(\lambda_{xy})$ denote the imaginary and real parts of the smooth power spectrum, respectively. Also, the lead-lag relationship between the time series of $x(t)$ and $y(t)$ is illustrated in Fig. 2.

4. Empirical results and discussion

In this paper, the nexus between solar energy consumption (Solar) and total energy-related CO_2 emissions (CO_2) in the USA economy is investigated by Morlet wavelet analysis for the period 1990:1–2022:6. Geothermal energy consumption (Geo), hydroelectric power consumption (Hydro), industrial production index (IP), and manufacturing industrial production (MANIP) variables are included as control variables in the analysis.

Fig. 3, Fig. 4, and Fig. 5 reveal the wavelet coherency analysis results of the relationship between solar energy use and CO_2 emission. The association between the variables, however, cannot be explicitly monitored through the figures. Partial wavelet coherence computations provide clearer co-movements by employing some control variables.

Fig. 6, Fig. 7, and Fig. 8 yield the outcomes of the partial wavelet coherence analysis for lead-lag relations (causality) of solar and CO_2 emission through the control variables (Geo, Hydro, and IP) employed in the model.

When Fig 6, and Fig 7 are considered simultaneously.

- There is a positive correlation between the variables in the period 1999:1–1999:12. The increase in solar energy usage is accompanied by an increase in CO_2 emissions.
- There exists a positive correlation between the variables in the 1994:4–1994:12; 1995:4–1996:8; 1997:4–1998:12; 2005:3–2008:12, and 2012:1–2021:12 periods. As the variable CO_2 leads the variable solar energy (and, as the solar energy variable is lagging), the increase in CO_2 emissions is accompanied by an increase in the consumption of solar energy.
- There is a negative correlation between variables in the period 1991:1–1994:3; 1997:1–1997:3, and 2011:1–2011:12. As solar energy is the leading variable (and, as the variable of CO_2 emissions is a

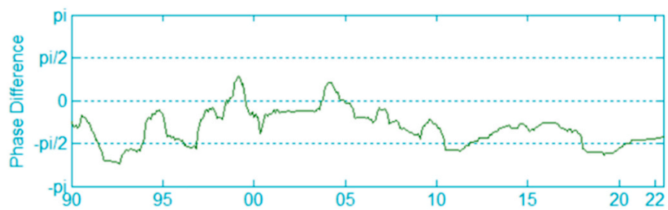

Fig. 10. 1–4 Frequency band.

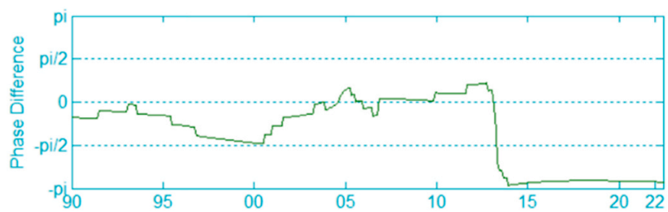

Fig. 11. 5–8 Frequency band.

lagging variable), a reduction in CO_2 emissions is associated with an increase in the use of solar energy.[1]

Therefore, one can claim that the emission-reducing effect of solar energy is limited in the 1–4 frequency range. This reducing impact appears only in the first half of the 1990s and at the beginning of the 2010s. When Fig. 6, and Fig.8 are evaluated simultaneously.

- In the period 2014:11–2022:1, there is a negative correlation between the variables, and the solar energy variable leads the CO_2 emissions series. The reducing direction in CO_2 emissions accompanies the increasing movement in solar energy consumption.

Figs. 9, Fig 10, and Fig. 11 consider the potential co-movements between solar energy and CO_2 emissions through partial wavelet coherence and frequency band analysis with the control variables of Geo, Hydro, and MANIP.

- Fig. 9, and Fig. 10 yield that there is a negative correlation between variables in the period 1991:1–1994:8; 2011:1–2011:12, and 2018:6–2020:12. The increase in the use of solar energy is associated with a reduction in CO_2 emissions.
- Figs. 9, and Fig. 11, on the other hand, underline that the reducing effect of solar energy use on carbon emissions is observed in a wider time interval.[2]

In the period 2014:1–2022:1, as solar energy is leading and CO_2 emissions are lagging variables, there appears a negative association between these time series. The reducing movement in CO_2 emissions accompanies the increasing direction in solar energy usage for the period 2014:1–2022:1.

In short, the empirical finding indicates a negative impact of solar energy consumption on carbon emissions in the long run. According to wavelet analysis results, Figs. 6 and 9 and Fig. 8 and 11 visualize the partial wavelet coherencies and their phase difference diagrams for 5–8 years of cycles, respectively. Partial wavelet coherencies that are depicted in Figs. 6 and 9 show that solar energy consumption and CO_2 emissions become more coherent (intense magenta-colored areas) after 2014 in lower frequencies of 5–8 years. This date, 2014, coincides with the design, discussion, and ratification period of the Renew300 Federal Renewable Energy Target Act of 2015 in 2014. This regulation sets a target of achieving 300 MW of renewable energy installments in federally assisted housing by 2020. Due to the nature of the act, which aims to construct on-site generation on federally subsidized roofs, solar power energy investments would be at the center of the program. Moreover, the Solar America Act of 2006 and the Solar America Initiative Act of 2009 mainly aimed at supporting research and development projects that maintain cost-reduction, technological progress, and integration into power markets to alter solar energy more competitive (IEA,2021). The common objective of these regulations is to diminish the ecological footprint of initial solar installments and reduce the long-run average cost of solar power to less than 5 cents/kWh by 2015. Since the year 2014 can be a probable candidate for a structural change in the relationship between solar energy consumption and CO_2 emissions, there exist high coherency areas in partial wavelet spectrums as well as a shift in phase difference diagrams after 2014.

On the other hand, prior to 2014, there is a positive CO_2 emission-leading relationship between solar energy consumption and CO_2 emission at lower frequencies (5–8 year frequencies). As an emerging energy technology in the 1990s and 2000s, solar energy investment decisions did likely arise depending on environmental degradation and its expected negative outcomes [101]. found that CO_2 emission causes solar energy consumption in India, where its solar energy market is developing and is similar to the USA renewable energy market in the 1990s. According to studies that employ quantile analysis, solar energy consumption significantly reduces CO_2 emissions in higher quantiles of CO_2 emissions or more developed renewable technology economies (Chien et al., 2021; [7]. Analogous to Refs. [93,101] state that solar energy consumption reduces CO_2 emissions in the USA and other developed countries except for Spain and India. These results support the structural shift in the US solar energy consumption and CO_2 emissions nexus at lower frequencies of investment in 2014.

At higher frequencies of 1–4 years (short/middle term), during the observed time intervals from 1994 to 1998, from 2005 to 2008, and from 2012 to 2021, partial wavelet coherencies and related phase differences imply that CO_2 emissions and solar energy consumption are positively coherent in the USA. This implies that CO_2 emissions, namely environmental concerns, support solar energy consumption, however, solar energy shocks do not affect CO_2 emissions in the short run. Increases in solar energy consumption were followed by mitigation in CO2 emissions in the long run (5–8 frequency band) after 2014.

5. Conclusion and policy recommendations

Global warming is among the top challenges for policymakers and governments across the globe. It has destroyed the ecosystem and threatened sustainable human survival on the earth. Literature records that recent spells of economic growth have spurred carbon emissions and hence global warming through the excessive consumption of fossil fuels. Therefore, it is crucial to switch from fossil fuels to renewable energy sources [126–130]. Considering the significance of climate change mitigation, the study has examined the influence of solar energy consumption on total energy-related CO_2 emissions in the USA during the monthly period 1990:1–2022:6 by using wavelet coherence analysis and partial wavelet transform analysis.

Solar energy consumption and CO_2 emissions have become more coherent after 2014 in the lower frequencies. An increase in solar energy usage was followed by a reduction in CO2 emissions in the long run at the 5–8 year cycle period after 2014. This date, 2014, coincides with the design, discussion, and ratification period of the Renew300 Federal

[1] Besides the wavelet coherency computations, we performed also the robustness check through wavelet-Monte Carlo simulations with 500 and 1000 replications. The results confirmed the main outputs of wavelet coherency computations given in Figs. 4 and 5 (Please see Figures A1-A1.1 and A2- A2.1 in Appendix).

[2] Besides the wavelet coherency computation, we performed also to robustness check of the Monte Carlo simulations with 500, and 1000 random error samples. The results confirmed the very minor differences (Please see Figures A1-A1.2 and A2- A2.2 in Appendix).

Renewable Energy Target Act of 2015 in 2014 which was aimed at achieving 300 MW of renewable energy installments by 2020 to diminish the ecological footprint of initial solar installments. Hence the year 2014 probably indicates the structural change in the relationship between solar energy consumption and CO_2 emissions. Before 2014, there exist a positive CO_2 emission-leading relationship between solar energy consumption and CO_2 emission at lower frequencies (5–8 years frequencies). As an emerging energy technology in the 1990s and 2000s, solar energy investment decisions induced environmental degradation.

Considering the empirical findings of the study, some policy recommendations are offered. As the consumption of solar energy has a positive influence on environmental quality. Hence it is desirable to boost the share of solar energy and other renewables to reduce the reliance on fossil fuels and safeguard environmental quality. To achieve this milestone, comprehensive, coordinated, and continuous efforts are required at all levels. For instance, policymakers and governments can introduce a stick-and-carrot policy by incentivizing investments in photovoltaic (PV) solar power systems and other renewables by providing tax exemptions, subsidies, and access to easy credit. At the micro level, homeowners and small enterprises should be provided easy loans and subsidies to install photovoltaic (PV) solar systems to restrict the usage of fossil fuel energy. On the other hand, governments might discourage the excessive production of fossil fuels by imposing environmental taxes and by withdrawing the incentives available to emission-led industries and sectors. Besides governments should prioritize investments in green research and development to boost environment-friendly inventions and innovations. Lastly, it is necessary to aware and educate the masses regarding the repercussions of emission-led climate change and global warming. Because the public is the ultimate sufferer of global warming. Besides they can curtail carbon emissions by boycotting the consumption of goods and services coming from industries that are destroying the environment.

The current research has some limitations. For instance, it investigates the linkage between solar energy and CO_2 emissions which are the major source of climate change, Due to the need for high-frequent data (i.e. weekly, monthly), this paper launched the monthly data for solar energy and CO_2 emissions and other control variables in the US. For comparison purposes, there is a need for high-frequent data for other developed and/or developing countries/regions, as well. Future works might consider monitoring the association between solar energy and CO_2 emissions for, i.e., European and/or Asian countries.

Future studies might also assess the influence of solar energy consumption on the emissions of other greenhouse gases like chlorofluorocarbons (CFCs), methane (CH_4), and Nitrous oxide (N_2O). Future researchers might consider, as well, the influence of green technology, green financing, and consumption of other renewables, such as wind and biofuels, on environmental quality for the panel of advanced countries.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Appendix

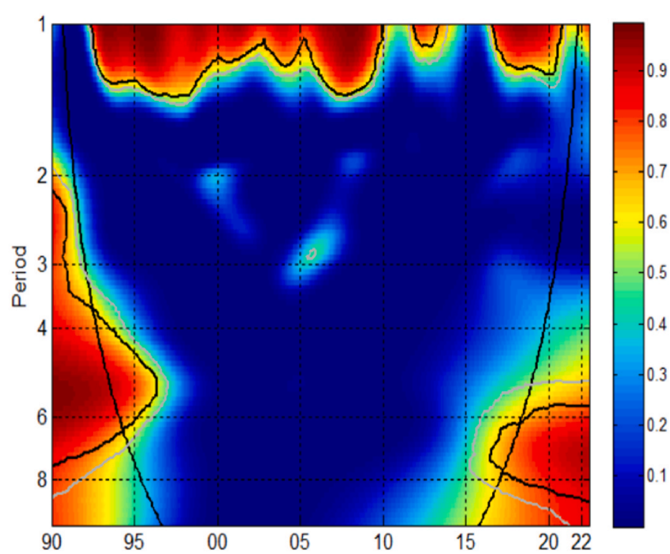

Fig. A1. Wavelet coherency (Solar, CO_2) by performing Monte Carlo simulations with 500 replications [p = 1; q = 1].

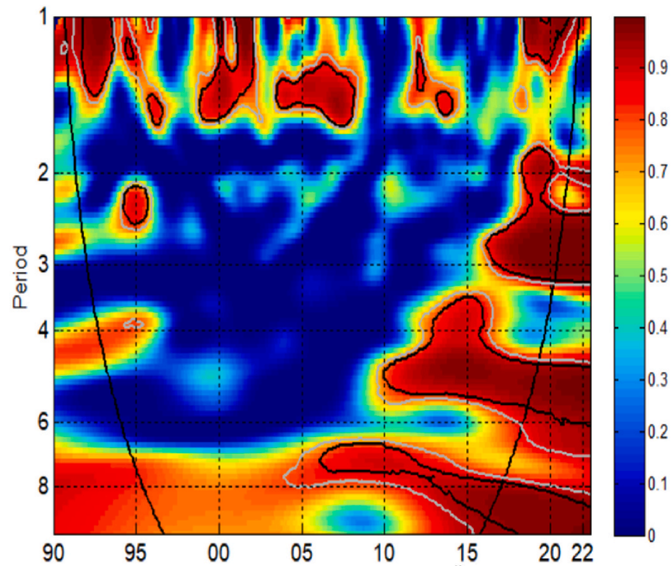

Fig. A1.1. Wavelet coherency (Solar, CO_2 ||Geo, Hydro,IP) by performing Monte Carlo simulations with 500 replications [p = 1; q = 1].

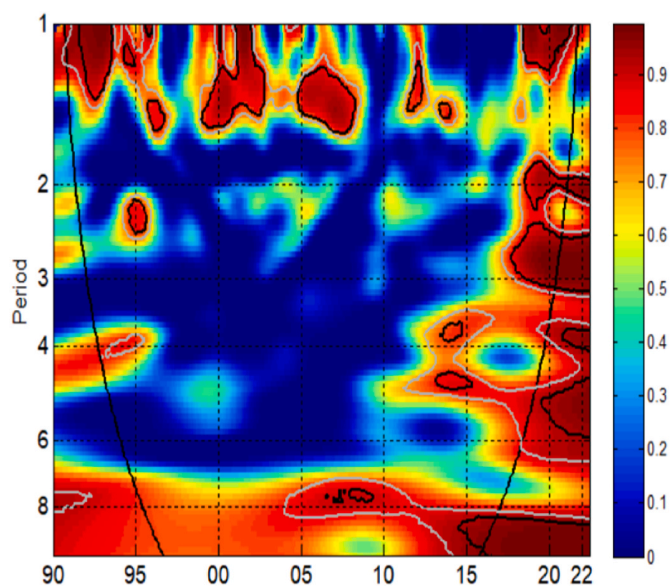

Fig. A1.2. Wavelet coherency (Solar, CO_2 ||Geo, Hydro, MANIP) by performing Monte Carlo simulations with 500 replications [p = 1; q = 1].

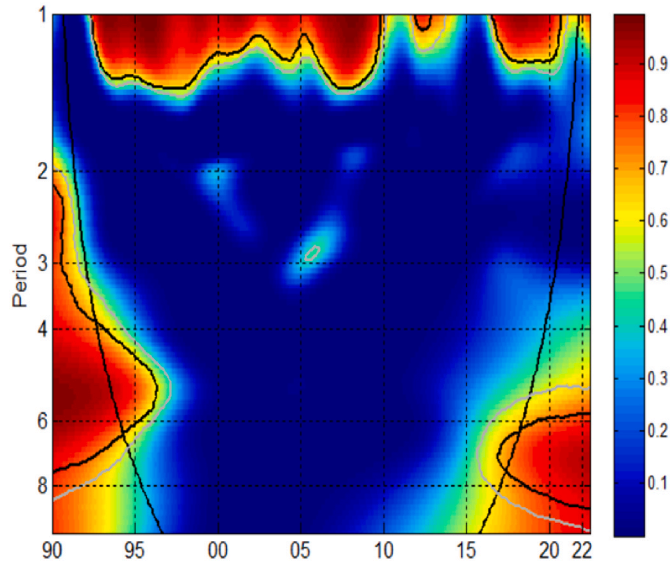

Fig. A2. Wavelet coherency (Solar, CO_2) by performing Monte Carlo simulations with 1000 replications [p = 1; q = 1].

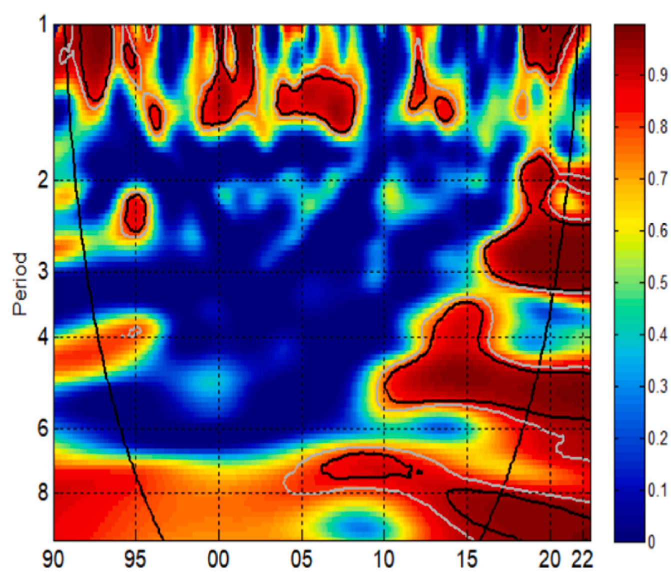

Fig. A2.1. Wavelet coherency (Solar, CO_2||Geo, Hydro, IP) by performing Monte Carlo simulations with 1000 replications [p = 1; q = 1].

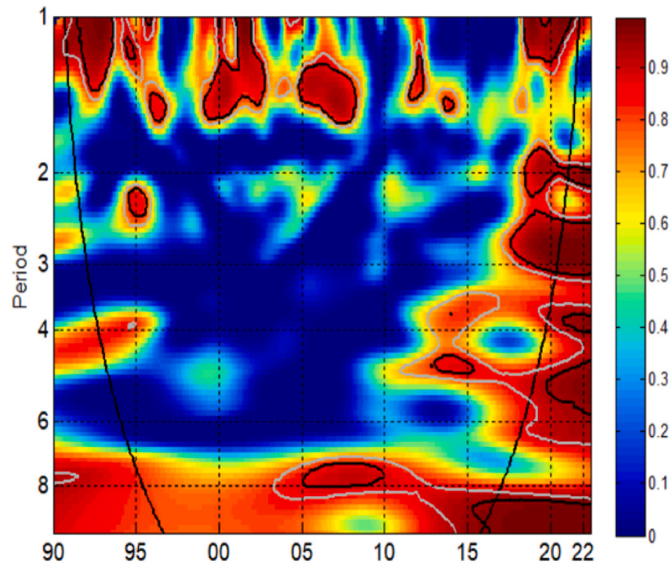

Fig. A2.2. Wavelet coherency (Solar, CO_2||Geo, Hydro, MANIP) by performing Monte Carlo simulations with 1000 replications [p = 1; q = 1].

References

[1] M.K. Mahalik, H. Mallick, H. Padhan, Do educational levels influence the environmental quality? The role of renewable and non-renewable energy demand in selected BRICS countries with a new policy perspective, Renew. Energy 164 (2021) 419–432, https://doi.org/10.1016/j.renene.2020.09.090.

[2] M.E. Karim, R. Karim, Md T. Islam, F. Muhammad-Sukki, N.A. Bani, M. N. Muhtazaruddin, Renewable energy for sustainable growth and development: an evaluation of law and policy of Bangladesh, Sustainability 11 (20) (2019) 5774, https://doi.org/10.3390/su11205774.

[3] F. Bilgili, İ. Öztürk, E. Koçak, Ü. Bulut, Y. Pamuk, E. Muğaloğlu, H.H. Bağlıtaş, The influence of biomass energy consumption on CO2 emissions: a wavelet coherence approach, Environ. Sci. Pollut. Control Ser. 23 (19) (2016) 19043–19061, https://doi.org/10.1007/s11356-016-7094-2.

[4] A. Dhar, M.A. Naeth, P. Dev Jennings, M.G. El-Din, Perspectives on environmental impacts and a land reclamation strategy for solar and wind energy systems, Sci. Total Environ. 718 (2020), 134602, https://doi.org/10.1016/j.scitotenv.2019.134602.

[5] UNEP, Carbon Emissions Gap Report 2022, 2022. https://www.unep.org/resources/emissions-gap-report-2022. (Accessed 1 November 2022).

[6] Climate Change, Impacts, Adaptation, and Vulnerability. Working Group II Contribution to the IPCC Sixth Assessment Report, 2022.

[7] J. Yu, Y.M. Tang, K.Y. Chau, R. Nazar, S. Ali, W. Iqbal, Role of solar-based renewable energy in mitigating CO2 emissions: evidence from quantilentile estimation, Renew. Energy 182 (2022) 216–226, https://doi.org/10.1016/j.renene.2021.10.002.

[8] M. Umar, X. Ji, D. Dervis Kirikkaleli, A.A. Andrew Adewale Alola, The imperativeness of environmental quality in the United States transportation sector amidst biomass-fossil energy consumption and growth, J. Clean. Prod. 285 (2021), 124863, https://doi.org/10.1016/j.jclepro.2020.124863.

[9] G.N. Ike, O. Usman, A.A. Alola, A. Samuel Asumadu Sarkodie, Environmental quality effects of income, energy prices and trade: the role of renewable energy consumption in G-7 countries, Sci. Total Environ. 721 (2020), 137813, https://doi.org/10.1016/j.scitotenv.2020.137813.

[10] M.W. Zafar, M. Shahbaz, A. Sinha, T. Sengupta, Q. Qin, How renewable energy consumption contribute to environmental quality? The role of education in OECD countries, J. Clean. Prod. 268 (2020), 122149, https://doi.org/10.1016/j.jclepro.2020.122149.

[11] T. Güney, Renewable energy, non-renewable energy and sustainable development, Int. J. Sustain. Dev. World Ecol. 26 (5) (2019) 389–397, https://doi.org/10.1080/13504509.2019.1595214.

[12] T. Tsoutsos, N. Frantzeskaki, V. Gekas, Environmental impacts from the solar energy technologies, Energy Pol. 33 (3) (2005) 289–296, https://doi.org/10.1016/S0301-4215(03)00241-6.

[13] M.M. Aman, K.H. Solangi, M.S. Hossain, A. Badarudin, G.B. Jasmon, A.H. A. Mokhlis, S.N. Bakar Kazi, A review of safety, health and environmental (SHE) issues of solar energy system, Renew. Sustain. Energy Rev. 41 (2015) 1190–1204, https://doi.org/10.1016/j.rser.2014.08.086.

[14] M.A. Khan, N. Latif, Environmental friendly solar energy in Pakistan's scenario, Renew. Sustain. Energy Rev. 14 (8) (2010) 2179–2181, https://doi.org/10.1016/j.rser.2010.03.016.

[15] T.A. Hamed, A. Alshare, Environmental impact of solar and wind energy-a review, J. Sustain. Dev. Energy, Water Environ. Syst. 10 (2) (2022) 1–23, https://doi.org/10.13044/j.sdewes.d9.0387.

[16] U. Mehmood, Contribution of renewable energy towards environmental quality: the role of education to achieve sustainable development goals in G11 countries, Renew. Energy 178 (2021) 600–607, https://doi.org/10.1016/j.renene.2021.06.118.

[17] M.K.H. Rabaia, M.A. Abdelkareem, E.T. Sayed, K. Elsaid, K.J. Chae, T. Wilberforce, A.G. Olabi, Environmental impacts of solar energy systems: a review, Sci. Total Environ. 754 (2021), 141989, https://doi.org/10.1016/j.scitotenv.2020.141989.

[18] IRENA, The Breakthrough Agenda Report 2022, The International Renewable Energy Agency, Abu Dhabi, 2022.

[19] F. Bilgili, S. Kuşkaya, N. Toğuç, E. Muğaloğlu, E. Kocak, Ü. Bulut, H.H. Bağlıtaş, A revisited renewable consumption-growth nexus: a continuous wavelet approach through disaggregated data, Renew. Sustain. Energy Rev. 107 (2019) 1–19, https://doi.org/10.1016/j.rser.2019.02.017.

[20] EIA, U.S. Energy Information Administration, 2022. https://www.eia.gov/. (Accessed 22 October 2022). Accessed.

[21] F. Bilgili, D. Balsalobre-Lorente, S. Kuşkaya, F. Ünlü, P. Gençoğlu, P. Rosha, The role of hydropower energy in the level of CO2 emissions: an application of continuous wavelet transform, Renew. Energy 178 (2021) 283–294, https://doi.org/10.1016/j.renene.2021.06.015.

[22] F. Bilgili, S. Kuşkaya, P. Gençoğlu, Y. Kassouri, A.P. Majok Garang, The co-movements between geothermal energy usage and CO2 emissions through high and low frequency- cycles, Environ. Sci. Pollut. Control Ser. 28 (2021) 63723–63738, https://doi.org/10.1007/s11356-020-11000-x.

[23] I. Al-Ayouty, H. Hoda, R. Reham, Clean Manufacturing Industries and Environmental Quality: the Case of Egypt, vol. 19, Environmental Development, 2017, https://doi.org/10.1016/j.envdev.2016.11.005. –25.

[24] A. Raihan, D.A. Muhtasim, S. Farhana, M.I. Pavel, O. Faruk, M. Rahman, A. Mahmood, Nexus between carbon emissions, economic growth, renewable energy use, urbanization, industrialization, technological innovation, and forest area towards achieving environmental sustainability in Bangladesh, Energy and Climate Change (2022), 100080, https://doi.org/10.1016/j.egycc.2022.100080.

[25] I. Khan, F. Hou, H. Phong Le, S.A. Ali, Do natural resources, urbanization, and value-adding manufacturing affect environmental quality? Evidence from the top ten manufacturing countries, Resour. Pol. 72 (2021), 102109, https://doi.org/10.1016/j.resourpol.2021.102109.

[26] A. Anwar, A. Nawaz, R.M. Ghulam, Industrialization, freight transport and environmental quality: evidence from belt and road initiative economies, Environ. Sci. Pollut. Control Ser. 27 (7) (2020) 7053–7070, https://doi.org/10.1007/s11356-019-07255-8.

[27] L.H. Phong, D.T. Bach Van, H.H.G. Bao, The role of globalization on carbon dioxide emission in Vietnam incorporating industrialization, urbanization, gross domestic product per capita and energy use, Int. J. Energy Econ. Pol. 8 (6) (2018) 275–283, https://doi.org/10.32479/ijeep.7065.

[28] X. Liu, J. Junghan Bae, Urbanization and industrialization impact of CO2 emissions in China, J. Clean. Prod. 172 (2018) 178–186, https://doi.org/10.1016/j.jclepro.2017.10.156.

[29] P.A. Kwakwa, The effect of industrialization, militarization, and government expenditure on carbon dioxide emissions in Ghana, Environ. Sci. Pollut. Control Ser. 29 (2022) 85229–85242, https://doi.org/10.1007/s11356-022-21187-w.

[30] S. Asumadu-Sarkodie, P.A. Owusu, The causal effect of carbon dioxide emissions, electricity consumption, economic growth, and industrialization in Sierra Leone, Energy Sources B Energy Econ. Plann. 12 (1) (2017) 32–39, https://doi.org/10.1080/15567249.2016.1225135.
[31] C. Schleicher, An Introduction to Wavelets for Economists, Bank of Canada, 2002. Working paper: 32.
[32] P.E. Brockway, H. Saunders, M.K. Heun, T.J. Foxon, J.K. Steinberger, Brockway PE. Barrett, H. Saunders, M.K. Heun, T.J. Foxon, J.K. Steinberger, J.R. Barrett, S. Sorrell, Energy rebound as a potential threat to a low-carbon future: findings from a new exergy-based national-level rebound approach, Energies 10 (1) (2017) 51, https://doi.org/10.3390/en10010051.
[33] J. Kraft, A. Kraft, On the Relationship between Energy and GNP, The Journal of Energy and Development, 1978, pp. 401–403. https://www.jstor.org/stable/24806805.
[34] A.T. Akarca, T.V. Long, On the relationship between energy and GNP: a reexamination, J. Energy Dev. (1980) 326–331.
[35] S.H. Eden, B.K. Hwang, The relationship between energy and GNP: further results, Energy Econ. 6 (3) (1984) 186–190, https://doi.org/10.1016/0140-9883(84)90015-X.
[36] S.H. Eden, J.C. Jin, Cointegration tests of energy consumption, income, and employment, Resour. Energy 14 (3) (1992) 259–266, https://doi.org/10.1016/0165-0572(92)90010-E.
[37] S.H. Eden, J.C. Jin, Cointegration tests of energy consumption, income, and employment, Resour. Energy 14 (3) (1992) 259–266, https://doi.org/10.1016/0165-0572(92)90010-E.
[38] D.I. Stern, Energy and economic growth in the USA: a multivariate approach, Energy Econ. 15 (2) (1993) 137–150, https://doi.org/10.1016/0140-9883(93)90033-N.
[39] B.S. Cheng, T.W. Lai, An investigation of co-integration and causality between energy consumption and economic activity in Taiwan, Energy Econ. 19 (4) (1997) 435–444, https://doi.org/10.1016/S0140-9883(97)01023-2.
[40] D.I. Stern, A multivariate cointegration analysis of the role of energy in the US macroeconomy, Energy Econ. 22 (2) (2000) 267–283, https://doi.org/10.1016/S0140-9883(99)00028-6.
[41] M. Mehrara, Energy consumption and economic growth: the case of oil exporting countries, Energy Pol. 35 (5) (2007) 2939–2945, https://doi.org/10.1016/j.enpol.2006.10.018.
[42] N. Apergis, J.E. Payne, Renewable energy consumption and economic growth: evidence from a panel of OECD countries, Energy Pol. 38 (1) (2010) 656–660, https://doi.org/10.1016/j.enpol.2009.09.002.
[43] M. Shahbaz, M. Mutascu, P. Azim, Environmental Kuznets curve in Romania and the role of energy consumption, Renew. Sustain. Energy Rev. 18 (2013) 165–173, https://doi.org/10.1016/j.rser.2012.10.012.
[44] I. Ozturk, U. Al-Mulali, Investigating the validity of the environmental Kuznets curve hypothesis in Cambodia, Ecol. Indicat. 57 (2015) 324–330, https://doi.org/10.1016/j.ecolind.2015.05.018.
[45] F. Bilgili, E. Koçak, Ü. Bulut, The dynamic impact of renewable energy consumption on CO2 emissions: a revisited Environmental Kuznets Curve approach, Renew. Sustain. Energy Rev. 54 (2016) 838–845, https://doi.org/10.1016/j.rser.2015.10.080.
[46] S.A. Kourtzidis, P. Tzeremes, N.G. Tzeremes, Re-evaluating the energy consumption-economic growth nexus for the United States: an asymmetric threshold cointegration analysis, Energy 148 (2018) 537–545, https://doi.org/10.1016/j.energy.2018.01.172.
[47] M.M. Rahman, E. Velayutham, Renewable and non-renewable energy consumption-economic growth nexus: new evidence from South Asia, Renew. Energy 147 (2020) 399–408, https://doi.org/10.1016/j.renene.2019.09.007.
[48] M. Salari, R.J. Javid, H. Noghanibehambari, The nexus between CO2 emissions, energy consumption, and economic growth in the US, Econ. Anal. Pol. 69 (2021) 182–194, https://doi.org/10.1016/j.eap.2020.12.007.
[49] I. Ozturk, A literature survey on energy–growth nexus, Energy Pol. 38 (1) (2010) 340–349, https://doi.org/10.1016/j.enpol.2009.09.024.
[50] E. Aramendia, P.E. Brockway, M. Pizzol, M.K. Heun, Moving from final to useful stage in energy-economy analysis: a critical assessment, Appl. Energy 283 (2021), 116194, https://doi.org/10.1016/j.apenergy.2020.116194.
[51] A. Naveed, N. Ahmad, R.F. Aghdam, A.N. Menegaki, What have we learned from Environmental Kuznets Curve hypothesis? A citation-based systematic literature review and content analysis, Energy Strategy Rev. 44 (2022), 100946, https://doi.org/10.1016/j.esr.2022.100946.
[52] A. Henningsen, G. Henningsen, E. van der Werf, Capital-labour-energy substitution in a nested CES framework: a replication and update of Kemfert (1998), Energy Econ. 82 (2019) 16–25, https://doi.org/10.1016/j.eneco.2017.12.019.
[53] E. Lagomarsino, Estimating elasticities of substitution with nested CES production functions: where do we stand? Energy Econ. 88 (2020), 104752 https://doi.org/10.1016/j.eneco.2020.104752.
[54] C. Papageorgiou, M. Saam, P. Schulte, Substitution between clean and dirty energy inputs: a macroeconomic perspective, Rev. Econ. Stat. 99 (2) (2017) 281–290, https://doi.org/10.1162/REST_a_00592.
[55] S.I. Khattak, M. Ahmad, Z. ul Haq, G. Shaofu, J. Hang, On the goals of sustainable production and the conditions of environmental sustainability: does cyclical innovation in green and sustainable technologies determine carbon dioxide emissions in G-7 economies, Sustain. Prod. Consum. 29 (2022) 406–420, https://doi.org/10.1016/j.spc.2021.10.022.
[56] E. Yildirim, Ş. Saraç, A. Aslan, Energy consumption and economic growth in the USA: evidence from renewable energy, Renew. Sustain. Energy Rev. 16 (9) (2012) 6770–6774, https://doi.org/10.1016/j.rser.2012.09.004.
[57] M.E. Bildirici, F. Özaksoy, The relationship between economic growth and biomass energy consumption in some European countries, J. Renew. Sustain. Energy 5 (2) (2013), 023141, https://doi.org/10.1063/1.4802944.
[58] F. Bilgili, I. Ozturk, Biomass energy and economic growth nexus in G7 countries: evidence from dynamic panel data, Renew. Sustain. Energy Rev. 49 (2015) 132–138, https://doi.org/10.1016/j.rser.2015.04.098.
[59] S.A. Solarin, I. Ozturk, On the causal dynamics between hydroelectricity consumption and economic growth in Latin America countries, Renew. Sustain. Energy Rev. 52 (2015) 1857–1868, https://doi.org/10.1016/j.rser.2015.08.003.
[60] D.Ş. Armeanu, G. Vintilă, Ş.C. Gherghina, Does renewable energy drive sustainable economic growth? multivariate panel data evidence for EU-28 countries, Energies 10 (3) (2017) 381, https://doi.org/10.3390/en10030381.
[61] U. Bulut, N. Apergis, 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 USA, Geojournal 86 (4) (2021) 1969–1980, https://doi.org/10.1007/s10708-020-10171-x.
[62] Q. Wang, L. Wang, R. Li, Renewable energy and economic growth revisited: the dual roles of resource dependence and anticorruption regulation, J. Clean. Prod. 337 (2022), 130514, https://doi.org/10.1016/j.jclepro.2022.130514.
[63] B. Ozcan, P.G. Tzeremes, N.G. Tzeremes, Energy consumption, economic growth and environmental degradation in OECD countries, Econ. Modell. 84 (2020) 203–213, https://doi.org/10.1016/j.econmod.2019.04.010.
[64] U. Soytas, R. Sari, B.T. Ewing, Energy consumption, income, and carbon emissions in the United States, Ecol. Econ. 62 (3–4) (2007) 482–489, https://doi.org/10.1016/j.ecolecon.2006.07.009.
[65] A. Omri, CO2 emissions, energy consumption and economic growth nexus in MENA countries: evidence from simultaneous equations models, Energy Econ. 40 (2013) 657–664, https://doi.org/10.1016/j.eneco.2013.09.003.
[66] A.O. Acheampong, Economic growth, CO2 emissions and energy consumption: what causes what and where? Energy Econ. 74 (2018) 677–692, https://doi.org/10.1016/j.eneco.2018.07.022.
[67] D. Debone, V.P. Leite, S.g. e. k. Miraglia, Modelling approach for carbon emissions, energy consumption and economic growth: a systematic review, Urban Clim. 37 (2021), 100849, https://doi.org/10.1016/j.uclim.2021.100849.
[68] P. Sadorsky, Renewable energy consumption, CO2 emissions and oil prices in the G7 countries, Energy Econ. 31 (3) (2009) 456–462, https://doi.org/10.1016/j.eneco.2008.12.010.
[69] U. Al-Mulali, I. Ozturk, S.A. Solarinn, Investigating the environmental Kuznets curve hypothesis in seven regions: the role of renewable energy, Ecol. Indicat. 67 (2016) 267–282, https://doi.org/10.1016/j.ecolind.2016.02.059.
[70] H. Jeon, CO2 emissions, renewable energy and economic growth in the US, Electr. J. 35 (7) (2022), 107170, https://doi.org/10.1016/j.tej.2022.107170.
[71] M.A. Ansari, Re-visiting the Environmental Kuznets curve for ASEAN: a comparison between ecological footprint and carbon dioxide emissions, Renew. Sustain. Energy Rev. 168 (2022), 112867, https://doi.org/10.1016/j.rser.2022.112867.
[72] S. Shafiei, R.A. Salim, Non-renewable and renewable energy consumption and CO2 emissions in OECD countries: a comparative analysis, Energy Pol. 66 (2014) 547–556, https://doi.org/10.1016/j.enpol.2013.10.064.
[73] M.B. Jebli, S.B. Youssef, I. Ozturk, Testing environmental Kuznets curve hypothesis: the role of renewable and non-renewable energy consumption and trade in OECD countries, Ecol. Indicat. 60 (2016) 824–831, https://doi.org/10.1016/j.ecolind.2015.08.031.
[74] H. Padhan, P.C. Padhang, A.K. Tiwari, R. Ahmed, S. Hammoudeh, Renewable energy consumption and robust globalization (s) in OECD countries: do oil, carbon emissions and economic activity matter? Energy Strategy Rev. 32 (2020), 100535 https://doi.org/10.1016/j.esr.2020.100535.
[75] T. Dogru, U. Bulut, E. Kocak, C. Isik, C. Suess, E. Sirakaya-Turk, The nexus between tourism, economic growth, renewable energy consumption, and carbon dioxide emissions: contemporary evidence from OECD countries, Environ. Sci. Pollut. Control Ser. 27 (32) (2020) 40930–40948, https://doi.org/10.1007/s11356-020-10110-w.
[76] C. Cheng, X. Ren, Z. Wang, The impact of renewable energy and innovation on carbon emission: an empirical analysis for OECD countries, Energy Procedia 158 (2019) 3506–3512, https://doi.org/10.1016/j.egypro.2019.01.919.
[77] A.J. López-Menéndez, R. Pérez, B. Moreno, Environmental costs and renewable energy: Re-visiting the environmental Kuznets curve, J. Environ. Manag. 145 (2014) 368–373, https://doi.org/10.1016/j.jenvman.2014.07.017.
[78] E. Dogan, F. Seker, Determinants of CO2 emissions in the European Union: the role of renewable and non-renewable energy, Renew. Energy 94 (2016) 429–439, https://doi.org/10.1016/j.renene.2016.03.078.
[79] T. Baležentis, D. Streimikiene, T. Zhang, G. Liobikiene, The role of bioenergy in greenhouse gas emission reduction in EU countries: an Environmental Kuznets Curve modelling, Resour. Conserv. Recycl. 142 (2019) 225–231, https://doi.org/10.1016/j.resconrec.2018.12.019.
[80] R. Zeb, L. Salar, U. Awan, K. Zaman, M. Shahbaz, Causal links between renewable energy, environmental degradation and economic growth in selected SAARC countries: progress towards green economy, Renew. Energy 71 (2014) 123–132, https://doi.org/10.1016/j.renene.2014.05.012.
[81] R. Akram, F. Chen, F. Khalid, Z. Ye, M.T. Majeed, Heterogeneous effects of energy efficiency and renewable energy on carbon emissions: evidence from developing countries, J. Clean. Prod. 247 (2020), 119122, https://doi.org/10.1016/j.jclepro.2019.119122.

[82] J.L. Liu, C.Q. Ma, Y.S. Ren, X.W. Zhao, Do real output and renewable energy consumption affect CO2 emissions? Evidence for selected BRICS countries, Energies 13 (4) (2020) 960, https://doi.org/10.3390/en13040960.
[83] Danish, R. Ulucak, How do environmental technologies affect green growth? Evidence from BRICS economies, Sci. Total Environ. 712 (2020), 136504, https://doi.org/10.1016/j.scitotenv.2020.136504. ISSN 0048-9697.
[84] E. Dogan, I. Ozturk, The influence of renewable and non-renewable energy consumption and real income on CO2 emissions in the USA: evidence from structural break tests, Environ. Sci. Pollut. Control Ser. 24 (11) (2017) 10846–10854, https://doi.org/10.1007/s11356-017-8786-y.
[85] O. Usman, A.A. Alola, S.A. Sarkodie, Assessment of the role of renewable energy consumption and trade policy on environmental degradation using innovation accounting: evidence from the US, Renew. Energy 150 (2020) 266–277, https://doi.org/10.1016/j.renene.2019.12.151.
[86] R. Sari, B.T. Ewing, U. Soytas, The relationship between disaggregate energy consumption and industrial production in the United States: an ARDL approach, Energy Econ. 30 (5) (2008) 2302–2313, https://doi.org/10.1016/j.eneco.2007.10.002.
[87] J. Zhao, A.K. Patwary, A. Qayyum, M. Alharthi, F. Bashir, M. Mohsin, Q. Abbas, The determinants of renewable energy sources for the fueling of green and sustainable economy, Energy 238 (2022), 122029, https://doi.org/10.1016/j.energy.2021.122029.
[88] W. Zhao, Y. Liu, L. Huang, Estimating environmental Kuznets Curve in the presence of eco-innovation and solar energy: an analysis of G-7 economies, Renew. Energy 189 (2022) 304–314, https://doi.org/10.1016/j.renene.2022.02.120.
[89] X. Zhao, T.S. Adebayo, X. Kong, M.A.S. Al-Faryan, Relating energy innovations and natural resources as determinants of environmental sustainability: the role of globalization in G7 countries, Resour. Pol. (2022), 103073, https://doi.org/10.1016/j.resourpol.2022.103073.
[90] A. Ohler, I. Fetters, The causal relationship between renewable electricity generation and GDP growth: a study of energy sources, Energy Econ. 43 (2014) 125–139, https://doi.org/10.1016/j.eneco.2014.02.009.
[91] T. Grijó, I. Soares, Solar photovoltaic investments and economic growth in EU: are we able to evaluate the nexus? Environ. Dev. Sustain. 18 (5) (2016) 1415–1432, https://doi.org/10.1007/s10668-016-9806-7.
[92] M.A. Destek, A. Aslan, Disaggregated renewable energy consumption and environmental pollution nexus in G-7 countries, Renew. Energy 151 (2020) 1298–1306, https://doi.org/10.1016/j.renene.2019.11.138.
[93] L. Zhu, W. Fang, S.U. Rahman, A.I. Khan, How Solar-Based Renewable Energy Contributes to CO2 Emissions Abatement? Sustainable Environment Policy Implications for Solar Industry, Energy & Environment, 2021, 0958305X211061886, https://doi.org/10.1177/0958305X211061886.
[94] S. Kuşkaya, Residential solar energy consumption and greenhouse gas nexus: evidence from Morlet wavelet transforms, Renew. Energy 192 (2022) 793–804, https://doi.org/10.1016/j.renene.2022.04.107.
[95] R. Elghamry, H. Hassan, A.A. Hawash, A parametric study on the impact of integrating solar cell panel at building envelope on its power, energy consumption, comfort conditions, and CO2 emissions, J. Clean. Prod. 249 (2020), 119374, https://doi.org/10.1016/j.jclepro.2019.119374.
[96] C. Gao, S. Zhu, N. An, H. Na, H. You, C. Gao, Comprehensive comparison of multiple renewable power generation methods: a combination analysis of life cycle assessment and ecological footprint, Renew. Sustain. Energy Rev. 147 (2021), 111255, https://doi.org/10.1016/j.rser.2021.111255.
[97] Z. Li, Y.K. Kuo, A.R. Mahmud, A.A. Nassani, M. Haffar, I. Muda, Integration of renewable energy, environmental policy stringency, and climate technologies in realizing environmental sustainability: evidence from OECD countries, Renew. Energy 196 (2022) 1376–1384, https://doi.org/10.1016/j.renene.2022.07.084.
[98] N.S.M.N. Izam, Z. Itam, W.L. Sing, A. Syamsir, Sustainable development perspectives of solar energy technologies with focus on solar photovoltaic—a review, Energies 15 (8) (2022) 2790, https://doi.org/10.3390/en15082790.
[99] X. Zheng, Y. Lu, J. Yuan, Y. Baninla, S. Zhang, N.C. Stenseth, D. Chen, Drivers of change in China's energy-related CO2 emissions, Proc. Natl. Acad. Sci. USA 117 (1) (2020) 29–36, https://doi.org/10.1073/pnas.1908513117.
[100] S. Das, E. Hittinger, E. Williams, Learning is not enough: diminishing marginal revenues and increasing abatement costs of wind and solar, Renew. Energy 156 (2020) 634–644, https://doi.org/10.1016/j.renene.2020.03.082.
[101] C. Magazzino, M. Mele, N. Schneider, A machine learning approach on the relationship among solar and wind energy production, coal consumption, GDP, and CO2 emissions, Renew. Energy 167 (2021) 99–115, https://doi.org/10.1016/j.renene.2020.11.050.
[102] A. Sharif, M. Bhattacharya, S. Afshan, M. Shahbaz, Disaggregated renewable energy sources in mitigating CO2 emissions: new evidence from the USA using quantile regressions, Environ. Sci. Pollut. Control Ser. 28 (41) (2021) 57582–57601, https://doi.org/10.1007/s11356-021-13829-2.
[103] K. Zaman, A.R.A. Aziz, S. Sriyanto, Y. Indrianti, H. Jambari, The role of solar energy demand in the relationship between carbon pricing and environmental degradation: a blessing in disguise, J. Publ. Aff. (2021), e2702, https://doi.org/10.1002/pa.2702.
[104] F. Chien, C.C. Hsu, Z. Andlib, M.I. Shah, T. Ajaz, M.G. Genie, The role of solar energy and eco-innovation in reducing environmental degradation in China: evidence from QARDL approach, Integr. Environ. Assess. Manag. 1 (2021) 17, https://doi.org/10.1002/ieam.4500.
[105] T. Güney, Solar energy, governance and CO2 emissions, Renew. Energy 184 (2022) 791–798, https://doi.org/10.1016/j.renene.2021.11.124.
[106] F. Emir, S. Karlilar, Application of RALS Cointegration Test Assessing the Role of Natural Resources and Hydropower Energy on Ecological Footprint in Emerging Economy, Energy & Environment, 2022, https://doi.org/10.1177/0958305X21107380, 0958305X211073807.
[107] EIA, Tax Credits and Solar Tariffs Affect Timing of Projected Renewable Power Plant Deployment, 2018. https://www.eia.gov/todayinenergy/detail.php?id=36212. (Accessed 20 November 2022). Accessed.
[108] EIA, Extending Investment Tax Credits through 2050 Increases U.S. Solar Generation by 10%, 2022. https://www.eia.gov/todayinenergy/detail.php?id=53219. (Accessed 20 November 2022). Accessed.
[109] IEA, IEA Policies Database, 2021. https://www.iea.org/policies/12729-consolidated-appropriations-act. (Accessed 15 November 2022).
[110] Fred, Federal Reserve Economic Data, 2022. https://fred.stlouisfed.org/. (Accessed 22 October 2022).
[111] EIA, Annual Energy Outlook 2022-Narrative Electricity Charts, 2022. https://www.eia.gov/outlooks/aeo/pdf/AEO2022_ChartLibrary_Electricity.pdf. (Accessed 26 November 2022). Accessed.
[112] EIA, EIA Projects Renewables Share of U.S. Electricity Generation Mix Will Double by 2050, 2021. https://www.eia.gov/todayinenergy/detail.php?id=46676. (Accessed 25 November 2022). Accessed.
[113] L. Aguiar-Conraria, M.J. Soares, The continuous wavelet transform: a Primer, in: NIPE Working Papers 16/2011, NIPE - Universidade do Minho, 2011.
[114] N. Bhatnagar, Introduction to Wavelet Transforms, first ed., Chapman and Hall/CRC, 2020 https://doi.org/10.1201/9781003006626.
[115] Y. Kassouri, F. Bilgili, S. Kuşkaya, A wavelet-based model of world oil shocks interaction with CO2 emissions in the US, Environ. Sci. Pol. 127 (2022) 280–292, https://doi.org/10.1016/j.envsci.2021.10.020.
[116] K. Belaid, A. Miloudi, H. Bournine, The processing of resonances excited by gear faults using continuous wavelet transform with adaptive complex Morlet wavelet and sparsity measurement, Measurement 180 (2021), 109576, https://doi.org/10.1016/j.measurement. 2021.109576.
[117] J. Sadowsky, Investigation of signal characteristics using the continuous wavelet transform, Johns Hopkins APL Tech. Dig. 17 (3) (1996) 258–269.
[118] Q. Shu, Z. Liu, B.C. Si, Characterizing scale and location dependent correlation of water retention parameters with soil physical properties using wavelet techniques, J. Environ. Qual. 37 (6) (2008) 2284–2292, https://doi.org/10.2134/jeq2007.0179.
[119] A. Biswas, B.C. Si, Application of continuous wavelet transform in examining soil spatial variation: a review, Math. Geosci. 43 (3) (2011) 379–396, https://doi.org/10.1007/s11004-011-9318-9.
[120] K. Kannan, T. Deepika, Analysis and Comparison of Different Wavelet Transform Methods Using Benchmarks for Image Fusion, 2020 *arXiv preprint arXiv:2007.11488*.
[121] C.-C. Chang, C.-P. Yu, Y. Lin, Distinction between crack echoes and rebar echoes based on Morlet wavelet transform of impact echo signals, NDT&E Int. 108 (2019), 102169, https://doi.org/10.1016/j.ndteint.2019.102169.
[122] J. Morlet, A. Grossmann, Decomposition of hardy functions into square integrable wavelets of constant shape, SIAM J. Math. Anal. 15 (1984) 723–736, https://doi.org/10.1137/0515056.
[123] O.P. Neto, A.O. Pinheiro, V.L. Pereira Jr., R. Pereira, O.C. Baltatu, L.A. Campos, Morlet wavelet transforms of heart rate variability for autonomic nervous system activity, Appl. Comput. Harmon. Anal. 40 (2016) 200–206, https://doi.org/10.1016/j.acha.2015.07.002.
[124] Q. Sun, W. Xu, Wavelet analysis of the co-movement and lead–lag effect among multi-markets, Phys. Stat. Mech. Appl. 512 (2018) 489–499, https://doi.org/10.1016/j.physa.2018.08.102.
[125] L. Vacha, J. Barunik, Co-movement of energy commodities revisited: evidence from wavelet coherence analysis, Energy Econ. 34 (2012) 241–247, https://doi.org/10.1016/j.eneco.2011.10.007.
[126] T.M. Letcher, Why do we have global warming? Manag. Global Warming Inter. Technol. Human Iss. (2019) 3–15, https://doi.org/10.1016/B978-0-12-814104-5.00001-6.
[127] F. Martins, C. Felgueiras, M. Smitkova, N. Caetano, Analysis of fossil fuel energy consumption and environmental impacts in European countries, Energies 12 (2019) 964, https://doi.org/10.3390/en12060964.
[128] J. Lelieveld, K. Klingmüller, A. Pozzer, R.T. Burnett, A. Haines, V. Ramanathan, Effects of fossil fuel and total anthropogenic emission removal on public health and climate, Proc. Natl. Acad. Sci. USA 116 (15) (2019) 7192–7197, https://doi.org/10.1073/pnas.1819989116.
[129] S.E. Schwartz, Does fossil fuel combustion lead to global warming? Energy 18 (12) (1993) 1229–1248, https://doi.org/10.1016/0360-5442(93)90012-3.
[130] D.J. Wuebbles, A.K. Jain, Concerns about climate change and the role of fossil fuel use, Fuel Process. Technol. 71 (2001) 99–119, https://doi.org/10.1016/S0378-3820(01)00139-4.