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Renewable Energy and CO2 Emissions: Evidence from Rapidly Urbanizing Countries

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Abstract
This study explores the relationship between renewable energy consumption and carbon dioxide emissions focusing on most rapidly urbanizing countries which has been overlooked in the empirical research. This study also investigates the presence of the Environmental Kuznets curve relationship between income and carbon emissions. Using two-step system GMM estimator for the years 2000–2015, we find that renewable energy reduces carbon dioxide emissions. Moreover, we document that quality of institutions mediates the relationship between renewables and environmental degradation. The important policy implications are discussed.

Keywords Renewable energy · CO2 emissions · Urbanization

Introduction

Global energy consumption is forecast to increase by more than 50% by 2050, led by rapid growth of urbanizing Asian countries (EIA, 2021). Thus, ensuring energy security is essential to support long run economic growth. Energy use is expected to be driven by construction sector, rising income, and residential electricity consumption in developing countries (EIA, 2021). At the same time, it is vital to decrease global carbon dioxide emissions (CO_2e) to "net zero," to limit the global warming to 1.5° of pre-industrial standings (IEA, 2021). One of the most recent studies finds that one billion metric tons of CO2 emissions released into atmosphere is responsible for 226,000 lives lost globally (Bressler, 2021). In a similar vein, World Health Organization (2017) reports that nearly 250,000 lives may be lost due to the negative impacts of climate change during the years 2030–2050.

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As a result, the use of renewable energy (RE) has been advocated by policymakers and scholars as it has been shown to decrease carbon footprint (Shafei & Salim, 2014; Leitão & Lorente, 2020) without harming economic growth (Kocak & Sarkgunesi, 2017). Indeed, the share of renewables in total capacity expansion increased from less than 20% in 2002 to 82% in 2020. This is followed by a rapid decrease in renewable energy production and storage costs globally (He et al., 2020). While there are significant untapped benefits of RE use to address the "social costs of climate change," the share of renewable energy in total energy consumption significantly differs across regions, for example, 37% in South Asia, 68% in Sub-Saharan Africa, and 28% in Latin America and Caribbean (World Bank Open Data, 2021) which is signaling huge potential for RE use in some regions, and thus it is vital to assess its advantages.

The main of goal of this study is thus to investigate the effect of RE consumption of CO2 emissions in top 50 rapidly urbanizing countries over the period 2000–2015. To take into account the problem of omitted variable bias, we control for a number of variables and use two-step system generalized method of moment (GMM) estimator. This paper makes a number of important contributions to extant research. First, comparing to other studies that focus on geographic regions (Shafei & Salim, 2014; Apergis & Payne, 2014; Dong et al., 2018), our sample includes countries that undergo significant demographic transitions, namely, rapid urbanization. The average growth rate of urbanization in our sample is 4.5% which suggests that urban population doubles every 15 years. Second, we explore the presence of the Environmental Kuznets Curve (EKC) in urbanizing countries. Third, we assess the moderating role of institutions in RE-CO2 nexus.

Recently, several studies examined the relationship between CO2 emissions, renewable and non-renewable energy consumption, economic growth and urbanization to achieve sustainable environment. Due to the increased rate of urbanization in the world today, environmental pollution has increased at an alarming rate, leading to problems such climate change and global warming. In this section, the authors mainly review the most relevant studies on the relationship between urbanization and carbon emissions, and renewable energy consumption as a solution of environment degradation.

Urbanization and CO2 Emissions

Urbanization is an important component of economic growth since it improves people's living conditions; nevertheless, increased energy consumption creates significant environmental pollution (Al-mulali et al., 2012). There is a numerous study that investigates the relationship between urbanization and carbon emissions in industrialized countries using various methodologies across different time periods.

Zhang and Lin (2012) empirically analyzed the impact of urbanization on energy consumption and carbon emissions in China using STIRPAT model over the period of 1995–2010. According to the results, urbanization significantly increases the usage of energy and carbon emissions in China and effects vary across the regions. It is suggested that the Chinese government delay the urbanization process in order to minimize global climate change. Similar evidence was obtained by Li and Yao (2009) and Liu (2009), both of whom indicated a rapid urbanization rate in China caused much pressure on energy consumption and environment. According to the research, China's building energy efficiency plan would optimize resources, preserve the environment, and minimize pollution.

In another study, Franco et al. (2017) investigated urbanization, energy consumption, and carbon emissions in the context of home to one fifth of the world's population—India. The paper attempts to find the temporal, dynamic, and causal relationships between the variables from 1901 to 2001. The research affirms that urbanization improves the quality of people's life; however, it has significant impact on CO2 emissions. Given the further growth of the population and the growing demand for energy in the future, the study recommends the use of alternative energy sources, more precisely implementation of renewable energies. Rahman and Vu (2020) examined the nexus between renewable energy, economic growth, urbanization, and environmental quality in the case of Australia and Canada from 1960 to 2015. The research used autoregressive distributed lag (ARDL) bounds and vector error correction model (VECM) Granger causality tests to explore the long-run and causal relationships between the variables. According to the findings in Australia, urbanization and economic growth increase CO2 emissions in both long and short term and in the case of Canada only in the long run, while renewable energy usage decreases CO2 emissions in Australia, but not in Canada after each country officially ratified the Kyoto Protocol in 2007 and 2002, respectively.

A recent study by Liu et al. (2021) focused on the nexus between urbanization, renewable energy, economic growth, and CO2 emissions in five Northern Asian countries (China, Japan, Mongolia, Russia, and South Korea). Panel methods were applied in this research to explore the relationships between the selected variables across a 20-year period from 1995 to 2014. Long-run estimations confirm that urbanization increases CO2 emissions, while economic growth decreases it. The findings suggest that governments should deploy urban resources more wisely in order to create smart cities. Zhang et al. (2017) analyzed the impact of urbanization on CO2 emissions using a panel data of 141 countries from 1961 to 2011. The study applied two-way fixed effects model based on the extended STIRPAT theoretical frameworks. Additionally, an inverted U-shaped link between urbanization and carbon emissions was founded, with a turn point of about 73.80%.

In the case of European countries, Destek et al. (2016) investigated the relationship between CO2 emission, real GDP, energy consumption, and urbanization for 10 selected Central and Eastern European countries from 1991 to 2011. According to the fully modified ordinary least squares (FMOLS) calculations, a 1% increase in energy consumption results in a 1.0863% rise in CO2 emissions. Besides, in the case of Asian countries, Behera and Dash (2017) examined the effect of urbanization, energy consumption, and CO2 emission for 17 countries in the South and Southeast Asia over the period of 1980–2012. The results reveal that urbanization and primary energy consumption significantly affect the CO2 emissions in the SSEA region.

Furthermore, number of researchers have studied the impact of urbanization on CO2 emissions and its negative influence on sustainable environment (Hashmi et al., 2021; Koengkan et al., 2020; Mahmood et al., 2020; Rahman & Alam, 2021; Sharif Hossain, 2011; Yu et al., 2012).

Renewable Energy and CO2 Emissions

Role of renewable energy to decrease the CO2 emissions is in the main focus of energy economic literature. Multiple empirical studies have studied to analyze the relationship between renewable energy consumption and CO2 emissions applying different techniques and models. For instance, Saidi and Omri (2020a) investigated the impact of renewable energy reducing the CO2 emissions in 15 OECD countries from 1990 to 2018 using FMOLS and VECM methods. The results of VECM methods reveal that renewable energies decrease CO2 emissions in the long term, while FMOLS indicate that investment in renewable energy reduces CO2 emissions in most of the selected countries.

In another study, Mbarek et al. (2018) examined relationship between renewable energy, CO2 emissions, and economic growth in the four Mediterranean countries for the period of 1980–2012. The empirical research applied Pedroni and Kao co-integration tests to analyze the long-term causal relationship among the variables. The results of FMOLS and DOLS estimators suggest that CO2 is significantly related with economic growth and there is a weak relationship with renewable energy consumption. Acheampong et al. (2019) and Adams (Adams et al., 2018) studied the impact of globalization and renewable energy contribution to mitigate CO2 emissions in the list of Sub-Saharan African countries over the period 1980–2015. According to the findings, renewable energy and foreign direct investment plays important role to decrease CO2 emissions, while population growth does the opposite. It is recommended that SSAC should shift from its dependence on fossil energy and improve alternative energy sources, mainly renewable energy.

In the case of European countries, Bekun et al. (2019) and Shahnazi and Dehghan Shabani (2021) investigated the nexus between renewable energy and CO2 emissions for the annual periods of 1996–2014 and 2000–2017, respectively. Compare to other regions, European countries are making more efforts to reduce the CO2 emissions. The obtained results proved that nonrenewable energy consumption and economic growth increase the carbon emissions, while renewable energy consumption decreases it. Both studies suggested effective policy recommendations mainly improve the environmentally friendly energy sources in order to achieve the Sustainable Development Goals.

Moreover, Prince and Okechukwu (2019) examined the role of renewable and non-renewable energy consumption on reduction of CO2 emissions in Africa from 1990 to 2014 using AMG estimation technique. The findings reveal that renewable energy decreases CO2 emissions insignificantly, while non-renewable energy increases CO2 emissions significantly and influence of both energy sources vary across the regions. In the case of major renewable energy-consuming countries, Saidi and Omri (2020b) studied the gap between CO2 emissions and economic development as a solution to achieve the sustainable development goals (SDGs). Fully modified ordinary least square (FMOLS) and vector error correction model (VECM) estimation techniques were applied to analyze the effectiveness of renewable energy and its role to mitigate the CO2 emissions. The empirical results show there is a bidirectional causality between the economic growth and renewable energy consumption. Implementation of sustainable renewable energy sources increases the economic growth, and it leads to the reduction of CO2 emissions. The findings suggest that urbanization is a significant driver of environmental pollution and effective policy measures should be adopted to reduce the environmental degradation.

One more study by Aydoğan and Vardar (2019) evaluated the role of renewable energy, economic growth and agriculture on CO2 emissions for a panel of E7 countries from 1990 to 2014. According to the results, there is a positive relationship between CO2 emissions and non-renewable energy consumption, while a negative link is available among CO2 emissions and renewable energy consumption. E7 countries represent the highest economic growth in global market share; therefore it is recommended to increase the renewable energy sources for the sake of growth in agricultural sector.

The following scientists have also achieved similar results by contributing to research in this field (Ben Jebli et al., 2015; Charfeddine & Kahia, 2019; Chiu & Chang, 2009; Ito, 2017; Key et al., 2020; Zoundi, 2017).

Data and Methodology

In this section, we discuss the econometric model and present the data and empirical strategy to explore the relationship between renewable energy and CO2 emissions in rapidly urbanizing countries. In line with Apergis and Payne (2009) and Ibrahim and Law (2014), we base our model on the non-linear relationship between carbon emissions (CO2) and GDP per capita with renewable energy as a main independent variable:

$$CO2_{i,t} = \alpha_0 + \alpha_1 CO2_{i,t-1} + \alpha_2 GDP_{i,t} + \alpha_3 GDP_{i,t} + \alpha_4 Renewable_{i,t} + \varepsilon_{i,t} \quad (1)$$

where subscript i represents country, t stands for year (time), *CO2* is carbon dioxide emissions (measured by tCO2 per person), *GDP* is GDP per capita (measured in constant 2017 international $), *Renewable* is renewable energy consumption (measured as % of total final energy consumption), ε is an error term, and α_0, α_1, α_2, α_3, and α_4 are parameters to be estimated. We also include lagged CO2 emissions to capture the inertia in environmental degradation. The GDP and its squared term are included to account for the existence of the EKC relationship between economic development and emissions in our sample (Kamoun et al., 2019). We extend this model by including additional variables as suggested by extant research. Namely, *trade* (measured by bilateral trade as % of GDP), *industry* (measured by industry value added as % of GDP), *government size* (measured by general final government consumption as % of GDP), *urbanization* (measure by the % of urban population), and *intensity* (measured by energy intensity level of primary energy in MJ/$2011

Table 1 Descriptive statistics

Variable	Description	Mean	Std. Dev	Min	Max
CO2	tCo2 emissions per person	3.50	8.57	0.02	67.01
GDP	GDP per capita, PPP (constant 2017 international $)	11,779.44	20,331.61	630.68	104,091.10
Industry	Industry value added as % of GDP	28.15	15.62	6.81	84.35
Government	General government final consumption expenditure (% of GDP)	14.08	5.83	0.95	54.80
Trade	Trade (% of GDP)	78.04	36.20	20.72	220.41
Urbanization	Urban population (% of total population)	45.94	24.99	8.25	100.00
Intensity	Energy intensity level of primary energy (MJ/$2011 PPP GDP)	7.78	6.73	1.09	43.35
Renewable	Renewable energy consumption (% of total final energy consumption)	54.23	34.51	0.00	98.34

Sources: World Bank, Global Carbon Atlas

PPP GDP). Table 1 presents the descriptive statistics. Our analysis is based on a sample of 50 countries for which complete data is available for the main variables for the years from 2000 to 2015. These countries experience the highest rates of urban population growth prior to 2015.

To estimate Eq. (1), we use fixed effects (FE), generalized least squares (GLS), and two-step system generalized method of moment (GMM) estimators. The key benefit of using FE method compared to conventional ordinary least squares (OLS) method is that it allows to reduce omitted variable bias by accounting for time invariant factors that were not included in the model such as geography and historical legacy. The GLS estimator has another advantage as it take into account heteroskedasticity and autocorrelation in our panel. Finally, following related studies (Asongu et al., 2018; Khan et al., 2019), we use two-step GMM estimator as our main empirical strategy for a number of reasons. First, in our sample, a number of countries ($n = 50$) significantly exceeds the number of years ($t = 16$). Second, including lagged dependent variable may bias downward the results from the OLS regression (Keele and Kelly, 2006). Moreover, two-step system GMM estimator takes into account the problem of endogeneity in cross-country empirical analysis (Roodman, 2009).

Empirical Results

Table 2 presents the baseline results from estimating Eq. (1). Column 1 reports the results for the fixed effects regression estimator. As expected, renewable energy is negatively correlated with CO2 emissions in our sample. The estimates suggest that 1 percentage point increase in renewable energy consumption is associated with 1.6% decrease in CO2 emissions. We use GLS in Column 2 as it takes into account the problems of heteroskedasticity and cross-correlation across panels. Again, renewable energy is negative and significant at the 1% level. Moreover, we find that GDP per capita has inverted U-shaped association with CO2 emissions with the turning point of approximately $39,000. In our sample, only three countries had GDP per capita above the turning point in 2015: Qatar, Kuwait, and UAE. Therefore, our results imply that economic development was associated with greater environmental degradation in rapidly urbanizing counties. Next, the two-step GMM estimator results are presented in Column 3. The soundness of two-step GMM estimator is confirmed by the second-order Arellano and Bond autocorrelation test (AR(2)) criteria and Hansen overidentification restriction (OIR).

Renewable energy retains its negative effect on CO2 emissions: 1 percentage point increase in renewable energy consumption leads to 1.7% drop in CO2 emissions per capita. We again confirm the presence of the EKC relationship in our data. We also find that trade openness leads to greater carbon emissions in our sample. This is in line with Sarkodie and Strezov (2018 p. 131) who argue that trade is an important variable that explains the EKC framework “if the sector with a competitive advantage stems from lax environmental regulations, then the effect of the trade liberalization will damage the environment.” Indeed, energy intensity and

Table 2 Main results

	FE	GLS	GMM
$CO2_{t-1}$	0.5224	0.9156	0.5142
	(10.86)***	(74.26)***	(15.74)***
GDP per capita	0.7885	0.3895	0.9946
	(2.07)**	(6.92)***	(3.62)***
GDP per capita squared	−0.0220	−0.0184	−0.0361
	(1.09)	(6.46)***	(2.71)***
Industry	0.0020	0.0022	0.0043
	(1.24)	(4.91)***	(2.60)**
Government	0.0049	−0.0019	0.0059
	(1.18)	(2.50)**	(1.51)
Trade	0.0014	0.0001	0.0011
	(2.82)***	(0.75)	(2.23)**
Urbanization	−0.0005	−0.0005	−0.0037
	(0.19)	(1.49)	(2.00)*
Intensity	0.2565	0.0614	0.2164
	(2.87)***	(5.70)***	(3.41)***
Renewable	−0.0164	−0.0020	−0.0169
	(7.78)***	(6.69)***	(10.58)***
Constant	−5.0286	−1.9940	−5.5835
	(2.73)***	(6.92)***	(3.78)***
AR(1)			0.000
AR(2)			0.711
Hansen p-value			0.112
N	663	663	663

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

industrialization is positive and significant in our sample, further confirming that rapidly urbanizing countries tend to depend on pollution-intensive industries with high levels of energy consumption, which in turn further increase carbon emissions. The results in Table 2 suggest that renewable energy has negative relationship with CO2 emissions.

We test the robustness of our main results in Table 3 by controlling for other potential determinants of CO2 emissions. In column 1, we include tourism earnings as a share of exports as tourism, urbanization, and CO2 emissions may be interrelated (Satrovic & Muslija, 2019). A number of studies suggest that rule of law is important in decreasing CO2 emissions in developing countries (Castiglione et al., 2012; Muhammad & Long, 2021). Thus, we include rule of law index from the World Bank Governance Indicators in column 2. Both renewable energy and rule of law have negative effects on CO2 emissions. Following Xie et al. (2020) and Lv (2017), we include foreign direct investment (FDI) and democracy index from Freedom House in columns 3 and 4. Of these two variables, CO2 emissions

Table 3 Robustness tests

	I	II	III	IV
$CO2_{t-1}$	0.5386	0.6247	0.5726	0.5130
	(10.74)***	(13.23)***	(12.13)***	(11.99)***
GDP per capita	1.2370	0.9051	0.9467	1.3101
	(5.41)***	(2.49)**	(3.24)***	(4.22)***
GDP per capita squared	−0.0474	−0.0288	−0.0351	−0.0514
	(3.62)***	(1.55)	(2.47)**	(3.13)***
Industry	0.0090	0.0002	0.0045	0.0028
	(3.51)***	(0.14)	(2.61)**	(1.67)
Government	0.0092	0.0017	0.0073	0.0058
	(2.32)**	(0.45)	(2.38)**	(1.48)
Trade	−0.0012	0.0011	0.0010	0.0009
	(2.09)**	(2.06)**	(1.76)*	(1.81)*
Urbanization	−0.0061	−0.0064	−0.0045	−0.0050
	(3.01)***	(2.78)***	(2.21)**	(1.63)
Intensity	0.2876	0.2660	0.2569	0.1868
	(3.67)***	(4.28)***	(5.68)***	(3.35)***
Renewable	−0.0168	−0.0145	−0.0152	−0.0158
	(7.84)***	(8.43)***	(8.96)***	(9.33)***
Tourism	−0.0006			
	(0.40)			
Rule of Law		−0.1487		
		(3.21)***		
FDI			−0.0002	
			(0.34)	
Democracy				−0.0376
				(2.50)**
Constant	−6.7756	−5.2721	−5.3795	−6.9365
	(5.65)***	(2.89)***	(3.47)***	(4.64)***
AR(1)	0.001	0.000	0.000	0.000
AR(2)	0.507	0.673	0.615	0.788
Hansen *p* value	0.599	0.288	0.244	0.283
N	545	663	662	663

$^{*}p < 0.1$; $^{**}p < 0.05$; $^{***}p < 0.01$

are lower in countries with higher levels of democratization. Again, renewable energy consumption is negative and significant.

We further check whether democratization and rule of law mediates the effect of renewable energy consumption on CO2 emissions. We do so by including interaction terms between rule of law, democracy, and renewable energy consumption in Table 4. Both interaction terms are significant at different levels of significance. The negative sign of the interaction effect between institutional

Table 4 Mediating effect of institutions

	I	II
$CO2_{t-1}$	0.6790	0.5465
	(15.30)***	(13.18)***
GDP per capita	0.8268	0.9604
	(1.95)*	(3.34)***
GDP per capita squared	−0.0281	−0.0341
	(1.27)	(2.22)**
Industry	0.0008	0.0061
	(0.50)	(2.72)***
Government	0.0010	0.0102
	(0.23)	(2.49)**
Trade	0.0002	0.0006
	(0.35)	(1.20)
Urbanization	−0.0077	−0.0051
	(2.96)***	(1.94)*
Intensity	0.2289	0.2040
	(3.71)***	(3.25)***
Rule of Law	−0.1301	
	(4.13)***	
Democracy		−0.0163
		(1.25)
Renewable	−0.0136	−0.0148
	(8.78)***	(6.12)***
Rule of Law * Renewable	−0.0026	
	(2.49)**	
Democracy * Renewable		−0.0010
		(2.89)***
Constant	−4.5128	−5.4330
	(2.14)**	(3.87)***
AR(1)	0.000	0.000
AR(2)	0.720	0.641
Hansen *p* value	0.691	0.521
N	663	663

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

variables and renewable energy suggests that rule of law and democratization enhance the effect of renewable energy consumption on the carbon emissions. These results are in line with Bhattacharya et al. (2017) for 85 developed and developing countries.

Conclusion and Policy Implications

This study explores the relationship between renewable energy consumption and carbon dioxide emissions focusing on most rapidly urbanizing countries which have been overlooked in the empirical research. This study also investigates the presence of the Environmental Kuznets curve relationship between income and carbon emissions. Using two-step system GMM estimator for the years 2000–2015, we find that renewable energy reduces carbon dioxide emissions. Moreover, we document that quality of institutions mediates the relationship between renewables and environmental degradation. In order to reduce the environmental degradation and improve sustainable development, following recommendations should be taken into consideration for the case of rapidly urbanizing countries.

Population control: As the population is growing in the largest cities from year to year, people's demand for better living is increasing and many rural areas are becoming more urbanized, resulting in increased CO_2 emissions in the long run. Rapidly urbanized countries are facing the environmental problems of traffic congestion, overcrowding, too dense urban settlements, usage of non-renewable energy, unregulated industrialization, and urban expansion difficulties. In this sense, the entire demography should be aware of population control, and governments should draft and implement appropriate regulations. Mainly it should be applied to Asian countries, which have a significantly higher population density than the rest of the globe (Xiong & Xu, 2021).

Planned urbanization: Different infrastructural developments among the rapidly urbanized countries can create negative impact on environment. In this regard, heads of the governments should formulate a proper urbanization policy, where disparities of the region will be considered in urban management.

Renewable energy sources: Governments of urbanized countries should immediately change their dependence from the main source of emissions-fossils to renewable energy consumption, as this is the main solution to reduce the environmental pollution. It is obvious that renewable energy sources require significant technical costs; hence, governments should develop new public policies to stimulate investment and enable the deployment of renewable energy technologies.

Implementation of AI: Environmental problems can be reduced by implementing the latest technology—AI (artificial intelligence). AI has the potential to accelerate global efforts to protect the environment and conserve resources by detecting energy emission reductions and CO_2 removal, helping develop greener transportation networks, monitoring deforestation, and predicting extreme weather conditions. Integration AI not only helps to decrease environmental impacts but it also helps to make operations more efficient and precise.

Imposing carbon tax: Governments should impose strict taxes on fossil fuel-dependent factories, industries, and other types of energy-consuming institutions in order to reduce the CO_2 emissions and support the renewable energy activities. This will significantly change the countries' behavior towards the consumption of clean energy.

Promoting Green Growth: Green Growth strategy aims to achieve economic growth and development ensuring natural assets continue to provide resources. Rapidly urbanizing countries should follow the strategy since the green economic development can ensure the pollution-free sustainable economic development.

Eco-friendly transportation: The transportation industry requires a complete overhaul, including the creation of energy-saving and low-carbon urban infrastructure and transportation systems for sustainable development. Public transportation should be developed, and cars powered by fossil fuels should be phased out of the market.

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