Renewable Energy and CO\textsubscript{2} Emissions: Empirical Evidence from Major Energy-Consuming Countries

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Abstract: The goal of this study was to contribute to the ongoing debate on the relationship between renewable energy (RE) and CO\textsubscript{2} emissions. In particular, we explored the link between RE and CO\textsubscript{2} emissions in a sample of major renewable energy-consuming countries for the period 2000–2015. Therefore, the major contribution of this study was to answer the question of whether a substantial shift to renewable energy consumption will lead to lower CO\textsubscript{2} emissions. Using the two-step generalized method of moments (GMM) estimator, our empirical results suggested that RE has a significant negative effect on CO\textsubscript{2} emissions. For example, a one percentage point increase in RE leads to a 0.5% decrease in CO\textsubscript{2} emissions.

Keywords: renewable energy; CO\textsubscript{2} emissions; two-step GMM

1. Introduction

According to World Bank, over the past three decades, the global level of CO\textsubscript{2} emissions has increased by nearly 70\% from 20.6 million kt in 1990 to 34.0 million kt in 2018\textsuperscript{[1]}. As a result, there has been growing scholarly interest in understanding the causes of CO\textsubscript{2} emissions across countries. Thus, the empirical research on the determinants of carbon dioxide emissions can be classified into three different groups. The first group explores the relationship between economic variables such as GDP per capita, trade openness, foreign direct investment, financial development, and CO\textsubscript{2} emissions\textsuperscript{[2–4]}. The second group assesses the predicting power of social variables in CO\textsubscript{2} modeling. For example, extant research suggests that social trust\textsuperscript{[5]}, cultural values\textsuperscript{[6]}, and cognitive abilities\textsuperscript{[7]} are significantly related to CO\textsubscript{2} emissions across countries. The third strand of research on the causes of CO\textsubscript{2} emissions focuses on energy consumption\textsuperscript{[8]}. Empirical studies seem to lend support to the fact that “energy consumption and economic growth are playing a significant role in degrading the environment”\textsuperscript{[9]}. At the same time, another sub stream of literature in the field of environmental research has evolved that explores the link between renewable energy and CO\textsubscript{2} emissions.

Indeed, scholars have proposed a number of arguments on the positive effect of renewable energy on CO\textsubscript{2} emissions. First, the shift to RE generates a minimal carbon footprint compared to fossil fuels consumption. For instance, coal use produces up to 3.6 pounds of CO\textsubscript{2} E/kWh compared to 0.04 pounds emitted by wind\textsuperscript{[10]}. Second, the use of coal and natural gas leads to significant negative health impacts due to pollution emitted by fossil energy use\textsuperscript{[11]}. Moreover, RE can contribute to the rising demand for energy use driven by demographic pressure and economic growth\textsuperscript{[12]}. The objective of this study was to explore and empirically assess the relationship between renewable energy use and CO\textsubscript{2} emissions in a sample of top energy-producing countries over the period 2000–2015. Therefore, the major contribution of this study was...
to answer the question of whether a substantial shift to renewable energy consumption will lead to lower CO$_2$ emissions. Earlier studies have rather focused on specific regions or nations with similar income groups; however, our research offers novel evidence based on a sample of nations that have comparably high levels of renewable energy use. While our sample consists of the countries with the highest levels of renewable energy consumption, these countries have different levels of economic development and quality of institutions. Hence, this allows us to generate additional insights on the relationship between renewable energy use and CO$_2$ emissions. Using the two-step GMM estimator, our empirical results suggested that RE has a significant negative effect on CO$_2$ emissions. For example, a one percentage point increase in RE leads to a 0.5% decrease in CO$_2$ emissions.

The remainder of this study is organized as follows: Section 2 provides an overview of the related literature; Section 3 discusses data and the empirical strategy. Section 4 offers the main results and robustness checks, and Section 5 concludes the study.

2. Literature Review

The relevance of renewable energy consumption in achieving a sustainable environment is a well-debated topic in the recent era [13–16]. Numerous studies have explored the nexus between renewable energy and CO$_2$ emissions [17–21]. For instance, Prince and Okechukwu [22] explored the importance of renewable and nonrenewable energy consumption on CO$_2$ reduction for 19 countries in Africa from 1990 to 2004 by using the augmented mean group (AMG) estimation technique. Findings from the study revealed that RE prevents CO$_2$ emissions insignificantly in Africa, while nonrenewable energy increases CO$_2$ emissions significantly. The author suggested policies to ensure a sustainable development through the usage of clean energy sources. In another study, Akram et al. [23] proposed heterogeneous effects of renewable energy on carbon emissions in 66 developing countries for the period of 1990 to 2014. Panel ordinary least squares and fixed-effect panel quantile regression (PQR) were used to complete the study. The results verified that energy efficiency and renewable energy contribute to reducing carbon emissions in developing countries.

Bekhet and Othman [24] investigated the role of RE to validate the interaction between CO$_2$ and GDP toward sustainable development in Malaysia. The study used F-bounds, VECM (vector error correction model), Granger causality, and CUSUM (cumulative sum) tests. From the results, an inverted N-shaped relationship appeared, which means RE diminishes CO$_2$ emissions in Malaysia. In a similar context, Robalino-López et al. [13] studied system dynamics modeling for RE and CO$_2$ emissions in Ecuador from 1980 to 2020. The main focus of the research was to study the impact of GDP on CO$_2$ emissions of the country. Their findings illustrated that CO$_2$ emissions can be kept under control even in the face of continual GDP growth.

The literature on the renewable energy and CO$_2$ emissions nexus provides mixed evidence for different countries in different time periods. A recent study by Wolde-rufael and Weldemeskel [25] investigated the relationship between renewable energy consumption and CO$_2$ emissions in BRIICCTS countries for the period 1993–2014. After applying the Panel Pooled Mean Group Autoregressive Distributive Lag estimator, researchers found that renewable energy consumption was negatively related to CO$_2$ emissions. The study recommended strengthening environmental policies and endorsing renewable energy in order to achieve sustainable development in these countries. In another review, Koengkan et al. [26] studied the relationship between CO$_2$ emissions, renewable energy consumption, and economic growth in the Southern Common Market, using a panel vector autoregression from 1980 to 2014. The results suggested a substitutability effect between the consumption of renewable energy and fossil fuels. To alleviate environmental damage in these countries, it is advised to speed up renewable energy reforms.

Bekun et al. [27] investigated the nexus between CO$_2$ emissions and renewable and nonrenewable energy in 16 selected EU countries for the period of 1996–2014 using the PMG-ARDL model. The study affirmed that nonrenewable energy consumption and
economic growth enhance the spread of carbon emissions, whereas renewable energy consumption decreases it.

Additionally, Leitão and Balsalobre Lorente [28] estimated the link between economic growth, renewable energy, tourism, trade, and CO$_2$ emissions in the 28 European Union countries for the period 1995–2014. The study used fully modified OLS, panel dynamic OLS, and GMM estimators to conduct the research. The econometric results proved that renewable energy and international trade reduce CO$_2$ emissions. Thus, policymakers should step up their efforts to attract high-tech investments with the economic impulses of local economies.

In a more recent study, Shahnazi and Dehghan Shabani [29] used a spatial dynamic panel data model to assess the factors affecting CO$_2$ emissions in the EU countries during 2000–2017. According to the affirmed results, the renewable energy consumption had a negative influence on CO$_2$ emissions, and a U-shaped relationship was found between economic freedom and CO$_2$ emissions.

Saidi and Omri [19] studied the impact of RE on CO$_2$ emissions and economic growth in 15 major renewable energy-consuming countries by using both fully modified OLS and vector error correction model techniques. The research affirmed that RE increases economic growth and reduces carbon emissions. It was suggested to set-up incentive mechanisms for the development of renewable energies to markets.

In another study, Key et al. [30] investigated the impact of GDP, population, and renewable energy generation on CO$_2$ emissions in the 50 largest world economies for the period of 1990–2015. The hierarchical regression modeling was used to proceed the study. Their findings identified four categories of barriers (financial, technical, political, and social) that prevent the growth of renewable energy in several countries. Ikram et al. [15] examined the linkage of renewable energy consumption, agriculture, and CO$_2$ emissions in SAARC countries covering the years 2000 to 2014. The study used multiple models, including Grey Relational Analysis, Conservative, and SSGRA. According to the findings, India had the highest CO$_2$ emissions among all the SAARC countries. The research suggested that SAARC countries should collaborate to organize, assist, and prioritize initiatives that will increase renewable energy generation.

Acheampong et al. [31] studied the impact of globalization and renewable energy on carbon emissions in the case of 46 sub-Saharan African countries from 1980 to 2015. According to the findings based on fixed and random-effects estimation approaches, renewable energy and foreign direct investment both help to reduce carbon emissions. On the other hand, population expansion and financial development contribute to the increase in carbon emissions.

From the above-discussed literature, it is evident that numerous studies of renewable energy consumption have focused on economic growth and the decrease in carbon emissions. Most of the studies proved that renewables are an important source of sustainable development and can significantly contribute to the economic growth.

3. Data and Empirical Strategy
3.1. Data Description

Annual data for 48 countries covering the years 2000–2015 were collected for the goals of our study. The dependent variables in this study were territorial emissions in tCO$_2$ per person and kg CO$_2$ emissions per 2010 USD of GDP. The data came from Carbon Atlas and World Bank, accordingly. As a measure of RE use, we relied on renewable energy consumption (% of total final energy consumption) from World Bank. Renewable energy consumption is the share of renewable energy in total final energy consumption. Figure 1 illustrates the renewable energy consumption data for the major consuming countries for the year 2015.
Figure 1. Renewable energy consumption for the year 2015. Notes: due to the lack of complete data, Eritrea, Liechtenstein, Papua New Guinea, and Somalia are not included in the empirical analysis.

3.2. Model Specification

We depart by modeling CO₂ emissions with an econometric equation that incorporates a rich set of control variables to reduce the omitted variable bias. Therefore, our regression model incorporates: RE, GDP per capita in constant 2010 USD (GDP) from World Bank, share of urban population (URB) from World Bank, internet users as % of population (ICT) from World Bank, exports and imports as % of GDP, a proxy for trade openness (TO) from World Bank, foreign direct investment as % of GDP (FDI) from World Bank, and education index (EDU) from UN. Its general form Equation (1) and linearized form Equation (2) model can be expressed as:

\[
CO_2 = f(RE, GDP, URB, ICT, TO, FDI, EDU)
\]

\[
CO_{2\text{t},i} = \alpha_0 + \alpha_1RE_{\text{t},i} + \alpha_2GDP_{\text{t},i} + \alpha_3URB_{\text{t},i} + \alpha_4TO_{\text{t},i} + \alpha_5FDI_{\text{t},i}
+ \alpha_6ICT_{\text{t},i} + \alpha_7EDU_{\text{t},i} + \epsilon_{\text{t},i}
\]

where \( \alpha_0 \) is a constant term, \( \alpha_1 \) to \( \alpha_7 \) are the parameters to be estimated, and \( \epsilon \) is an error term. In order to account for the two major problems associated with panel data (omitted variable bias and endogeneity), following [32,33], we used the fixed-effects regression method and two-step GMM estimator as our main empirical tools. The two-step GMM estimator was particularly useful in our study as the number of countries exceeds the number of years, there is inertia in CO₂ trends, and it is important to identify the causal effect of RE on CO₂ emissions. The descriptive statistics are reported in Table 1.

Table 1. Descriptive statistics.

| Variable     | Description                                      | Mean   | Std. Dev. | Min   | Max   |
|--------------|--------------------------------------------------|--------|-----------|-------|-------|
| CO₂/p        | kg CO₂ emissions per 2010 USD of GDP              | 1.02   | 2.20      | 0.02  | 12.30 |
| CO₂/GDP      | kg CO₂ emissions per 2010 USD of GDP              | 0.29   | 0.17      | 0.04  | 1.07  |
| Renewable    | Renewable energy consumption (% of total final energy consumption) | 76.12  | 14.43     | 34.91 | 98.34 |
| Urbanization | Urbanization rate, %                             | 37.09  | 20.88     | 8.25  | 95.05 |
| GDP          | GDP per capita in constant 2010 USD              | 5439.12| 16,063.72 | 194.87| 141,192.50 |
| Internet     | Internet users %                                 | 11.83  | 22.71     | 0.00  | 98.20 |
| Trade        | Trade as % of GDP                                | 69.36  | 34.94     | 0.17  | 311.35 |
| FDI          | FDI as % of GDP                                  | 14.24  | 87.16     | -7.30 | 1282.63 |
| Education    | Education index                                 | 0.44   | 0.17      | 0.12  | 0.92  |

Sources: World Bank, UN, Carbon Atlas.
4. Main Results

The main results for per capita CO\textsubscript{2} emissions are presented in Table 2. Column 1 offers the baseline findings by employing the OLS model. The estimate for RE is negative and significant, suggesting that there is a negative correlation between RE and CO\textsubscript{2} emissions. For example, a 1 percentage point increase in RE is associated with a 0.13% decrease in CO\textsubscript{2} emissions per capita. Our results are comparable to [19]. The authors using data for 15 major renewable energy-consuming countries found that a 1% increase in RE use leads to an up to 0.28% decrease in CO\textsubscript{2} emissions. Moreover, Özbuğday and Erbas [18], using data from 36 countries, showed that a 1% increase in RE use decreases CO\textsubscript{2} emissions by 0.11%.

Table 2. Main results: CO\textsubscript{2} emissions per capita.

|        | OLS     | FE      | FE AR (1) | GMM    |
|--------|---------|---------|-----------|--------|
| CO\textsubscript{2t–1} | 0.9546   | 0.6128  | 0.1804    | 0.7267 |
| (78.10)*** | (14.89)*** | (4.61)*** | (19.17)*** |
| RE      | –0.0013  | –0.0107 | –0.0246   | –0.0050|
| (3.03)*** | (6.16)*** | (12.67)*** | (2.70)*** |
| URB     | –0.0004  | 0.0061  | 0.0076    | 0.0007 |
| (1.04)   | (1.72)*  | (0.96)  | (0.38)    |
| GDP     | 0.0344   | 0.2016  | 0.0850    | 0.4038 |
| (2.08)** | (3.59)*** | (1.53)  | (9.02)*** |
| ICT     | –0.0003  | 0.0001  | 0.0028    | –0.0025|
| (0.86)   | (0.05)   | (1.87)* | (2.04)** |
| TO      | 0.0002   | 0.0004  | 0.0007    | 0.0007 |
| (1.15)   | (1.31)   | (1.93)* | (2.42)** |
| FDI     | 0.0019   | 0.0023  | 0.0015    | 0.0023 |
| (2.39)** | (5.72)*** | (1.76)* | (4.45)*** |
| EDU     | 0.0298   | 0.2866  | 0.6621    | –1.0406|
| (0.54)   | (1.04)   | (1.75)* | (4.00)*** |
| α\textsubscript{0} | –0.1921  | –1.4852 | –0.3863   | –2.4093|
| (1.51)   | (3.37)*** | (2.97)*** | (6.39)*** |
| R\textsuperscript{2} | 0.99     | 0.77    |           |
| AR (1)  |         |         | 0.000     |        |
| AR (2)  |         |         | 0.335     |        |
| Hansen p-value |         |         | 0.199     |        |
| N       | 667     | 667     | 619       | 667    |

\* p < 0.1; \*\* p < 0.05; \*\*\* p < 0.01.

Column 2 now provides estimates for fixed-effects (FE) regression. The RE is negatively related to CO\textsubscript{2} emissions even once we account for all time-invariant omitted factors that are not included in our regression. The coefficient for RE remains negative and significant when we rely on the FE model with AR (1) disturbance (column 3). Column 4 reports the coefficient from our main estimator two-step GMM estimator. The Hansen p-value and AR (2) are insignificant, suggesting that our results are consistent and credible. The coefficient for RE is also negative and significant. If causal, a one percentage point increase in RE leads to a 0.5% decrease in CO\textsubscript{2} emissions. Turning to control variables, we find that GDP has a positive impact on CO\textsubscript{2} emissions. One potential explanation is that the average GDP per capita in our sample is approximately USD 5500, which is significantly below the threshold levels, as suggested by the EKC research [9]. In line with Zhang and Liu [34], we find that ICT is negative and significant: a one percentage point increase in the internet users leads to a 0.25% decline in CO\textsubscript{2} emissions. Trade openness and FDI are positive and significant, confirming the presence of a ‘pollution haven’ effect. Human capital investment decreases CO\textsubscript{2} emissions. This is in line with Dauda et al. [35] who showed that RE and human capital decrease CO\textsubscript{2} emissions in a sample of nine African countries.

Next, the effect of RE on economic intensity of CO\textsubscript{2} emissions are examined in Table 3. Again, we find that RE is negative and significant across all methods of empirical modeling.
In column 4, the AR (2) and Hansen p-value confirm the consistency of two-stem GMM coefficients. Quantitatively, a one percentage point increase in RE leads to a 0.85% decrease in kg CO₂ per USD of GDP. Overall, the results in Tables 2 and 3 show that the renewable energy industry contributes to the reduction in CO₂ emissions in top renewable energy producers.

Table 3. Main results: CO₂ emissions (kg per 2010 USD of GDP).

|            | OLS     | FE      | FE AR (1) | GMM     |
|------------|---------|---------|-----------|---------|
| CO₂t-1     | 0.9674  | 0.6879  | 0.1253    | 0.6953  |
|            | (99.40) *** | (19.50) *** | (3.21) *** | (17.75) *** |
| RE         | -0.0012 | -0.0099 | -0.0198   | -0.0085 |
|            | (3.10) *** | (5.69) *** | (12.07) *** | (6.29) *** |
| URB        | 0.0000  | 0.0006  | 0.0213    | 0.0025  |
|            | (0.04)  | (0.14)  | (2.77) *** | (1.43)  |
| GDP        | -0.0185 | -0.1801 | -0.1598   | 0.0255  |
|            | (1.71) * | (2.75) *** | (3.08) *** | (0.52)  |
| ICT        | -0.0001 | 0.0006  | -0.0012   | -0.0026 |
|            | (0.41)  | (0.62)  | (0.92)    | (2.31) ** |
| TO         | 0.0001  | -0.0000 | 0.0005    | -0.0002 |
|            | (0.62)  | (0.18)  | (1.73) *  | (1.11)  |
| FDI        | 0.0011  | 0.0012  | 0.0006    | 0.0005  |
|            | (1.69) * | (2.70) *** | (0.87)    | (1.05)  |
| EDU        | 0.0226  | 0.3627  | -0.1368   | -0.6379 |
|            | (0.46)  | (1.24)  | (0.41)    | (2.59) ** |
| α₀         | 0.1596  | 1.4006  | 0.5846    | 0.2714  |
|            | (2.17) ** | (2.76) *** | (6.38) *** | (0.82)  |
| R²         | 0.96    | 0.69    |           |         |
| AR (1)     |         |         | 0.000     |         |
| AR (2)     |         |         | 0.819     |         |
| Hansen p-value |       |         | 0.229     |         |
| N          | 667     | 667     | 619       | 667     |

* p < 0.1; ** p < 0.05; *** p < 0.01.

We also checked the robustness of our main results by including additional controls in Table 4. The research on the drivers of CO₂ emissions have explored the predicting power of financial development. As suggested by Lv and Li [36] “financial development can allow enterprises to access financing at a lower cost and can also facilitate investment in environment-friendly projects, thereby leading to less environmental pollution”. Therefore, from the financial development (FD) index from the International Monetary Fund (IMF) in column 1, we find that FD reduces air pollution in our sample. Additionally, we include the interaction term between FD and RE in column 2 to check the role of RE in decreasing CO₂ emissions conditionally on the level of the nation’s FD. The interaction term is insignificant, implying that FD is not a complementary or substitute factor to RE in reducing CO₂ emissions. Extant research suggests that tourism development is another significant determinant of cross-country variations in CO₂ emissions [37]. In column 2, we add tourism receipts as % of total exports (TEX) as a proxy for tourism development. The results show that a one percentage point increase in TEX leads to a 0.5% rise in CO₂ per capita emissions. Following the works of Mirziyoyeva and Salahodjaev [38] and Kalayci [39], we add the share of women in parliament (WP) and KOF index of globalization in columns 4 and 5, respectively. Of these two variables, only globalization is negative and marginally statically significant. Across all specifications, RE is negative and statistically significant. The results for kg CO₂ emissions per 2010 USD of GDP are reported in Table 5. Again, RE retains its sign and statistical significance.
Table 4. CO₂ per capita: additional controls.

|        | I         | II        | III        | IV         | V         |
|--------|-----------|-----------|------------|------------|-----------|
| CO₂t-1 | 0.8979    | 0.9640    | 0.8747     | 0.7020     | 0.7082    |
|        | (27.91) *** | (28.65) *** | (18.62) *** | (21.65) *** | (25.35) *** |
| RE     | −0.0031   | −0.0021   | −0.0045    | −0.0094    | −0.0075   |
|        | (2.03) *   | (3.14) *** | (4.67) *** | (3.98) *** |           |
| URB    | −0.0032   | −0.0041   | −0.0012    | 0.0011     | 0.0007    |
|        | (2.34) **  | (3.01) *** | (0.72)     | (0.50)     | (0.45)    |
| GDP    | 0.2748    | 0.1091    | 0.1743     | 0.2956     | 0.4271    |
|        | (5.34) *** | (1.80) *   | (2.93) *** | (8.85) *** |           |
| ICT    | 0.0007    | 0.0022    | −0.0016    | −0.0008    | −0.0033   |
|        | (0.55)    | (1.64)    | (1.21)     | (0.68)     |           |
| TO     | 0.0008    | 0.0010    | 0.0002     | 0.0000     | 0.0005    |
|        | (2.71) *** | (3.05) *** | (0.56)     | (1.90) *   |           |
| FDI    | 0.0022    | 0.0025    | 0.0012     | 0.0012     | 0.0020    |
|        | (3.95) *** | (4.27) *** | (1.25)     | (2.67) **  | (8.45) *** |
| GDP    | −0.0451   | −0.3163   | −0.3616    | −0.4902    | −0.8293   |
|        | (1.30)    | (0.80)    | (2.20) **  | (1.39)     | (3.26) *** |
| RE * FD| 0.0028    |           |           |           |           |
|        |           |           |           |           |           |
| TEX    |           |           |           | 0.0051    |           |
|        |           |           |           | (3.53) *** |           |
| WP     |           |           |           | 0.0013    |           |
|        |           |           |           | (0.64)    |           |
| KOF    |           |           |           | −0.0047   |           |
|        |           |           |           | (1.68) *  |           |
| α₀     | −1.4117   | −0.3768   | −0.8428    | −1.5631    | −2.2317   |
|        | (4.15) *** | (0.98)    | (1.66)     | (3.84) *** | (5.06) *** |
| AR (1) | 0.000     | 0.000     | 0.000      | 0.000      | 0.000     |
| AR (2) | 0.602     | 0.599     | 0.775      | 0.332      | 0.329     |
| Hansen | 0.370     | 0.636     | 0.568      | 0.317      | 0.304     |
| p-value | 637       | 637       | 529        | 643        | 667       |

*p < 0.1; ** p < 0.05; *** p < 0.01.

Table 5. CO₂ emissions (kg per 2010 USD of GDP): additional controls.

|        | I         | II        | III        | IV         | V         |
|--------|-----------|-----------|------------|------------|-----------|
| CO₂t-1 | 0.7837    | 0.8232    | 0.8915     | 0.6739     | 0.6964    |
|        | (26.35) *** | (29.37) *** | (27.40) *** | (15.31) *** | (22.31) *** |
| RE     | −0.0078   | −0.0062   | −0.0043    | −0.0094    | −0.0099   |
|        | (5.77) *** | (4.75) *** | (4.04) *** | (5.24) *** | (5.75) *** |
| URB    | 0.0017    | 0.0016    | −0.0002    | 0.0055     | 0.0022    |
|        | (1.09)    | (1.02)    | (0.14)     | (2.66) **  | (1.46)    |
| GDP    | 0.0804    | 0.0336    | 0.0156     | −0.0661    | 0.0304    |
|        | (1.85) *  | (0.82)    | (0.48)     | (1.25)     | (0.63)    |
| ICT    | −0.0006   | 0.0004    | −0.0015    | −0.0015    | −0.0021   |
|        | (0.48)    | (0.31)    | (1.72) *   | (1.29)     | (1.86) *  |
| TO     | 0.0001    | −0.0000   | −0.0002    | −0.0004    | −0.0002   |
|        | (0.66)    | (0.20)    | (0.58)     | (1.67)     | (0.75)    |
| FDI    | 0.0007    | 0.0005    | −0.0014    | 0.0001     | 0.0007    |
|        | (1.47)    | (1.35)    | (1.84) *   | (0.19)     | (1.99) *  |
| EDU    | −0.5060   | −0.4559   | −0.2527    | −0.4356    | −0.4629   |
|        | (1.84) *  | (1.35)    | (1.46)     | (1.43)     | (1.77) *  |
| FD     | −0.9656   | −0.4606   |           |           |           |
|        | (2.99) *** | (1.93) *  |           |           |           |
Table 5. Cont.

|     | I   | II  | III | IV  | V     |
|-----|-----|-----|-----|-----|-------|
| RE * FD | 0.0070 (0.99) | 0.0023 (1.69) * | 0.0017 (1.04) | -0.0055 (1.78) * |
| TEX   | 0.0023 (1.69) * |
| WP    | 0.0017 (1.04) |
| KOF   | -0.0055 (1.78) * |
| $\alpha_0$ | 0.0297 (0.11) | 0.2143 (0.69) | 0.2211 (0.83) | 0.7354 (1.93) * | 0.5505 (1.39) |
| AR (1) | 0.000 | 0.000 | 0.000 | 0.000 |
| AR (2) | 0.965 | 0.955 | 0.408 | 0.952 |
| Hansen | 0.246 | 0.522 | 0.396 | 0.365 |
| $p$-value | 0.210 |
| $N$ | 637 | 637 | 529 | 643 | 667 |

*p < 0.1; **p < 0.05; ***p < 0.01.

5. Conclusions

According to the world energy outlook [40], energy demand will be at a peak until 2040. If the policymakers do not take substantial steps to reform their current policies, the world’s energy system will shift. The total energy consists of renewable and nonrenewable energy [41]; hence, 84% of the world’s primary energy consumption is used by oil, coal, and natural gas, which is considered nonrenewable energy. This shows that the use of nonrenewable energy facilitates the process of production in every field but is also the leading factor of environmental degradation. Therefore, to increase the production, it is advisable to use renewable energy sources, eventually decreasing usage of nonrenewable energy sources.

This study explored the relationship between renewable energy and CO$_2$ emissions in a sample of top renewable energy-consuming countries over the period 2000–2015. The study used the fixed-effects regression method and two-step GMM estimator as main empirical tools. The study found a negative effect of RE on CO$_2$ emissions. According to the results, a one percentage point increase in renewable energy leads to a 0.5% decrease in CO$_2$ emissions. The empirical results from major RE-consuming countries confirmed that green energy may not only improve economic growth but also promote sustainable environment.

Our study makes a distinct contribution to nascent research as it focused on a very specific set of countries that are compiled not by geographical boundaries or GDP thresholds but rather by the share of renewables in total energy consumption. Moreover, in our empirical modeling, we included a rich set of control variables to take into account the quality of institutions, human capital, and soundness of macroeconomic policies. Therefore, this study offers a number of policy recommendations. First, one of the core reasons for the slow shift to RE across less developed countries is the lack of financial resources. Therefore, policymakers should provide subsidies on renewable energy sources to promote clean energy consumption and should increase the taxes on nonrenewable energy sources to discourage dirty energy consumption. Second, renewable energy sources can only be produced through using modern technologies, and these specific materials are rare even in developed countries. The high cost of technology and overall barriers to implement renewable energy sources are distracting most of the investors. Therefore, to achieve stable and sustainable development in renewable energy, the head of the states of the highest-energy-consumption countries should design support policies that will encourage more foreign investors and facilitate these technologies. Moreover, it is important to understand for policymakers that implementing renewable energy strategies is the most essential way to achieve sustainable development goals. The policy implications of our study are indeed
far-reaching, as promoting renewable energy will have positive implications for ecological sustainability, quality of life, and improvements in health, one of the core components of human capital. Therefore, indirectly, renewable energy adoption is going to contribute to the long-term sustainable economic growth of developing countries.

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References

1. World Bank. World Bank Open Data: CO₂ Emissions. 2021. Available online: https://data.worldbank.org/indicator/EN.ATM.CO2E.KT (accessed on 23 July 2021).
2. Zubair, A.O.; Samad, A.R.A.; Dankumo, A.M. Does gross domestic income, trade integration, FDI inflows, GDP, and capital reduces CO₂ emissions? Empirical evidence from Nigeria. *Curr. Res. Environ. Sustain.* 2020, 2, 100009. [CrossRef]
3. Saboori, B.; Sulaiman, J.; Mohd, S. Economic growth and CO₂ emissions in Malaysia: A cointegration analysis of the environmental Kuznets curve. *Energy Policy* 2012, 51, 184–191. [CrossRef]
4. Mikayilov, J.I.; Galeotti, M.; Hasanov, F.J. The impact of economic growth on CO₂ emissions in Azerbaijan. *J. Clean. Prod.* 2018, 197, 1558–1572. [CrossRef]
5. Carattini, S.; Jo, A.; Trust and CO₂ Emissions: Cooperation on a Global Scale. Working Paper. 2016. Available online: https://pdfs.semanticscholar.org/0541/b6201a6c6ce5ae859b67487ab86ec1472e8813.pdf (accessed on 23 July 2021).
6. Disli, M.; Ng, A.; Askari, H. Culture, Income, and CO₂ emission. *Renew. Sustain. Energy Rev.* 2016, 62, 418–428. [CrossRef]
7. Omanbayev, B.; Salahdajaev, R.; Lynn, R. Are greenhouse gas emissions and cognitive skills related? Cross-country evidence. *Environ. Res.* 2018, 160, 322–330. [CrossRef]
8. Shafiei, S.; Salim, R.A. Non-renewable and renewable energy consumption and CO₂ emissions in OECD countries: A comparative analysis. *Energy Policy* 2014, 66, 547–556. [CrossRef]
9. Shahbaz, M.; Sinha, A. Environmental Kuznets curve for CO₂ emissions: A literature survey. *J. Econ. Stud.* 2019, 46, 106–168. [CrossRef]
10. Siddique, H.M.A.; Majeed, D.M.T.; Ahmad, D.H.K. The impact of urbanization and energy consumption on CO₂ emissions in South Asia. *South Asian Stud.* 2020, 31, 745–757.
11. IPCC. *IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation. Prepared by Working Group III of the Intergovernmental Panel on Climate Change*; Edenhofer, O., Pichs-Madruga, R., Sokona, Y., Seyboth, K., Matschoss, P., Kadner, S., Zwickel, T., Eickemeier, P., Hansen, G., Schlämer, S., et al., Eds.; Chapter 7 and 9; Cambridge University Press: Cambridge, UK; New York, NY, USA, 2011.
12. Rasoulinezhad, E.; Taghizadeh-Hesary, F; Taghizadeh-Hesary, F. How is mortality affected by fossil fuel consumption, CO₂ emissions and economic factors in CIS region? *Energies* 2020, 13, 2255. [CrossRef]
13. Robalino-López, A.; Mena-Nieto, A.; García-Ramos, J.E. System dynamics modeling for renewable energy and CO₂ emissions: A case study of Ecuador. *Energy Sustain. Dev.* 2014, 20, 11–20. [CrossRef]
14. Adams, S.; Nsiah, C. Reducing carbon dioxide emissions; Does renewable energy matter? *Sci. Total Environ.* 2019, 693, 133288. [CrossRef] [PubMed]
15. Ikram, M.; Zhang, Q.; Sroufe, R.; Shah, S.Z.A. Towards a sustainable environment: The nexus between ISO 14001, renewable energy consumption, access to electricity, agriculture and CO₂ emissions in SAARC countries. *Sustain. Prod. Consum.* 2020, 22, 218–230. [CrossRef]
16. Zoundi, Z. CO₂ emissions, renewable energy and the Environmental Kuznets Curve, a panel cointegration approach. *Renew. Sustain. Energy Rev.* 2017, 72, 1067–1075. [CrossRef]
17. Jan, I.; Durrani, S.F.; Khan, H. Does renewable energy efficiently spur economic growth? Evidence from Pakistan. *Environ. Dev. Sustain.* 2021, 23, 373–387. [CrossRef]

18. Ozbugday, F.C.; Erbas, B.C. How effective are energy efficiency and renewable energy in curbing CO₂ emissions in the long run? A heterogeneous panel data analysis. *Energy* 2015, 82, 734–745. [CrossRef]

19. Saidi, K.; Omri, A. The impact of renewable energy on carbon emissions and economic growth in 15 major renewable-energy-consuming countries. *Environ. Res.* 2020, 186, 109567. [CrossRef] [PubMed]

20. Ullah, I.; Rehman, A.; Khan, F.U.; Shah, M.H.; Khan, F. Nexus between trade, CO₂ emissions, renewable energy, and health expenditure in Pakistan. *Int. J. Health Plan. Manag.* 2020, 35, 818–831. [CrossRef]

21. Qayyum, M.; Ali, M.; Nizamani, M.M.; Li, S.; Yu, Y.; Jahanger, A.; Arana, G. Nexus between Financial Development, Renewable Energy Consumption, Technological Innovations and CO₂ Emissions: The Case of India. *Energies* 2021, 14, 4505. [CrossRef]

22. Prince, S.; Okechukwu, C. Science of the Total Environment Carbon dioxide abatement in Africa: The role of renewable and non-renewable energy consumption. *Sci. Total Environ.* 2019, 679, 337–345. [CrossRef]

23. Akram, R.; Chen, F.; Khalid, F.; Ye, Z.; Majeed, M.T. Heterogeneous effects of energy efficiency and renewable energy on carbon emissions: Evidence from developing countries. *J. Clean. Prod.* 2020, 247, 119122. [CrossRef]

24. Bekhet, H.A.; Othman, N.S. The role of renewable energy to validate dynamic interaction between CO₂ emissions and GDP toward sustainable development in Malaysia. *Energy Econ.* 2018, 72, 47–61. [CrossRef]

25. Wolde-rufael, Y.; Weldemeskel, E.M. Environmental policy stringency, renewable energy consumption and CO₂ emissions: Panel cointegration analysis for BRIICTS countries Environmental policy stringency, renewable energy consumption and CO₂ emissions. *Int. J. Green Energy* 2020, 17, 1–15. [CrossRef]

26. Koengkan, M.; Fuinhas, J.A. Exploring the effect of the renewable energy transition on CO₂ emissions of Latin American & Caribbean countries. *Int. J. Sustain. Energy* 2020, 39, 515–538. [CrossRef]

27. Bekun, F.V.; Alola, A.A.; Sarkodie, S.A. Toward a sustainable environment: Nexus between CO₂ emissions, resource rent, renewable and nonrenewable energy in 16-EU countries. *Sci. Total Environ.* 2019, 657, 1023–1029. [CrossRef] [PubMed]

28. Leitão, N.C.; Lorente, D.B. The Linkage between Economic Growth, Renewable Energy, Tourism, CO₂ Emissions, and International Trade: The Evidence for the European Union. *Energies* 2020, 13, 4838. [CrossRef]

29. Shahnazi, R.; Dehghan Shabani, Z. The effects of renewable energy, spatial spillover of CO₂ emissions and economic freedom on CO₂ emissions in the EU. *Renew. Energy* 2021, 169, 293–307. [CrossRef]

30. Key, A.; Mendonça, D.S.; De Andrade, G.; Barni, C.; Fernandez, M.; de Seve, A.; Fernandez, L. Hierarchical modeling of the 50 largest economies to verify the impact of GDP, population and renewable energy generation in CO₂ emissions. *Sustain. Prod. Consump.* 2020, 22, 58–67. [CrossRef]

31. Acheampong, A.O.; Adams, S.; Boateng, E. Science of the Total Environment Do globalization and renewable energy contribute to carbon emissions mitigation in Sub-Saharan Africa? *Sci. Total Environ.* 2019, 677, 436–446. [CrossRef]

32. Kiviet, J.F. On bias, Inconsistency, and efficiency of various estimators in dynamic panel data models. *J. Econom.* 1995, 68, 53–78. [CrossRef]

33. Asonwu, S.A.; Le Roux, S.; Biekpe, N. Enhancing ICT for environmental sustainability in sub-Saharan Africa. *Technol. Forecast. Soc. Chang.* 2018, 127, 209–216. [CrossRef]

34. Zhang, C.; Liu, C. The impact of ICT industry on CO₂ emissions: A regional analysis in China. * Renew. Sustain. Energy Rev.* 2015, 44, 12–19. [CrossRef]

35. Dauda, L.; Long, X.; Mensah, C.N.; Salman, M.; Boamah, K.B.; Anpont-Wireko, S.; Dogbe, C.S.K. Innovation, trade openness and CO₂ emissions in selected countries in Africa. *J. Clean. Prod.* 2021, 281, 125143. [CrossRef]

36. Lv, Z.; Li, S. How financial development affects CO₂ emissions: A spatial econometric analysis. *J. Environ. Manag.* 2021, 277, 111397. [CrossRef]

37. Shakouri, B.; Khoshnevis Yazdi, S.; Ghorchebigi, E. Does tourism development promote CO₂ emissions? *Anatolia* 2017, 28, 444–452. [CrossRef]

38. Mirzoyeva, Z.; Salahodjaev, R. Women’s Parliamentary Representation and Sustainable Development Goals: A Cross-Country Evidence. *Appl. Res. Qual. Life* 2021, 1, 1–13. [CrossRef]

39. Kalayci, C. The impact of economic globalization on CO₂ emissions: The case of NAFTA countries. *Int. J. Energy Econ. Policy* 2019, 9, 356. [CrossRef]

40. World Energy Outlook. 2019. Available online: https://www.iea.org/reports/world-energy-outlook-2019 (accessed on 26 November 2019).

41. Szmyczyn, K.; Sahin, D.; Bagci, H.; Kaygyn, C.Y. The Effect of Energy Usage, Economic Growth, and Financial Development on CO₂ Emission Management: An Analysis of OECD Countries with a High Environmental Performance Index. *Energies* 2021, 14, 4617. [CrossRef]