Economic Research-Ekonomska Istraživanja

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/rero20

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To cite this article: Xiaoxi Liu & Xiaoling Yuan (2023) Novel research methods for energy use, carbon emissions, and economic growth: evidence from the USA, Economic Research-Ekonomska Istraživanja, 36:1, 1735-1750, DOI: 10.1080/1331677X.2022.2092763

To link to this article: https://doi.org/10.1080/1331677X.2022.2092763

ECONOMIC RESEARCH-EKONOMSKA ISTRAŽIVANJA
2023, VOL. 36, NO. 1, 1735–1750
https://doi.org/10.1080/1331677X.2022.2092763

Novel research methods for energy use, carbon emissions, and economic growth: evidence from the USA

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ABSTRACT

Researchers and governments are debating whether to use renewable energy sources or fossil fuels. The impact of the final decision on developed and developing regions is either the same or different. To investigate the answers to these issues, the current study used panel data for the US economy from 1985 to 2020. Following preliminary diagnostic testing, the researchers discovered that the data is stationary at the level and has long-run cointegration. Furthermore, the influence of economic growth (GDP), nonrenewable energy (EU), and renewable energy consumption was investigated using the quantile regression approach (REC). The analysis discovered that the impact of GDP and the EU on carbon emissions is lowest in industrialized countries and highest in underdeveloped countries. However, the corrective influence of REC on carbon emissions is lowest in industrialized countries and highest in developing regions. Although the GDP and EU have less influence on carbon emissions, the corrective effect of REC is also the least; consequently, policymakers should encourage the aggregate production system to use more REC than the EU as a sustainable alternative.

ARTICLE HISTORY
Received 31 March 2022
Accepted 18 June 2022

KEYWORDS
Carbon emission; fossil fuel consumption; renewable energy; US; quantile regression

JEL CODES
N82; O13; Q4; Q54

1. Introduction

In 2020, the United States used less energy than it did at the millennium's start. This is encouraging, as the federal, state, and municipal governments have long promoted the advantages of energy efficiency and conservation. Despite this, average GDP has been quite low throughout this time, roughly a percentage point and a half below the long-run average. Is there a link between these two facts? Is there a connection between the two? Up till now, none of the studies have provided any strong conclusions to combat climate change. Our research incorporates earlier findings and pulls some of the many threads together in the framework of the United States.

According to the Emission Database for Global Atmospheric Research, the United States was the second most polluting country in the world in 2015, with 14.34 percent

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of total carbon emissions, trailing only China with 29.51 percent. To make matters more complicated, the nature of the link between consumption of energy and development in the United States is not constant—and the relative relevance of each theory may change depending on the economy's structure. Some of this is represented in the types of fuels consumed as a percentage of total consumption through time; variations in these proportions reflect changing tastes, technology, and other economic developments (Silva Rodríguez de San Miguel, 2020). Overall, the developed and developing economies are struggling with the rising carbon emissions (Shahzad et al., 2020).

The Paris Climate Agreement was signed by 196 countries, including the United States, to decrease greenhouse gas emissions. However, the United States' new administration announced in 2017 that it would withdraw from the agreement, which was devastating news for ecologists worldwide. Nonetheless, the biggest polluters, such as the United States, should work harder to control carbon emissions in the short and long term, as should the least developed areas. Climate change, particularly global warming, is the most dangerous challenge that threatens human survival; thus, greater research into this vast problem and related fields is required to alert policymakers to the gravity of the threat. Economic growth is essential for an area or country to attain greater economic success while also using natural resources (Dwumfour & Ntow-Gyamfi, 2018; Nawaz et al., 2019; Shahzad et al., 2021). Where EU resources play a large role, such as coal, which accounted for around 38% of US energy consumption in 1949 but had decreased to 19% by 2013. Natural gas became more important throughout this period, growing from around 16 percent of total energy usage in 1949 to slightly more than 27 percent in 2013. From start to end, oil's share of the whole EU was little less than 35%, although it peaked at about 48% in the 1970s. As a result, given the relevance of environmental variables and carbon emission sources, we were obligated to conduct this research and analyse the connection between fossil-fuel energy consumption (EU), renewable energy consumption (REC), GDP, and carbon emissions in the United States (Shahzad et al., 2021).

Sustained economic development and consumption of energy are two of the key momentum for rising carbon emissions, and both of these might be the main options for increasing carbon emissions (Paramati et al., 2022; Shahzad et al., 2022). As a result, numerous scholars in both the developing and the developed nations have explored the nexus between energy use, economic development, and carbon emissions (Acaravci & Ozturk, 2010; Rafique et al., 2022). Remarkably, as we shall comprehend in the next sections, the pragmatic results do not always agree with previous studies' conclusions, which might be due to differences in economic structures and statistical methodologies used by researchers.

This paper adds to the current literature in four ways. First, from 1985 to 2020, the research uses statistics on energy utilization as a future predictor of nonrenewable energy and renewable energy consumption as a proportion of total final energy consumption. Second, we use a more efficient cointegration approach developed by Bayer and Hanck (2013), which has the unique property of combining the findings of several separate cointegration experiments to provide a more decisive conclusion. Third, this study employed a quantile regression technique to test the long-run connection over the quantile and provides a more adaptable econometric model (Le et al., 2019) to evaluate the linkages between carbon emissions of various types, REC energy, and EU utilization. Quantile regression has certain advantages over OLS regression. To begin, rather than merely describing the conditional probabilities (mean values) of the explained variables, quantile regression may convey the entire representation of the conditional distribution of the explained variables. The properties of the explanatory variables on carbon emissions at different quantiles are generally diverse, as are the regression coefficients of different quantiles (Koenker & Hallock, 2001; Magazzino et al., 2022). Furthermore, deviations frequently indicate critical information with a substantial impact. Second, quantile regression's estimated coefficients are substantially more resilient than OLS regressions. Random error terms are not required in quantile regression to rigorously meet conventional econometric assumptions like zero mean, homogeneity of variance, and normally distributed. The calculated parameters in quantile regression are far more resilient for quasi-distributed data (Buchinsky, 1998).

Fourth, to explain long-run statistical estimates produced by the quantile regression method, the Fully Modified OLS (FMOLS), Dynamic Ordinary Least Squares (DOLS), and Canonical Cointegration Regression (CCR) approaches are applied. These strategies each have their own set of benefits, and they all avoid the endogenic problems of the variables, which is a by-product of cointegration. The above-mentioned methods address the long-run connection concerning the cointegration and stochastic regressions, as well as the challenge of being asymptotically unbiassed with a completely competent asymptotic blend.

The following process is alienated into five parts: The section 2 goes through prior research. The research technique is described in Section 3. The econometric strategy is presented in Section 4. The pragmatic findings are discussed in Section 5, and the policy implications are discussed in Section 6.

2. Literature review

A two-part review of the relevant literature review is conducted. We first look at the literature on the association between carbon emissions and GDP, and then we look at the association between carbon emissions, EU and REC.

2.1. Nexus between carbon emission and economic growth

Until the 1980s, scholarly research focused largely on a positive association between carbon emissions and development (Balassa, 1980; Bauchet & Rostow, 1961). There has been much research on the issue in underdeveloped nations, but it appears that there are few studies on wealthy countries, particularly the United States. Soytas et al. (2007) examined the Granger causality link amongst economic growth, EU, and carbon emissions in the United States in research focusing on developed nations. In the long term, they discovered that while growth does not increase carbon emissions, energy usage does. Shahbaz et al. (2018) suggested that the US economy raised the EU to boost economic development through knowledge distribution and the country's sustained GDP. The study indicates that even at the core of the global economic crunch, smart use of natural resources to promote GDP might be employed as a strategy for economic development.

From 1992 to 2017, Gokmenoglu and Rustamov (2019) explored the influence received by the economic development from the carbon emission and consumption of energy in Russia, Turkmenistan, Kazakhstan, and Azerbaijan, finding that the richness of consumption of energy multiply the economic growth while carbon emission deteriorates. Acaravci and Ozturk (2010) inspected the association between EU, carbon emissions, and development from 1960 to 2005. The ARDL bound testing technique demonstrates that in Greece, Denmark, Germany, Iceland, Portugal, Italy, and Switzerland, there is a long-run association between GDP per-capita, EU, and carbon emissions. In the UK, Sweden, Norway, the Netherlands, France, Hungary, Belgium, Luxembourg, Austria, and Finland, however, there is no long-term association. Pao and Tsai (2010) looked at the association in BRIC economies and found that GDP, EU, and carbon emissions are all bidirectionally interrelated. Economic progress, according to Tamazian et al. (2009), minimises environmental deterioration in BRIC economies. The EKC hypothesis is recognised in 21 nations, according to Narayan et al. (2016), who studied the link between carbon emissions and GDP in 181 economies. Economic development, on the other hand, will lower carbon emissions in 49 nations in the long run. Zaman et al. (2016) investigated GDP, EU, and carbon emissions in 34 countries, found that the EU is the primary source of carbon emissions while GDP growth deteriorates the carbon emission. Özokcu and Özdemir (2017) investigated the GDP and carbon emissions nexus using data from 26 OECD economies and 52 developing economies, finding an N-shaped relationship. An advanced economic system would allow a country's economy to expand faster by compensating for the detrimental impact of high carbon emissions on GDP. Energy sources are distributed for productive investment projects that power GDP through sound economic activity (Shahbaz et al., 2018). Rather than being the primary source of growth, optimal energy use has been proven to be the motor of development and expansion.

2.2. Nexus between carbon emission and energy utilization

Numerous research on REC, EU, and carbon emissions are available for various economies and areas. The outcomes of the investigation were based on a range of approaches and geographical locations. The following is a list of some of the literature.

Utilizing panel data analysis-NPARDL from 1990 to 2014, Akram et al. (2020) researched EU and RE over carbon emission for BRICS nations, and their findings reveal Asymmetric effects. Furthermore, Lin and Xu (2015) looked at China's energy use and carbon emissions and discovered an adverse association between the two. Furthermore, Abban et al. (2020) and Özbuğday and Erbas (2015) observed the same negative association between carbon emissions and EU in 36 DEE nations, 43 nations that are part of the BRI, 26 major economies, and 27 EU countries, respectively.

Chien and Hu (2008) discovered an inverse association between REC and EU, finding that substantial use of the former has a favourable influence on a country's economy, whilst the latter has a negative one. Paramati et al. (2017) conducted a similar study for emerging economies and discovered that REC had an encouraging impact on GDP though also benefiting the environment.

Tang and Tan (2015) used quarterly data from 1972 to 2011 to inspect the association between REC and economic development. They discovered that REC has a feedback hypothesis influence on GDP, whereas the other aspects have a long-term link. Another research looked at Pakistan's energy situation and discovered that EU and GDP are linked in both directions; nonetheless, energy usage contributes to environmental degradation (Ajmi et al., 2015). As a result, they proposed that a significant share of energy sources be REC in order to maintain GDP while avoiding environmental harm. Apergis and Payne (2011) studied the link between REC and GDP in Eurasia from 1992 to 2007. The long-run stability between GDP, capital creation, labour, and REC consumption is demonstrated by the heterogeneous panel cointegration test. In both the short and long run, the error correction model revealed a bidirectional relationship between economic development and REC usage. In most developing countries, biogases, a key component of REC, are plentiful. In order to optimise their potential contribution to energy utilisation, biogas installed capacity in underdeveloped nations may be increased (Craig & Feng, 2017).

According to the literature analysis above, the majority of extant research studied the agricultural sector and carbon emissions while using the classic ordinary least squares (OLS) technique, which is centred on the notion that variables follow a normal distribution (Ben Jebli & Ben Youssef, 2017; Fei & Lin, 2017). Due to the complexity and variety of socio-economic phenomena, the data distribution of socioeconomic variables is skewed. Furthermore, excessive levels of socioeconomic factors can indicate significant information. Quantile regression reveals the varied effect of explanatory factors on distinct quantiles of the explained variable. As a result, quantile regression is used in this article to inspect the influence of the dynamic factors of carbon emissions on China's agriculture industry. Finally, several studies have used different parameters to account for energy use, but none have taken into account EU usage at the regional level, which might lead to different conclusions.

Esso and Keho (2016) utilized panel data from 1971 to 2010 to consider the association between carbon emissions and the EU in 12 sub-Saharan African nations, finding a positive correlation between variables. Raza et al. (2016) investigated the relationship between electricity use (as an energy source) and carbon emissions in South Asian countries, finding unidirectional causation between carbon emissions and REC. Song et al. (2021) used the wavelet coherence method to look at the relationship between biomass EU and carbon emissions in the US from 1984 to 2015. After 2005, they discovered that biomass usage reduces greenhouse gases in the long run.

3. Methodology

Economic development is driven by the efficient utilization of energy-related resources, which, ultimately, stimulate growth in the economy (Ibrahim & Sare, 2018; Nawaz et al., 2019). Acaravci and Ozturk (2010) suggested sustained economic growth is important for sustained carbon emission. Tamazian et al. (2009), Zaman et al. (2016) found that economic growth causes environmental deterioration; whereas, Narayan et al. (2016) found economic growth has correcting effect on carbon emission in case of 49 out of 181 countries, similar findings presented by Acaravci and Ozturk (2010), Özokcu and Özdemir (2017). Lin and Xu (2015), Abban et al. (2020) and Özbuğday and Erbas (2015) found an inverse relationship between EU and carbon emission. Whereas, Tang and Tan (2015), Apergis and Payne (2011), Ben Jebli and Ben Youssef (2017), Fei and Lin (2017) and Chien and Hu (2008) discovered an association between EU and REC and concluded that deteriorating effect of EU on carbon emission whilst found correcting effect in case of REC. Paramati et al. (2017) explained the mechanism through which EU negatively affect GDP growth and ultimately deteriorates the carbon emission and, further, they found REC as encouraging factor for GDP growth rate.

In light of the foregoing debate, a modified framework is established that incorporates economic development, the EU, and the REC into the analysis of the impact of carbon emissions in developed nations.

The carbon emission function takes the following general form:

$$CO_2 = f(GDP,\ EU,\ REC) \tag{1}$$

The present study looks at the influence of GDP, EU, and REC on carbon emission in the case of the US for the period of 1985–2020. The endogenous variable in this research is carbon emission measured in kgCO2. GDP at constant US dollars, RE and EU retrieved from the U.S. Bureau of Economic Analysis (BEA), the U.S. Energy Information Administration (EIA), and World Bank (World Bank, 2020).

3.2. Specification of the theoretical model

The current study looks at the factors that have an impact on carbon in the United States. The intuitive econometric model current study is given:

$$CO_{2i,t} = \eta_0 + \eta_1 GDP_{i,t} + \eta_2 EU + \eta_3 REC_{i,t} + \varepsilon_{i,t} \tag{2}$$

Where $CO_{2i,t}$ stands for carbon emissions, $GDP_{i,t}$ for gross domestic product, $EU_{i,t}$ and $REC_{i,t}$ for non-renewable and renewable energy consumption, η_i for parameters, and $\varepsilon_{i,t}$ for error term for region i at time t. The use of the variables in Eq. (2) is based on previous research with a strong theoretical foundation. Except for Nasreen et al. (2017) and Shahbaz et al. (2015) other research by Shahbaz et al. (2016), and Halicioglu (2009) have overlooked the influence of *EU and REC*.

As a result, it is critical to investigate the effect of EU and REC on carbon emissions. This study, like Lu (2017), Seker et al. (2015), and Lamb et al. (2014) uses GDP as an explanatory variable. Economic growth, as measured by GDP, is strongly linked to utilization of natural resources and is projected to have a favourable association with carbon emissions, i.e., $\eta_1 = \frac{\delta\ CCO_{2i,t}}{\delta\ GDP_{i,t}} > 0$. According to previous research, EU in a region or country directly translates the carbon emission, therefore, it is expected to positively affect CARBON emissions, such as $\eta_2 = \frac{\delta\ CO_{2i,t}}{\delta\ EU_{i,t}} > 0$. This analysis adds REC as an explanatory variable, following Hasanov et al. (2018) and Khan et al. (2020). Carbon emissions are corrected when REC is used (Hasanov et al., 2018; Knight & Schor, 2014). As a result, REC is expected to reduce consumption-based carbon emissions $\eta_3 = \frac{\delta \ CCO_{2i,t}}{\delta \ REC_{i,t}} < 0$. The outcomes are anticipated as, $\eta_1 > 0$, $\eta_2 > 0$, $\eta_3 > 0$ and $\eta_4 < 0$.

4. Econometric strategy

4.1. Stationary test

Before performing a cointegration test, it is critical to identify the series of integration. As a result, the research will use a unit root-test to determine the order of stationarity at both the level and first difference. The testing procedure for the ADF test is the same as for the Dickey–Fuller test but it is applied to the model

$$\Delta y_t = \phi + \beta t + \rho_1 \Delta y_{t-1} + \ldots + \rho_{m-1} \Delta y_{t-p+1} + \epsilon_t$$

Where ϕ is a constant, β is the temporal coefficient and p is the autoregressive process's lag order. Modelling random walk with a drift relates to imposing the constraints $\phi = 0$ and $\beta = 0$ and employing the constraint $\beta = 0$ equates to modeling a random walk with a drift. As a result, there are three main primary variations of the test, which are similar to the Dickey–Fuller test.

4.2. Cointegration test

Bayer and Hanck (2013) conducted recent test for the presence of cointegration among the selected variables. Engle and Granger (1987) (EG), Johansen (1991) (JOH), Peter Boswijk (1994) (BO), and Banerjee et al. (1998) (BDM) on early methods are examples of such metrics. For Bayer and Hanck's joint integration method to work, the series must integrate into order one, I(1). Fisher used the following equation for Bayer and Hanckis cointegration:

$$EG - JOH = \quad -2\left[\ln(P_{EG}) + \ln(P_{JOH})\right] \tag{3}$$

$$EG - JOH - BO - BDM = \quad -2\left[\ln(P_{EG}) + \ln(P_{JOH}) + \ln(P_{BO}) + \ln(P_{BDM})\right] \tag{4}$$

The preceding Eqs. (3) and (4) can be used to calculate P values for various cointegration tests. The F-statistic is used to verify the cointegration of time series data. If Bayer and Hanck's critical range is less than F-statistic, we accept cointegration and reject the null hypothesis, and vice versa.

4.3. Quantile regression

When the assumptions of the ordinary least squares (OLS) regression technique are not satisfied, the predictions of the OLS regression do not succeed as an effective forecast in regression analysis (Osborne, 2000). The OLS approach may not estimate the direction effectively and consistently in the situation of heterogeneous structure in the variance. In these cases, we require unconventional regression models, such as quantile regression models, which take into account the data's heterogeneity and quantile structure (Abdullahi & Yahaya, 2015). Because no postulations are set out about the scattering of the error term it forecasts, quantile regression is more adaptable and resilient than OLS estimations (Belaïd et al., 2020). The OLS approach yields predictions based on the dependent variable's reaction to the independent variable's conditional mean (anticipated mean value) (s). On the other hand, quantile regression seeks to estimate the conditional median or other values of the response variable, such as the 10th, 25th, 75th, and 90th quantiles.

The quantile regression method, first proposed by Koenker and Bassett (1978) and later modified by Koenker and Hallock (2001), does not need the sequence of economic variables to be normal. Quantile regression defines the model for the specified quantiles in the dependent variable's conditional distribution (Sirin & Yilmaz, 2020). As a result, the linear regression model is generally represented:

$$y_j = \phi_0 + \phi_1 z_j + \ldots + \phi_m z_m \qquad j = 1, \ldots, m \tag{5}$$

The number of factors in the equation is indicated by the parameter m in Eq. (5). The number of data points is denoted by the letter j. The quantile regression model equation may be stated in the same way as the linear regression model:

$$\begin{gathered} Q(y_j) = \phi_0(\pi) + \phi_1(\pi) z_{j1} + \ldots + \phi_m(\pi) z_m \\ j = 1, \ldots, m \end{gathered} \tag{6}$$

Thus, ϕ coefficients in Eq. (6) have convert functions that vary depending on the quantile, (Galvao & Montes-Rojas, 2010).

Finally, Eq. (7) depicts the quantile regression model.

$$\begin{gathered} Q\ y_{jt}\left(\prod | y_{jt-1},\ r_{jt}\right) = w_j + \gamma_1\left(\prod\right) y_{j,t-1} + x_{it}^T B\left(\prod\right) \\ j = 1, \ldots, m, T = 1, \ldots, t \end{gathered} \tag{7}$$

where $y_{j,t}$ is the estimated output, $y_{j,t-1}$ is the lag of the $y_{j,t}$, x_{it}^Tdepicts the exogenous variables, and $w = (w_1, \ldots, w_j)$ denotes the $w \times 1$ vector of intercepts. The effects of the covariates ($y_{j,t-1}$, $x_{j,t}$ are allowed to depend upon the quantile, $\prod$, of interest (Galvao & Montes-Rojas, 2010).

4.4. Robustness check

Explanatory variables can be estimated using the DOLS, FMOLS, and CCR techniques suggested by Phillips and Hansen (1990), Stock and Watson (1993), and others once the cointegration connections have been confirmed. Except for the bias and non-centrality of the second-order, all three techniques use distinct correction strategies. They do, however, yield the same estimations asymptotically. As a result, it makes sense to utilize it as a secondary robustness check. The FMOLS rectifies all genetic components and projections in the function computation, whereas the CCR simply rectifies data and picks associations that indicate the CCR class connection. DOLS, on the

Table 1. Descriptive statistics.

Variable	Obs	Mean	Std. Dev.	Min	Max
Years	36	2002.5	10.53565	1985	2020
co2	36	6.714031	.0321753	6.652493	6.761658
Eu	36	1.930381	.0083942	1.916074	1.945969
Gdp	36	13.13433	.116141	12.92034	13.30048
rec	36	.7789832	.1380874	.611579	1.004631

Source: Author's own calculation.

other hand, includes abbreviation factors that rectify second order and asymmetric bias. The ability to apply these approaches to both stationary and non-stationary variables is a key characteristic. We apply several ways and compare the outcomes because there is no consensus on which methods are consistently superior. In the next part, the outcomes of various empirical methodologies are reported.

5. Results and discussion

Our data is obtained from the U.S. Bureau of Economic Analysis (BEA), the U.S. Energy Information Administration (EIA), and the World Development Indicator (World Bank, 2020). The descriptive statistics for the listed variables are tabulated in Table 1, where the period ranges from 1985 to 2020 and the rest of the variables.

This study used an ADF unit-root test at the level and first difference to investigate the variables' unit-root features. Table 2 shows the empirical findings of the ADF. We discover that carbon emissions, EU, GDP, and REC all exhibit unit root difficulties, with only EU being stationary at the level while the rest of the variables, including EU, are stationary at first difference, implying that the variables are integrated in a mixed order.

The Bayer and Hanck (2013) test is appropriate for finding long-run relationships between variables since all the selected variables are integrated into an order I(1). At a 5% significance level, the *F*-statistics in Table 3 is greater than the critical levels in stated models for integrated cointegration. As a result, we can discover a long-term link between carbon emissions, GDP, EU, and REC and reject the null-hypothesis of no cointegration. These findings are in line with those of Shahbaz et al. (2018).

At different quantiles, quantile regression may completely expose the influence of explanatory factors on the dependent variable (Zhao et al., 2022). This study uses the 25th, 50th, 75th, and 85th quantile points to execute regression estimation, and then conducts a full analysis and discussion of the estimate findings. This work employs the quantile regression and ordinary least squares (OLS) approaches based on location and size to construct regression estimates to verify the robustness of the quantile regression (Table 4, Figure 1). The influence of the driving forces on carbon emissions at different quantile points passes the significance test, as can be shown in Table 4.

The first finding is that in the higher 85th and 75th quantile provinces, the influence of GDP on carbon emissions is smaller than in the 50th–75th, 25th–50th, and lower 25th quantile areas (Table 4, Figure 1). This means that when the economy grows, the amount of carbon emitted decreases. However, the results for each quantile reveal that GDP have a beneficial impact on carbon emissions; the only difference is that the higher the GDP, the lesser the contribution to carbon emissions. The

Table 2. Unit-root test (augmented Dicky-Fuller technique).

Variables	Level	First difference
CO2	−1.435194	−6.161620***
EU	−4.061729***	
GDP	−0.380586	−3.268613*
REC	−2.019996	−7.872555***

Source: Author's own calculation.

Table 3. Fisher type test statistics, Bayer and Hanck cointegration test.

Model specification	Test statistics		*p*-value	
Engle-Granger	−2.7273		0.5470	
Johansen	39.1968		0.0011	
Banerjee	−4.9291		0.0013	
Boswijk	48.4683		0.0000	
Bayer and Hanck (2013) Test for Cointegration	*F* statistic	5% CV	*F* statistic	5% CV
	EG-J 14.831503	10.637	EG-J-Ba-Bo 83.384327	20.486

Source: Author's own calculation.

Table 4. Quantile regression and OLS (based on location and scale).

Variable	Location	Scale	25th	50th	75th	85th
Constant	−3.890373***	.3635947	−4.265313***	−3.899812***	−3.616813***	−3.453082***
	(1.443757)	(.8519873)	(1.612193)	(1.443589)	(1.64941)	(1.867217)
gdp	.5841087***	−.0160854	.600696***	.5845262***	.5720064***	.564763***
	(.0385714)	(.0227617)	(.043317)	(.0386626)	(.0444209)	(.0502877)
eu	1.665181***	−.0789947	1.746641***	1.667232***	1.605747***	1.570175***
	(.6830939)	(.4031061)	(.7608264)	(.6822496)	(.7775509)	(.8802195)
rec	−.3618875***	.0128509	−.3751394***	−.3622211***	−.3522188***	−.3464319***
	(.0496868)	(.0293211)	(.0554966)	(.0496855)	(.0567825)	(.0642806)

Source: Author's own calculation.

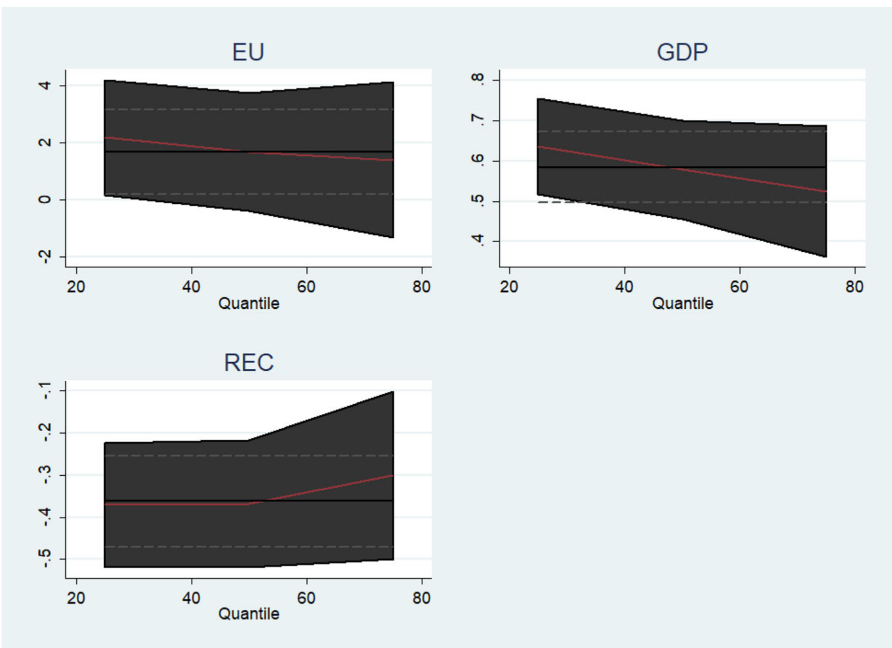

Figure 1. Quantile estimates.
Notes: The shaded regions reflect a 95% confidence interval. The OLS estimate's confidence interval is represented by the red parallel line.
Source: Author's own calculation.

Table 5. Robustness using FMOLS, DOLS, and CCR.

Variable	FMOLS	DOLS	CCR
Constant	−3.269474*	−3.644754*	−3.451991
	(1.898154)	(2.359627)	(1.776715)
gdp	0.602659***	0.668255***	0.597307
	(0.053322)	(0.106829)	(0.050492)
eu	1.238512*	0.996053*	1.365778
	(0.937850)	(1.304593)	(0.826269)
rec	−0.416336***	−0.460057***	−0.407236
	(0.070497)	(0.119240)	(0.062155)
R-squared	0.827549	0.919283	0.828243
Adjusted *R*-squared	0.810861	0.870852	0.811622

Source: Author's own calculation.

United States' long-term policy is called 'Pathways to Net-Zero Greenhouse Gas Emissions by 2050'. In contrast, this study discovered that the United States' corrective actions have already begun to have an influence on the environment, with many areas taking measures to use ecologically friendly goods and resources.

Second, the impact of EU on carbon emission is increased at 50th–25th and 25th and below quantiles, while it has decreased at 75th–85th and 85th and above. This points toward the fact that the smaller the economy the more dependency on EU consumption to lift up their GDP in the short run. As the US policy issued in November 2021 has long-term plans to achieve net-zero carbon emission by 2050, which means that the US still has many regions to reform and reshape their economies to utilize only environmentally friendly products and resources, which is also evident from Figure 1.

Whereas the correcting impact of REC on carbon emission is evident where its impact is higher at 75th–50th, 50th–25th and 25th and below while lower at 75th–85th and 85th and above. These results are validating our former results of GDP impact on carbon emission. Where one can see that the regions having the deteriorating impact of GDP on carbon emission are having higher correcting impact from REC on carbon emission at 75th–50th, 50th–25th and 25th and below, whereas regions having least deteriorating impact of GDP on carbon is having, comparatively, least correcting impact from REC on carbon emission.

Former statements present the picture of more environmentally sustainable economies, as being developed country different regions of US are contributing less to the environmental hazards. In the case of smaller economies, their dependency on EU consumption is inversely related to the increase in economic development and positively contributes to the carbon emission of smaller economies, whereas, correcting impact of the REC decreases with economic development.

Furthermore, the current study has also conducted the long-run panel coefficient estimations as a robust check following the FMOLS, DOLS, and CCR methodologies. Both the FMOLS and DOLS show significant results for all selected variables where results of DOLS results are larger than FMOLS in the case of EU and REC while in the case of GDP DOLS reports larger results. Whereas CCR results as a whole are insignificant (Table 5).

6. Conclusion

This study examines the relationship between carbon emissions, GDP, EU usage, and REC consumption in the United States. The link between the variables was examined using panel data from the US Bureau of Economic Analysis (BEA), the US Energy Information Administration (EIA), and the World Development Indicator (World Bank, 2020). This study looks into the relationship between carbon emissions, GDP, REC, and the EU. Economic development is determined by the effective use of energy-related resources, which has an impact on GDP.

The ADF test found that all of the chosen variables are stationary at the first difference, and cointegration tests confirmed that the variables are cointegrated and have a long-run relationship in the United States. When dealing with data problems, the quantile regression model was applied, which is a useful method. This study also selects five common quantiles: the 25th, 50th, 75th, and 85th. First, the influence of GDP on carbon emissions is smaller in the 75th and higher quantiles than in the 75th and lower quantiles, meaning that more developed regions of the United States contribute less to carbon emissions and vice versa. Second, EU consumption has the same influence on carbon emissions as it does on GDP, meaning that more economic progress results in less reliance on EU supply. Finally, the usage of REC consumption is the most essential component of carbon emission reduction. According to the findings of this study, regions with a higher degree of economic development have the least corrective influence of REC on carbon emissions, whereas emerging regions have a greater correcting impact.

Despite the fact that the United States has established a target of reaching net-zero carbon emissions by 2050, views toward using environmentally friendly resources differed across the country. The findings of this study, which demonstrate that GDP and EU use contribute less to carbon emissions in more developed nations and more to carbon emissions in emerging regions, may provide solutions to these worries. While RECs have a less impact on carbon emissions in developed regions, they have a greater impact in developing places. This third finding is a concerning fact for legislators in industrialized regions who are attempting to develop their economies by utilizing less REC and maybe relying more on EU suppliers.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This work was funded by the research on the long-term mechanism to promote the development of high-quality urban construction. Funding agency: Major Projects of China Ministry of Education (No.20JZD012).

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