TYPE Original Research
PUBLISHED 14 July 2023
DOI 10.3389/fenrg.2023.1123269

Check for updates

OPEN ACCESS

EDITED BY
Michael Carbajales-Dale,
Clemson University, United States

REVIEWED BY
Amir Waseem,
Quaid-i-Azam University, Pakistan
Antonio Rodriguez Andres,
German University in Cairo, Egypt

*CORRESPONDENCE
Raufhon Salahodjaev,
salahodjaev@gmail.com

RECEIVED 13 December 2022
ACCEPTED 30 June 2023
PUBLISHED 14 July 2023

CITATION
Mirziyoyeva Z and Salahodjaev R (2023), Renewable energy, GDP and CO_2 emissions in high-globalized countries. *Front. Energy Res.* 11:1123269. doi: 10.3389/fenrg.2023.1123269

Renewable energy, GDP and CO_2 emissions in high-globalized countries

Ziroat Mirziyoyeva[1] and Raufhon Salahodjaev[1,2]*

[1]Tashkent Institute of Irrigation and Melioration, Tashkent, Uzbekistan, [2]School of Business, Central Asian University, Tashkent, Uzbekistan

Introduction: Policymakers devote significant efforts to decrease CO_2 emissions, as climate change has Q7 numerous adverse impacts on society. While the global level of CO_2 emissions has been gradually rising since the 1990s, the highest growth was observed in low- and middle-income economies. This study differs from nascent research as it fills the gap by exploring the GDP-energy-CO_2 emissions nexus for the top 50 highly globalized countries under analysis. Our study explores the multidimensional relationship between economic growth, renewable energy, globalization, and climate change, using CO_2 emissions as a proxy for air pollution, and focusing on the most globalized countries.

Methods: In this study, we rely on dynamic panel estimators such as the two-step system GMM estimator. System GMM estimator is recommended to use with the panel data when 1) the correlation between a dependent variable and its lag is above 0.8; and 2) the number of countries (i.e., 50 countries) exceeds the time frame (i.e., 19 years). As our study design fits these conditions, we use extension of a two-step system GMM estimator which restricts the expansion of instruments. Moreover, a two-step system GMM estimator is especially efficient as it controls for heteroskedasticity.

Results: We find that renewable energy and globalization decrease CO_2 emissions. If causal, a 1 percentage point increase in the share of renewable energy in total energy consumption leads to a 0.26% decrease in per capita CO_2 emissions. Similarly, we find that a larger representation of women in national parliament contributes to the reduction in CO_2 emissions. GDP per capita has an inverted U-shaped relationship with CO_2 emissions and the turning point is approximately 67,200 international dollars adjusted for PPP.

Discussion: Our results suggest that renewable energy significantly contributes to the reduction of carbon emissions while GDP per capita has an inverted U-shaped link with CO_2 emissions. Thus, we confirm the presence of the EKC hypothesis for highly-globalized countries. Consequently, our study offers several policy implications. Firstly, it is important for developing countries to increase the share of energy consumed from renewable energy sources. This will have a positive effect not only on air quality, but also on economic growth. Thus, it is essential to increase investment in the renewable energy sector and create conditions and benefits for the rapid adoption of renewable technologies by the private sector and households. Secondly, it is crucial to increase the quality of investment climate. Developing countries can significantly gain from globalization-driven FDI as this can lead to technology transfer, especially in the energy sector. Thirdly, our results suggest that improving female empowerment can significantly reduce the vulnerability to climate change. This can be achieved by increasing women's human capital and investing in women-led organizations and communities.

KEYWORDS

renewable energy, GDP, CO_2 emissions, women in parliament, globalization

Introduction

Policymakers devote significant efforts to decrease CO_2 emissions, as climate change has numerous adverse impacts on society. While the global level of CO_2 emissions has been gradually rising since the 1990s, the highest growth was observed in low- and middle-income economies. Scholarly literature suggests that economic growth and energy consumption are considered as main antecedents of CO_2 emissions at global and regional levels (Acaravci and Ozturk, 2010; Saboori and Sulaiman, 2013). As a result, the transition towards energy efficient and green economic growth has been acknowledged as a new sustainable development agenda. Indeed, the examination of the GDP-energy-CO_2 emissions links has grown considerably in size over the past two decades. Along these lines, with the focus on environmental degradation, the literature can be separated into three streams. The first line of research explores the relationship between economic development and CO_2 emissions through the underpinnings of the Environmental Kuznets curve (EKC) framework stemming from the study by Grossman and Krueger (Grossman and Krueger, 1991). The EKC theory suggests inverted U-shape relationship between economic growth and environmental degradation and posits that "environmental pressure increases faster than income in the early stage of development and slows down relative to GDP growth in higher income levels" (Dinda, 2004). In low-income countries, industrialization and rapid growth of related industries spur pollution due to intensified economic activities and prioritization of economic growth. However, as GDP *per capita* increases the adoption of energy-efficient technologies and the development of industries with lower carbon footprint remove thepressure on the environment, and carbon emissions decrease. The empirical assessment of the existence of the EKC has proliferated with the increased availability of cross-country data [see, e.g., Anwar et al. (2022) for an excellent bibliometric analysis]. For example, the EKC has been confirmed for single countries such as Kenya (Sarkodie and Ozturk, 2020), Malaysia (Suki et al., 2020), Bangladesh (Murshed et al., 2021) and Brazil (Polloni-Silva et al., 2021). In a similar vein, inverted U-shaped link between GDP and CO_2 emissions has been validated for various regions, including PIIGS countries (Balsalobre-Lorente et al., 2022), E7 countries (Bekun et al., 2021), East African countries (Demissew Beyene and Kotosz, 2020), among others. At the same time some studies fail to identify EKC [see, e.g., Dogan and Inglesi-Lotz (2020) for European region, Dogan et al. (2020) for BRICST, Haliru et al. (2020) for West African countries, Ansari et al. (2020) for GCC countries].

The second group of studies explores how renewable energy in the total energy mix influences air quality, and, especially how it can mitigate climate change effects without harming economic growth trajectories. Indeed, a meta-analysis of more than 79,000 studies by (Kılıç Depren et al., 2022) shows that "the number of renewable energy-related studies has exceeded the number of fossil fuel-related studies regarding environmental degradation" (p. 1). Energy is considered an instrumental driver of economic growth (Tang et al., 2016) but it has also been shown to be linked to air pollution (Wang et al., 2018). In contrast, a shift towards the use of renewable energy as a replacement for fossil fuels has been documented to increase air quality and improve energy security (Aized et al., 2018). Moreover, numerous studies confirm the positive contribution of renewable energy to quality of life by showing that investment in renewable energy increases longevity (Rodriguez-Alvarez, 2021) and decreases human mortality (Shah et al., 2022) and income inequality (Topcu and Tugcu, 2020). The International Energy Agency expects that global renewable energy supply can increase by more than 60% compared to the year 2020 (IEA, 2021). Thus, increase deployment of renewables can have numerous positive implications as suggested by extant research. The third strand of studies considers the role of additional macroeconomic factors beyond renewable energy and GDP *per capita*. Within this stream of published evidence global integration is recognized as one of the essential predictors of CO_2 emissions. Under the assumptions of the pollution haven hypothesis (PHH), globalization drives the relocation of carbon-intensive industries to countries with less stringent environmental regulations. Thus, PHH conjectures a positive link between globalization and CO_2 emissions. However, the pollution halo hypothesis postulates that globalization leads to the export of green energy-efficient technologies which expands economic activity without pressure on the environment (Zhang and Zhou, 2016). A number of studies have indeed confirmed that globalization improves environmental quality and increases energy efficiency (Baloch et al., 2021; Liu et al., 2022). The analysis of the effects of renewable energy and GDP *per capita* on CO_2 emissions in the context of high-globalized countries is exceptionally relevant. A significant breakthrough in globalization can affect CO_2 emissions via shifts in energy demand (Doğan et al., 2022), effective distribution of production inputs, technological diffusion, and increased exchange of knowledge (Samimi and Jenatabadi, 2014). To the best of our knowledge, extant studies have explored the joint effects of economic growth, renewable energy, and globalization on CO_2 emissions and reported mixed results. This study differs from nascent research as it fills the gap by exploring the GDP-energy-CO_2 emissions nexus for the top 50 highly globalized countries under analysis. Our study explores the multidimensional relationship between economic growth, renewable energy, globalization, and climate change, using CO_2 emissions as a proxy for air pollution, and focusing on the most globalized countries. As (Leal and Marques, 2020) suggest "globalization is a complex phenomenon made up of many components. Its effect on the environment, when studied as a whole, leaves many questions unanswered" (p. 37). Over the last two decades, two important trends have emerged: a surge in renewable energy deployment and increased globalization in less-developed countries. All these advancements indicate that renewable energy use and economic growth are thus likely to have impacts on greenhouse gas emissions depending. The rest of the study is structured as follows. Section 2 provides a brief overview of the recent empirical literature. Section 3 presents the data and methodology. Section 4 discusses the main results while Section 5 concludes the study.

Literature review

Carbon emissions and GDP *per capita*

Theoretical claims and empirical studies of the link between GDP *per capita* and CO_2 emissions overall suggest the existence of an inverted U-shaped (the so-called EKC) relationship. (Murshed et al., 2020) investigated the EKC hypothesis for OPEC member states using panel spatial regression models. The results for the years 1992–2015 confirm the validity of the EKC hypothesis. At the same time, the sectoral analysis also shows the significance of the non-linear relationship between value added and air pollution varies depending on the sub-sector. (Dogan and Inglesi-Lotz, 2020) examined the relationship between GDP, economic structure, and CO_2 emissions, under the EKC framework for Europe for the years 1980–2014. The study discovered that aggregate economic growth exerts an inverted U-shaped link with CO_2 emissions. However, economic structure has a U-shaped effect on air pollution. (Bibi and Jamil, 2021) tests the existence of the EKC hypothesis for six regions over the period 2000–2018. The study using random effects and fixed effects models documents that EKC is valid for the majority of the regions. Using panel data for EU countries, (Bekun et al., 2021) endorses the existence of an inverted U-shaped relationship between economic development and environmental degradation. The Granger causality test further shows that causality runs from GDP growth to air pollution. (Heidari et al., 2015) found that economic growth is non-monotonically related to CO_2 emissions in ASEAN countries. The panel smooth transition regression (PSTR) validates the EKC hypothesis with the threshold regime at 4,686 USD. (Leal and Marques, 2020) examined the presence of the EKC hypothesis in the top 20 highest CO_2 producing economies over the period 1990–2016. The Driskoll-Kraay estimator showed that EKC is only valid for highly-globalized countries. Noteworthy, a number of studies explored the EKC hypothesis focusing on a single country. (Pata, 2018) analyzed Turkey over the period 1974–2014 using ARDL and FMOLS regressions, documenting the statistically significant inverted U-shaped evidence between GDP and CO_2 emissions. However, the long-run estimates showed that the turning point is 13,523–14,077 US Dollars which is outside the sample data. (Katircioğlu, 2014) document the validity of the tourism-driven EKC hypothesis for Singapore between 1971–2010, using Maki cointegration and other time series regression methods. At the same time, (Işik et al., 2020) explored the presence of the tourism-induced EKC hypothesis for G7 countries from 1995–2015. The authors discovered that the tourism-induced EKC hypothesis holds only for France.

Renewable energy and CO_2 emissions

The relationship between renewable energy and carbon emissions was examined by using regional and single-country cases. The majority of these studies report that renewable energy deployment mitigates CO_2 emissions. Using a number of panel data methods (Haldar and Sethi, 2021) found that renewable energy decreases CO_2 emissions in the long run in the case of 39 developing countries over the period 1995–2017. Moreover, the study highlights that it is instrumental to improve quality of institutions and increase the use of renewable energy to raise air quality. (Zoundi, 2017) tests the hypothesis of whether renewable energy can act as an efficient replacement for fossil fuels for 25 African countries over the period 1980–2012. While the study fails to confirm EKC for selected African countries, renewable energy has a negative and significant effect on CO_2 emissions. By using the cointegration estimator and Granger causality test, (Ben Jebli et al., 2019a) examines the relationship between renewable energy, GDP growth, and CO_2 emissions across 22 Central and South American countries between 1995–2010. The study found that there is unidirectional causality from renewable energy and FDI to CO_2 emissions. The study stresses the need to encourage renewable energy adoption to mitigate climate change. (Dogan and Seker, 2016) assess the drivers of CO_2 emissions in EU member states over the period 1980–2012. Using the dynamic OLS regression method, the authors find that renewable energy mitigates CO_2 emissions and GDP has an EKC type relationship with air pollution. The study also documents bi-directional causality between renewable energy and CO_2 emissions. In turn, using the generalized spatial two-stage least squares (GS2SLS) method, (Radmehr et al., 2021) found a unidirectional causality running from renewable energy to CO_2 emissions. (Leitão and Lorente, 2020) confirms that trade, tourism, and renewable energy reduce climate change in EU member states, using FMOLS, DOLS, and GMM estimators. At the same time, the study showed that economic growth is positively associated with environmental degradation. In turn, (Huang et al., 2021) focus on major energy-consuming economies to assess the relationship between renewable energy and carbon emissions over the period of 2000–2015. Using a two-step GMM estimator, the authors show that the renewable energy sector has substantial potential to mitigate climate change effects in countries with the highest demand for energy use. Mentel et al. (2022b) examine the relationship between industrialization, renewable energy, and CO_2 emissions in 48 countries of Europe and Central Asia (ECA). The study using a two-step GMM estimator finds that 1) renewable energy decrease CO_2 emissions; 2) renewable energy offsets the positive effect of industrialization on CO_2 emissions; 3) the EKC hypothesis is verified for ECA countries. In the case of single-country studies, the importance of renewable energy to decrease CO_2 emissions was verified for Ecuador, Thailand, China, India, and Portugal, among others (Robalino-López et al., 2014; Sinha and Shahbaz, 2018; Chen et al., 2019; Abbasi et al., 2021a; Adebayo et al., 2022).

Globalization and CO_2 emissions

A separate strand of studies has explored the role of globalization in the presence of EKC framework. For example, Farooq et al. (2022)

assessed the relationship between globalization and environmental quality in a sample of 180 nations over the period 1980–2016. Using panel quantile regression methods, the authors find that only economic dimension of globalization has negative effect on CO_2 emissions. Liu et al. (2020), using semi-parametric fixed effects regression estimator for a sample G7 countries over the period 1970–2015, find that globalization exerts non-linear impact on CO_2 emissions. Mehmood (2021) documents that social and economic globalization decrease CO_2 emissions in Singapore using ARDL estimator. Mehmood and Tariq (2020) observed mixed results for South Asian countries over the period 1972–2013. The authors find that inverted U-shaped relationship exists in Nepal, Afghanistan, Bangladesh and Sri Lanka, while U-shaped relationship is observed for Pakistan and Bhutan. Nguyen and Le (2020) use ARDL estimator to assess the relationship between globalization and CO_2 emissions in Vietnam over the period 1990–2016. The results show that globalization increases CO_2 emissions while export oriented policies lead to a reduction in environmental degradation. Overall, the review of studies shows that the effects of globalization are at best mixed for different regions and countries.

Empirical model and data

Empirical model

Although there is no universally adopted empirical model for CO_2 emissions, numerous scholars such as (Mirziyoyeva and Salahodjaev, 2022b; Khoshnevis Yazdi and Shakouri, 2018; Sun et al., 2022; Satrovic and Muslija, 2019; Salahodjaev et al., 2022) included urbanization, tourism, and women's presence in parliament among others to model the relationship between renewable energy, GDP *per capita*, and CO_2 emissions. These studies report that these variables are essential and exhibit significant effects on greenhouse gas emissions. Therefore, our suggested model, which appears to be in line with the general empirical literature on CO_2 emissions discussed above can be expressed as:

$$CO_2 = f(GDP, RE, URB, TR, WP, KOF) \quad (1)$$

This generally implies that CO_2 emissions is a function of GDP *per capita* (GDP), renewable energy consumption (RE), urban population growth (URB), tourism receipts (TR), proportion of women in parliament (WP) and KOF index of Globalization as a proxy for globalization. Considering the panel structure of our data, Eq. 1 can be re-written in the following manner:

$$CO_{2i,t} = a_0 + a_1 GDP_{i,t} + a_2 GDP^2_{i,t} + a_3 RE_{i,t} + a_4 URB_{i,t} + a_5 TR_{i,t} + a_6 WP_{i,t} + a_7 KOF_{i,t} + \varepsilon_{i,t} \quad (2)$$

where i represents country (in this research, we have 50 countries), t stands for time (the time period for this study is between 2000 and 2019) and ε is an error term. We also include GDP squared term to examine the presence of the EKC hypothesis in our sample.

Data and summary statistics

The data applied in this paper come from the World Bank and cover 2000–2019. The variables used are CO_2 emissions (measured in metric tons *per capita*), GDP *per capita* (measured in constant 2017 international $), renewable energy consumption (measured in percentage of total final energy consumption), urbanization (measured in annual urban population growth, %), tourism (as a ratio to GDP), female parliamentarians (proportion of seats held by women in national parliaments) and KOF index as a proxy for globalization.

TABLE 1 Summary statistics.

Variable	Description	Mean	Std. dev.
CO_2	CO_2 per capita emissions, logged	1.9230	0.6431
GDP	GDP per capita, PPP	37.5912	21.3106
URB	Urban population growth, annual	1.1291	1.9385
KOF	KOF Index of globalization	77.5039	8.0932
RE	Renewable energy consumption, %	15.9982	14.0854
WP	Representation of women in national parliaments, %	21.9301	11.0574
TP	Tourism receipts as % of GDP	1.0726	1.4253

The descriptive statistics are reported in Table 1. In this study, following related research on CO_2 emissions, we rely on dynamic panel estimators such as the two-step system GMM estimator. For example, (Asongu et al., 2017), highlights that "(system GMM estimator) considers cross-country variations; accounts for potential endogeneity in all regressions via instrumentation and controls for the unobserved heterogeneity and eliminates potential small sample biases from the difference estimator" (p. 355). System GMM estimator is recommended to use with the panel data when 1) the correlation between a dependent variable and its lag is above 0.8; and 2) the number of countries (i.e., 50 countries) exceeds the time frame (i.e., 19 years). As our study design fits these conditions, we use (Roodman, 2009) extension of a two-step system GMM estimator which restricts the expansion of instruments. Moreover, a two-step system GMM estimator is especially efficient as it controls for heteroskedasticity. The GMM estimator has been intensively used in energy and environmental studies to model the predictors of CO_2 emissions (Bakhsh et al., 2021; Mentel et al., 2022a; Mentel et al., 2022b; Jiang and Khan, 2023). Our suggested model under the condition of a two-step GMM estimator can be presented as follows:

$$CO2_{i,t} = \sigma_0 + \sigma_1 CO2_{i,t-\tau} + \sigma_2 RE_{i,t} + \sum_{h=1}^{k} \gamma_h X_{h,i,t-\tau} + \nu_{i,t} \quad (3)$$

$$CO2_{i,t} - CO2_{i,t-\tau} = \sigma_1 (CO2_{i,t-\tau} - lnCO2_{i,t-2\tau}) + \sigma_2 (RE_{i,t} - RE_{i,t-\tau}) + \sum_{h=1}^{k} \delta_h (X_{h,i,t-\tau} - X_{h,i,t-2\tau}) + (\nu_{i,t} - \nu_{i,t-\tau}) \quad (4)$$

where σ are the coefficients to be estimated, X is the vector of control variables (GDP, WP, URB, TR, KOF), τ is the coefficient of auto-regression and υ is two-way disturbance term.

Results

We present our empirical results in Table 2. We use both fixed and random effects estimators, although the Hausman test suggests

TABLE 2 Fixed effects regression.

Dependent variable: CO_2	Coefficients	Prob. value
CO_2, lagged	0.7035	0.000
GDP	0.0081	0.004
GDP * GDP	−0.0000	0.016
RE	−0.0100	0.000
WP	−0.0015	0.017
KOF	−0.0005	0.769
URB	−0.0062	0.000
TR	−0.0195	0.001
Constant	0.5286	0.000
N	794	
R. sq.	0.95	
Fisher stat	506.55	0.000

TABLE 3 System GMM results.

Dependent variable: CO_2	Coefficients	Prob. value
CO_2, lagged	0.8537	0.000
GDP	0.0118	0.000
GDP * GDP	−0.0001	0.000
RE	−0.0026	0.006
WP	−0.0029	0.008
KOF	−0.0038	0.002
URB	−0.0045	0.015
TR	0.0063	0.281
Constant	0.3583	0.000
N	794	
R. sq.	—	
Fisher stat	89676.01	0.000
AR (1)	−3.84	0.000
AR (2)	0.32	0.748
Hansen *p*-value	30.11	0.460

that a fixed effects estimator is suitable for the baseline analysis (Chi-Sq. stat = 204.77, Chi-sq. Prob. = 0.0000). Therefore, we only interpret the results from a fixed effects regression (Table 2). First, we find that GDP *per capita* has an inverted U-shaped association with CO_2 emissions. The turning point for GDP *per capita* beyond which economic growth decreases CO_2 emissions is 90,000 international dollars. The estimate of the RE is in line with theoretical assumptions. The obtained estimate of −0.0100 documented for renewable energy use is statistically significant at the 1% level. The results suggest that one standard deviation increase in RE is associated with a 14% decrease in CO_2 emissions. In a similar trend, the representation of women in parliament leads to improvement in air quality. These results confirm the importance of female empowerment for environmental sustainability documented by (Lv and Deng, 2019) and (Mirziyoyeva and Salahodjaev, 2022a). We observe that urban population growth decreases CO_2 emissions in high-globalized countries. In accordance with (Ben Jebli et al., 2019b), we find that tourism contributes to the decrease in carbon emissions: one standard deviation increase in *per capita* tourism receipts leads to a 2.7% decrease in CO_2 emissions. The KOF index of globalization is negative, although statistically insignificant. This may imply that globalization does not induce direct reduction in CO_2 emissions, once countries pass certain threshold levels. The impact of globalization may be moderated by other variables such as economic development or tourism sector development.

However, the results in Table 2 only offer correlational evidence for our variables of interest. Thus, to assess the impact of renewable energy and globalization on CO_2 emissions we need to correct for the potential endogeneity. Therefore, Table 3 reports the results for the two-step system GMM estimator. Hansen J-test and second-order autocorrelation [AR (2)] tests confirm the validity of the instruments based on the difference and level equations.

We find that renewable energy and globalization decrease CO_2 emissions. If causal, a 1 percentage point increase in the share of renewable energy in total energy consumption leads to a 0.26% decrease in *per capita* CO_2 emissions. These results can be compared to findings from other regions. For example, Mirziyoyeva and Salahodjaev (2022) find that 1 percentage point increase in renewable energy leads to 0.98% decrease in CO_2 emissions in top carbon intense economies. Radmehr et al. (2021) for the EU member states show that 1% increase in *per capita* renewable energy use leads to 0.05% decrease in CO_2 emissions. In addition, these results are similar to (Abbasi et al., 2021b) for Thailand and (Fu et al., 2021) for BRICS. The enhancing impact of globalization on air quality can be interpreted by the fact that globalization promotes the transfer of technologies that are friendly to air quality (Rahman, 2020). Similarly, we find that a larger representation of women in national parliament contributes to the reduction in CO_2 emissions. Extant research suggests that an increase in the women's share of seats in parliament improves the quality of institutions and the adoption of policies aimed at improvement in quality of life (Ergas and York, 2012; Mavisakalyan and Tarverdi, 2019; Salahodjaev and Jarilkapova, 2019). GDP *per capita* has an inverted U-shaped relationship with CO_2 emissions and the turning point is approximately 67,200 international dollars adjusted for PPP. The AR (2) test and Hansen *p*-value estimates confirm the validity of the use of the econometric approach and the credibility of instruments derived by the system GMM estimator.

We test the robustness of our main results by considering whether the effect of renewable energy on CO_2 emissions in high-globalized countries holds after accounting for the dynamics in the GDP structure. We do so by including the level of industrialization to capture the shift from agriculture to industry driven economic growth. A number of studies how that (Li and Lin, 2015; Liu and Bae, 2018) industrialization increases energy consumption and contributes to CO_2 emissions. At the same time, Mehmood and Tariq (2020) and Mentel et al. (2022c) show that renewable energy consumption can influence the effect of industrialization on CO_2

TABLE 4 Industrialization, renewable energy, and CO_2 emissions.

Dependent variable: CO_2	Coefficients	Prob. value
CO_2, lagged	0.7695	0.000
GDP	0.0135	0.000
GDP * GDP	−0.0001	0.000
RE	−0.0033	0.000
WP	−0.0018	0.004
KOF	−0.0017	0.402
URB	−0.0015	0.010
IND	0.0027	0.000
IND * RE	−0.0001	0.003
Constant		
N	914	
R. sq.	—	
Fisher stat	165738.38	0.000
AR (1)	−4.23	0.000
AR (2)	0.48	0.644
Hansen *p*-value	37.78	0.301

emissions. Therefore, we check whether the effect of renewable energy on CO_2 emissions retains its significance once we account for the level of industrialization in high-globalized countries (Table 4). The results show that industry value added as a share of GDP is positively linked to *per capita* CO_2 emissions. At the same time, the interaction term between renewable energy and CO_2 emissions is negative and significant, at the 1% level. This suggests that increasing renewable energy consumption can help to promote industrial transformation, not at the expense of environmental degradation. The estimates for other variables are not affected and remain robust.

Conclusion

Greenhouse gas emissions have emerged as one of the key topics of discussion within the international agenda. Consequently, policymakers in developed and developing countries attempt to identify the predictors of CO_2 emissions that can help to select and enforce policies which can lead to a reduction in air pollution without harming economic growth. Against this backdrop, environmental research suggests that energy consumption and GDP are among the core predictors of CO_2 emissions in global and single-country studies. Despite that research on renewable energy, economic growth, and CO_2 emissions has grown considerably over the past decade, no study explored the effect of GDP growth and renewable energy consumption on CO_2 emission in highly-globalized countries. Our results are based on panel data between 2000 and 2019. We particularly focused on the top 50 countries by KOF index of Globalization. Our results suggest that renewable energy significantly contributes to the reduction of carbon emissions while GDP *per capita* has an inverted U-shaped link with CO_2 emissions. Thus, we confirm the presence of the EKC hypothesis for highly-globalized countries. Moreover, we found that an increase in the share of female parliamentarians decreases CO_2 emissions. Consequently, our study offers several policy implications. Firstly, it is important for developing countries to increase the share of energy consumed from renewable energy sources. This will have a positive effect not only on air quality, but also on economic growth. Thus, it is essential to increase investment in the renewable energy sector and create conditions and benefits for the rapid adoption of renewable technologies by the private sector and households. Secondly, it is crucial to increase the quality of investment climate. Developing countries can significantly gain from globalization-driven FDI as this can lead to technology transfer, especially in the energy sector. Thirdly, our results suggest that improving female empowerment can significantly reduce the vulnerability to climate change. This can be achieved by increasing women's human capital and investing in women-led organizations and communities. The adoption of these measures can be anticipated to help emerging economies in decreasing CO_2 emissions under the international greenhouse gas emissions targets. Our study has a number of limitations that can serve as avenue for future research. For example, we did not assess the bi-directional causality between globalization, renewable energy and CO_2 emissions. However, scholars can test these relationships for single top-globalization countries to extend our understanding of the interlinks between renewable energy and carbon emissions. In addition, it is essential to assess the impact of other energy-related variables on the CO_2 emissions in high-globalized countries such as energy intensity, fossil fuel consumption or electricity consumption.

Data availability statement

Publicly available datasets were analyzed in this study. This data can be found here: World Bank.

Author contributions

ZM and RS: data collection and methodology. RS: formal analysis. ZM: writing original draft and conceptualization. All authors contributed to the article and approved the submitted version.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

References

Abbasi, K. R., Adedoyin, F. F., Abbas, J., and Hussain, K. (2021). The impact of energy depletion and renewable energy on CO2 emissions in Thailand: Fresh evidence from the novel dynamic ARDL simulation. *Renew. Energy* 180, 1439–1450. doi:10.1016/j.renene.2021.08.078

Acaravci, A., and Ozturk, I. (2010). On the relationship between energy consumption, CO2 emissions and economic growth in Europe. *Energy* 35 (12), 5412–5420. doi:10.1016/j.energy.2010.07.009

Adebayo, T. S., Oladipupo, S. D., Adeshola, I., and Rjoub, H. (2022). Wavelet analysis of impact of renewable energy consumption and technological innovation on CO2 emissions: Evidence from Portugal. *Environ. Sci. Pollut. Res.* 29 (16), 23887–23904. doi:10.1007/s11356-021-17708-8

Aized, T., Shahid, M., Bhatti, A. A., Saleem, M., and Anandarajah, G. (2018). Energy security and renewable energy policy analysis of Pakistan. *Renew. Sustain. Energy Rev.* 84, 155–169. doi:10.1016/j.rser.2017.05.254

Ansari, M. A., Ahmad, M. R., Siddique, S., and Mansoor, K. (2020). An environment Kuznets curve for ecological footprint: Evidence from GCC countries. *Carbon Manag.* 11 (4), 355–368. doi:10.1080/17583004.2020.1790242

Anwar, M. A., Zhang, Q., Asmi, F., Hussain, N., Plantinga, A., Zafar, M. W., et al. (2022). Global perspectives on environmental kuznets curve: A bibliometric review. *Gondwana Res.* 103, 135–145. doi:10.1016/j.gr.2021.11.010

Asongu, S. A., Le Roux, S., and Biekpe, N. (2017). Environmental degradation, ICT and inclusive development in Sub-Saharan Africa. *Energy Policy* 111, 353–361. doi:10.1016/j.enpol.2017.09.049

Bakhsh, S., Yin, H., and Shabir, M. (2021). Foreign investment and CO2 emissions: Do technological innovation and institutional quality matter? Evidence from system GMM approach. *Environ. Sci. Pollut. Res.* 28 (15), 19424–19438. doi:10.1007/s11356-020-12237-2

Baloch, M. A., Ozturk, I., Bekun, F. V., and Khan, D. (2021). Modeling the dynamic linkage between financial development, energy innovation, and environmental quality: Does globalization matter? *Bus. Strategy Environ.* 30 (1), 176–184. doi:10.1002/bse.2615

Balsalobre-Lorente, D., Ibáñez-Luzón, L., Usman, M., and Shahbaz, M. (2022). The environmental Kuznets curve, based on the economic complexity, and the pollution haven hypothesis in PIIGS countries. *Renew. Energy* 185, 1441–1455. doi:10.1016/j.renene.2021.10.059

Bekun, F. V., Alola, A. A., Gyamfi, B. A., and Yaw, S. S. (2021a). The relevance of EKC hypothesis in energy intensity real-output trade-off for sustainable environment in EU-27. *Environ. Sci. Pollut. Res.* 28 (37), 51137–51148. doi:10.1007/s11356-021-14251-4

Bekun, F. V., Gyamfi, B. A., Onifade, S. T., and Agboola, M. O. (2021b). Beyond the environmental kuznets curve in E7 economies: Accounting for the combined impacts of institutional quality and renewables. *J. Clean. Prod.* 314, 127924. doi:10.1016/j.jclepro.2021.127924

Ben Jebli, M., Ben Youssef, S., and Apergis, N. (2019). The dynamic linkage between renewable energy, tourism, CO2 emissions, economic growth, foreign direct investment, and trade. *Lat. Am. Econ. Rev.* 28 (1), 2. doi:10.1186/s40503-019-0063-7

Bibi, F., and Jamil, M. (2021). Testing environment Kuznets curve (EKC) hypothesis in different regions. *Environ. Sci. Pollut. Res.* 28, 13581–13594. doi:10.1007/s11356-020-11516-2

Chen, Y., Wang, Z., and Zhong, Z. (2019). CO2 emissions, economic growth, renewable and non-renewable energy production and foreign trade in China. *Renew. Energy* 131, 208–216. doi:10.1016/j.renene.2018.07.047

Demissew Beyene, S., and Kotosz, B. (2020). Testing the environmental kuznets curve hypothesis: An empirical study for East African countries. *Int. J. Environ. Stud.* 77 (4), 636–654. doi:10.1080/00207233.2019.1695445

Dinda, S. (2004). Environmental kuznets curve hypothesis: A survey. *Ecol. Econ.* 49 (4), 431–455. doi:10.1016/j.ecolecon.2004.02.011

Doğan, B., Ghosh, S., Shahzadi, I., Balsalobre-Lorente, D., and Nguyen, C. P. (2022). The relevance of economic complexity and economic globalization as determinants of energy demand for different stages of development. *Renew. Energy* 190, 371–384. doi:10.1016/j.renene.2022.03.117

Dogan, E., and Inglesi-Lotz, R. (2020). The impact of economic structure to the environmental Kuznets curve (EKC) hypothesis: Evidence from European countries. *Environ. Sci. Pollut. Res.* 27 (11), 12717–12724. doi:10.1007/s11356-020-07878-2

Dogan, E., and Seker, F. (2016). Determinants of CO2 emissions in the European Union: The role of renewable and non-renewable energy. *Renew. Energy* 94, 429–439. doi:10.1016/j.renene.2016.03.078

Dogan, E., Ulucak, R., Kocak, E., and Isik, C. (2020). The use of ecological footprint in estimating the environmental Kuznets curve hypothesis for BRICST by considering cross-section dependence and heterogeneity. *Sci. Total Environ.* 723, 138063. doi:10.1016/j.scitotenv.2020.138063

Ergas, C., and York, R. (2012). Women's status and carbon dioxide emissions: A quantitative cross-national analysis. *Soc. Sci. Res.* 41 (4), 965–976. doi:10.1016/j.ssresearch.2012.03.008

Farooq, S., Ozturk, I., Majeed, M. T., and Akram, R. (2022). Globalization and CO2 emissions in the presence of EKC: A global panel data analysis. *Gondwana Res.* 106, 367–378. doi:10.1016/j.gr.2022.02.002

Fu, Q., Álvarez-Otero, S., Sial, M. S., Comite, U., Zheng, P., Samad, S., et al. (2021). Impact of renewable energy on economic growth and CO2 emissions—evidence from BRICS countries. *Processes* 9 (8), 1281. doi:10.3390/pr9081281

Grossman, G. M., and Krueger, A. B. (1991). *Environmental impacts of North American free trade agreement*. New Delhi: NBER Working Paper Series. *Working Paper No. 3914*, 1–57.

Haldar, A., and Sethi, N. (2021). Effect of institutional quality and renewable energy consumption on CO2 emissions–an empirical investigation for developing countries. *Environ. Sci. Pollut. Res.* 28 (12), 15485–15503. doi:10.1007/s11356-020-11532-2

Halliru, A. M., Loganathan, N., Hassan, A. A. G., Mardani, A., and Kamyab, H. (2020). Re-Examining the environmental kuznets curve hypothesis in the economic community of West African states: A panel quantile regression approach. *J. Clean. Prod.* 276, 124247. doi:10.1016/j.jclepro.2020.124247

Heidari, H., Turan Katircioğlu, S., and Saeidpour, L. (2015). Economic growth, CO2 emissions, and energy consumption in the five ASEAN countries. *Int. J. Electr. Power & Energy Syst.* 64, 785–791. doi:10.1016/j.ijepes.2014.07.081

Huang, Y., Kuldasheva, Z., and Salahodjaev, R. (2021). Renewable energy and CO2 emissions: Empirical evidence from major energy-consuming countries. *Energies* 14 (22), 7504. doi:10.3390/en14227504

IEA (2021). *Renewables 2021: Analysis and forecast to 2026*. Paris, France: IEA, 175. https://www.iea.org/reports/renewables-2021.

Işik, C., Ahmad, M., Pata, U. K., Ongan, S., Radulescu, M., Adedoyin, F. F., et al. (2020). An evaluation of the tourism-induced environmental kuznets curve (T-EKC) hypothesis: Evidence from G7 countries. *Sustainability* 12 (21), 9150. doi:10.3390/su12219150

Jiang, Y., and Khan, H. (2023). The relationship between renewable energy consumption, technological innovations, and carbon dioxide emission: Evidence from two-step system GMM. *Environ. Sci. Pollut. Res.* 30 (2), 4187–4202. doi:10.1007/s11356-022-22391-4

Katircioğlu, S. T. (2014). Testing the tourism-induced EKC hypothesis: The case of Singapore. *Econ. Model.* 41, 383–391. doi:10.1016/j.econmod.2014.05.028

Khoshnevis Yazdi, S., and Shakouri, B. (2018). The effect of renewable energy and urbanization on CO_2 emissions: A panel data. *Energy Sources, Part B Econ. Plan. Policy* 13 (2), 121–127. doi:10.1080/15567249.2017.1400607

Kılıç Depren, S., Kartal, M. T., Çoban Çelikdemir, N., and Depren, Ö. (2022). Energy consumption and environmental degradation nexus: A systematic review and meta-analysis of fossil fuel and renewable energy consumption. *Ecol. Inf.* 70, 101747. doi:10.1016/j.ecoinf.2022.101747

Leal, P. H., and Marques, A. C. (2020). Rediscovering the EKC hypothesis for the 20 highest CO2 emitters among OECD countries by level of globalization. *Int. Econ.* 164, 36–47. doi:10.1016/j.inteco.2020.07.001

Leitão, N. C., and Lorente, D. B. (2020). The linkage between economic growth, renewable energy, tourism, CO2 emissions, and international trade: The evidence for the European union. *Energies* 13 (18), 4838. doi:10.3390/en13184838

Li, K., and Lin, B. (2015). Impacts of urbanization and industrialization on energy consumption/CO2 emissions: Does the level of development matter? *Renew. Sustain. Energy Rev.* 52, 1107–1122. doi:10.1016/j.rser.2015.07.185

Liu, F., Jea-yeon, S., Sun, H., Edziah, B. K., Adom, P. K., and Song, S. (2022). Assessing the role of economic globalization on energy efficiency: Evidence from a global perspective. *China Econ. Rev.* 77, 101897. doi:10.1016/j.chieco.2022.101897

Liu, M., Ren, X., Cheng, C., and Wang, Z. (2020). The role of globalization in CO2 emissions: A semi-parametric panel data analysis for G7. *Sci. Total Environ.* 718, 137379. doi:10.1016/j.scitotenv.2020.137379

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

Lv, Z., and Deng, C. (2019). Does women's political empowerment matter for improving the environment? A heterogeneous dynamic panel analysis. *Sustain. Dev.* 27 (4), 603–612. doi:10.1002/sd.1926

Mavisakalyan, A., and Tarverdi, Y. (2019). Gender and climate change: Do female parliamentarians make difference? *Eur. J. Political Econ.* 56, 151–164. doi:10.1016/j.ejpoleco.2018.08.001

Mehmood, U. (2021). Globalization-driven CO2 emissions in Singapore: An application of ARDL approach. *Environ. Sci. Pollut. Res.* 28 (9), 11317–11322. doi:10.1007/s11356-020-11368-w

Mehmood, U., and Tariq, S. (2020). Globalization and CO2 emissions nexus: Evidence from the EKC hypothesis in South Asian countries. *Environ. Sci. Pollut. Res.* 27 (29), 37044–37056. doi:10.1007/s11356-020-09774-1

Mentel, G., Tarczyński, W., Azadi, H., Abdurakmanov, K., Zakirova, E., and Salahodjaev, R. (2022c). R&D human capital, renewable energy and CO2 emissions: Evidence from 26 countries. *Energies* 15 (23), 9205. doi:10.3390/en15239205

Mentel, G., Tarczyński, W., Dylewski, M., and Salahodjaev, R. (2022a). Does renewable energy sector affect industrialization-CO2 emissions nexus in Europe and central Asia? *Energies* 15 (16), 5877. doi:10.3390/en15165877

Mentel, U., Wolanin, E., Eshov, M., and Salahodjaev, R. (2022b). Industrialization and CO2 emissions in sub-saharan africa: The mitigating role of renewable electricity. *Energies* 15 (3), 946. doi:10.3390/en15030946

Mirziyoyeva, Z., and Salahodjaev, R. (2022b). Renewable energy and CO2 emissions intensity in the top carbon intense countries. *Renew. Energy* 192, 507–512. doi:10.1016/j.renene.2022.04.137

Mirziyoyeva, Z., and Salahodjaev, R. (2022a). Women's parliamentary representation and sustainable development goals: A cross-country evidence. *Appl. Res. Qual. Life* 17 (2), 871–883. doi:10.1007/s11482-021-09940-8

Murshed, M., Alam, R., and Ansarin, A. (2021). The environmental kuznets curve hypothesis for Bangladesh: The importance of natural gas, liquefied petroleum gas, and hydropower consumption. *Environ. Sci. Pollut. Res.* 28 (14), 17208–17227. doi:10.1007/s11356-020-11976-6

Murshed, M., Nurmakhanova, M., Elheddad, M., and Ahmed, R. (2020). Value addition in the services sector and its heterogeneous impacts on CO2 emissions: Revisiting the EKC hypothesis for the OPEC using panel spatial estimation techniques. *Environ. Sci. Pollut. Res.* 27 (31), 38951–38973. doi:10.1007/s11356-020-09593-4

Nguyen, T., Le, Q., Koshy, S., and Morgan, M. V. (2020). A validation and cost-analysis study of a targeted school-based dental check-up intervention: Children's dental program. *Decis. Sci. Lett.* 9 (2), 257–270. doi:10.3390/children7120257

Pata, U. K. (2018). Renewable energy consumption, urbanization, financial development, income and CO2 emissions in Turkey: Testing EKC hypothesis with structural breaks. *J. Clean. Prod.* 187, 770–779. doi:10.1016/j.jclepro.2018.03.236

Polloni-Silva, E., Ferraz, D., Camioto, F. D. C., Rebelatto, D. A. D. N., and Moralles, H. F. (2021). Environmental kuznets curve and the pollution-halo/haven hypotheses: An investigation in Brazilian Municipalities. *Sustainability* 13 (8), 4114. doi:10.3390/su13084114

Radmehr, R., Henneberry, S. R., and Shayanmehr, S. (2021). Renewable energy consumption, CO2 emissions, and economic growth nexus: A simultaneity spatial modeling analysis of EU countries. *Struct. Change Econ. Dyn.* 57, 13–27. doi:10.1016/j.strueco.2021.01.006

Rahman, M. M. (2020). Environmental degradation: The role of electricity consumption, economic growth and globalisation. *J. Environ. Manag.* 253, 109742. doi:10.1016/j.jenvman.2019.109742

Robalino-López, A., Mena-Nieto, A., and García-Ramos, J. E. (2014). System dynamics modeling for renewable energy and CO2 emissions: A case study of Ecuador. *Energy Sustain. Dev.* 20, 11–20. doi:10.1016/j.esd.2014.02.001

Rodriguez-Alvarez, A. (2021). Air pollution and life expectancy in Europe: Does investment in renewable energy matter? *Sci. Total Environ.* 792, 148480. doi:10.1016/j.scitotenv.2021.148480

Roodman, D. (2009). A note on the theme of too many instruments. *Oxf. Bull. Econ. Statistics* 71 (1), 135–158. doi:10.1111/j.1468-0084.2008.00542.x

Saboori, B., and Sulaiman, J. (2013). CO2 emissions, energy consumption and economic growth in association of southeast asian nations (ASEAN) countries: A cointegration approach. *Energy* 55, 813–822. doi:10.1016/j.energy.2013.04.038

Salahodjaev, R., and Jarilkapova, D. (2019). Female parliamentarism and genuine savings: A cross-country test. *Sustain. Dev.* 27 (4), 637–646. doi:10.1002/sd.1928

Salahodjaev, R., Sharipov, K., Rakhmanov, N., and Khabirov, D. (2022). Tourism, renewable energy and CO2 emissions: Evidence from Europe and central Asia. *Environ. Dev. Sustain.* 24 (11), 13282–13293. doi:10.1007/s10668-021-01993-x

Samimi, P., and Jenatabadi, H. S. (2014). Globalization and economic growth: Empirical evidence on the role of complementarities. *PLoS ONE* 9 (4), e87824. doi:10.1371/journal.pone.0087824

Sarkodie, S. A., and Ozturk, I. (2020). Investigating the environmental kuznets curve hypothesis in Kenya: A multivariate analysis. *Renew. Sustain. Energy Rev.* 117, 109481. doi:10.1016/j.rser.2019.109481

Satrovic, E., and Muslija, A. (2019). The empirical evidence on TOURISM-URBANIZATION-CO2 emissions nexus. *Adv. Hosp. Tour. Res. (AHTR)*. doi:10.30519/ahtr.484287

Shah, M. H., Salem, S., Ahmed, B., Ullah, I., Rehman, A., Zeeshan, M., et al. (2022). Nexus between foreign direct investment inflow, renewable energy consumption, ambient air pollution, and human mortality: A public health perspective from non-linear ARDL approach. *Front. Public Health* 9, 814208. doi:10.3389/fpubh.2021.814208

Sinha, A., and Shahbaz, M. (2018). Estimation of environmental kuznets curve for CO2 emission: Role of renewable energy generation in India. *Renew. Energy* 119, 703–711. doi:10.1016/j.renene.2017.12.058

Suki, N. M., Sharif, A., Afshan, S., and Suki, N. M. (2020). Revisiting the environmental kuznets curve in Malaysia: The role of globalization in sustainable environment. *J. Clean. Prod.* 264, 121669. doi:10.1016/j.jclepro.2020.121669

Sun, Y., Li, H., Andlib, Z., and Genie, M. G. (2022). How do renewable energy and urbanization cause carbon emissions? Evidence from advanced panel estimation techniques. *Renew. Energy* 185, 996–1005. doi:10.1016/j.renene.2021.12.112

Tang, C. F., Tan, B. W., and Ozturk, I. (2016). Energy consumption and economic growth in Vietnam. *Renew. Sustain. Energy Rev.* 54, 1506–1514. doi:10.1016/j.rser.2015.10.083

Topcu, M., and Tugcu, C. T. (2020). The impact of renewable energy consumption on income inequality: Evidence from developed countries. *Renew. Energy* 151, 1134–1140. doi:10.1016/j.renene.2019.11.103

Wang, S., Li, G., and Fang, C. (2018). Urbanization, economic growth, energy consumption, and CO2 emissions: Empirical evidence from countries with different income levels. *Renew. Sustain. Energy Rev.* 81, 2144–2159. doi:10.1016/j.rser.2017.06.025

Zhang, C., and Zhou, X. (2016). Does foreign direct investment lead to lower CO2 emissions? Evidence from a regional analysis in China. *Renew. Sustain. Energy Rev.* 58, 943–951. doi:10.1016/j.rser.2015.12.226

Zoundi, Z. (2017). CO2 emissions, renewable energy and the Environmental Kuznets Curve, a panel cointegration approach. *Renew. Sustain. Energy Rev.* 72, 1067–1075. doi:10.1016/j.rser.2016.10.018