energies

Article

# Renewable Energy and $CO_2$ Emissions: Empirical Evidence from Major Energy-Consuming Countries

**Yongming Huang [1], Zebo Kuldasheva [1,2,*] and Raufhon Salahodjaev [3]**

[1] Institute for Region and Urban-Rural Development, Center for Industrial Development and Regional Competitiveness, Wuhan University, Wuhan 730072, China; hym@whu.edu.cn
[2] Department of World Economy, Tashkent State University of Economics, Tashkent 100003, Uzbekistan
[3] Department of Mathematical Methods in Economics, Tashkent State University of Economics, Tashkent 100003, Uzbekistan; r.salahodjaev@tsue.uz
* Correspondence: kuldashevazebo@gmail.com; Tel.: +998-979070592

**Abstract:** The goal of this study was to contribute to the ongoing debate on the relationship between renewable energy (RE) and $CO_2$ emissions. In particular, we explored the link between RE and $CO_2$ 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 $CO_2$ emissions. Using the two-step generalized method of moments (GMM) estimator, our empirical results suggested that RE has a significant negative effect on $CO_2$ emissions. For example, a one percentage point increase in RE leads to a 0.5% decrease in $CO_2$ emissions.

**Keywords:** renewable energy; $CO_2$ emissions; two-step GMM

check for updates

**Citation:** Huang, Y.; Kuldasheva, Z.; Salahodjaev, R. Renewable Energy and $CO_2$ Emissions: Empirical Evidence from Major Energy-Consuming Countries. *Energies* **2021**, *14*, 7504. https://doi.org/10.3390/en14227504

Academic Editors: Nuno Carlos Leitão and Vincenzo Bianco

Received: 7 August 2021
Accepted: 8 October 2021
Published: 10 November 2021



## 1. Introduction

According to World Bank, over the past three decades, the global level of $CO_2$ emissions has increased by nearly 70% from 20.6 million kt in 1990 to 34.0 million kt in 2018 [1]. As a result, there has been growing scholarly interest in understanding the causes of $CO_2$ 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 $CO_2$ emissions [2–4]. The second group assesses the predicting power of social variables in $CO_2$ modeling. For example, extant research suggests that social trust [5], cultural values [6], and cognitive abilities [7] are significantly related to $CO_2$ emissions across countries. The third strand of research on the causes of $CO_2$ emissions focuses on energy consumption [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" [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 $CO_2$ emissions.

Indeed, scholars have proposed a number of arguments on the positive effect of renewable energy on $CO_2$ 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 $CO_2$ E/kWh compared to 0.04 pounds emitted by wind [10]. Second, the use of coal and natural gas leads to significant negative health impacts due to pollution emitted by fossil energy use [11]. Moreover, RE can contribute to the rising demand for energy use driven by demographic pressure and economic growth [12].

The objective of this study was to explore and empirically assess the relationship between renewable energy use and $CO_2$ 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 BRIICTS 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.

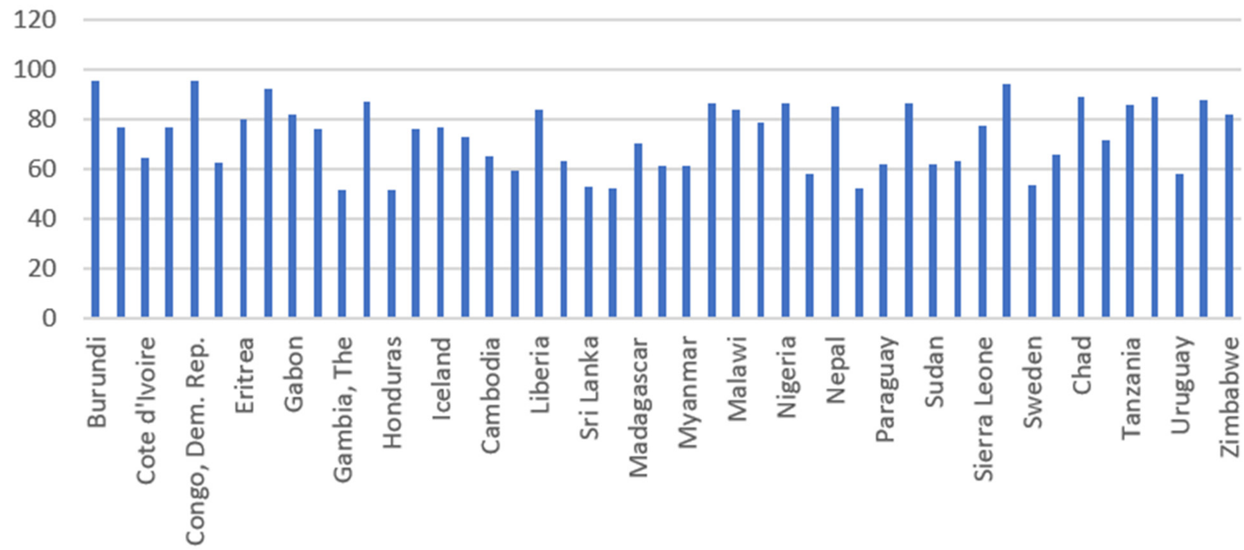


**Figure 1.** Renewable energy consumption for the year 2015. Notes: due to the lack of complete data, Eritrea, Liechtenstein, Papua New Guinea, and Somalia are not included in the empirical analysis.

### *3.2. Model Specification*

We depart by modeling $CO_2$ 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:

$$CO_2 = f(RE, GDP, URB, ICT, TO, FDI, EDU) \tag{1}$$

$$\begin{aligned} CO_{2i,t} = \alpha_0 + \alpha_1 RE_{i,t} + \alpha_2 GDP_{i,t} + \alpha_3 URB_{i,t} + \alpha_5 TO_{i,t} + \alpha_6 FDI_{i,t} \\ + \alpha_7 ICT_{i,t} + \alpha_7 EDU_{i,t} + \varepsilon_{i,t} \end{aligned} \tag{2}$$

where $\alpha_0$ is a constant term, $\alpha_1$ to $\alpha_7$ are the parameters to be estimated, and $\varepsilon$ 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 $CO_2$ trends, and it is important to identify the causal effect of RE on $CO_2$ emissions. The descriptive statistics are reported in Table 1.

**Table 1.** Descriptive statistics.

| Variable | Description | Mean | Std. Dev. | Min | Max |
|---|---|---|---|---|---|
| $CO_2/p$ | $tCO_2$ per person | 1.02 | 2.20 | 0.02 | 12.30 |
| $CO_2$/GDP | kg $CO_2$ 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 $CO_2$ 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 $CO_2$ emissions. For example, a 1 percentage point increase in RE is associated with a 0.13% decrease in $CO_2$ 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 $CO_2$ emissions. Moreover, Özbuğday and Erbas [18], using data from 36 countries, showed that a 1% increase in RE use decreases $CO_2$ emissions by 0.11%.

**Table 2.** Main results: $CO_2$ emissions per capita.

| | OLS | FE | FE AR (1) | GMM |
|---|---|---|---|---|
| $CO_{2t-1}$ | 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 | 0.2966 | 0.6621 | −1.0406 |
| | (0.54) | (1.04) | (1.75) * | (4.00) *** |
| $\alpha_0$ | −0.1921 | −1.4852 | −0.3863 | −2.4093 |
| | (1.51) | (3.37) *** | (2.97) *** | (6.39) *** |
| $R^2$ | 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 $CO_2$ 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 $CO_2$ emissions. Turning to control variables, we find that GDP has a positive impact on $CO_2$ 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 $CO_2$ emissions. Trade openness and FDI are positive and significant, confirming the presence of a 'pollution haven' effect. Human capital investment decreases $CO_2$ emissions. This is in line with Dauda et al. [35] who showed that RE and human capital decrease $CO_2$ emissions in a sample of nine African countries.

Next, the effect of RE on economic intensity of $CO_2$ 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 $CO_2$ per USD of GDP. Overall, the results in Tables 2 and 3 show that the renewable energy industry contributes to the reduction in $CO_2$ emissions in top renewable energy producers.

**Table 3.** Main results: $CO_2$ emissions (kg per 2010 USD of GDP).

| | OLS | FE | FE AR (1) | GMM |
|---|---|---|---|---|
| $CO_{2t-1}$ | 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) ** |
| $\alpha_0$ | 0.1596 | 1.4006 | 0.5846 | 0.2714 |
| | (2.17) ** | (2.76) *** | (6.38) *** | (0.82) |
| $R^2$ | 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 $CO_2$ 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 $CO_2$ 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 $CO_2$ emissions. Extant research suggests that tourism development is another significant determinant of cross-country variations in $CO_2$ 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 $CO_2$ 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 $CO_2$ emissions per 2010 USD of GDP are reported in Table 5. Again, RE retains its sign and statistical significance.

**Table 4.** $CO_2$ per capita: additional controls.

| | I | II | III | IV | V |
|---|---|---|---|---|---|
| $CO_{2t-1}$ | 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) ** | (1.76) * | (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) *** | (5.86) *** | (8.85) *** |
| ICT | −0.0007 | 0.0022 | −0.0016 | −0.0008 | −0.0033 |
| | (0.55) | (1.64) | (1.21) | (0.68) | (2.82) *** |
| TO | 0.0008 | 0.0010 | 0.0002 | 0.0000 | 0.0005 |
| | (2.71) *** | (3.05) *** | (0.56) | (0.11) | (1.90) * |
| FDI | 0.0022 | 0.0025 | 0.0012 | 0.0012 | 0.0020 |
| | (3.95) *** | (4.27) *** | (1.25) | (2.67) ** | (4.85) *** |
| EDU | −0.4051 | −0.3163 | −0.3616 | −0.4902 | −0.8293 |
| | (1.30) | (0.80) | (2.20) ** | (1.39) | (3.26) *** |
| FD | −0.9427 | −0.3033 | | | |
| | (2.91) *** | (1.46) | | | |
| RE * FD | | 0.0028 | | | |
| | | (0.45) | | | |
| TEX | | | 0.0051 | | |
| | | | (3.53) *** | | |
| WP | | | | 0.0013 | |
| | | | | (0.64) | |
| KOF | | | | | −0.0047 |
| | | | | | (1.68) * |
| $\alpha_0$ | −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 *p*-value | 0.370 | 0.636 | 0.568 | 0.317 | 0.304 |
| *N* | 637 | 637 | 529 | 643 | 667 |

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

**Table 5.** $CO_2$ emissions (kg per 2010 USD of GDP): additional controls.

| | I | II | III | IV | V |
|---|---|---|---|---|---|
| $CO2_{t-1}$ | 0.7837 | 0.8232 | 0.8915 | 0.6739 | 0.6964 |
| | (26.35) *** | (29.37) *** | (27.40) *** | (15.31) *** | (22.11) *** |
| 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) | | | |
| TEX | | | 0.0023 | | |
| | | | (1.69) * | | |
| WP | | | | 0.0017 | |
| | | | | (1.04) | |
| KOF | | | | | −0.0055 |
| | | | | | (1.78) * |
| $\alpha_0$ | 0.0297 | 0.2143 | 0.2211 | 0.7354 | 0.5505 |
| | (0.11) | (0.69) | (0.83) | (1.93) * | (1.39) |
| AR (1) | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| AR (2) | 0.965 | 0.955 | 0.408 | 0.952 | 0.870 |
| Hansen *p*-value | 0.246 | 0.522 | 0.396 | 0.365 | 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.

**Author Contributions:** Conceptualization, Y.H.; methodology, R.S.; software, R.S.; validation, Z.K. and R.S.; formal analysis, R.S.; investigation, Y.H.; resources, Y.H.; data curation, R.S.; writing—original draft preparation, Z.K. and R.S.; writing—review and editing, Z.K.; supervision, Y.H. All authors have read and agreed to the published version of the manuscript.

**Funding:** This work is supported by Chinese National Funding of Social Sciences (No. 21BJL008).

**Institutional Review Board Statement:** Not applicable.

**Informed Consent Statement:** Not applicable.

**Data Availability Statement:** The is available upon reasonable request from the corresponding author.

**Acknowledgments:** This research work belongs to the second author PhD studies in Wuhan university, China. We thank to anonymous reviewers for their useful comments and suggestions which helped improve the presentation of the manuscript.

**Conflicts of Interest:** The authors declare no conflict of interest.

## References

1. World Bank. World Bank Open Data: $CO_2$ 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 $CO_2$ emissions? Empirical evidence from Nigeria. *Curr. Res. Environ. Sustain.* **2020**, *2*, 100009. [CrossRef]
3. Saboori, B.; Sulaiman, J.; Mohd, S. Economic growth and $CO_2$ 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 $CO_2$ emissions in Azerbaijan. *J. Clean. Prod.* **2018**, *197*, 1558–1572. [CrossRef]
5. Carattini, S.; Jo, A.; Trust and $CO_2$ Emissions: Cooperation on a Global Scale. Working Paper. 2016. Available online: https://pdfs.semanticscholar.org/0541/b6201ac6ce5ae859b7487ab86ce1472e8813.pdf (accessed on 23 July 2021).
6. Disli, M.; Ng, A.; Askari, H. Culture, Income, and $CO_2$ emission. *Renew. Sustain. Energy Rev.* **2016**, *62*, 418–428. [CrossRef]
7. Omanbayev, B.; Salahodjaev, 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 $CO_2$ emissions in OECD countries: A comparative analysis. *Energy Policy* **2014**, *66*, 547–556. [CrossRef]
9. Shahbaz, M.; Sinha, A. Environmental Kuznets curve for $CO_2$ 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 $CO_2$ 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., Schlömer, 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, $CO_2$ 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 $CO_2$ 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 $CO_2$ emissions in SAARC countries. *Sustain. Prod. Consum.* **2020**, *22*, 218–230. [CrossRef]
16. Zoundi, Z. $CO_2$ 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. Özbuğday, F.C.; Erbas, B.C. How effective are energy efficiency and renewable energy in curbing $CO_2$ 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, $CO_2$ 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 $CO_2$ 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 $CO_2$ 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 $CO_2$ emissions: Panel cointegration analysis for BRIICTS countries Environmental policy stringency, renewable energy consumption and $CO_2$ 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 $CO_2$ 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 $CO_2$ 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, $CO_2$ 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 $CO_2$ emissions and economic freedom on $CO_2$ emissions in the EU. *Renew. Energy* **2021**, *169*, 293–307. [CrossRef]
30. Key, A.; Mendonça, D.S.; De Andrade, G.; Barni, C.; Fernando, M.; Cezar, A.; Kupek, E.; Fernandes, L. Hierarchical modeling of the 50 largest economies to verify the impact of GDP, population and renewable energy generation in $CO_2$ 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. Asongu, 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 $CO_2$ 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.; Ampon-Wireko, S.; Dogbe, C.S.K. Innovation, trade openness and $CO_2$ emissions in selected countries in Africa. *J. Clean. Prod.* **2021**, *281*, 125143. [CrossRef]
36. Lv, Z.; Li, S. How financial development affects $CO_2$ emissions: A spatial econometric analysis. *J. Environ. Manag.* **2021**, *277*, 111397. [CrossRef]
37. Shakouri, B.; Khoshnevis Yazdi, S.; Ghorchebigi, E. Does tourism development promote $CO_2$ emissions? *Anatolia* **2017**, *28*, 444–452. [CrossRef]
38. Mirziyoyeva, Z.; Salahodjaev, R. Women's Parliamentary Representation and Sustainable Development Goals: A Cross-Country Evidence. *Appl. Res. Qual. Life* **2021**, 1–13. [CrossRef]
39. Kalayci, C. The impact of economic globalization on $CO_2$ emissions: The case of NAFTA countries. *Int. J. Energy Econ. Policy* **2019**, *9*, 356.
40. World Energy Outlook. 2019. Available online: https://www.iea.org/reports/world-energy-outlook-2019 (accessed on 26 November 2019).
41. Szymczyk, K.; Şahin, D.; Bağcı, H.; Kaygın, C.Y. The Effect of Energy Usage, Economic Growth, and Financial Development on $CO_2$ Emission Management: An Analysis of OECD Countries with a High Environmental Performance Index. *Energies* **2021**, *14*, 4617. [CrossRef]