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Renewable Energy and CO_2 Emissions in Top Natural Resource Rents Depending Countries: The Role of Governance

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This study analyzes the relationship between renewable energy and CO_2 emissions in top natural resource depending countries over the period 2000–2015. An important contribution of this study is to assess the role of governance. The Ordinary Least Squares Fixed effects Generalized Least Squares methods and two-step GMM estimators are used for panel data. The empirical results show that renewable energy has significant negative impact on per capita CO_2 emissions. The estimates show that 1 percentage point increase in renewable energy consumption leads to 1.25% decrease in CO_2 emissions per capita. We also find that renewable energy consumption decreases CO_2 emissions faster in countries with higher rule of law and voice and accountability. gross domestic product per capita has inverted U-shaped relationship with CO_2 emissions.

Keywords: renewable energy, CO_2 emisisons, natural resources, GDP, governance

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1 INTRODUCTION

Over the past 2 decades, the research on the drivers of CO_2 emissions has proliferated (Andreoni and Galmarini, 2016; Henriques and Borowiecki, 2017; Dong et al., 2020). One of the main theories to explain the long-term trends in CO_2 emissions across nations is the pioneering study by Grossman and Krueger (1991) who documents that there is non-linear (inverted U-shaped) relationship between gross domestic product (GDP) per capita and environmental outcomes such as SO_2 emissions, the so-called Environmental Kuznets Curve (EKC) framework. The EKC theory has been validated in a number of review studies (Cavlovic et al., 2000; Sarkodie and Strezov, 2019). In an updated meta-analysis of 101 published studies by Saqib and Benhmad (2021) the authors conclude that there is "a strong evidence in support of EKC . . . irrelevant to the choice of econometric tools employed or type of data used" (p. 1). However, a number of review and empirical studies highlight that in the case of CO2 emissions there is no robust confirmation of the EKC hypothesis (Pao et al., 2011; Liu et al., 2017) and the turning point for GDP per capita may be far outside existing range of data (Koirala et al., 2011). As a result, a large stream of research has emerged that explores the effects of other variables such as financial development, trade openness, urbanization and globalization, among others, on CO2 emissions in the context of the EKC framework (Al-Mulali et al., 2015; Liu et al., 2020). The goal of this study is to explore the relationship between renewable energy and CO2 emissions. This study makes several important contributions to nascent research. First, we focus on a sample of top natural resource dependent countries. According to the resource curse theory,

TABLE 1 | Descriptive statistics.

Variable	Description	Mean	Std. Dev	Min	Max
CO2	Per capita tCO2 emissions	6.37	9.98	0.02	67.01
GDP	GDP per capita, US$	8.78	1.32	6.57	11.55
Trade	Trade as % of GDP	83.29	39.57	19.10	311.35
Urbanization	Urban population (%)	51.63	22.63	8.25	100.00
Intensity	Level of primary energy measured in MJ/$2011 PP P GDP	8.49	6.42	1.09	34.96
FD	Financial Development Index	0.19	0.14	0.00	0.67
RE	Renewable energy as % of total final energy consumption	36.92	37.76	0.00	98.34
RL	Rule of Law Index	−0.74	0.67	−2.03	0.96
CC	Control of Corruption Index	−0.71	0.63	−1.77	1.57
RQ	Regulatory Quality Index	−0.71	0.72	−2.63	1.21
GE	Government Effectiveness Index	−0.69	0.71	−3.18	1.39
PS	Political Stability Index	−0.60	0.96	−3.18	1.39
VA	Voice and Accountability Index	−0.85	0.66	−2.26	0.61

Sources: World Bank, IMF.

dependence on natural resources has numerous negative impacts on society such as income inequality (Leamer et al., 1999), reduction in longevity (Madreimov and Li, 2019), infant mortality (Wigley, 2017), corruption (Dong et al., 2019) and even environmental degradation (Balsalobre-Lorente et al., 2021). Therefore, it is important to assess whether renewable energy may act as one of the solutions to decrease CO2 emissions in resource dependent countries. Second, while the relationship between renewable energy and CO2 emissions has been extensively explored for different groups of countries, the role of institutions is neglected by extant research. At the same time, Mehlum et al. (2006) documents that resource rich countries perform well when they have higher scores on various dimensions of quality of institutions indices. For example, Botswana is one of the fastest growing resource rich African countries has one of the best anti-corruption policies on the continent. In this study, we bridge resource curse literature and research on RE-emissions nexus by testing whether quality of institutions affects the RE and CO_2 emissions relationship in most resource dependent countries. Moreover, a number of most recent studies document that political and institutional variables are significant predictors of renewable consumption across countries (Uzar, 2020; Acheampong et al., 2021).

Our regression results from 43 most resource dependent countries over the period 2000–2015 show that renewable energy has negative impact on CO_2 emissions and we confirm the EKC with the turning point of $25,700. The rest of the study is structured as follows. **Section 2** reviews related empirical research. **Section 3** presents data and methodology and **Section 4** provides main results. **Section 5** concludes the study.

2 REVIEW OF RELATED RESEARCH

Extant research offers plethora evidence on the relationship between renewable energy and CO2 emissions. Chen et al. (2019) explores the relationship between RE, GDP, trade and CO2 emissions in China using autoregressive distributed lag (ARDL) bounds technique and vector error correction model (VECM) for the years 1980–2014. The results show that RE and trade has negative impact on emissions, while GDP has inverted U-shaped relationship with CO2 emissions. The Granger causality tests show that there is bi-directional relationship between RE, trade and CO2 emissions. In an earlier study, Qi et al. (2014) for China finds that renewable energy targets may lead to nearly 1.8% decrease in CO2 emissions over the period 2010–2020 in reference to No Policy scenario. Inglesi-Lotz and Dogan (2018) assess the relationship between RE and CO2 emissions in top 10 electricity producing countries in Sub-Saharan Africa for the years 1980–2011. The study documents long run relationship between GDP, RE, non-RE and CO2 emissions. Moreover, there is causality running from RE to CO2 emissions and from CO2 emissions to trade.

Shahnazi and Dehghan Shabani (2021) assess the relationship between RE, economic freedom and CO2 emissions in a sample of EU member states over the period 2000–2017. Using spatial econometric model, the study finds that there is non-linear relationship between economic freedom and CO2 emissions, and renewable energy reduces CO2. Bilan et al. (2019) explores the effect of RE, GDP growth on CO2 emissions in EU and potential EU member states over the period 1995–2015. Using cointegration and other empirical methods such as VECM, the authors show that RE adoption leads to improvement in environmental quality (decrease in CO2 emissions). Dong et al. (2018) explore the importance of RE in mitigating CO2 emissions in the context of EKC in China over the years 1993–2016. Renewable energy decreases CO2 emissions both in short- and long-run. In contrast fossil fuel consumption leads to an increase in CO2 emissions.

Mendonça et al. (2020) assess the drivers of CO2 emissions in 50 largest economies over the period 1990–2015. Using hierarchical the authors show that GDP and population increase CO2 emissions, while RE decrease CO2 emissions. Pata (2018) explores the links between GDP, financial development, CO2 emissions and RE consumption using ARDL and canonical cointegration method in Turkey over the period 1974–2014. There is inverted U-shaped relationship between GDP per capita and emissions with the turning point far exceeding the existing GDP per capita levels of Turkey. Renewable energy has no impact on emissions, while urbanization and financial development increase

TABLE 2 | Main results.

	I	II	III	IV
$CO2_{t-1}$	0.8996	0.5764	0.9116	0.5178
	(57.32)***	(19.65)***	(83.31)***	(10.64)***
GDP	0.4616	0.9224	0.3655	1.3371
	(5.58)***	(3.27)***	(7.27)***	(4.59)***
GDP^2	−0.0196	−0.0297	−0.0145	−0.0529
	(5.05)***	(2.02)**	(6.08)***	(3.84)***
Trade	0.0003	0.0007	0.0002	0.0010
	(2.73)***	(2.95)***	(2.17)**	(5.45)***
Urbanization	0.0003	0.0000	0.0000	0.0041
	(0.66)	(0.01)	(0.07)	(2.01)*
Intensity	0.0746	0.3338	0.0703	0.3057
	(4.51)***	(8.48)***	(6.57)***	(5.03)***
Finance	−0.0162	0.1977	−0.0646	0.1747
	(0.37)	(1.32)	(2.09)**	(1.21)
Renewable energy	−0.0017	−0.0115	−0.0016	−0.0125
	(5.49)***	(7.48)***	(6.68)***	(6.67)***
Constant	−2.5784	−5.8892	−2.0957	−7.8242
	(5.65)***	(4.36)***	(7.62)***	(5.04)***
R^2	0.99	0.73	—	—
AR(1)	—	—	—	0.001
AR(2)	—	—	—	0.836
Hansen p-value	—	—	—	0.126
N	607	607	607	607

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

environmental degradation. Fatima et al. (2021) contributes to extant research by exploring the relationship between GDP, RE, CO2 emissions using global panel data. Using various econometric methods, the study shows that GDP moderates the relationship between RE and CO2 emissions. At the same time, GDP has effect on non-RE consumption which in turn also increases CO2 emissions. Awosusi et al. (2022) explore the relationship between globalization, renewable energy, rents and CO2 emissions in Colombia over the period 1970–2017. The authors use FMOLS, DOLS and ARDL and show that globalization and renewable energy mitigates CO2 emissions. Dou et al. (2021) investigate the links between natural gas consumption, innovation and CO2 emissions in 73 countries over the period 1990–2019. The regression results show presence of the EKC hypothesis and innovation reduces CO2 emissions globally.

3 DATA, METHODOLOGY AND MODEL SPECIFICATION

3.1 Data Description

We use panel of 43 most resource dependent countries over the period 2000–2015. Our study includes the following countries: Angola, United Arab Emirates, Azerbaijan, Burundi, Brunei Darussalam, Central African Republic, Congo, Dem. Rep, Congo, Rep, Algeria, Ecuador, Egypt, Arab Rep, Ethiopia, Gabon, Ghana, Guinea, Guinea-Bissau, Equatorial Guinea, Guyana, Iran, Islamic Rep, Kazakhstan, Kuwait, Liberia, Libya, Mongolia, Mauritania, Malaysia, Nigeria, Oman, Papua New Guinea, Qatar, Russian Federation, Saudi Arabia, Sudan, Solomon Islands, Sierra Leone, Suriname, Chad, Togo, Turkmenistan, Timor-Leste, Uganda, Uzbekistan, Zambia. Six widely accepted measures of governance are obtained from Worldwide Governance Indicators (WGI): Voice and Accountability, Political Stability and Absence of Violence/Terrorism, Government Effectiveness, Regulatory Quality, Rule of Law and Control of Corruption. Renewable energy is measured in % of total final energy consumption. For example, in 2015 renewable energy consumption ranged from 0% in Oman to 95% in Congo Democratic Republic. CO2 emissions are measured in metric tons per capita.

We control for a number of variables in order to reduce the omitted variable. We include GDP per capita and GDP per capita squared term to account for the existence of EKC. GDP per capita is measured in constant 2010 US$. We include trade as % of GDP in order to take into consideration the effect of trade liberalization on CO2 emissions. Urbanization, represented by % of urban population. In line with Ulucak and Khan (2020) and Shahbaz et al. (2015) we control for energy intensity. We use energy intensity (EI) level of primary energy measured in MJ/$2011 PP P GDP. Finally, we also include financial development (FD) index from the IMF. For example, Shoaib et al. (2020) using data from G8 and D8 countries over the period 1999–2013 shows that financial development has significant and positive effect on CO2 emissions in the long run.

3.2 Methodology

To explore the relationship between renewable energy, governance and CO2 emissions in a panel data, we use several econometric techniques. Our baseline results are obtained using Ordinary Least Squares (OLS), Fixed effects (FE) and Generalized Least Squares (GLS) methods. These methods provide us with the correlational relationship between renewable energy and CO2 emissions. However, we use two-step GMM estimator as it has a number of advantages. First, in our dataset number of panel (countries) is above number of periods (years). Therefore, two-step GMM estimator offers more efficient estimates to other abovementioned methods. Second, it is important to address the problem of endogeneity for renewable energy, GDP, governance and others. Moreover, two-step GMM estimator is more advantageous to other panel data methods to resolve the problem of omitted variable bias. Finally, extant research on environmental sustainability (Asongu et al., 2018; Rashid Khan et al., 2019), we use two-step GMM estimator. Following related research (Apergis and Payne, 2009; Ibrahim and Law, 2014), we rely on conventional empirical model which specifies CO2 emissions as a function of GDP, GDP squared, energy consumption and control variables:

$$CO_{2it} = a_0 + a_1 CO_{2it-1} + a_2 GDP_{it} + a_3 GDP_{it}^2 + a_4 EI_{it} + a_5 RE_{it} + \gamma X_{it}^{'} + \varepsilon_{it} \quad (1)$$

where subscripts i and t stand for country and year respectively, X is a vector of control variables and ε is an error term. We include lagged CO2 emissions to account for inertia in the environmental degradation. In line with the EKC framework, we anticipate $\alpha_2 > 0$ and $\alpha_3 < 0$. Thus, we can calculate the turning point of inverted U-shaped relationship between GDP and CO2 emissions as - α_2/

TABLE 3 | The role of institutional quality.

	I	II	III	IV	V	VI
$CO2_{t-1}$	0.5205	0.5690	0.5772	0.5645	0.5559	0.6191
	(9.69)***	(10.43)***	(10.90)***	(10.94)***	(11.16)***	(11.81)***
GDP	1.5109	1.4534	1.1878	1.3089	0.9005	1.3159
	(4.31)***	(3.77)***	(3.25)***	(3.50)***	(2.74)***	(4.11)***
GDP^2	−0.0598	−0.0592	−0.0427	−0.0526	−0.0322	−0.0544
	(3.46)***	(3.28)***	(2.58)**	(3.02)***	(1.93)*	(3.30)***
Trade	0.0008	0.0006	0.0008	0.0008	0.0013	0.0008
	(2.85)***	(2.10)**	(2.72)***	(3.26)***	(5.41)***	(3.54)***
Urban	0.0018	0.0022	−0.0005	0.0025	0.0028	0.0033
	(0.76)	(0.95)	(0.19)	(1.01)	(1.36)	(1.73)*
Intensity	0.4236	0.3446	0.3625	0.3176	0.2486	0.2863
	(4.63)***	(4.19)***	(3.24)***	(3.60)***	(3.36)***	(4.33)***
FD	−0.4918	−0.2653	−0.2380	−0.2261	0.2978	−0.1223
	(0.96)	(0.78)	(0.46)	(0.42)	(0.80)	(0.70)
RE	−0.0126	−0.0112	−0.0102	−0.0119	−0.0117	−0.0095
	(8.08)***	(5.25)***	(3.41)***	(3.90)***	(4.55)***	(3.90)***
RL	0.0328	—	—	—	—	—
	(0.56)	—	—	—	—	—
RL*RE	−0.0021	—	—	—	—	—
	(1.84)*	—	—	—	—	—
CC	—	−0.0182	—	—	—	—
	—	(0.56)	—	—	—	—
CC*RE	—	−0.0018	—	—	—	—
	—	(1.49)	—	—	—	—
RQ	—	—	0.0801	—	—	—
	—	—	(2.45)**	—	—	—
RQ*RE	—	—	0.0007	—	—	—
	—	—	(0.63)	—	—	—
GE	—	—		−0.0024	—	—
	—	—	—	(0.07)	—	—
GE*RE	—	—	—	−0.0017	—	—
	—	—	—	(1.58)	—	—
PS	—	—	—	—	0.0364	—
	—	—	—	—	(1.57)	—
PS*RE	—	—	—	—	0.0012	—
	—	—	—	—	(2.09)**	—
VA	—	—	—	—	—	−0.0094
	—	—	—	—	—	(0.28)
VA*RE	—	—	—	—	—	−0.0012
	—	—	—	—	—	(1.79)*
Constant	−8.7547	−8.2999	−7.1241	—	−5.5243	−7.5259
	(4.86)***	(4.03)***	(3.47)***	(3.66)***	(3.20)***	(4.54)***
AR (1)	0.001	0.001	0.001	0.001	0.001	0.000
AR (2)	0.788	0.797	0.711	0.729	0.877	0.753
Hansen *p*-value	0.502	0.599	0.482	0.646	0.501	0.850
N	607	607	607	607	607	607

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

α_3. In order to examine the role of governance in RE and CO2 emissions we extend **Eq. 1** by including governance indicators (GI) interactively with RE. Namely,

$$CO_{2it} = a_0 + a_1 CO_{2it-1} + a_2 GDP_{it} + a_3 GDP_{it}^2 + a_4 EI_{it} + a_5 RE_{it} + a_6 GI_{it} + a_7 RE{*}GI_{it} + \gamma X_{it}^{'} + \varepsilon_{it} \quad (2)$$

where GI is replaced with one of the governance indicators from the World Bank. The descriptive statistics are reported in **Table 1**.

Equation 2 can be transformed in order to apply two step-GMM regression method (the technical presentation comes from Roodman (2009). Thus, we can re-specify **Eq. 2** in level 3) and first difference 4) forms:

$$CO2_{i,t} = \sigma_0 + \sigma_1 CO2_{i,t-\tau} + \sigma_2 E_{i,t} + \sum_{h=1}^{k} \rho_h X_{h,i,t-\tau} + u_{i,t} \quad (3)$$

$$CO2_{i,t} - CO2_{i,t-\tau} = \sigma_1 \left(CO2_{i,t-\tau} - CO2_{i,t-2\tau}\right) + \sigma_2 \left(E_{i,t} - E_{i,t-\tau}\right) + \sum_{h=1}^{5} \rho_h \left(X_{h,i,t-\tau} - X_{h,i,t-2\tau}\right) + \left(u_{i,t} - u_{i,t-\tau}\right) \quad (4)$$

where σ_0 is an intercept, τ stands for the parameter of auto regression, X incorporates other independent variables (GDP, EI, GI, Governance) and u is an error term. The validity of the instruments generated by two-step GMM estimator can be confirmed by non-significant Hansen test's *p*-values ($p > 0.1$).

The descriptive statistics reported in **Table 1** suggest that average level of CO2 emissions per in our sample is 6.37 tCO2, ranging from 0.02 (Congo Democratic Republic) to 67.01 (Qatar). At the same time, average level of renewable energy consumption is nearly 37% and it reaches 98.3% in Congo Democratic Republic. These figures lend evidence that CO2 emissions should be negatively linked to RE consumption. Trade openness ranges from 19.1% in Sudan to 311.35% in Liberia.

4 MAIN RESULTS

In **Table 2** we provide main results using OLS, FE, GLS and two-step GMM. Across all models, the coefficient for renewable energy is negative and statistically significant suggesting that in resource dependent countries renewable energy consumption can reduce CO2 emissions. For example, 1 percentage point increase in renewable energy consumption leads to 1.25% decrease in CO2 emissions per capita (column 4). Our results are similar to findings of Leitão and Lorente (2020) for a sample of 28 European Union countries over the period 1995–2014. In addition, we also find that trade openness and energy intensity increase CO2 emissions in our sample. For example, 1% increase in energy intensity leads to 0.31% rise in CO2 emissions. Following extant research, we document the inverted U-shaped relationship between income per capita and CO2 emissions with the turning point of $25,700 (Ummalla and Goyari, 2021). In a similar vein, the turning points for other regions are $30,900 for G-7 countries (Anser et al., 2020), $35,428 for 130 countries (Holtz-Eakin and Selden, 1995) and $29,687 for 16 developing countries (Richmond and Kaufmann, 2006). Urbanization is only marginally significant and financial development has insignificant effect on CO2 emissions in resource dependent country. For example, Shahbaz et al. (2016) also documents that urbanization does not have direct linear effect on CO2 emissions in Malaysia over the period 1970–2011. The study shows that the impact is non-linear, with the EKC pattern in the long run. The Hansen *p*-values exceed the threshold of 0.1 and confirm that instruments generated by the two-step GMM estimator are credible and reliable.

In order to assess the role of governance in RE-CO2 emissions relationship, we introduce the interaction terms between six dimensions of governance and renewable energy consumption in **Table 3**. We document that the interaction terms for Rule of Law and Voice and Accountability indices are negative and significant (column 1 and 6). This implies that renewable energy consumption decreases CO2 emissions faster in countries with higher rule of law and voice and accountability. On the other hand, renewable energy reduces CO2 emissions by a larger margin in countries with lower levels of political stability (column 5). This may be explained by Zahid (2014) who argues that political stability may restraint innovation and lead to volatile economic growth. Finally, control of corruption (column 2), regulatory quality (column 3) and government effectiveness (column 4) do not influence the RE-CO2 emissions relationship. For example, Baloch and Wang (2019) using data for BRICS over the period 1996–2017 finds that governance indicators have effect on the EKC hypothesis and directly improve quality of environment by reducing CO2 emissions.

5 CONCLUSION

In this article, we explore the relationship between renewable energy, governance and CO2 emissions in most natural resource dependent countries over the years 2000–2015. Using, two-step GMM estimator our study finds that:

i. EKC framework is confirmed for natural resource dependent countries
ii. The turning point for GDP per capita beyond which further economic progress improves environment is US$ 25,700
iii. Renewable energy reduces CO2 emissions in resource dependent economies
iv. The effect of renewable energy on CO2 emissions is stronger in countries with higher scores on Rule of Law index and Voice and Accountability index.

This study demonstrates that renewable energy is crucial channel through which resource dependent countries can mitigate the carbon dioxide emissions. Therefore, our policy offers a number of policy implications. As suggested by Liang and Fiorino (2013) p. 97) "government support and commitment are of particular importance for renewable energy technology innovation activities, which are highly contingent on policy and market uncertainty". It is important to offer incentives for rapid adoption of renewable energy technologies by households and private sector. This can be achieved via low interest credits, tax cuts for higher share of electricity consumed by economic agents or grants for communities that would like to install renewable electricity generating appliances. In addition, greater public spending should be devoted to R&D in the energy sector to promote green innovation. Innovation in this field can substantially reduce the costs of renewable energy technology. Existing empirical research for other regions supports our findings. For example, Zheng et al. (2021) using data for Chinese provinces over the period 2005–2017 finds that 1% rise in renewable energy technology innovation leads to 0.4% growth in renewable energy generation.

The limitation of our study are as follows. Due to the lack of enough reliable and complete data series we have used the period 2000–2015. Earlier period would include Post-Soviet countries that have undergone significant transition period and economic shocks. In addition, due to the choice of our main empirical method, we did not test asymmetric effects of RE and other control variables on CO2 emissions. This remains avenue for future research.

Our study can be extended in a number of ways. First, prospective research should explore whether this relationship holds for other regions or countries in different income groups (Salahodjaev and Isaeva, 2021; Mentel et al., 2022). Second, it is important to consider the role of other variables such as gender equality, industrialization or human capital can influence RE-CO2 nexus in this region. For instance, Salahodjaev et al. (2022) shows that renewable energy and tourism have significant effect on CO2 emissions. Future studies should also use other empirical methods to take into account non-monotonic asymmetries, long-and short-run relationship or convergence among countries in the levels of CO2 emissions and RE adoption.

DATA AVAILABILITY STATEMENT

Publicly available datasets were analyzed in this study. This data can be found here: World Bank.

AUTHOR CONTRIBUTIONS

Conceptualization, BS, AM, and PJ; methodology, BD and RS; software, BD and RS; validation, BS, AM, and PJ; formal analysis, RS; investigation, RS; writing—"original draft preparation, B.S. AM, PJ, RS, BD; writing—"review and editing, BS, AM, PJ, RS; All authors have read and agreed to the published version of the manuscript.

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