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Building a greener environment: education levels and their links to CO₂ reduction

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ABSTRACT

Exploring the factors affecting CO₂ emissions is important for governments and policymakers to control the increasing trend of CO₂ emissions. Although many factors have been studied by researchers, education as a potential factor did not attract their attention. Thus, this study focuses on education levels as a new perspective to examine how education levels can contribute to CO₂ emission reductions in the USA. Autoregressive Distributed Lag Model (ARDL) was conducted, using relevant factors, such as: Gross Domestic Product (GDP), total primary energy consumption (EC), elementary school enrolment ratio (EER), high school enrolment ratio (HER), and college enrolment ratio (CER). The results reveal that GDP and EC have positive and significant effects on CO₂ emissions in the short- and long-run. The effects of the three education levels are significant and negative in the long-run, while in the short-run only the coefficient of CER is significant. This study confirms a significant link between education levels and CO₂ emissions reduction in the long-run, and hopes to provide insight for governments and policymakers that investing on education levels, prioritizes the environmental awareness and leads to a more environmentally conscious society.

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KEYWORDS

CO₂ emissions; education; climate change; sustainable development; autoregressive distributed lag model

Introduction

Global climate change is one of the major threats to the environment, as it has been demonstrated by many scientific studies (Jorgenson et al. 2019; Selim et al. 2020; Steffen et al. 2001). According to the scientists, the next 0.5°C augmentation in the average global temperature (which would raise the global mean temperature from 1.0°C to 1.5°C) will be associated with more dangers per unit temperature than the previous 0.5°C augmentation (Hoegh-Guldberg et al. 2019). The Gallup Health of the Planet Survey has already reported in 1992 that the majority of the respondents in 13 out of 24 countries considered climate change as a grave issue (Lorenzoni and Pidgeon 2006). In particular, the increase in atmospheric CO₂ emissions as concluded by Kar (2022) poses a great threat to the environment. As reported by Hasanov et al. (2019), CO₂ emissions have the largest share of total greenhouse gases worldwide. Despite the fact that the increments in the CO₂ emission rates have slowed down in recent years, as economic growth has become less carbon-intensive, the Climate Science Special Report (CSSR) predicts that without a major reduction in CO₂ emissions the global temperature could rise by minimum 5°C by the end of the current century. Therefore, researchers, policymakers and politicians have started to focus on the preparation and implementation of action plans for reducing greenhouse gas emissions. In 2015, 196 parties negotiated the Paris Agreement at the United Nations Climate Change Conference (COP21) in Paris. By the international treaty, they aim to regulate the augmentation in the average global temperature to at most 2°C above pre-industrial levels.

Considering the sources and the impacts of greenhouse gas emissions, many factors have been identified as key indicators influencing the level of CO₂ emissions. Urbanization, financial development, income distribution, energy consumption, tourism, economic growth and employment levels are usually considered as the main indicators. In the present study, we examine the effect of education which is an essential tool for reducing CO₂ emissions. Education can raise awareness and understanding of the sources and impacts of CO₂ emissions and climate change. People can perceive the role of human activities that play in contributing to climate change and take actions to reduce their own emissions, such as by reducing energy consumption and adopting other modes of transportation. Education can also motivate people to develop new environmentally friendly technologies and renewable energy sources. Innovative solutions can be accelerated through education and the involvement of researchers and experts. Moreover, education can also have a crucial role in making and adopting policies and regulations to reduce CO₂ emissions and influence system and lifestyle changes. We focus on the USA, the third most populous country in the world with a population of 327.7 million people. The industry is the second-largest end-use sector in the USA, and in 2018 it was solely responsible for 22% of greenhouse gas emissions (Selim et al. 2020). According to the National Climate Assessment, by 2016 the average annual temperature in the United State has risen by 1.0°C since 1901. Over the next few decades (until 2050), the mean yearly temperature is expected to increase by 1.4°C in the United States. It has been reported by the EPA that almost 79% of all the USA greenhouse gas emissions were caused by human actions in 2022. Based on the EPA report in 2022, CO₂ emissions in the USA decreased by 8% between 1990 and 2020. These changes are affected by several short-run and long-run factors, including changing behaviour, population growth, changing energy prices, economic growth, new technologies, and seasonal temperatures.

The present study introduces a new perspective and conducts a case study based on publicly available data to examine how education can contribute to CO₂ emission reductions in the USA. Exploring the factors related to public education that might affect CO₂ emissions is an important aspect for governments and policymakers, and it can help to control the increasing trend of CO₂ emissions in the USA and worldwide. Accordingly, this paper is structured into seven sections. The first section introduces the problem of increased CO₂ emissions and states the aim of the study. The second section reports the existing literature on the research topic. Section three provides information regarding the data, and describes the variables that are relevant for the study. Section four introduces the statistical methods. Section five reveals the results. Section six examines the findings of the research, and the last section closes the research work with suggestions for the governments and policymakers on how to help to control the excessive CO₂ emissions in the USA and worldwide.

Literature review

Due to the pressing need for sustainable development and environmental conservation, researchers are interested to examine the potential factors affecting the CO₂ emissions for example: Uzar and Eyuboglu (2019) investigated the effects of the distribution of income on CO₂ emissions in the Republic of Türkiye from 1984 to 2014. They showed a statistically significant positive impact of income distribution on the CO₂ emission level. A similar investigation by Padilla and Serrano (2006) proved that the imbalance in CO₂ emissions is mainly explained by the difference between groups with unequal levels of income per capita. However, Wolde-Rufael and Idowu (2017) identified that the difference in the income was the least significant factor in assessing CO₂ emissions, and reported the absence of causality in both directions between CO₂ emissions and income inequality in China and India.

Urbanization and economic advancement are also reported as key factors affecting the increment in CO₂ emissions, and so polluting the environment (Wang et al. 2020). A study by Kongkuah, Yao, and Yilanci (2022) found out that while energy consumption, economic growth, and

trade have a statistically significant contribution to CO₂ emissions in the long-run, urbanization significantly reduces the contamination from CO₂ emissions. Temireyeva et al. (2022) highlighted the effect of landfilling on greenhouse gases and proposed seven optimal waste management scenarios for the capital city of Kazakhstan.

The experimental results revealed cointegration in the long-run relation between economic growth, financial development, energy consumption, trade openness, and CO₂ emissions in Indonesia. Applying panel analyses, Zhao and Yang (2020) showed that on average, one unit standard increase in provincial financial development levels will decrease the CO₂ emissions by 4–5% in some provinces and increase emissions in other provinces. They argue that in the long-run, two-way causality exists between CO₂ emissions and regional financial development, however, they did not observe this pattern in the short-run.

Shakouri, Yazdi, and Ghorchebigi (2017) studied the influence of economic growth and tourism on CO₂ emissions using panel data. They concluded that tourism has a statistically significant positive effect on carbon dioxide emissions in the long-run. A similar study examined the associations between economic growth, tourist arrivals and CO₂ emissions for the period 1960–2014 in the Republic of Türkiye (Eyuboglu and Uzar 2021). They identified that both tourism and economic growth influence positively the CO₂ emissions in the short-run and in the long-run. León, Arana, and Alemán (2014) analysed the relations between tourism and CO₂ emissions in less developed and in developed countries between 1998 and 2006. They claimed that tourism significantly contributes to CO₂ emissions in the less developed countries as well as in the developed countries. However, in developed countries the impact of this relationship is more significant than in the less developed countries.

Kopidou, Tsakanikas, and Diakoulaki (2016) studied the sustainable development indicators, focusing on the effects of several factors on employment and industrial CO₂ emissions, in various countries of the European Union during 2000–2011. They identified two main factors that affect employment and industrial CO₂ emissions, which were the resource intensity and economic growth that counterbalance each other.

Caporale, Claudio-Quiroga, and Gil-Alana (2021) revealed a long-run equilibrium association between GDP and CO₂ emissions in China. Cosmas, Chitedze, and Mourad (2019) investigated the macroeconomic indicators of carbon dioxide emissions in Nigeria and found an N-shaped relationship by using both linear and non-linear Autoregressive Distributed Lag models. In a recent study, Onofrei, Vatamanu, and Cigu (2022) showed that a 1% change in GDP triggers a 0.072 change in CO₂ emissions in EU countries. They also demonstrated that higher levels of income account for an escalated demand for environmental protection.

The relationship between energy consumption and CO₂ emissions has also been studied in many research works. Can and Gozgor (2017) evaluated the impacts of economic complexity and energy consumption in France and found that the Environmental Kuznets Curve (EKC) hypothesis is valid. Tong et al. (2020) examined the cointegration and causality relations between energy consumption, economic growth, and carbon dioxide emissions in the E7 countries by using a bootstrap ARDL bound test with structural breaks. Although the results differed for each country, they pointed out that energy consumption is the most significant cause of CO₂ emissions. Similar conclusions were reported by Assad et al. (2021), who used predictive models to show that energy consumption, the share of energy sources and the extent of economic activities are relevant factors to predict CO₂ emissions. Differing from most of the literature, Saidi and Hammami (2015) revealed a positive effect of CO₂ emissions and economic growth on energy consumption using simultaneous equation models and a growth framework for 58 countries. Fard et al. (2022) investigated the usage of renewable energy in a case study for 100 households, with the aim of reducing CO₂ emissions. Their study showed that incorporating the usage of renewables significantly reduces the energy costs. They considered all the variables together in a single ARDL model and concluded that the agriculture sector does not harm the environment.

Examining the relationship between education levels and CO₂ emissions has received increasing attention recently. Alkhateeb et al. (2020) revealed the role of education and energy consumption as the driving determinants of CO₂ emissions, warming, and environmental quality in Saudi Arabia. In the analysis of the theoretical and empirical underpinnings of the EKC, Hill and Magnani (2002) identified education as a significant factor that exacerbates the quality of environment. Balaguer and Cantavella (2018) used Australian data, and revealed that education has a direct impact on environmental quality. They studied both linear and non-linear impacts. By using secondary school enrolment as a proxy for human capital, Zafar et al. (2019) studied the impact of education, information, and communication technology on environmental quality in Asian countries between 1990 and 2018. Their findings revealed that information and communication technology as well as financial development increase environmental quality, whereas education decreases environmental quality. Engin Balin (2021) identified a significant and negative relationship between the share of public expenditures on education in GDP and CO₂ emissions. Valerio (2018) considered education expenditure and gross enrolment rate and discussed the positive impact of education and the negative impact of youth fertility on GDP and economic development in Asian countries. Zafar et al. (2022) reviewed the existing literature to examine the long-run effects of information and technology and education on environmental quality. They identified the importance of economic policy and argued that the country's energy resources depend heavily on its human capital and education system.

This study, in line with the sustainability development goals, primarily aims to examine the potential relationships between education levels and CO₂ emissions in both the short-run and long-run, using the ARDL model.

Specifically, the study aims to test the following hypotheses:

Hypothesis 1: There are short-run significant associations between education levels, GDP per capita, total primary energy consumption, and CO₂ emissions in the US.

Hypothesis 2: There are long-run significant associations between education levels, GDP per capita, total primary energy consumption, and CO₂ emissions in the US.

The proposed hypotheses allow us to examine the immediate and sustained impact of independent variables (education levels, GDP per capita and total primary energy consumption) on CO₂ reductions in the US.

Material and methods

Using publicly available datasets provided by the US Census Bureau and the World Bank from 1964 to 2019, we employ time series data analysis. We perform statistical analyses to test the relationship between CO₂ emissions (in metric tons per capita) in the USA and students enrolled in elementary, high school, and college, GDP per capita, and energy usage. The USA has the second-largest higher education system after China. Elementary and secondary education in the USA takes 12 years for most students, including kindergarten. The last four or sometimes three years of school are usually known as high school.

Carbon dioxide emissions are measured in metric tons per capita. They originate from burning fossil fuels and from manufacturing cement, including CO₂ produced during the consumption of gas, liquid and solid, fuels and gas flaring.

GDP per capita is given in constant 2015 US dollars. It is calculated as the GDP divided by mid-year population. GDP is determined as the summation of gross value added by all local manufacturers in the economy and of product taxes. Then the subsidies not included in the value of the products are subtracted from this sum. GDP calculations do not consider deductions for the depreciation of fabricated assets, neither for the degradation and depletion of natural resources.

EC is measured in kg of oil equivalent per capita (kgoe). It is defined as the usage of primary energy before it is transformed to other end-use fuels. It is calculated as the sum of indigenous

production, stock changes and imports. The exports and fuels supplied to aircraft and ships engaged in international transport are then subtracted from this sum.

Elementary education provides pupils with basic writing, reading, and calculation skills. It also supports the pupils with an introductory understanding of art, music, geography, history, natural and social sciences. The number of pupils in elementary education is defined as the total number of pupils enrolled at primary level education in public and private schools. EER is the ratio of enrolment in elementary education to the population.

High school education continues the basic education that started at the elementary school level, focusing on skill- or subject-oriented training. It aims at laying the foundations for human development and lifelong learning, with the help of more specialized teachers. The term high school enrolment refers to the total number of students enrolled in public and private high schools, regardless of age. Typically, students attending high school are from 14 to 18 years old. HER is the ratio of high school enrolment to the population.

College education or higher education which is optional in the USA is the final stage of formal learning. CER is the ratio of total college enrolment, to the population, regardless of age.

Table 1 lists the descriptive statistics of the selected variables, which summarize the minimum, maximum, average, median, standard deviation, and quartiles for the period 1964–2019. The time series plots of the studied variables are also displayed in Figure 1.

Figure 1(a) shows that low CO₂ emissions occurred in 1964, 1965, and 2009, and between 2011 and 2019. High values are observed between 1972 and 1975, and between 1976 and 1979. In general, after 2000 the average CO₂ emissions are smaller (18.27) than before 2000 (20.19). A clear increasing pattern can be observed in Figure 1(b). The lowest GDP per capita observed in 1964 is 21,599.82 USD, while the highest GDP per capita observed in 2019 is 60,836.77 USD. The energy consumption plot given in Figure 1(c) shows a similar pattern with CO₂ emissions. The lowest EC observed in 1964 is 270 kgoe. The highest EC is above 359 kgoe, observed in 1979. In general, after 2000 the average EC is smaller (320.35 kgoe) than before 2000 (331.00 kgoe). Elementary school enrolment is shown in Figure 1(d). There is a clear decreasing pattern followed by an increasing pattern for the elementary school enrolment between 1969 and 2001, ranging from 33,788 to 26,838. After 2001, stationary data can be observed. There is no evidence of any specific pattern. The high school enrolment plot given in Figure 1(e), presents a similar pattern with a long-run fluctuation: a positive trend between 1964 and 1977, a negative trend up to 1990, another increase with the same slope until 2007, and no apparent trend after 2007. In Figure 1(f), there is a clear increasing trend without any other specific patterns ranging from 4,643 to 18,289. Large increases occur in the year 1994 and between 2006 and 2011. Although there is a decrease after 2011, it is not strong and seems like a part of a long random fluctuation.

Before studying the linkages between the selected variables, the time series data are examined to reveal basic patterns in the time series. The data analysis is performed using the R software (version 4.0.3). Six continuous variables are analysed: CO₂ emissions are the dependent variable, GDP per capita, EC, EER, HER, and CER are the five independent variables. First, the summary statistics are calculated, including the mean, the median, the standard deviation (SD), the minimum, the maximum, and the quartiles. The retrieved data are in the form of time series, so, the unit root test is performed for analysing the stationarity of the time series. Unit roots are one cause of non-

Table 1. Descriptive statistics of CO₂ emissions, GDP, energy consumption and school enrolment ratios.

	CO ₂	GDP	EC	EER	HER	CER
Min.	15.7	21,599.82	270	9.93	4.99	2.42
Q1	18.75	30,463.57	311	10.92	5.36	4.46
Median	20	39,402.78	333.5	11.7	5.72	4.66
Mean	19.51	40,485.11	327.2	12.35	5.98	4.95
Q3	20.5	52,092.28	342.25	12.92	6.69	5.75
Max.	22.3	60,836.77	359	16.83	7.31	6.55
SD	1.70	11,758.67	20.32	2.11	0.75	1.00

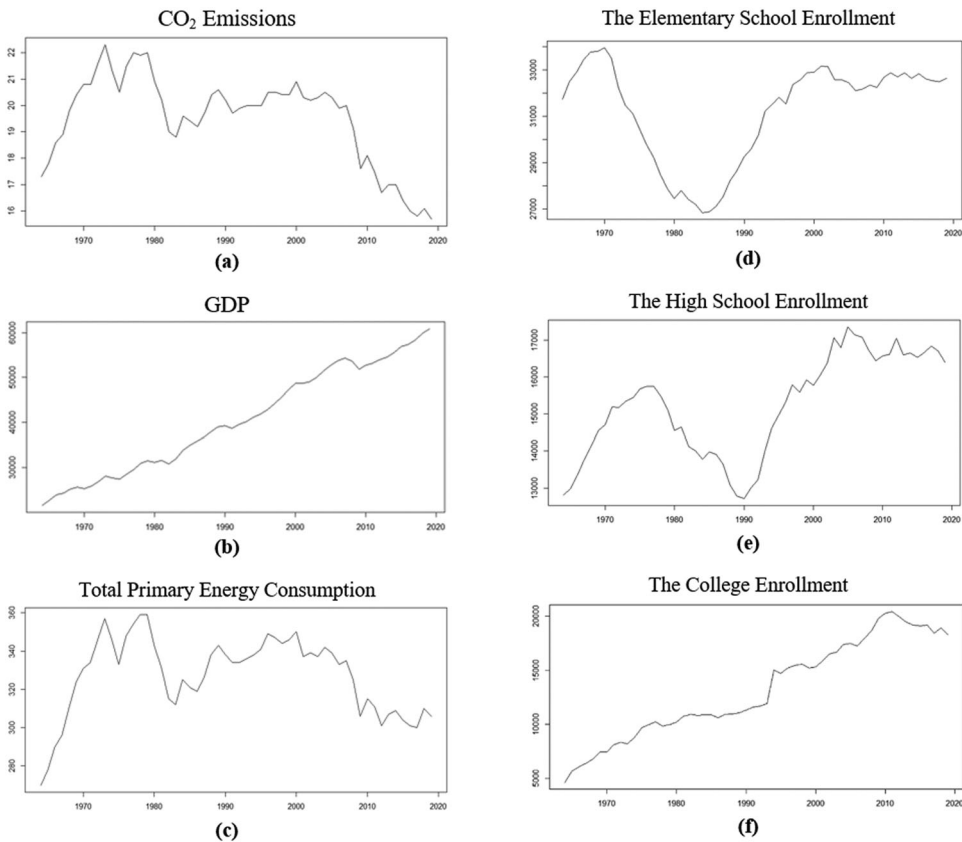


Figure 1. Time series plots for (a) CO₂ emissions in the USA from 1964 until 2019 (in metric tons per capita) (b) GDP per capita (c) Total primary energy consumption per capita (d) Elementary school enrolment (e) High school enrolment (f) College enrolment in the USA from 1964 until 2019.

stationarity; therefore, we test the null hypothesis stating that a unit root is present. As unit root tests are known for having low statistical power, we assess the presence of stationarity by comparing the Augmented Dickey-Fuller (ADF) test results, the Hansen's Covariate Augmented Dickey-Fuller (CADF) test results, the Phillips-Perron (PP) test results, and the Kwiatkowski-Phillips-Schmidt-Shin (KPSS) test results.

The ADF test considers three types of linear regression models. The first regression model is a linear model without linear trend and without drift with respect to time. The second regression model is a linear model with drift and without linear trend, and the third regression model is a linear model with a drift and with a linear trend. The ADF test statistic is defined as the ratio of the coefficient estimation and the estimation of standard error for each linear model. The p -value is obtained by interpolating the test statistics from the tables containing the critical values (see Table 10.A.2 in (Krämer 1996)) for each linear model with the given sample size. Similarly, to the conventional ADF test, the CADF test is based on the t -statistic with the null hypothesis stating that a unit root is present. The CADF unit root test is computed as proposed by Hansen (1995). The asymptotic p -values of the test are calculated as proposed in (Costantini, Lupi, and Popp 2007). Compared with the ADF test, the PP test makes corrections to the test statistics, and it is robust to the heteroscedasticity and unspecified autocorrelation in the errors. The KPSS test decomposes the time series into the sum of a deterministic trend, a random walk, and a stationary error.

Next, we use the ARDL bounds test to examine short-run and long-run associations between the dependent variable and the independent variables. We consider the following general model:

$$CO_2t = \beta_0 + \beta_1 GDP + \beta_2 EC + \beta_3 EER + \beta_4 HER + \beta_5 CER + \varepsilon_t \quad (1)$$

where $\beta_0, \beta_1, \beta_2, \beta_3, \beta_4, \beta_5$ are the regression coefficients, and ε_t is the error term. Assessing an optimal lag order for the ARDL bounds test has a key importance on the test results since it affects all the inferences about the short-run and long-run relationships between the dependent and independent variables in the series. The ARDL test provides the order, constructs the underlying unrestricted and restricted error correction model (ECM), and performs the bounds test for cointegration, providing the multipliers and the cointegrating equation. Our ARDL model is expressed as:

$$\begin{aligned} \Delta CO_2t = & \alpha_0 + \sum_{i=1}^k \alpha_{1i} \Delta CO_2t - i + \sum_{i=1}^k \alpha_{2i} \Delta GDP_{t-i} + \sum_{i=1}^k \alpha_{3i} \Delta EC_{t-i} + \sum_{i=1}^k \alpha_{4i} \Delta EER_{t-i} + \\ & \sum_{i=1}^k \alpha_{5i} \Delta HER_{t-i} + \sum_{i=1}^k \alpha_{6i} \Delta CER_{t-i} + \gamma_1 GDP_{t-1} + \gamma_2 EC_{t-1} + \gamma_3 EER_{t-1} + \\ & \gamma_4 HER_{t-1} + \gamma_5 CER_{t-1} + \varepsilon_t \end{aligned} \quad (2)$$

where Δ shows the difference operator, α_i $i = 1, \dots, 6$ are short-run coefficients, and γ_j $j = 1, \dots, 5$ are long-run coefficients. The existence of the cointegration relationship among the variables is tested through an F -statistic. It is ensured by rejecting $\gamma_j = 0$, for all j .

Once the cointegration is explored the ARDL model is reformulated in ECM for estimating short-run dynamics:

$$\begin{aligned} \Delta CO_2t = & \lambda_0 + \sum_{i=1}^k \lambda_{1i} \Delta CO_2t - i + \sum_{i=1}^k \lambda_{2i} \Delta GDP_{t-i} + \sum_{i=1}^k \lambda_{3i} \Delta EC_{t-i} + \sum_{i=1}^k \lambda_{4i} \Delta EER_{t-i} \\ & + \sum_{i=1}^k \lambda_{5i} \Delta HER_{t-i} + \sum_{i=1}^k \lambda_{6i} \Delta CER_{t-i} + \delta EC_{t-1} + \mu_t \end{aligned} \quad (3)$$

where EC is the error correction term and δ is the coefficient of EC . If δ negative and significant, there exist short-run relationships.

ARDL models are estimated by least squares techniques and for reliable conclusions, the models must satisfy the classical regression model assumptions. To examine the assumptions regarding autocorrelation, homoscedasticity, normality, model specification, and model stability, we apply diagnostic tests, Breusch–Godfrey tests, Breusch–Pagan tests, Shapiro–Wilk tests, Ramsey’s RESET tests, and cumulative sum control charts, to the regression models (Wetherill and Brown 1991).

Results

In general, [Figure 1](#) shows random fluctuations in the data, and no seasonal variation. This allows describing the time series by using an additive model. Although the ARDL cointegration test does not require pre-assumption about the unit roots, we perform unit root tests in order to ensure that the variables are not integrated of $I(2)$. The test results, as listed in [Table 2](#), help to reveal stationarity in the time series. We test the null hypothesis that a unit root is present. The time series has stationarity (T) if a shift in time does not cause a change in the shape of the distribution. The time series is non-stationary (F) otherwise, thus unit roots are one cause of non-stationarity. Most of the commonly used unit root tests such as BOX, CADF, PP, ADF, and KPSS reveal that the time series is non-stationary. The corresponding test statistic values and p -values confirm these findings.

Table 2. Unit root test statistics, p -values, and results for analysing the stationarity of the time series.

Variable	CADF	PP	ADF	KPSS
EER	−2.08 (0.55) F	−2.91 (0.94) F	−3.4 (0.07) F	1.18 (0.01) F
HER	−1.78 (0.7) F	−5.9 (0.77) F	−2.12 (0.53) F	1.12 (0.01) F
CER	−1.68 (0.75) F	−10.98 (0.46) F	−1.95 (0.59) F	1.36 (0.01) F
CO ₂	−2.55 (0.3) F	−7.18 (0.69) F	−2.42 (0.4) F	0.64 (0.02) F
GDP	−3 (0.14) F	−10.85 (0.47) F	−2.49 (0.38) F	1.5 (0.01) F
EC	−3.3 (0.08) F	−9.07 (0.57) F	−3.38 (0.07) F	0.23 (0.1) T

Table 3 indicates the short-run coefficients with the corresponding test statistics and p -values. The results show high p -values for EER and HER which means the enrolment ratios are not statistically significant. However, GDP and EC have positive effects and CER has negative effect in the short-run.

The best Autoregressive Distributed Lag Model for CO₂ emissions as a function of GDP, EC, EER, HER, and CER, has the optimal lag of (4, 5, 5, 0, 3, 5). The findings in **Table 4** reveal the existence of a long-run cointegration for the tested model. Therefore, it can be concluded that CO₂ emissions, GDP, and EC move together in the long-run. These study findings are supported by empirical studies conducted by Eyuboglu and Uzar (2021).

Next, we perform ARDL bound test. The results of the Wald bounds-test for no cointegration on the parameters are given in **Table 5**, expressed as an F -statistic with unrestricted intercept and no trend. Variables are cointegrated, if the calculated F -statistic is greater than the critical value's upper bound. On the other hand, there is no cointegration if the calculated F -statistic is lower than the critical value's lower bound. The F -statistic (12.18571) is higher than the upper bound (4.68), and the null hypothesis of no cointegration among the variables is rejected at the significance level of 0.01 (p -value = 0.000006).

To confirm the efficiency and consistency of the model the required diagnostic tests are performed regarding the residuals. **Table 6** gives Breusch–Godfrey (autocorrelation), Breusch–Pagan (homoscedasticity), Shapiro–Wilk (normality), and Ramsey's RESET (model specification) tests' test statistics and p -values. The results indicate all the p -values are large so that the null hypothesis cannot be rejected which means the ARDL model passes all the tests.

Table 3. ARDL (4, 5, 5, 0, 3, 5) model with the estimated short-run coefficients and association test results between education levels, GDP per capita, total primary energy consumption, and CO₂ emissions in the US.

Variable	Estimate	t -statistic	P -value
GDP	0.0001	3.701	0.0012
EC	0.0582	16.601	0.0000
EER	0.1135	2.624	0.1015
HER	−0.0073	−0.038	0.9703
CER	−0.2281	−2.666	0.0138

Table 4. ARDL long-run results, with the estimated long-run coefficients and association test results between education levels, GDP per capita, total primary energy consumption, and CO₂ emissions in the US.

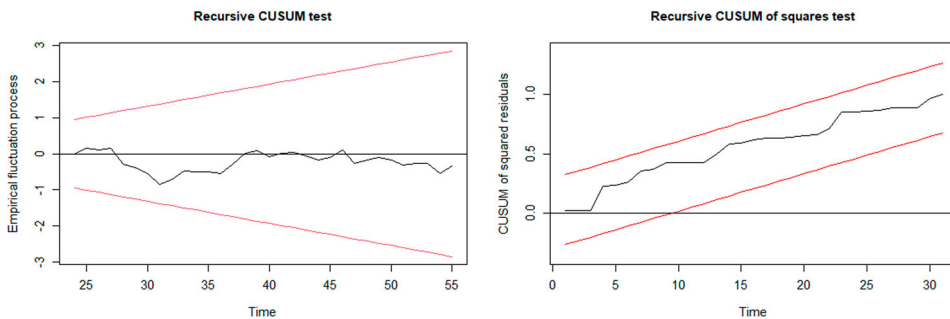
Variable	Estimate	t -statistic	P -value
GDP	0.00052	1.84139	0.04849
EC	0.02699	0.00937	0.00842
EER	−0.38654	−2.31178	0.03009
HER	−0.71032	−3.58669	0.00156
CER	−0.72988	−2.30032	0.03083

Table 5. Bound test for the ARDL model.

<i>F</i> -statistic	<i>P</i> -value	Lower bound	Upper bound	Result
12.18571	0.000006	3.41	4.68	Cointegrated

Table 6. ARDL model diagnostic tests.

Test	Test-statistic	<i>P</i> -value
Breusch–Godfrey	0.69311	0.4927
Breusch–Pagan	45.062	0.3857
Shapiro–Wilk	0.97995	0.5902
Ramsey's RESET	1.0093	0.4189

**Figure 2.** Cumulative sum test for parameter stability.

Moreover, we use the recursive cumulative sum test and the recursive cumulative sum of squared test for parameter stability (CUSUM and CUSUMQS) to support our findings.

The straight lines in [Figure 2](#) represent the critical bounds at 5% significance level, and the values on the *x*-axis represent the count of the years for which complete data were available. We can observe that all values in [Figure 2](#) are within the critical bounds, which lets us conclude that the estimated results are stable.

Discussion

The present study placed public education enrolment in the focus of the analyses, in relation to CO₂ emissions. Based on the proposed hypotheses the current study investigated short- and long-run relationships between CO₂ emissions and other independent factors such as GDP, EC, EER, HER, and CER. The study employed ARDL bound testing on publicly available data of the USA from 1964 to 2019 provided by the US Census Bureau and the World Bank. The USA is one of the countries with high CO₂ emissions, and it has the second largest higher education system after China. Therefore, it makes the USA a representative country for testing the nexus between CO₂ emissions and the education levels in public education.

Focusing on education levels, the results of the study show that in the short-run there is no significant relationship between CO₂ emissions, EER, and HER. However, in the long-run, there are significant negative associations between the three levels of education levels and CO₂ emissions. The findings of the study confirm that while there is no immediate impact of education levels on CO₂ reductions, there is sustained and long-term impact on the level of CO₂ emissions in the US. The significant long-run relationship suggests the potential importance of education in addressing environmental sustainability and mitigating climate change, which allows us to discuss several key points as follows:

Policy recommendations

First, by improving access to education for all in the society, the chance of understanding the consequence of their sustainable behaviour (e.g. renewable energy usage, and waste reduction) will increase, which contributes to reduce the level of CO₂ emissions.

Second, higher education levels are often associated with innovation, research and employing technological advances (e.g. generating clean energy sources, or adoption of electric vehicles) resulting in lower level of CO₂ emissions in the long-run.

Furthermore, the findings of the statistical analyses indicate that EC and GDP significantly and positively affect CO₂ in the long- and short-run, confirming that economic growth has negative environmental effects by producing more CO₂ emissions. Thus, having educated workforce shifts heavy industries towards knowledge-based sectors with more focus on sustainability, resulting in lower carbon footprints compared to heavy manufacturing industries. With the help of this new perspective introduced by the present study, governments and policymakers might consider controlling the increasing trend of CO₂ emissions by employing further developments in education.

Conclusion

This present research investigates the effect of education on CO₂ emissions. The results indicate that GDP and EC tend to increase CO₂ emissions. CER affects CO₂ emissions in both the short- and long-run. On the other hand, the effects of EER and HER are significant only in the long-run. It has been reported that the education systems of the USA are based on new technologies and aim to increase the quality of human lives. Thus, the results of this improvement would help to reduce damage caused to the environment by using the latest technologies and increasing environmental awareness. The results also indicate that both GDP and EC contribute to the increase in CO₂ emissions in the short- and long-run. The findings of this study have important implications for education and environmental policies. Although there has been a considerable increment in the number of people who attend schools in recent years, it is essential to ensure high quality and universal standards. In particular, raising awareness of clean energy technologies at each level of schooling is crucial for supporting sustainability. In this context, schools' or colleges' research and development activities should be encouraged by the state to develop renewable energy technologies to minimize the negative effects on the environmental quality. Resulting in switching the USA energy portfolio to renewable sources in the long-run which will help cut CO₂ emissions and ensure energy efficiency.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Data availability statement

The datasets analysed during the current study are publicly available in the 'The U.S. Census Bureau' and 'World Bank Data' repositories, <https://www.census.gov> Accessed 22 January 2023 and <https://data.worldbank.org/> Accessed 22 January 2023.

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