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Environmental Kuznets Curve Model for the United States: A Consideration of Foreign Direct Investment Variable

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ABSTRACT

This paper analyzes the causal link between CO_2 emission, energy consumption, GDP, the square of GDP, and foreign direct investment in the Environmental Kuznets Curve for the United States from 1979-2021. Three steps are used: bound tests to verify the presence of cointegration, autoregressive distributed lag (ARDL) model to check the effects of the dependent variables on the independent variable in the short run and long run, and finally, the vector error correction (VECM) was used the detect the causal relationships among variables. We found that the coefficients of energy consumption and foreign direct investments variables were significant at the 10% level. The variables GDP and GDP^2 were found to be insignificant. Energy consumption positively impacts CO_2 emissions, while FDI negatively influences CO_2 emissions. In addition, in causal analysis, it is found that GDP and GDP^2 indirectly affect CO_2 emissions. GDP and GDP^2 impact energy consumption and FDI; later, FDI was passed through CO_2 emission. Finally, the federal government should accelerate investment policies, tax credits, regulatory actions, state policies, research and development, and market trends to drive significant renewable deployment.

Keywords: CO_2 Emissions, Energy Consumption, GDP, Foreign Direct Investment, The Environmental Kuznets Curve
JEL Classifications: C54, Q4, Q5

1. INTRODUCTION

A consequence of the study of the relationship of variables in the Environmental Kutznets curve by empirical evidence of a long-run environmental Kuznets curve (EKC) for Ecuador by Zambrano-Monserrate et al. (2016), including Bunnag (2021) and Bunnag (2023) was a case study in Thailand. It later expanded its interest to the United States, the world's second-largest carbon emitter, second to China.

This empirical study discusses the environmental degradation of one of the six superpowers and one of the most developed countries-the United States of America, which comprises 52 well-developed states. The GDP of the United States is ranked first globally. Moreover, it ranks eighth in gross domestic product per capita. Due to its highly developed economy, the United States has to face the effects of energy pollutants and carbon emissions, mainly caused by the financial sector, economic activity, urbanization rate, industrialization speed, and the utilization of advanced technology (Khan et al., 2019a).

Climate change already inflicts severe damage on the United States and other regions (Murshed et al.), particularly the most vulnerable that are least equipped to adapt. The science is precise that, without faster global action, these impacts will become much more frequent and severe. Two recent reports from the Intergovernmental Panel on Climate Change IPCC (2018) and IPCC (2021) affirm with complete scientific confidence the need to keep warming under 1.5°C to reduce the most extraordinary global risks and avoid significant, wide-ranging, and severe impacts. To keep 1.5°C within reach, the United States aims to achieve net-zero emissions economy-wide by 2050 (United States Department of State (2021)).

The United States is planning multiple pathways to a net-zero economy by 2050 (United States Department of State (2021);

United States Executive Office of the President (2021); G7 (2021)). It confirms how actions are taken now and through this decade are critical to making these net-zero pathways possible by mobilizing to achieve net-zero will deliver benefits for all Americans.

Driving down GHGs will spur investments that modernize the American economy, address the distributional inequities of environmental pollution and climate vulnerability, improve public health in every community, and reduce climate change's severe costs and risks. Benefits include:

Firstly, public health: reducing air pollution through clean energy will avoid 85,000-300,000 premature deaths and health and climate damages of $150-250 billion through 2030. It will prevent $1-3 trillion in damages through 2050 in the United States alone. These measures will also help alleviate the pollution burdens proportionately borne by communities of color, low-income communities, and indigenous communities.

Secondly, economic growth: Investments in nascent clean industries will enhance competitiveness and propel sustained growth. The United States can lead in crucial clean technologies like batteries, electric vehicles, and heat pumps without sacrificing critical worker protections.

Thirdly, reduced conflict: Drought, floods, and other disasters fueled by climate change have caused large-scale displacements and conflict. The United States Department of Defense recognizes climate change as a vital, globally destabilizing national security threat (United States Department of Defense, 2021). Early action by the United States will encourage faster global climate action, including driving down the costs of carbon-free technologies. These actions will ultimately support security and stability worldwide.

Fourthly, the quality of life: Modernizing the American economy to achieve net zero can improve our lives. High-speed rail and transit-oriented development reduce emissions and create more connected, accessible, and healthier communities.

Many factors affecting the Environmental Kuznets curve, whether it is energy consumption, economic growth, or an additional variable included in this study is a foreign direct investment that affects the United States carbon emissions. As a powerful tool for transferring technology, financial capital, and other skills, foreign direct investments (FDIs) have three economic, political, and social impacts. The political effects focus mainly on the insecurity of national independence, and the social effects are primarily concerned with the possibility of the cultural transformation of society. On the other hand, economic effects imply various outcomes regarding output, the balance of payments, and market structure (Moosa, 2002). Most studies agree that FDI contributes to economic growth by providing capital, increasing productivity, creating new job probabilities, and boosting competitiveness (Choong and Lam, 2010). However, some studies have explained that there is no direct impact of FDI on economic growth (Carkovic and Levine, 2002; Durham, 2004).

To further this research, we investigate the impact of foreign direct investments, energy consumption, and economic growth on CO_2 emissions using the autoregressive distributed lag (ARDL) modeling approach to cointegrate and causality analysis. The study aims to explore the relationship between the environment, foreign direct investments, economic growth, and energy consumption in the short and long run to support the United States government in making a policy. The following content consists of a literature review on the nexus of related variables and the primary methodologies used in the analysis. It continues with the findings and finalizes with a conclusion.

2. REVIEW OF LITERATURE

The relationship between economic growth and carbon emission has been widely investigated since the 1990s. Initially, this relationship was derived from the final work of Simon Kuznets in 1955. He showed that income inequality has increased along with revenue growth, fixed at a specific criterion, then decreased, representing an inverted U-shaped relationship between these two variables (Kuznets, 1955). Environmental economists have hypothesized a relationship between income growth and environmental degradation. For example, Grossman and Kruger examined the relationship between economic growth, sulfur dioxide, and carbon dioxide emission intensity as environmental pollution. Their results confirm an upward trend in pollutants as per capita income rises to a certain level and then a decreasing trend among high-income groups (Grossman and Krueger, 1991). In 1992, Shafik and Bandyopadhyay demonstrated a U-shaped relationship between environmental pollution and economic growth (Shafik and Bandyopadhyay, 1992). Economic development in developing and developed countries is called Environmental Kuznets Curve (EKC). His results confirmed the inverted U-shaped relationship between the two countries' groups at different turning points (Panayotou, 1993).

It should be noted that there is extensive literature consisting of empirical studies of the EKC hypothesis; those studies have yet to produce consensus results. In addition to analyzing the relationship between these variables, the researchers also included additional economic variables to avoid the problem of omitted variables such as energy consumption, capital, labor, exports, imports, trade openness, and foreign direct investment (FDI) (Al-Mulali and Ozturk, 2015; Apergis and Payne, 2009). Research on the environmental Kuznets curve hypothesis has included using renewable energy as one of the variables under study. Evidence shows that increased use of renewable energy can help reduce carbon emissions and dependence on fossil fuels (Al-Mulali and Ozturk, 2016; Zoundi, 2017).

Research on FDI inflows and carbon emissions, for example, over the past decade, there is a growing body of literature on the role of FDI inflows in carbon emissions. However, the impact of FDI inflows on carbon emissions has long been debated. The latest research on this topic primarily includes the following three categories.

Firstly, several previous studies have examined the direct effects of FDI inflows on carbon emissions and proposed a hypothesis for the pollution refuge. This suggests that inflows of FDI are associated with higher carbon emissions, on the one hand, to increase profits. Developed countries tend to invest in developing countries with less stringent environmental regulations or lower environmental taxes. This leads to transferring polluting industries to these regions (Aller et al., 2021). As a result, host countries' carbon emissions increase with FDI-led economic activity expansion (Mahadevan and Sun, 2020). Grimes and Kentor (2003) proposed that FDI inflows significantly accelerated carbon emission growth in less developed countries. Finally, Cole et al. (2006) used data from 33 countries to examine the link between FDI inflows and environmental policy austerity, local carbon emissions will increase. This is because multinationals may lobby local governments for lax ecological policies.

Secondly, many previous studies have proposed a conflicting pollution radius hypothesis. This indicates that the influx of FDI can bring cleaner and more efficient technologies to the destination country, significantly reducing positive CO_2 emissions. Zhu et al. (2016) suggested that the effect of FDI influx on emissions was negative and became significant at higher doses in Indonesia, Malaysia, the Philippines, Singapore, and Thailand.

Thirdly, some studies have reached broad conclusions. For example, using panel data from 32 OECD countries, Alshubiri and Elheddad's (2019) cohort data cited a nonlinear relationship between FDI inflows and carbon emissions at the left end of the turning point. FDI inflows are positively correlated with carbon emissions. On the contrary, at the far right of the influx, FDI inflows are negatively associated with carbon emissions. Shahbaz et al. (2015) utilized data from 99 countries, and empirical results suggested that the impacts of FDI inflows on carbon emissions are heterogeneous due to differences in national income. Moreover, an upside-U-shaped link exists between FDI inflows and carbon emissions in middle-income countries. The influx of FDI could reduce carbon emissions, while in low-income countries, the relationship was reversed (Shahbaz et al., 2015).

Many previous studies have documented earlier studies on other factors. Other factors influence carbon emissions, such as FDI inflows and other aspects of CO_2 emissions. For example, studies have not explored the relationship between economic development and carbon emissions. Some people know the hypothesis of the Environmental Kuznets Curve, purported to be a U-shaped inversion between income and environmental pollution. Governments may sacrifice the environment when the economy is underdeveloped (for example, by increasing CO_2 emissions) to grow the economy. However, when the country has higher incomes, environmental oversight costs are reduced, making people pay more attention to the quality of the environment. Thus, the government should choose a more environmentally friendly approach (Ren et al., 2021). Grossman and Krueger (1992) summarized three effects of economic development on the environment. The first is the scale effect. It indicates that increased economic activity without technological innovation is associated with a greater demand for natural resources. This leads to more waste and carbon emissions. In this case, the rapid growth of economic activity hurts the environment. The second is the composition effect. This means that wealth accumulation coincides with a change in the structure of production institutions. In industrial society, environmental degradation is exacerbated when the economic structure shifts from rural to urban but is reversed with the structural change from energy-intensive industries to technical and knowledge-based services.

3. THEORETICAL AND MODELING FRAMEWORK

The paper follows the framework of Halicioglu (2009), Jalil and Mehmud (2009), and Shahbaz et al. (2011) in estimating an environmental degradation equation. These studies evaluated the emissions-growth and energy-growth nexus in a single equation model. In addition, we include energy consumption and foreign direct investment as variables to proxy for reflecting the rapid movements from the economy's growth. In Equation 1, we suggest that CO_2 emission (CO_2) in the United States depends on energy consumption (electric power consumption) (EC), GDP, the square of GDP (GDP^2), and Foreign Direct Investment (FDI).

$$CO_2 = f(EC, GDP, GDP^2, FDI) \tag{1}$$

We convert the linear specification of the model into a log-linear specification. It is noted that log-linear specification provides more relevant and efficient results than the simple linear functional form of the model. Furthermore, a logarithmic form of variables gives direct elasticities for interpretations in Equation 2.

$$lnCO_2 = \alpha_1 + \alpha_{EC} lnEC + \alpha_{GDP} lnGDP + \alpha_{GDP^2} lnGDP^2 + \alpha_{FDI} lnFDI + \mu \tag{2}$$

Where μ is stood for residual or error term, we hypothesize that economic activity is positively stimulated by increased electric power consumption or energy use, resulting in increased environmental pollutants or carbon emissions, leading us to expect $\alpha_{EC} > 0$. The EKC hypothesis suggests that $\alpha_{GDP} > 0$ and $\alpha_{GDP}{}^{2<0}$ or $\alpha_{GDP}{}^{2}>0$, according to the study of Hatmanu et al. (2022), the sign of $\alpha_{FDI} < 0$ is followed by the analysis of Melane-Lavado et al. (2018).

3.1. ARDL Approach Specification

The empirical methodology that we use in this paper is the autoregressive distributive lag (ARDL) bounds test proposed by Pesaran and Pesaran (1997) and Pesaran et al. (2001). Then, the error correction model (ECM) can be easily derived from the ARDL framework, making it possible to estimate the long-run adjustment process toward equilibrium. One of the advantages of this method is that the time series regression can be carried out regardless of the nature of variables, whether they are I(1) or I(0). Given that most macroeconomic variables are proved to be either of those two orders, this methodology is convenient with the aim of examining long-run relationships. However, as Pesaran and Shin (1999) demonstrated, another tremendous advantage is that serial correlation and endogeneity problems are removed when long-run and short-run components are simultaneously taken with appropriate lags.

The relationship among CO_2 per capita, energy consumption, GDP per capita, the square of GDP, and foreign direct investment (FDI) postulated in Equation 3 follows a time path before a long-term nexus is achieved. Thus, Equation 3 would be written as an unrestricted error correction representation:

$$\Delta lnCO_{2_t} = \alpha_0 + \sum_{i=1}^{p} \beta_i \Delta \ln CO_{2_{t-i}} + \sum_{i=1}^{p} \varphi_i \Delta lnEC_{t-i}$$
$$+\sum_{i=1}^{p} \gamma_i \Delta lnGDP_{t-i} + \sum_{i=1}^{p} \delta_i \Delta (lnGDP_{t-i})^2$$
$$+\sum_{i=1}^{p} \theta_i \Delta lnFDI_{t-i} + \gamma_1 lnCO_{2_{t-1}} + \gamma_2 lnEC_{t-1}$$
$$+\gamma_3 lnGDP_{t-1} + \gamma_4 lnFDI_{t-1} + \mu_t \quad (3)$$

Where μ_t are the new serially independent errors. The estimation procedures used here involve two stages. In the first stage, we will analyze, through the ARDL bound tests, whether or not there is evidence of a cointegration relationship. With this purpose, the null hypothesis of no cointegration among the variables (H_0: $\gamma_1 = \gamma_2 = \gamma_3 = \gamma_4 = 0$) should be tested against the alternative(H_1: $\gamma_1 \neq \gamma_2 \neq \gamma_3 \neq \gamma_4 = 0$). Ordinary least squares report F-statistics, compared to the critical values given in Pesaran and Shin (1996) and Pesaran et al. (2001). If they go beyond the upper bound, the null hypothesis will be rejected, and there will be a cointegrating relationship among the variables.

On the contrary, if the F-statistics are below the lower bound, the null hypothesis will not be rejected. The test result should be inconclusive if the F-statistics are between the upper and lower critical values. The second stage is to estimate the long-run coefficients of the cointegrating relation and make inferences about their values.

Finally, the empirical methodology involves the modeling of a restricted error correction representation, which takes a similar form to Equation 4 but now includes the long-run terms in the error correction variable lagged one period:

$$\Delta lnCO_{2_t} = \alpha_0 + \sum_{i=1}^{p} \beta_i \Delta \ln CO_{2_{t-i}} + \sum_{i=1}^{p} \varphi_i \Delta lnEC_{t-i}$$
$$+\sum_{i=1}^{p} \gamma_i \Delta lnGDP_{t-i} + \sum_{i=1}^{p} \delta_i \Delta (lnGDP_{t-i})^2$$
$$+\sum_{i=1}^{p} \theta_i \Delta lnFDI_{t-i} + \gamma ECT_{t-1} + \mu_t \quad (4)$$

Where ECT_{t-1} is the error correction term represented by the OLS residuals series from the long-run cointegration relationship, the coefficient indicates the speed of γ adjustment towards this long-run equilibrium. Diagnostic and stability tests will reveal the soundness of the model.

3.2. Causality Analysis

ARDL cointegration method tests the existence or absence of a long-run relationship between all variables. It does not indicate the direction of causality. Once estimating the long-run model in Equation 4 obtains the estimated residuals, the next step is to evaluate a Vector Error Correction Model (VECM), with the variables in first differences and including the long-run relationships as the error correction term in the system. Therefore, the following dynamic VECM is estimated to investigate the Granger causality (Granger, 1969) between the variables in Equations 5, 6, 7, 8, and 9, respectively:

$$\Delta lnCO_{2_t} = \alpha_1 + \sum_{i=1}^{p} \beta_{1i} \Delta \ln CO_{2_{t-i}} + \sum_{i=1}^{p} \varphi_{1i} \Delta lnEC_{t-i}$$
$$+\sum_{i=1}^{p} \gamma_{1i} \Delta lnGDP_{t-i} + \sum_{i=1}^{p} \delta_{1i} \Delta (lnGDP_{t-i})^2$$
$$+\sum_{i=1}^{p} \theta_{1i} \Delta lnFDI_{t-i} + \pi_1 ECT_{t-1} + \mu_{1t} \quad (5)$$

$$\Delta lnEC_t = \alpha_2 + \sum_{i=1}^{p} \beta_{2i} \Delta lnEC_{t-i} + \sum_{i=1}^{p} \varphi_{2i} \Delta lnGDP_{t-i}$$
$$+\sum_{i=1}^{p} \gamma_{2i} \Delta (lnGDP_{t-i})^2 + \sum_{i=1}^{p} \delta_{2i} \Delta lnFDI_{t-i}$$
$$+\sum_{i=1}^{p} \theta_{2i} \Delta \ln CO_{2_{t-i}} + \pi_2 ECT_{t-2} + \mu_{2t} \quad (6)$$

$$\Delta lnGDP_t = \alpha_3 + \sum_{i=1}^{p} \beta_{3i} \Delta lnGDP_{t-i} + \sum_{i=1}^{p} \varphi_{3i} \Delta (lnGDP_{t-i})^2$$
$$+\sum_{i=1}^{p} \gamma_{3i} \Delta lnFDI_{t-i} + \sum_{i=1}^{p} \delta_{3i} \Delta lnEC_{t-i} + \sum_{i=1}^{p} \theta_{3i} \Delta \ln CO_{2_{t-i}}$$
$$+\pi_3 ECT_{t-3} + \mu_{3t} \quad (7)$$

$$\Delta ln(GDP_t)^2 = \alpha_4 + \sum_{i=1}^{p} \beta_{4i} \Delta (lnGDP_{t-i})^2 + \sum_{i=1}^{p} \varphi_{4i} \Delta lnFDI_{t-i}$$
$$+\sum_{i=1}^{p} \gamma_{4i} \Delta lnGDP_{t-i} + \sum_{i=1}^{p} \delta_{4i} \Delta lnEC_{t-i} + \sum_{i=1}^{p} \theta_{4i} \Delta \ln CO_{2_{t-i}}$$
$$+\pi_4 ECT_{t-4} + \mu_{4t} \quad (8)$$

$$\Delta lnFDI_t = \alpha_5 + \sum_{i=1}^{p} \beta_{5i} \Delta lnFDI_{t-i} + \sum_{i=1}^{p} \varphi_{5i} \Delta (lnGDP_{t-i})^2$$
$$+\sum_{i=1}^{p} \gamma_{5i} \Delta lnGDP_{t-i} + \sum_{i=1}^{p} \delta_{5i} \Delta lnEC_{t-i} + \sum_{i=1}^{p} \theta_{5i} \Delta \ln CO_{2_{t-i}}$$
$$+\pi_5 ECT_{t-5} + \mu_{5t} \quad (9)$$

Where α_1 to α_5, β,ϕ,γ,δ, and θ represent the coefficients to be estimated. π_1 to π_2 is the coefficient of long-run equilibrium of the dependent variables, while ECT is the error correction term of a long run, and μ_1 to μ_5 represent the white noise term error.

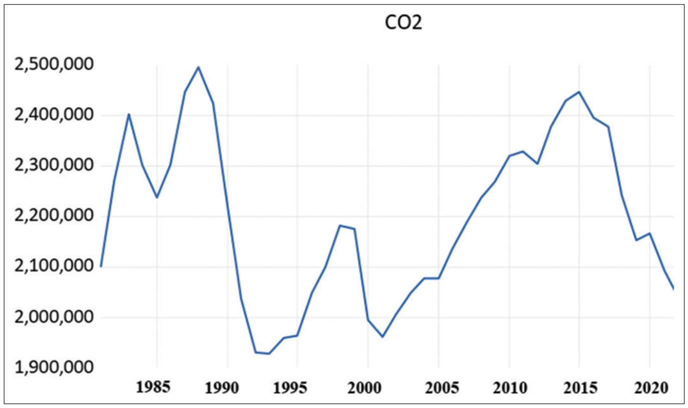
4. DATA COLLECTION AND VARIABLES

We have used yearly data on CO_2 emissions, energy consumption (electric power consumption), GDP per capita, and foreign direct investment in the United States from 1979 to 2021. The United States Census Bureau (USCB) has been the data source for all variables, such as CO_2 emission was measured in kt, energy consumption per capita was measured in kWh, gross domestic product per capita data was measured in the constant LCU, and inflows of foreign direct investment were estimated in current USD. The movement of CO_2 emission, energy consumption, GDP, and foreign direct investment can show in Figures 1-4, respectively.

5. EMPIRICAL ANALYSIS AND RESULTS

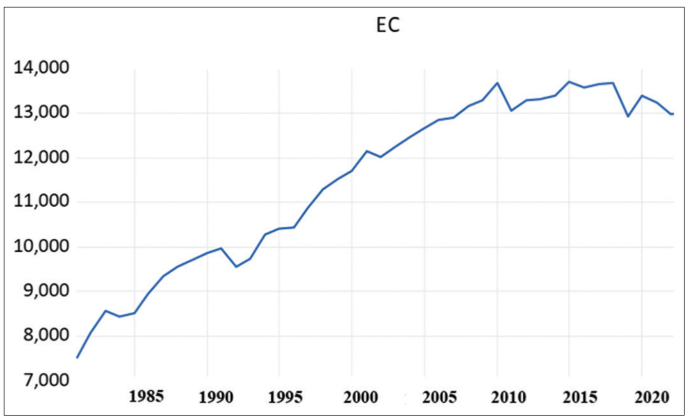
In this part of this study, we try to analyze the different relationships between variables. However, generally, in time series analysis, the primary stage is to investigate the integrated order of the study

Figure 1: The movement of CO_2 emissions in the United States from 1979 to 2021



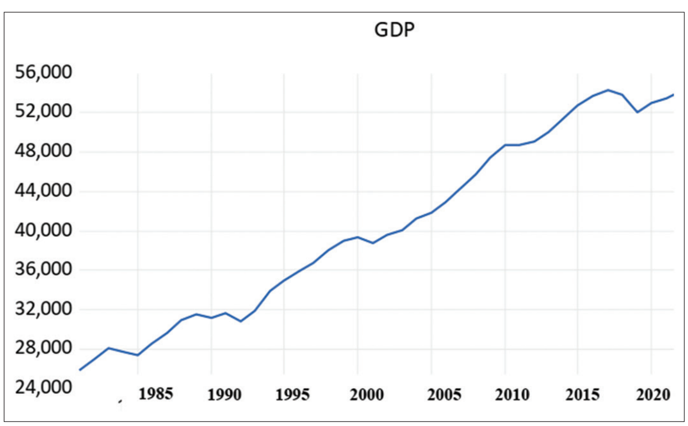
Source: The United States Census Bureau (USCB), 2022

Figure 2: The movement of energy consumption in the United States from 1979 to 2021



Source: The United States Census Bureau (USCB), 2022

Figure 3: The movement of the GDP of the United States from 1979 to 2021

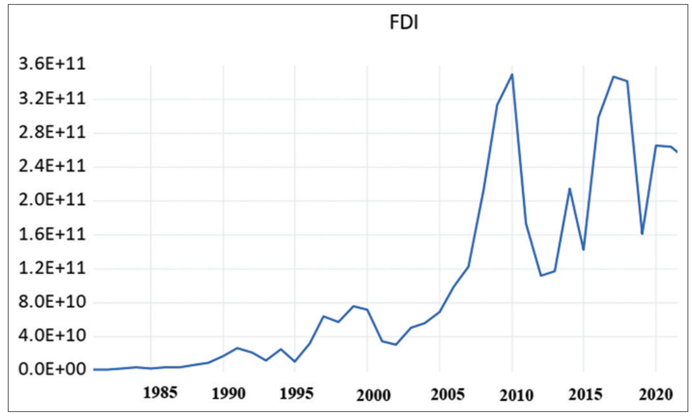


Source: The United States Census Bureau (USCB), 2022

variables. ADF (see Dickey and Fuller, 1981) and PP (see Phillips and Perron, 1988) approaches have been used in this study to check the order of integration. Finally, we want to test the hypothesis of the existence of a unit root. The null and alternative hypotheses can be formulated as follows:

H_0: $\alpha = 1$ (unit root)

Figure 4: The movement of foreign direct investment in the United States from 1979 to 2021



Source: The United States Census Bureau (USCB), 2022

H_1: $\alpha < 1$ (Integrated of order zero)

These two tests are based on the null of non-stationarity, which indicates the presence of a unit root, and the alternative hypothesis of the non-existence of a unit root, which means that the variable examined is stationary.

5.1. Results of the Unit Root Test

All data for CO_2 emissions, energy consumption, GDP, GDP^2, and foreign direct investment variables have been converted into a log form and shown in Table 1. The different results of the stationarity test are indicated in Table 1. The results show that all variables are stationary in the first difference, meaning that there are integrated into order one I(1). In this case, we can reject the null hypothesis of the presence of unit root, and we can accept the alternative hypothesis. After determining the order of integration, we will verify the existence of cointegration between variables using the bound test.

5.2. Results of the ARDL Model

We now estimate $(p + 1)^k$, the number of regressions, where p is the maximum number of lags and k is the number of variables in the model, to determine the model lag selection. To select the optimum lag order for the model, we focus on the Akaike Information Criterion (AIC) and the Schwarz Bayesian Criterion (SBC). We use a high enough order to ensure that the optimal one is not exceeded. As shown in Table 2, the optimum lag order is (2, 0, 0, 1, 0) according to the AIC and is the same as the lag according to SBC, so we finally chose the order selected from said before.

Once the properties of the time series have been analyzed, the optimum lag order is determined. We must check whether a cointegrating relationship (long-run nexus) exists in the ARDL model and estimate the long-run coefficients. Therefore, a bounds test is carried out. As shown in Table 3, the computed F-statistics (4,42) equal to 5.031 indicate the cointegrating relationship among $lnCO_2$, lnEC, lnGDP, $lnGDP^2$, and lnFDI at a 1% level. It means that there are long-run relationships among these variables. Moreover, Table 3 presents the estimated ARDL model that has passed several diagnostic tests that indicate no serial correlation

Table 1: Unit root test for lnCO_2, lnEC, lnGDP, lnGDP^2 and lnFDI

Variables	ADF test statistic				PP test statistic			
	Intercept		Intercept and trend		Intercept		Intercept and trend	
	I (0)	I (1)	I (0)	I (1)	I (0)	I (1)	I (0)	I (1)
lnCO_2	−3.090**	−4.056***	−3.071	−3.958 ***	−1.667	−3.865***	−2.005	−3.727**
lnEC	−3.549**	−6.464***	−1.347	−7.578***	−3.700***	−6.481***	−1.294	−8.110***
lnGDP	−1.079	−4.929***	−2.055	−4.967***	−1.863	−4.775***	−1.624	−4.839***
lnGDP^2	−1.011	−4.913***	−2.145	−4.933***	−1.668	−4.751***	−1.677	−4.782***
lnFDI	−3.304**	−4.780***	−2.771	−6.057***	−2.933**	−7.503***	−2.730	−10.932***

=5% significant level, *=1% significant level

Table 2: Optimum lag order for model selection

Order for ARDL model selection	AIC	SBC
CO_2=f (EC, GDP, GDP^2, FDI)	(2,0,0,1,0)	(2,0,0,1,0)
Standard error of the regression	0.023	0.023

Table 3: Cointegration results and estimation of the ARDL (2,0,0,1,0) model

Variables	Coefficient	t-statistics
C	26.912	1.056
lnCO_2(-1)	1.135***	10.047
lnCO_2(-2)	−0.324***	−2.456
lnEC	0.258	1.473
lnGDP	−4.911	−1.015
lnGDP^2	0.270	1.216
lnGDP^2(−1)	−0.039***	−3.544
lnFDI	−0.021**	−2.419

F-bounds test	Value	Significant	I (0)	I (1)
F-statistic (4,42)	5.031	10%	2.20	3.09
		5%	2.56	3.49
		2.5%	2.88	3.87
		1%	3.29	4.37

LM test	Value	Prob.
F-statistic (2,32)	0.672	0.517

Heteroskedasticity test: Breusch-Pagan-Godfrey (HT)	Value	Prob.
F-statistic (7,34)	1.441	0.221

***=1% significant level, **=5% significant level

and heteroscedasticity by considering from LM test equal to 0.672 and HT equal to 1.441, respectively.

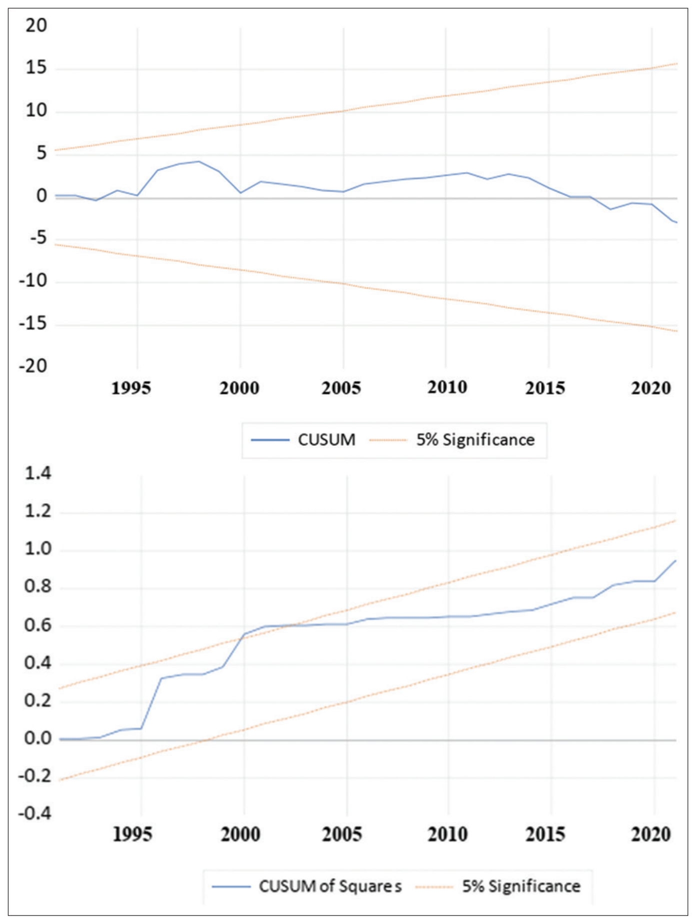
F-bounds test is the ARDL cointegration test. The critical values for the lower I(0) and upper I(1) bounds are taken from Narayan (2005). LM is the Lagrange multiplier test for serial correlation with a y^2 distribution with two degrees of freedom. HT is the Heteroskedasticity test with a y^2 distribution.

In addition, due to the structural changes in the economies of the United States, the macroeconomic series is likely subject to one or multiple structural breaks. For this purpose, the stability of the short-run and long-run coefficients is checked through the cumulative sum (CUSUM) and cumulative sum of squares (CUSUMSQ) test proposed by Brown et al. (1975). Figure 5 presents the United States CUSUM and CUSUMSQ test statistics plotting within the critical bounds of 5% significance. This result implies that the estimated parameters are stable from 1979 to 2021.

Table 4: Long run estimates of the ARDL model

Variable	Coefficient	t-statistic	P-value
C	142.308	1.350	0.185
lnEC	1.367	1.680	0.100
lnGDP	−25.972	−1.268	0.212
lnGDP^2(−1)	1.223	1.301	0.201
lnFDI	−0.112	−1.645	0.100

Figure 5: Presents the plot of CUSUM and CUSUMSQ test statistics for the United States from 1979 to 2021



Based on our consideration of the F-bound test, we confirmed that the relationship between the independent and dependent variables was long-run. However, we can prove from the long-run estimation from Table 4 that we look at the relationship between the independent and dependent variables in a long-run relationship. We found that the coefficients of energy consumption and foreign direct investments variables were significant at the 10% level. The variables GDP and GDP^2 were found to be insignificant.

Table 5: Error correction representation for the selected model

Variable	Coefficient	t-statistic	P-value
$\Delta lnCO_2$ (-1)	0.324	3.358	0.001
$\Delta lnGDP^2$	0.270	6.307	0.000
ECT(-1)	−0.189	−5.884	0.000

Energy consumption positively impacts CO_2 emissions, while FDI negatively influences CO_2 emissions. We can interpret this as follows: A 1% increase in energy consumption would result in a 1.367% increase in CO_2 emissions, and a 1% increase in FDI would result in a 0.112% decrease in CO_2 emissions. In addition, from the previous long-run relationship, it can be seen that the relationship between GDP and CO_2 emission, including GDP^2 and CO_2 emission were insignificant. Therefore, to further prove the relationship, we will use the Granger causal analysis method to help to support it. And finally, considering the elasticity of carbon emissions on various factors, it was found that energy consumption on carbon emissions was highly flexible. Therefore, the United States must focus on controlling this factor.

Statistics

R^2 = 0.651, Adjusted R^2 = 0.633, S.E. of regression = 0.021 and F-statistic = 36.435.

In terms of the relationship between the independent and dependent variables in a long-run relationship, a short-run relationship is likely to happen. Table 5 shows a relationship between GDP^2 and CO_2 emissions of 0.270 with a significant coefficient at a 1% level. We can interpret this as follows: A 1% increase in GDP^2 would result in a 0.270% increase in CO_2 emissions. Additionally, values for the ECT (−1) coefficients are statistically significant and negative. This result provides evidence of a cointegration relationship among the variables established by the ARDL Bounds testing procedure. The coefficient of the ECT term represents the proportion by which the long-run disequilibrium in the dependent variable is corrected in each short-run period. The coefficients of the ECT terms are equal to −0.189, meaning that the deviation from the long-run path of CO_2 emissions is corrected by 18.90% each year.

5.3. Empirical Findings from the Granger Causality Test

The different results are reported in Table 6. In the case of the United States, the results indicate that three unidirectional causal relationships exist in the short run. The first relationship is between FDI and CO_2 emission, the second is between CO_2 emission and GDP, and the third is between CO_2 emission and GDP^2.

The results of long-run causal relationships show two bidirectional causal relationships between GDP and FDI, including GDP^2 and FDI. Moreover, there are three unidirectional relationships: FDI influences CO_2 emission, GDP affects energy consumption, and GDP^2 influences energy consumption.

According to the previous ARDL method, the coefficients of GDP and GDP^2 were insignificant. But on causal analysis, it is found

Table 6: Shows granger causality tests among variables in the environmental Kuznets Curve model for the United States

The null hypotheses	Chi-square (P-value)
Short-run Granger causality	
$\Delta lnEC \rightarrow \Delta lnCO_2$	0.142 (0.705)
$\Delta lnGDP \rightarrow \Delta lnCO_2$	0.283 (0.594)
$\Delta lnGDP^2 \rightarrow \Delta lnCO_2$	0.301 (0.583)
$\Delta lnFDI \rightarrow \Delta lnCO_2$	4.515 (0.033)**
$\Delta lnCO_2 \rightarrow \Delta lnEC$	1.754 (0.185)
$\Delta lnGDP \rightarrow \Delta lnEC$	1.153 (0.282)
$\Delta lnGDP^2 \rightarrow \Delta lnEC$	1.213 (0.270)
$\Delta lnFDI \rightarrow \Delta lnEC$	0.332 (0.564)
$\Delta lnCO_2 \rightarrow \Delta lnGDP$	10.209 (0.001)***
$\Delta lnEC \rightarrow \Delta lnGDP$	0.011 (0.913)
$\Delta lnGDP^2 \rightarrow \Delta lnGDP$	0.015 (0.900)
$\Delta lnFDI \rightarrow \Delta lnGDP$	1.794 (0.180)
$\Delta lnCO_2 \rightarrow \Delta lnGDP^2$	10.284 (0.001)***
$\Delta lnEC \rightarrow \Delta lnGDP^2$	0.023 (0.878)
$\Delta lnGDP \rightarrow \Delta lnGDP^2$	0.001 (0.975)
$\Delta lnFDI \rightarrow \Delta lnGDP^2$	1.767 (0.183)
$\Delta lnCO_2 \rightarrow \Delta lnFDI$	0.234 (0.628)
$\Delta lnEC \rightarrow \Delta lnFDI$	0.003 (0.952)
$\Delta lnGDP \rightarrow \Delta lnFDI$	0.282 (0.595)
$\Delta lnGDP^2 \rightarrow \Delta lnFDI$	0.291 (0.589)
Long-run Granger causality	
$lnEC \rightarrow lnCO_2$	0.795 (0.372)
$lnGDP \rightarrow lnCO_2$	0.136 (0.712)
$lnGDP^2 \rightarrow lnCO_2$	0.155 (0.693)
$lnFDI \rightarrow lnCO_2$	8.632 (0.003)***
$lnCO_2 \rightarrow lnEC$	0.000 (0.986)
$lnGDP \rightarrow lnEC$	3.625 (0.056)**
$lnGDP^2 \rightarrow lnEC$	3.586 (0.058)**
$lnFDI \rightarrow lnEC$	1.509 (0.219)
$lnCO_2 \rightarrow lnGDP$	1.234 (0.266)
$lnEC \rightarrow lnGDP$	0.038 (0.843)
$lnGDP^2 \rightarrow lnGDP$	0.131 (0.716)
$lnFDI \rightarrow lnGDP$	2.580 (0.100)*
$lnCO_2 \rightarrow lnGDP^2$	1.159 (0.281)
$lnEC \rightarrow lnGDP^2$	0.032 (0.858)
$lnGDP \rightarrow lnGDP^2$	0.169 (0.680)
$lnFDI \rightarrow lnGDP^2$	2.582 (0.100)*
$lnCO_2 \rightarrow lnFDI$	1.183 (0.276)
$lnEC \rightarrow lnFDI$	1.227 (0.268)
$lnGDP \rightarrow lnFDI$	6.649 (0.010)***
$lnGDP^2 \rightarrow lnFDI$	6.552 (0.010)***

* is significant at the 10% level, ** is significant at the 5% level, and *** is significant at the 1% level

that GDP and GDP^2 indirectly affect CO_2 emissions. GDP and GDP^2 impact energy consumption and FDI; later, FDI was passed through CO_2 emission.

6. CONCLUSION

This study uses data from the World Bank indicator to examine the causal link between CO_2 emission, energy consumption, GDP, the square of GDP, and foreign direct investment in the Environmental Kuznets Curve for the United States from 1979 to 2021. Three steps are used: bound tests to verify the presence of cointegration, autoregressive distributed lag (ARDL) model to check the effects of the dependent variables on the independent variable in the short run and long run, and finally, the vector error correction (VECM) was used the detect the causal relationships among variables.

Based on our consideration of the F-bound test, we confirmed that the relationship between the independent and dependent variables was long-run. We found that the coefficients of energy consumption and foreign direct investments variables were significant at the 10% level. The variables GDP and GDP^2 were found to be insignificant. Energy consumption positively impacts CO_2 emissions, while FDI negatively influences CO_2 emissions. In addition, from the previous long-run relationship, it can be seen that the relationship between GDP and CO_2 emission, including GDP^2 and CO_2 emission were insignificant. Therefore, to further prove the relationship, we will use the Granger causal analysis method to help to support it. In causal analysis, it is found that GDP and GDP^2 indirectly affect CO_2 emissions. GDP and GDP^2 impact energy consumption and FDI; later, FDI was passed through CO_2 emission.

Therefore, from the results of both short-run and long-run studies of the relationship of variables in the EKC model, it was found that energy consumption, economic growth, and foreign direct investment affect increasing carbon emissions. Therefore, in terms of policy, the electricity sector in the United States should be decarbonizing rapidly, with significant increases in renewable deployment.

In addition, the sum of coal and natural gas generation should also decline, pointing to the critical role of renewable energy.

One of the challenges to reaching the 2050 net-zero goal (as well as the 2035 100% clean electricity goal) is the large amount of new zero-emission capacity (primarily renewables) that will need to be deployed annually to enable an increasingly large share of clean electricity generation, especially solar and wind capacity additions. Moreover, the federal government should accelerate investment policies, tax credits, regulatory actions, state policies, research and development, and market trends to drive significant renewable deployment.

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