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Industrialization and CO_2 Emissions in Sub-Saharan Africa: The Mitigating Role of Renewable Electricity

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Abstract: This study aims to explore the relationship between industry value added, renewable energy, and CO_2 emissions in a sample of 44 Sub-Saharan African countries over the period 2000–2015. This study makes several important contributions to extant research. While existing research was focused on the renewable energy-CO_2 emissions nexus, the current study assesses the moderating role of the renewables sector in the industrialization-CO2 emissions relationship. In addition, this study considers whether EKC relationships will hold after accounting for structural transformations (including industrial contributions to GDPs). Moreover, we are revising the existence of the EKC framework for the Sub-Saharan African countries. Using a two-step system GMM estimator, we found that the share of industry in GDP has a significant positive impact on CO_2 emissions, while renewable electricity output reduces CO_2 emissions. If causal, a one percentage point increase in renewable electricity output reduces carbon emissions by 0.22%. Moreover, the renewable energy sector then mediates the positive effect of industry value added on CO_2 emissions. We also find evidence for the statistical significance of the inverted U-shaped relationship between GDP per capita and CO_2 emissions.

Keywords: industry; renewable energy; CO_2 emissions; Sub-Saharan Africa

Citation: Mentel, U.; Wolanin, E.; Eshov, M.; Salahodjaev, R. Industrialization and CO_2 Emissions in Sub-Saharan Africa: The Mitigating Role of Renewable Electricity. *Energies* **2022**, *15*, 946. https://doi.org/10.3390/en15030946

Academic Editor: Štefan Bojnec

Received: 13 December 2021
Accepted: 23 January 2022
Published: 27 January 2022

1. Introduction

Research on the causes of CO_2 emission has proliferated in recent years [1–5]. One of the most important frameworks explored in this context was the existence of a non-linear (inverted U-shaped) relationship between GDP per capita and CO_2 emissions across countries, the so-called environmental Kuznets curve (EKC) phenomena. For example, the EKC framework was explored for Malaysia [6], China [7], Croatia [8], Turkey [9], Algeria [10], and Sub-Saharan Africa [11]. At the same time, another strand of studies suggested that economic growth, urbanization, trade, and renewable energy use are also important predictors of CO2 emissions across countries [12–14]. These studies have relied on the STRIPAT econometric framework [15,16].

While the global level of renewable energy consumption has been relatively stable over the past decade, Sub-Saharan African countries are among the top performers using renewables. At the same time, Figure 1 suggests significant differences in the levels of CO_2 emissions in this region, ranging from 0.04 tCO2 per capita in the Democratic Republic of Congo to 8.15 tCO_2 in South Africa. Therefore, the goal of this study is to explore the relationship between renewable energy use and CO_2 emissions in 44 Sub-Saharan Africa countries over the period 2000–2015. Our results make several important contributions to extant research. First, while existing research focused on the renewable energy-CO_2

emissions nexus, the current study assesses the moderating role of the renewables sector in the industrialization-CO_2 emissions relationship. Second, this study considers whether the EKC relationship holds after accounting for structural transformations (including industrial contribution to GDP). Third, in this study, we relied on a two-step system generalized method of moment (GMM) to explore the impact of renewable electricity output and industrialization on CO_2 emissions. Fourth, we suggest possible revisions to existing EKC frameworks in Sub-Saharan African countries.

The rest of the study is structured as follows: Section 2 reviews related literature, Section 3 presents data and methodology, Section 4 provides the empirical results, and Section 5 concludes the study.

2. Review of Related Literature

The role of renewable energy in explaining CO_2 emissions has been investigated in the context of the Environmental Kuznets Curve framework to assess the influence on GDP. For example, Zoundi [17], using the cointegration method for a sample of 25 African countries over the period 1980–2012, found that GDP increased CO_2 emissions, while renewable energy reduced air pollution in the long run. In a similar vein, Shafiei and Salim [18], analyzing data for the OECD countries for the years 1980–2011, documented that using renewable energy reduced CO2 emissions. Moreover, GDP per capita also had a positive impact on CO_2 emissions. Dogan and Seker [19] used the EKC theory to model the relationship between renewables and CO_2 emissions in the European Union from 1980–2012. Their dynamic ordinary least squares estimator results showed that trade openness and renewable energy reduced CO_2 emissions. Moreover, the Dumitrescu–Hurlin non-causality tests show a bi-directional relationship between renewable energy and CO2 emissions.

Saidi and Omri [20] further revisit the link between renewable energy and CO_2 emissions in a sample of 15 major energy-consuming countries. Results from the Granger causality test show the presence of bi-directional causality between renewable energy and CO_2 emissions in the long run and the absence of causality in the short run. Salahuddin et al. [21] found that renewable energy decreased CO_2 emissions and increased aggregate national savings in a sample of 34 Sub-Saharan Africa countries over the period 1984–2016. Sadorsky [22] also explored the relationship between renewable energy consumption and CO_2 emissions in a sample of G7 countries. The study used the panel cointegration method to find that causality runs from GDP per capita and CO_2 emission to renewable energy consumption in the long run. Therefore, renewable energy is not an instrumental variable to curb emissions in G7 countries.

Sebri and Ben-Salha [23] also did not report a significant causal influence of renewables on CO_2 emissions in BRICS over 1971–2010, using an ARDL estimator. The study found that economic growth and renewable energy are interrelated. Baloch et al. [24] also explored the relationship between renewable energy, GDP growth, and CO_2 emissions in BRICS over 1990–2015, using an augmented mean group estimator. In contrast, the study found that renewable energy use led to decreased CO_2 emissions for all BRICS countries except South Africa. Tiwari [25] explored the relationship between economic growth, renewable energy consumption, and carbon emissions in India from 1960–2009 using the vector auto-regression method. The findings show, an impulse leading to a rise in renewable energy use will also increase economic growth and reduce CO_2 emissions.

Moreover, economic growth has led to a rise in air pollution. Boontome et al. [26] assessed the relationship between renewable energy use, economic growth, and carbon emissions in Thailand from 1971 to 2013. The panel cointegration results suggest that non-renewable energy use and GDP growth increase CO_2 emissions. The authors suggested that shifting to green energy sources will decrease environmental degradation without hampering economic growth prospects. Dong et al. [27] also assessed the relationship between renewable energy, GDP growth, and CO_2 emissions in a sample of 128 nations for the years 1990–2014 using the common correlated effects mean group method. The results suggested that renewable energy was instrumental in reducing CO_2 emissions across each geographic region. The observed effects were strongest in South America and Eurasia.

Mahmoodi [28] revisited the renewable energy- CO_2 emissions nexus for a sample of eleven developing countries over the period 2000–2014. Using panel cointegration estimation and VECM models, the study found bidirectional causality between renewable energy consumption and carbon emissions. Moreover, the alternative estimation methods demonstrated that renewables decrease emissions in general.

Abbasi et al. [29] explored the role of renewable energy within the framework of decreasing CO_2 emissions in Thailand by 25% by 2030. The ARDL simulation model for the years 1980–2018 showed that depletion of fossil fuels increased CO_2 emissions, while renewable energy consumption negatively affected CO_2 emissions in the short run. The authors highlighted a need for rapid energy sector transformation towards green energy consumption to achieve carbon mitigation targets.

Jebli and Youssef [30] assessed the links between renewable energy and CO2 emissions in North Africa over the period 1980–2011. The long-run estimates show a unidirectional causality from renewable energy to CO_2 emissions. In a similar vein, but for Pakistan, Waheed et al. [31], using ARDL estimator, find that greater renewable energy consumption leads to a decrease in carbon emissions.

Bhattacharya et al. [32] explored the role of renewable energy in reducing CO_2 emissions in 85 countries over the period 1991–2012. The study used a GMM estimator to find that rapid deployment of renewable energy technologies should lead to a decline in CO2 emissions. Nathaniel and Iheonu [33] also explored the effect of renewable and non-renewable demands on CO_2 emissions in a sample of 19 countries in Africa for the period 1990–2014 using the AMG method. The results showed that renewable energy use had no significant impact on environmental degradation while fossil fuel consumption led to a rise in CO_2 emissions.

While energy is considered one of the most important predictors of CO_2 emissions, industrialization is another factor of environmental degradation that has received attention in empirical literature [34]. For example, consider BRI countries such as China: "despite the economic benefits accrued from rapid industrialization, [China] has strained resource sources as labor, materials, and investment, and has incurred significant environmental degradation" [35] (p. 178). Li and Lin [36] argue that at earlier stages of economic development, industrialization was associated with greater energy demand and altered energy consumption models, increasing CO_2 emissions. The negative impact of industrialization on CO_2 emissions may be offset by the efficient use of infrastructure and agglomeration. However, many other factors should be considered when exploring the industrialization and CO_2 emissions nexus. For example, industrialization has led to urbanization and greater trade openness, which has also affected CO_2 emissions [37].

Other studies have explored the direct effect of industrialization on CO_2 emissions. For example, Shahbaz et al. [38] explored the relationship between industrialization, energy use, and CO_2 emissions in Bangladesh over the period 1975–2010. Using the ARDL bounds testing approach, the study found that energy use increased environmental degradation, while there was a non-linear, inverted U-shaped relationship between industrialization and CO_2 emissions. Ullah et al. [39] examined the relationship between industrialization and CO_2 emission in Pakistan over the period 1980–2018 using the ARDL estimator. Results suggest that an increase in the share of industry contributing to GDP led to a rise in CO_2 emissions, both in the short- and long-run. In addition, the study confirmed that urbanization and economic growth exerted a positive effect on environmental degradation. Mahmood et al. [40] further relied on the ARDL model to explore the industrialization- CO_2 emissions nexus in Saudi Arabia over the period 1968–2014. The results show that industrialization has had a significantly positive impact on environmental degradation (CO_2 emissions). The authors have suggested that it is important to enact more stringent industrial policies to reduce CO_2 emissions. Other studies also confirmed the significant effect of industrialization on CO_2 emissions in Korea, China, and the UAE [41–43].

Based on the abovementioned discussion we formulate the following hypothesis:

Hypothesis 1 (H1). *Industrialization leads to a rise in* CO_2 *emissions in Sub-Saharan Africa.*

Hypothesis 2 (H2). *Renewable energy enhances environmental quality in Sub-Saharan Africa.*

Hypothesis 3 (H3). *Renewable energy sector development offsets the negative effects of industrialization on* CO_2 *emissions in Sub-Saharan Africa.*

3. Data and Methods

In order to reach the goals of this study following extant research, we specified CO_2 emissions as a function of economic development (GDP), trade openness (T), urbanization (U), industrialization (I), and renewable energy (R). Thus, the econometric model can be specified as:

$$CO2_{i,t} = \alpha_0 + \alpha_1 CO2_{i,t-1} + \alpha_2 GDP_{i,t} + \alpha_3 GDP_{i,t}^2 + \alpha_4 T_{i,t} + \alpha_5 U_{i,t} + \alpha_6 I_{i,t} + \alpha_7 R_{i,t} + \varepsilon_{i,t} \quad (1)$$

where i is the country, t denotes time (year), $\alpha_1 \ldots \ldots \ldots \alpha_7$ are parameters to be calculated, and ε is an error term. We also include the GDP per capita squared term to account for the EKC hypothesis in Sub-Saharan Africa [44,45]. Equation (1) is an estimated two-step system generalized method of moments (GMM) estimator. The two-step GMM estimator is used when (1) the number of panels (countries) is above the number of time periods (in years); (2) the empirical model includes lagged dependent variables; and (3) it is important to account for the problem of endogeneity and simultaneity. For example, if the inclusion of lagged CO_2 emissions leads to an emergence of this issue. For these reasons, many studies use the two-step system GMM to model the drivers of CO_2 emissions across countries [46–50].

Our data spanned the years 2000–2015 and covered 44 Sub-Saharan African countries. CO_2 emissions were measured as tCo2 emissions per person (Figure 1). GDP per capita was measured in constant international USD. As a proxy for FDI, we used net FDI inflows as percentage of GDP. Trade was the sum of exports and imports relative to GDP. Urbanization was the share of the urban population. Renewable energy was proxied by renewable electricity output as percentage of total electricity output, while industrialization was industry (including construction) value added as percentage of GDP. The descriptive statistics are presented in Table 1. The correlation matrix is reported in Table 2.

Table 2 shows that correlations between main variables do not exceed 0.8; thus, multicollinearity should not be a problem in our study. The correlations matrix also shows that industry, GDP, trade openness, and urbanization are positively correlated with CO_2 emissions, while renewable energy has a negative correlation coefficient with CO_2 emissions. Figures 2 and 3 provide the visual associations between industry, renewable energy, and CO_2 emissions.

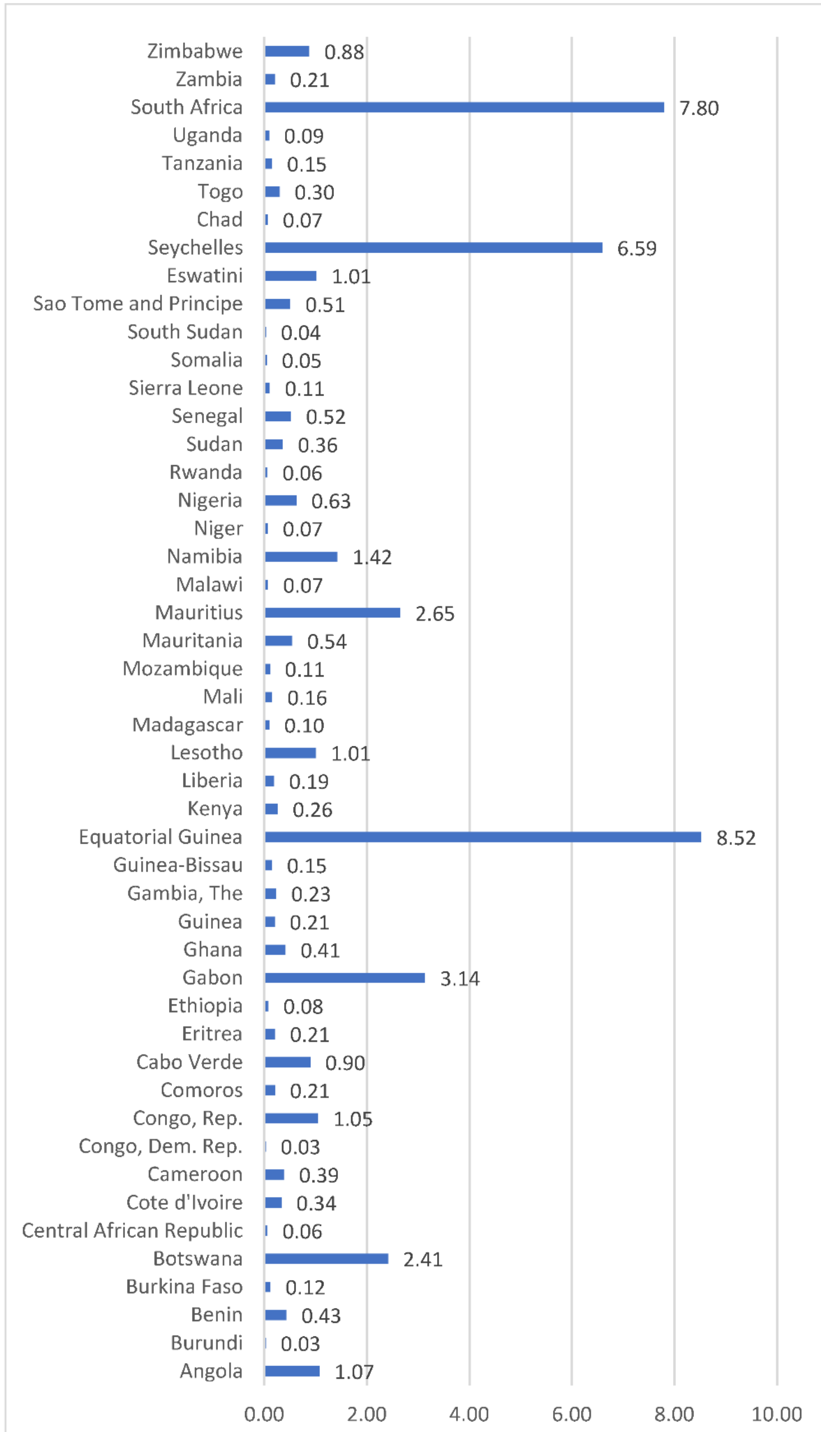

Figure 1. CO_2 emissions per person in Sub-Saharan Africa, 2000–2015.

Table 1. Summary statistics.

Variable	Description	Mean	Std. Dev.	Min	Max
CO_2	tCO_2 emissions per person Source: Global Carbon Atlas	0.96	1.92	0.02	10.49

Industry	Industry (including construction), value added (percentage of GDP) Source: World Bank	25.05	13.87	2.07	84.35
Renewable energy	Renewable electricity output (percentage of total electricity output) Source: World Bank	43.09	37.82	0.00	100.00
GDP	GDP per capita, PPP (constant 2017 international USD) Source: World Bank	4.71	6.08	0.63	41.25
Trade	Trade as percentage of GDP Source: World Bank	73.39	38.86	19.10	311.35
Urbanization	Urbanization rate, percentage Source: World Bank	38.15	15.91	8.25	88.12

Table 2. Correlation matrix.

	CO_2	Industry	Renewable Energy	GDP	Urbanization	Trade
CO_2	1					
Industry	0.4476	1				
Renewable Energy	−0.3279	0.1454	1			
GDP	0.7983	0.5035	−0.2719	1		
Trade	0.5165	0.3366	−0.1027	0.4666	1	
Urbanization	0.6846	0.5121	−0.2625	0.5717	0.4076	1

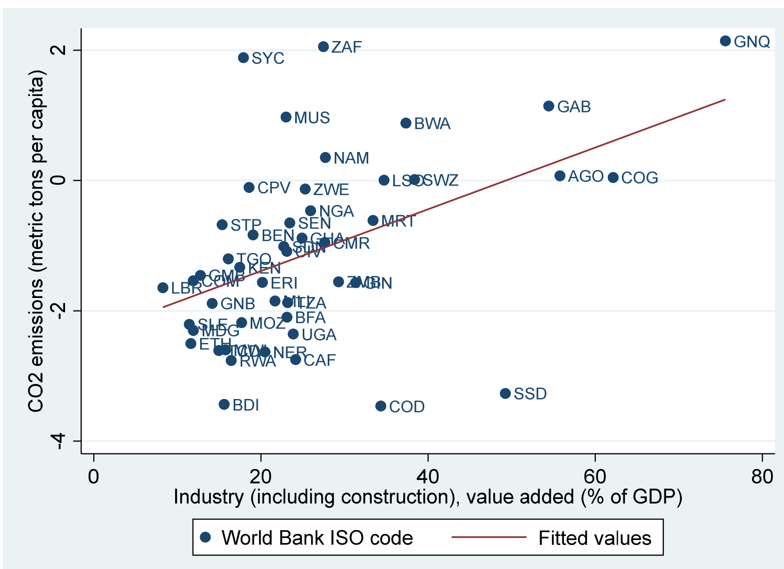

Figure 2. CO_2 emissions and industrialization, 2000–2015.

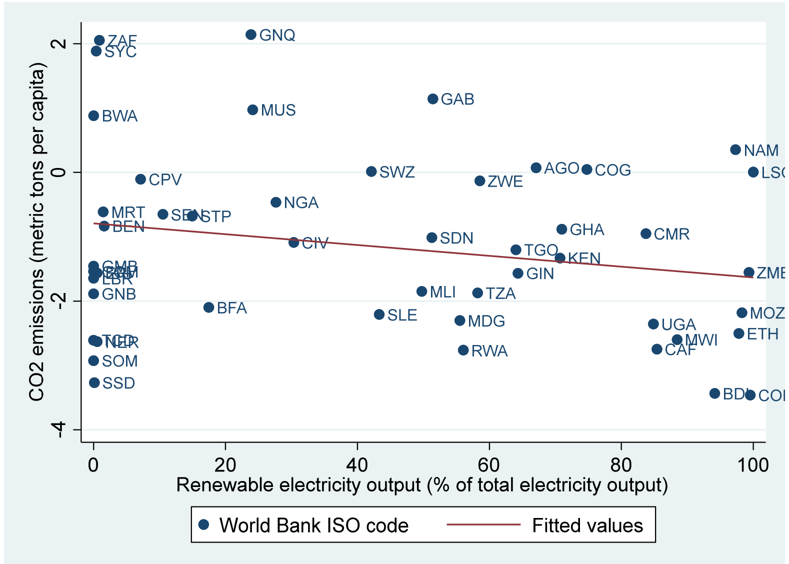

Figure 3. CO_2 emissions and renewable energy output, 2000–2015.

4. Results

The main results are reported in Table 3. Column 1 estimates the relationship between industry, control variables, and CO_2 emissions. First, we found that there was a positive relationship between industrialization and CO_2 emissions in Sub-Saharan Africa: a 1 percentage point increase in the share of industry in GDP led to a 0.3% increase in CO_2 emissions per person. We also documented an inverted U-shaped link between GDPs per capita and CO_2 emissions, confirming the statistical presence of the EKC in our sample with a turning point at approximately international constant USD 27,000. However, Figure 4 shows that only the GDP per capita of Equatorial Guinea was above the turning point in 2015. Therefore, the EKC did not have an economic implication in our study [30] and [45] we also failed to discover the EKC for African countries. Turning to other variables, we found that trade openness had a positive impact on CO_2 emissions in Sub-Saharan African countries. For example, a one percentage point increase in trade led to a 0.11% increase in CO_2 emissions. These results are in line with existing cross-country research [51]. Moreover, the positive effect of trade openness on environmental degradation was also documented [44]. Our results imply that trade liberalization has not improved the region's environmental conditions, suggesting that trade structure should change from energy-intensive products to knowledge-intensive goods and services. Indeed, Ncanywa et al. [52] found that the economic complexity of products produced in Sub-Saharan Africa is low, and this has had a negative impact on trade diversification in the region. Urbanization is insignificantly related to CO_2 emissions.

In column 2, we included renewable electricity production. As expected, the coefficient for renewable energy was negative and significant at the 1% level. If causal, a one percentage point increase in renewable electricity output reduces carbon emissions by 0.22%. These results align with existing cross-country evidence [18] highlighting the importance of switching from fossil fuel energy to renewable energy consumption. We further include an interaction term between industry and renewable energy in Column 3. The interaction term is negative and significant, suggesting that the renewable energy sector is important to offset the negative effects of industrialization on CO_2 emissions. The coefficients in columns 1–3 change as we include additional variables and an interaction term between renewable energy and industrialization. The AR (2) and Hansen *p*-values confirm that our instruments are valid and reliable. The F-statistics exceed the threshold value of 10 confirming that overall; the econometric specification is significant in our analysis.

Table 3. Main results.

	I	II	III
$CO2_{t-1}$	0.864609	0.856769	0.877561
	(38.08) ***	(33.13) ***	(45.63) ***
GDP	0.002957	0.003745	0.003537
	(3.59) ***	(4.05) ***	(4.68) ***
GDP squared	0.052024	0.050493	0.043806
	(4.76) ***	(3.82) ***	(5.70) ***
Trade	−0.096047	−0.099811	−0.101737
	(5.03) ***	(4.17) ***	(6.33) ***
Urbanization	0.001055	0.000886	0.001142
	(7.34) ***	(4.59) ***	(8.50) ***
Industry	−0.000016	0.000750	0.001124
	(0.01)	(0.38)	(0.74)
Renewable		−0.002203	0.000019
		(4.84) ***	(0.03)
Renewable * Industry			−0.000036
			(2.80) ***
Constant	−0.472627	−0.403860	−0.484623
	(5.14) ***	(3.55) ***	(5.68) ***
AR(1)	0.000	0.000	0.000
AR(2)	0.325	0.297	0.348
Hansen *p*-value	0.231	0.165	0.367
F-stat	51,985.22	407,952.02	794,403.81
N	628	628	628

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

We also assess the robustness of our results by considering the role of non-economic control variables in Table 4. Extant research shows that the quality of institutions, such as in anti-corruption policies, may significantly affect CO_2 emissions [53]. Therefore, we include the corruption perceptions index (CPI) from Transparency International (Column 1). Additionally, empirical evidence shows that it is important to account for the human capital when modeling environmental indicators [54,55]. Therefore, we include the education index from the UN in Column 2. Finally, in Column 3, we include the proportion of women in parliament to capture the effect of female political empowerment on environmental degradation [56]. Across all models, renewable energy mediates the effect of industrialization on CO_2 emissions. Therefore, the results confirm that industrialization and renewable energy play an important role in predicting CO_2 emissions in Sub-Saharan African countries.

Table 4. Additional controls**.**

	I	II	III
$CO2_{t-1}$	0.847266	0.884571	0.858646
	(43.46) ***	(48.64) ***	(49.06) ***
Industry	0.002438	0.002772	0.003614
	(2.04) **	(2.28) **	(4.66) ***
Renewable	0.000283	0.000183	0.000762
	(0.39)	(0.31)	(1.37)
Renewable * Industry	−0.000051	−0.000039	−0.000049
	(2.39) **	(4.02) ***	(3.15) ***
GDP	0.051276	0.033394	0.050422

	(4.84) ***	(3.21) ***	(7.65) ***
GDP squared	−0.116404	−0.074215	−0.110335
	(4.86) ***	(3.04) ***	(7.10) ***
Trade	0.001144	0.001014	0.001154
	(5.60) ***	(6.75) ***	(6.88) ***
Urbanization	0.000859	0.000736	0.000391
	(0.50)	(0.44)	(0.28)
CPI	0.000108		
	(0.08)		
Education		0.247795	
		(0.83)	
Parliament			0.000753
			(0.95)
Constant	−0.526451	−0.511391	−0.538134
	(4.14) ***	(3.07) ***	(6.29) ***
AR(1)	0.000	0.000	0.000
AR(2)	0.969	0.362	0.357
Hansen *p*-value	0.339	0.430	0.218
F-stat	90,807.81	60,291.78	168,723.20
N	539	622	611

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

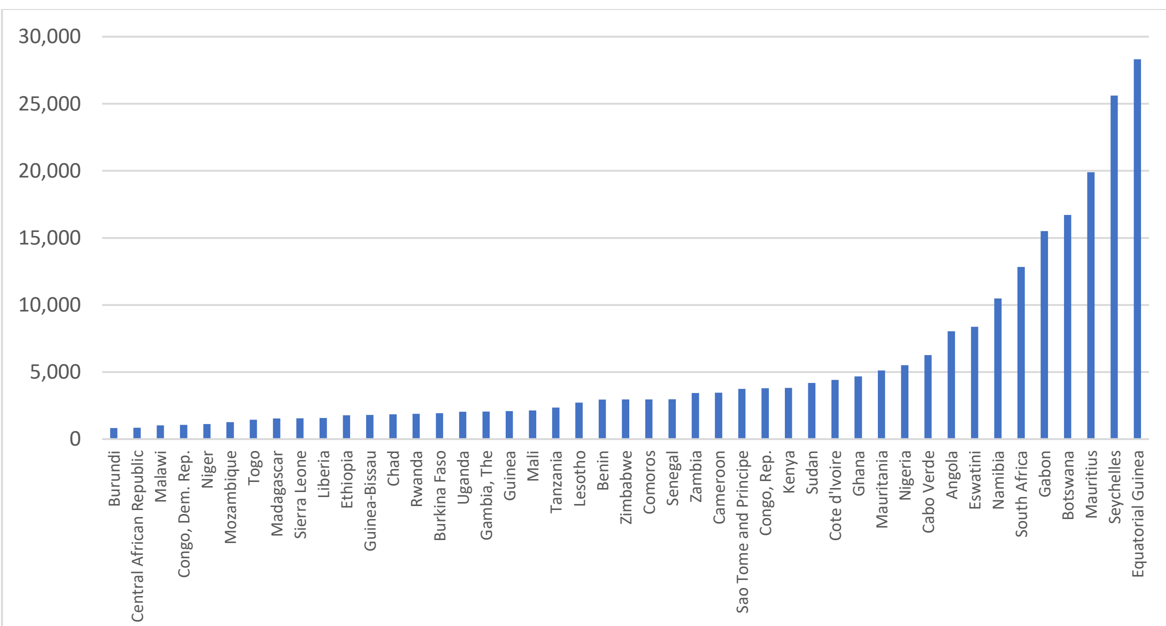

Figure 4. GDP per capita, 2000–2015.

5. Conclusions

This study aims to explore the relationship between industrialization, renewable energy, and CO_2 emissions in a sample of 44 Sub-Saharan Africa countries for the period 2000–2015. We relied on the two-step system GMM estimator for this aim, which accounts for endogeneity and omits variable bias. We depart from the EKC framework by incorporating the industry and renewable energy sectors. Our results suggest that industry value adds increased CO_2 emissions while renewable electricity output decreased environmental degradation. If causal, a one percentage point increase in renewable electricity output reduces carbon emissions by 0.22%. Moreover, we find that renewable energy use mediates the relationship between industry value adds and CO_2 emissions.

Our findings have several important policy implications. First, to promote the development of renewables, policymakers can offer low interest loans and tax cuts for purchasing and installing renewable energy generators. In addition, each country can adopt a local renewable energy deployment strategy that outlines the key vision of the government in this sector. Apart from that, the governments can adopt a policy where buildings with an area exceeding a certain threshold are required to replace some of the energy consumption with renewables. It is possible to use subsidies for biogas or hydro power producers in certain countries. Second, it is crucial to institute policies aimed at the promotion of renewable energy technologies across industries. This can be achieved by reducing tax rates for green energy technology adopters, offering low-interest loans and grants to companies and households, and subsidizing green energy.

Moreover, studies show that guaranteed prices act as a potential tool to promote the development of the renewable energy sector [57]. Third, we fail to find the economic presence of the EKC. This highlights that regional economic growth leads to environmental degradation.

Prospective studies can extend our results in many ways. It is essential to assess the role of other factors such as human capital, population, agriculture, or FDI in explaining CO_2 emissions in the Sub-Saharan Africa countries [58–62]. It is important to assess the factors associated with renewable energy adoption [63] and the role of renewable energy in economic growth in the region [64,65].

Author Contributions: Conceptualization, U.M., E.W. and M.E.; methodology, R.S.; software, R.S.; validation, U.M., M.E., E.W. and R.S.; formal analysis, R.S.; and writing—review and editing, R.S., E.W. and U.M. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data are available from sources cited in the study.

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

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