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Renewable Energy, Agriculture and CO_2 Emissions: Empirical Evidence From the Middle-Income Countries

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This study explores the effect of renewable energy and agriculture on CO_2 emissions in a sample of 94 middle-income countries for the years 2000–2015. Using two-step generalized method of moments (GMM) regression, we find there is a negative relationship between renewable energy production, agriculture value added and per capita CO2 emissions. If causal, a 1% increase in renewable electricity output leads to a 0.18% decrease in CO2 emissions. Our results remain robust when we include additional control variables. Our study suggests that policy tools such as subsidies or low interest loans can be used to promote renewable energy consumption in middle-income countries.

Keywords: agriculture, renewable, energy, CO2 emission, middle-income countries

INTRODUCTION

Air pollution and climate change are the most crucial ecological threats for humanity in the 21st century. A recent study shows that global excess mortality from all ambient air pollution is estimated at 8.8 million/year, exceeding that of tobacco smoking, AIDS and all types of social conflicts and violence (Lelieveld et al., 2020 p. 1910). Indeed, air pollution has numerous negative health impacts in developing and high-income countries. For example, air pollution has been related to lung problems (Wang et al., 2019), bronchitis (Hooper et al., 2018), and cancer (Cheng et al., 2020). The prospective societal costs associated by greenhouse gas emissions are reflected by Sustainable Development Goal 13 Climate Action, which envisages the integration of climate change measures into national policies, strategies and vision.

According to the US Environmental Protection Agency, CO_2 emissions account for 65% of global greenhouse gas emissions. According to the data from World Bank, the highest growth in CO_2 emissions based on income groups was observed among middle-income countries, where carbon emissions have increased by more than 130% over the period 1960–2016, compared to 40% in high-income countries and 25% in OECD member states.

The CO_2 emissions normalized for populations in middle-income countries for the years 2000–2016 are plotted in **Figure 1**. Evidently, there is a rising trend of carbon emissions, which seems to follow economic growth trends, demographic changes and other socio-economic processes that were taking place in this group of nations. Considering that rising carbon emissions have negative implications for societal wellbeing, empirical research on the drivers of CO_2 emissions has proliferated over the past 2 decades (Azam et al., 2016; Akram et al., 2019; Dong et al., 2019).

The research on the determinants of CO_2 emissions stems from the studies exploring the effect of economic growth (development) on environmental degradation. A number of earlier studies have reported that economic growth does not have a common effect on environmental degradation as

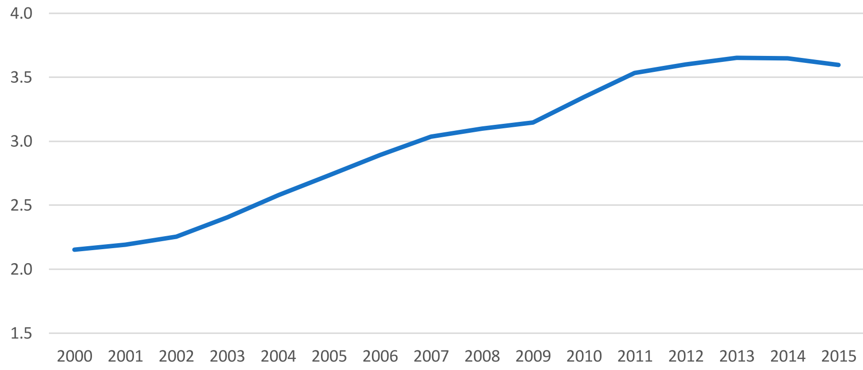

FIGURE 1 | CO_2 emission per capita.

countries climb up the GDP per capita ladder, the so-called environmental Kuznets curve phenomenon (Grossman and Krueger, 1991). As suggested by Shahbaz and Sinha (2019) (p. 107), "With rise in the level of income, when economy starts to develop, the pace of deterioration slows down, and at a particular level of income, environmental degradation starts to come down and environmental quality improves." In one of the earlier empirical studies, Shafik (1994), using simple regression methods on data for 149 nations for the years 1960–1990, shows that GDP explains 85% of variation in CO_2 emissions. On the other hand, one of the most recent large-N studies by Dong et al. (2016) documents that GDP explains only up to 48% of carbon emissions in a sample of 189 nations for the period 1990–2012. Considering the decreasing explanatory power of economic growth in modeling the antecedents of CO_2 emissions, the impact of other factors on environmental quality has gained growing attention in recent environmental research literature. These studies report that institutional and macroeconomic indicators, such as trade openness, energy consumption, globalization, urbanization, financial development, ICT sector and tourism, are related to carbon dioxide emissions (Boutabba, 2014; Begum et al., 2015; Wang et al., 2016; Chaabouni and Saidi, 2017). Moreover, within research on the energy- CO_2 emissions nexus, another strand of research has emerged that highlights the importance that the renewable energy sector plays in empirical modeling of CO_2 emission across nations.

It is essential to explore the effect of renewable energy on CO_2 emissions, as it has been related to economic growth (Pao and Fu, 2013) and "financing costs for renewable energy technologies have decreased substantially over the past 18 years, helping make renewables more cost competitive" (Egli et al., 2019 p. 835). Moreover, a better understanding of the effect of renewable energy on CO_2 emissions is needed within the background of the recent research investigating the relationship within the energy-environment nexus (Acheampong, 2018). The global market indicators such as US interest rate and oil prices will contribute to the shift towards renewable energy consumption in some of the developing and developed economies (Samour et al., 2022; Samour and Pata, 2022). Indeed, a case study from Ecuador shows that "it is possible to control the CO2 emissions even under a scenario of continuous increase of the GDP, if it is combined with an increase of the use of renewable energy" (Robalino-López et al., 2014 p. 11). The importance of renewable energy has been highlighted in the policy reforms in developing countries. According to the "Development Strategy of New Uzbekistan for 2022–2026″, special attention is paid to the development of "green" energy in the country. Thus, as a result, 25% of the electricity produced in Uzbekistan by 2026 will come from renewable energy sources[1].

A number of empirical studies explore the relationship between renewable energy and CO_2 emissions across countries with different income levels (Ayobamiji et al., 2022; Szetela et al., 2022). For example, Maslyuk and Dharmaratna (2013) investigate the relationship between renewable energy and CO_2 emissions in 11 middle-income countries in Asia for the period 1980–2010. Using structural vector auto-regression (SVAR), the authors find that renewable electricity generation leads to an increase in carbon emission. Inglesi-Lotz and Dogan (2018) empirically model the predictors of CO_2 emissions in 10 Sub-Saharan Africa countries over the years 1980–2011. The study finds that there is a long-run relationship between renewable energy and CO_2 emissions, and renewable energy decreases carbon emissions. In a more recent study, Dong et al. (2020), using data for 120 countries over the years 1995–2015, explore the link between renewables and CO_2 emissions. The authors find that renewable energy exerts a negative, although insignificant, effect on carbon emissions for all income levels.

Overall, the empirical research on the energy-emissions nexus suggests that an increase in renewable energy is instrumental in reducing carbon emissions, but the growth in non-renewable energy consumption is not. These findings are confirmed for OECD (Shafiei and Salim, 2014), developing countries (Ito, 2017), Thailand (Boontome et al., 2017), top renewable energy countries (Dogan and Seker, 2016), and 74 nations (Sharif et al., 2019).

A few separate studies explore the effect of renewable energy along with other factors on environmental degradation. One strand of research that explores global interrelations between

[1]https://minenergy.uz/ru/news/view/1856.

renewable energy and CO2 emissions considers, in particularly, the role of institutions. For example, Bhattacharya et al. (2017) investigates the role that renewable energy and quality of institutions have on CO_2 emissions in a sample of 85 nations during 1991–2012. The results suggest that an increase in renewable energy consumption and quality of institutions reduce carbon emissions. Leitão (2021) tests the role of corruption, renewable energy and economic growth in predicting CO2 emissions in selected European countries over the period 1995–2015. The results from various econometric methods show that corruption and GDP growth lead to environmental degradation, while renewable energy use mitigates CO2 emissions. Acheampong et al. (2021) uses two-step GMM estimator on a sample of 45 Sub-Saharan Africa countries to capture the role of institutions in renewable energy and CO2 emissions relationship. The study documents mixed evidence. First, institutions offset the negative effect of economic growth on CO2 emissions. However, the study fails to uncover causal relationship between renewable energy and CO2 emissions in their sample. Hamid et al. (2022) explore complex links between governance, energy use and CO2 emissions in BRICS over the period 2006–2017. The empirical results show that democracy and good governance has negative effect on environmental degradation. Moreover, these variables mediate the link between economic growth and CO2 emissions. The study also shows that renewable energy reduces CO2 emissions in the long run. Overall, these and other studies show that institutions have negative effect on CO2 emissions, globally (Lv, 2017; Ahmed et al., 2022).

The remaining recent research investigates the relationship between renewable energy, various economic variables and CO2 emissions across nations. For example, Jebli et al. (2020) explore the relationship between renewable energy use, industry value added, services value added and carbon dioxide emissions across 102 countries. The results suggest that renewable energy use decreases CO_2 emissions across all income groups, except lower-middle income countries. Tiba et al. (2016) investigate the relationship between renewable energy, trade and CO_2 emissions in 24 high- and middle-income countries over the period 1990–2011. The results show that in high-income countries, there is bi-directional causality between renewable energy and emissions, while in middle-income countries there is unidirectional causality, running from renewable energy to environmental degradation. At the same time, there is bi-directional causality between trade and CO_2 emissions. Alola and Joshua (2020) find that renewable energy use decreases CO2 emissions only in the short run. In turn, globalization has negative (positive) effect on CO2 emissions in short (long) run. Saidi and Omri (2020), using data for 15 major renewable energy consuming countries, assess the relationship between renewable energy, economic growth and carbon emissions. The study applies the cointegration technique and the vector error correction model for the years 1990–2014. The study reports a bi-directional relationship between renewable energy and CO_2 emissions in the short run and no causal link in the long run. Akram et al. (2020) explore the effect of renewable energy,

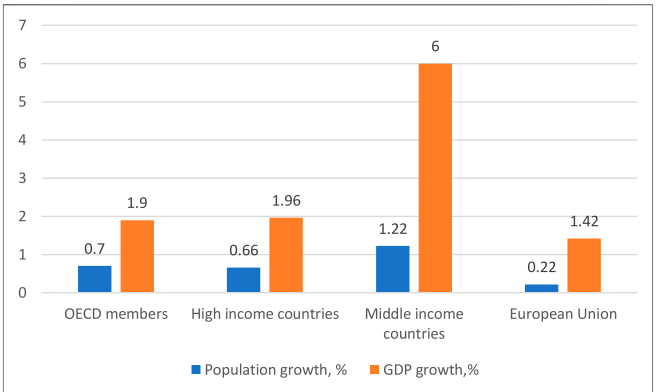

FIGURE 2 | GDP growth and population growth in selected regions, 2000–2015. Source: World Bank.

energy efficiency and other macro-social variables on CO_2 emissions in a sample of 66 developing nations over the period 1990–2014, using fixed-effect panel quantile regression (PQR). First, the study confirms the existence of environmental Kuznets curve in developing countries. Second, the authors show that renewable energy decreases CO_2 emissions in their sample. Adams and Acheampong (2019) investigate the effect of democracy and renewable energy on CO_2 emissions in a sample of 46 countries in Sub-Saharan Africa for the years 1980–2015. The study documents that renewable energy decreases CO_2 emissions; thus, the authors highlight the importance of further investment in green energy sector to curb emissions. In a follow-up study, Acheampong et al. (2019) explore the role of globalization and renewable energy on CO_2 emissions in Sub-Saharan Africa over the period 1980–2015. The empirical results suggest that renewable energy and FDI decrease air pollution, while trade openness promotes environmental degradation. The results in these and other findings lead to a conclusion that exploring and shifting to environment-friendly energy generating projects and exploiting sources like water, wind, solar, nuclear and hydrogen-based energy, natural gas exploration and other low-carbon generating sources of energy, and raising the productivity of the energy input, should be the target to achieve sustainable economic development (Jebli et al., 2020 p. 409).

The goal of this study is to contribute to this line of scholarly research by exploring the effect that renewable energy production and the agriculture sector have on CO_2 emissions in a particular region, namely, middle-income countries, during the period of 2000–2015, which captures the pre- and post-global financial crisis years. One of the reasons to consider the role of agriculture in the renewables–environmental quality nexus is its rising importance over the past decade. Ongoing negative impacts of climate change will have significant negative implication for food security and human wellbeing (Lake et al., 2012). Therefore, understanding how various economic sectors such as agriculture and energy can adapt to climate change and mitigate CO_2 emissions to improve quality of life has significant policy implications (Di Falco et al., 2011). The FAO

(2009) forecasts suggest that the global demand for food may plummet to 70% in the next 3 decades. As a result, the contribution of agriculture to global GDP is projects to increase in some countries. Consequently, it is essential to explore the nature of relationship between agriculture and CO_2 emissions in middle-income countries. Middle income countries are associated with higher rates of population and economic growth compared to other regions such as OECD, EU or high-income countries. Therefore, these economic and demographic transitions exert additional pressure on agriculture sector among the middle-income countries (**Figure 2**).

Moreover, while a number of studies explore the link between agriculture and CO_2 emissions, the results are at best mixed. Jebli and Youssef (2017) examine five North African countries over the period 1980–2011 and find a bidirectional causality between CO_2 and agriculture in both the short and long run. The authors conclude that policymakers in this region should promote the adoption of renewable energy technologies as it enhances the agriculture production and serves as a tool to curb global climate change. Mahmood H. et al. (2019) use symmetrical and asymmetrical analyses to explore the effect of agriculture on CO_2 emissions in Saudi Arabia, and they report that agriculture reduces CO_2 emissions once its share in GDP exceeds 3.22%. Sarkodie et al. (2019) demonstrate that an increase in the agriculture value added decreases CO_2 emissions in a sample of 14 African countries over the period 1990–2013. In a more recent study, Ikram et al. (2020) investigate this effect for South Asian Association for Regional Cooperation (SAARC) countries using grey relational analysis (GRA) models and confirm the negative effect. Moreover, the single country results show that the effect is largest for Pakistan and smallest for Bhutan. In contrast, Doğan (2018) studied China over the period 1971–2010 using cointegration and autoregressive distributed lag (ARDL) methods and demonstrates that agriculture escalates carbon emissions in the long run. The author concludes, "Government should promote projects such as organic farming through using new environmentally friendly technologies, reasonable use of pesticides and chemical fertilizers to reduce the country's pollution level and CO_2 emissions." Ali et al. (2019) have also reported positive effect of agriculture value added on the CO_2 emissions in Pakistan using data covering 1961–2014 and utilizing autoregressive distributed lag (ARDL) model and pairwise Granger causality test. Considering mixed evidence suggested by nascent research our study attempts to further shed some light on the agriculture and CO_2 emissions nexus.

Our study contributes to the related empirical environmental research in a number of ways. First, it provides empirical evidence on the effect of renewable energy and agriculture on CO_2 emissions in middle-income countries. By focusing on this group of economies, we attempt to reduce the role and influence that GDP per capita has in energy- CO_2 emissions nexus. Second, we also use two-step GMM regression to account for the problems of heteroskedasticity, autocorrelation and endogeneity.

DATA AND METHODS

A panel data of 94 middle-income countries for the years 2000–2015 is used in our empirical analysis[2]. The nations were chosen based on the criteria of the World Bank's income level classification methodology. The final set of countries in our study is dictated by the availability of relevant data points for the main variables of interest. We use panel data as it captures both time series and cross-section dimensions of the data. As a result, the panel data should offer us more credible and reliable results.

One of the conventional theoretical models to assess the link between development and CO_2 emissions is the EKC framework. This model posits quadratic relationship between GDP and environmental degradation:

$$CO2_{i,t} = f\left(GDP, GDP^2\right)_{i,t} \tag{1}$$

We extend EKC framework by additionally incorporating agriculture and renewable energy sectors and a set of controls suggested by empirical research. The empirical model in its generalized form is expressed below, and the subscripts i and t represent country and year, accordingly.

$$CO2_{i,t} = f\left(GDP, GDP^2\, \Delta GDP, RE, AG, TO, FDI, EF\right)_{i,t} \tag{2}$$

where CO_2 is carbon emissions per capita; AG is agriculture as a percentage of GDP; RE is renewable electricity output as a percentage of total electricity; GDP is GDP per capita; ΔGDP is GDP growth; TO is trade as a percentage of GDP; FDI is foreign direct investment as a percentage of GDP; EF represents economic freedom index.

In our study, the dependent variable is carbon dioxide (CO_2) emissions. CO_2 emissions data is obtained from the Global Carbon Atlas dataset (http://www.globalcarbonatlas.org/en/CO2-emissions). CO_2 emissions are measured as territorial emissions in tCO_2 per capita.

The main independent variables in this study are renewable energy and agriculture. Renewable energy is measured as renewable electricity output as a percentage of total electricity output. Renewable electricity is the share of electricity generated by renewable power plants in total electricity generated by all types of plants. Agriculture is measured by agriculture, forestry,

[2]Angola, Albania, Argentina, Armenia, Azerbaijan, Bangladesh, Bulgaria, Bosnia and Herzegovina, Belarus, Belize, Bolivia, Brazil, Bhutan, Botswana, China, Cote d'Ivoire, Cameroon, Congo, Rep., Colombia, Cabo Verde, Costa Rica, Djibouti, Dominica, Dominican Republic, Algeria, Ecuador, Egypt, Arab Rep., Micronesia, Fed. Sts., Gabon, Georgia, Ghana, Equatorial Guinea, Guatemala, Guyana, Honduras, Croatia, Indonesia, India, Iran, Islamic Rep., Jamaica, Jordan, Kazakhstan, Kenya, Kyrgyz Republic, Cambodia, Kiribati, Lao PDR, Lebanon, Libya, Sri Lanka, Lesotho, Morocco, Moldova, Maldives, Mexico, North Macedonia, Myanmar, Montenegro, Mongolia, Mauritania, Mauritius, Malaysia, Namibia, Nigeria, Nicaragua, Pakistan, Panama, Peru, Philippines, Papua New Guinea, Paraguay, Romania, Russian Federation, Sudan, El Salvador, Serbia, Suriname, Eswatini, Syrian Arab Republic, Thailand, Tajikistan, Turkmenistan, Timor-Leste, Tonga, Tunisia, Turkey, Ukraine, Uzbekistan, Venezuela, Vietnam, Vanuatu, Samoa, South Africa, Zambia.

TABLE 1 | Descriptive statistics.

Variable	Description	Mean	Std. Dev	Min	Max
CO_2	Territorial emissions in tCO_2 per capita Source: Atlas Carbon	2.62	2.64	0.15	16.42
AG	Agriculture, forestry, and fishing, value added (% of GDP) Source: World Bank	12.72	8.56	0.89	57.24
RE	Renewable electricity output (% of total electricity output) Source: World Bank	32.00	32.57	0	100
GDP	GDP per capita, in '000 constant international $ Source: World Bank	9.21	6.04	1.09	41.25
GDP growth	GDP growth (annual %) Source: World Bank	4.42	5.93	−62.08	123.14
TO	Trade (% of GDP) Source: World Bank	85.82	37.41	0.17	348.00
FDI	Foreign direct investment, net inflows (% of GDP) Source: World Bank	4.58	5.56	−10.26	64.38
EF	Economic Freedom Index Source: Heritage Foundation	56.07	8.51	15.6	77

TABLE 2 | Correlation matrix.

	CO2	CO2, Lag	Agriculture	Renewable	GDP	Trade	Freedom	FDI	GDP Growth
CO2	1.00								
CO2, lag	0.99	1.00							
Agriculture	−0.58	−0.58	1.00						
Renewable	−0.47	−0.47	0.11	1.00					
GDP	0.72	0.73	−0.65	−0.19	1.00				
Trade	0.08	0.08	−0.11	−0.10	0.05	1.00			
Freedom	0.07	0.07	−0.33	0.09	0.21	0.08	1.00		
FDI	0.10	0.10	−0.08	−0.03	0.03	0.31	0.08	1.00	
GDP growth	−0.08	−0.10	0.19	0.03	−0.15	0.02	−0.20	0.19	1.00

and fishing, value added as a percentage of GDP. The data for these variables is obtained from World Bank Indicators.

As discussed above, we extend the EKC framework by including variables that are linked to CO_2 emissions in cross-country research. First, we control for the GDP growth as economic activity is interlinked with carbon emissions (Cai et al., 2018). The economic growth is measured by the annual rate of GDP growth (%). The data comes from the World Bank. In addition, we control for trade openness and FDI (Haug and Ucal, 2019). Both trade and FDI are measured as % of GDP and obtained from the World Bank. In order to capture the role that economic institutions play in predicting CO_2 emissions, we include the economic freedom index (EFI) from Heritage Foundation in our analysis. A number of studies explore the effect of economic freedom on CO_2 emissions in Africa (Adesina and Mwamba, 2019) and EU (Rapsikevicius et al., 2021). The descriptive statistics are reported in **Table 1**. The correlation matrix reported in **Table 2** shows the absence of multicollinearity in our data.

In our study, the econometric results may suffer from the issue of reverse causality and simultaneity. For example, empirical research shows that renewable energy may have bi-directional causality to economic growth (Omri, 2014). Furthermore, our model may suffer from omitted variable bias. Studies show that human capital is linked to CO_2 emissions (Mahmood N. et al., 2019) and renewable energy consumption (Khan et al., 2020). Therefore, following Asongu et al. (2018), we use a two-step GMM estimator to take into account the problem of endogeneity in cross-country studies. The technical discussion of the two-step GMM estimator can be found in Arellano and Bover (1995). Moreover, considering that panel data suffers from heteroskedasticity and autocorrelation, Blundell and Bond (1998) show that the two-step GMM estimator efficiently resolves these two problems. Moreover, GMM estimator is used by extant research to understand the drivers of CO_2 emissions (Abid, 2016; Nuber and Velte, 2021; Mentel et al., 2022). The two-step GMM estimator is particularly used when 1) the number of nations in the study is greater than the time period; 2) there is a high correlation between CO_2 emissions and its lagged value; 3) there is a need to address the existing problems of endogeneity and simultaneity in the model. Our case satisfies all the above-mentioned conditions. We use the following specifications in level 3) and first difference 4) forms:

$$CO2_{i,t} = \sigma_0 + \sigma_1 CO2_{i,t-\tau} + \sigma_2 RE_{i,t} + \sigma_3 AG_{i,t} + \sum_{h=1}^{k} \delta_h W_{h,i,t-\tau} + \nu_{i,t} \quad (3)$$

$$CO2_{i,t} - CO2_{i,t-\tau} = \sigma_1 \left(CO2_{i,t-\tau} - CO2_{i,t-2\tau}\right) + \sigma_2 \left(RE_{i,t} - RE_{i,t-\tau}\right) + \sigma_3 \left(AG_{i,t} - AG_{i,t-\tau}\right) + \sum_{h=1}^{k} \delta_h \left(W_{h,i,t-\tau} - W_{h,i,t-2\tau}\right) - \left(\nu_{i,t} - \nu_{i,t-\tau}\right) \quad (4)$$

TABLE 3 | Baseline results.

	I	II	III
CO_2, lag	0.9100	0.8304	0.8272
	(30.49)***	(25.47)***	(26.50)***
Agriculture	−0.0089	−0.0096	−0.0088
	(3.24)***	(4.67)***	(3.05)***
Renewable	−0.0018	−0.0037	−0.0017
	(2.18)**	(5.36)***	(2.32)**
GDP	0.0309	0.0355	0.0440
	(3.81)***	(3.65)***	(5.32)***
GDP squared	−0.0993	−0.0901	−0.1096
	(6.12)***	(4.23)***	(6.42)***
Trade	−0.0008	0.0001	0.0003
	(1.74)*	(0.21)	(1.02)
Freedom		−0.0014	0.0014
		(1.05)	(1.04)
FDI		0.0045	0.0043
		(5.71)***	(4.58)***
GDP growth		0.0061	0.0064
		(8.10)***	(8.58)***
Agriculture * Renewable			0.0000
			(0.04)
Constant	0.1296	0.1350	−0.1765
	(1.31)	(1.18)	(1.70)*
AR (1)	0.000	0.000	0.000
AR (2)	0.420	0.570	0.613
Hansen *p*-value	0.001	0.194	0.063
N	1,371	1,206	1,206

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

where σ_0 constant; σ and δ are parameters to be estimated; W is a set of control variables; τ denotes the parameter of auto-regression; v is the disturbance term.

EMPIRICAL RESULTS

The two-step GMM results are reported in **Table 3**. Column 1 presents the reduced specification of **Eq 1** where apart from renewable energy and agriculture we include only GDP per capita and trade openness to capture the role of Environmental Kuznets curve. First, we find that GDP per capita has inverted U-shaped relationship with CO_2 emissions confirming the existence of EKC. In particular the turning point is approximately 15,000 constant international dollars. In turn other studies show that turning points for selected countries and regions are $4,700 for Malaysia (Saboori et al., 2012), $625 for Pakistan (Nasir and Rehman, 2011) and between $18,955 and $89,540 for OECD states (Churchill et al., 2018).

Turning to our main variables of interest, agriculture and renewable energy has negative effect on CO_2 emissions. For example, one percentage point increase in renewable electricity output leads to 0.18% decrease in CO_2 emissions. In comparison, Mert et al. (2019) shows that 1% rise in renewable energy use leads to 0.005–0.008% decrease in CO_2 emissions. In turn, the coefficient for agriculture suggests 1% increase in this sector leads to 0.9% decrease in CO2 emissions. These results are nearly identical to Jebli and Youssef (2017).

It is important to note that this model also includes lagged dependent variable to account for the inertia in CO_2 emissions. The high absolute value of lagged CO_2 emissions is closer to 1, suggesting there is significant effect of past emissions on future levels of environmental degradation. These results are similar to the ones obtained by Asongu et al. (2018).

Next, in column 2 we add remaining control variables: economic freedom index, FDI and GDP growth. Of these variables, GDP growth and FDI are positively related to CO_2 emissions. In this sense, a one percentage point increase in FDI leads to 0.45% increase in carbon emissions. The positive effect of FDI on CO_2 emissions, so-called 'pollution haven' hypothesis has been documented for Turkey (Gökmenoğlu and Taspinar, 2016) and Pakistan (Bukhari et al., 2014) which are also part of our sample. Agriculture and renewable energy remain negative and significant, at the 1% level. Finally, we introduce interaction term of agriculture and renewable to assess whether these variables may be complementary in reducing CO_2 emissions. However, the interaction term is not statistically significant suggesting that these variables are not substitutes or complements.

In **Table 4** we check the robustness of our main results by including additional control variables. In column 1, we control for the urbanization rate from the World Bank to capture the role that demographic transitions play in CO_2 emissions. While

TABLE 4 | Additional controls.

	I	II	III	IV
CO_2, lag	0.8296	0.8500	0.8167	0.8146
	(28.06)***	(19.83)***	(24.35)***	(25.01)***
Agriculture	−0.0102	−0.0099	−0.0079	−0.0097
	(4.35)***	(4.24)***	(3.90)***	(4.11)***
Renewable	−0.0036	−0.0028	−0.0033	−0.0031
	(5.19)***	(2.94)***	(4.55)***	(4.45)***
GDP	0.0433	0.0281	0.0454	0.0318
	(4.60)***	(2.21)**	(4.43)***	(3.84)***
GDP squared	−0.1102	−0.0735	−0.1096	−0.0781
	(5.43)***	(2.30)**	(5.23)***	(4.64)***
Trade	−0.0002	0.0004	0.0001	−0.0004
	(0.41)	(0.89)	(0.26)	(0.88)
Freedom	−0.0021	0.0033	−0.0005	−0.0024
	(1.33)	(2.25)**	(0.36)	(1.59)
FDI	0.0039	0.0045	0.0048	0.0039
	(5.15)***	(4.19)***	(4.53)***	(3.24)***
GDP growth	0.0061	0.0068	0.0063	0.0075
	(7.60)***	(6.79)***	(8.87)***	(9.00)***
Urbanization	−0.0008			
	(0.70)			
Tourism		−0.0000		
		(3.73)***		
Internet			−0.0007	
			(0.95)	
Finance				0.0016
				(2.53)**
Constant	0.2004	−0.1293	−0.0007	0.1707
	(1.25)	(1.10)	(0.01)	(1.62)
AR (1)	0.000	0.000	0.000	0.000
AR (2)	0.588	0.410	0.506	0.691
Hansen *p*-value	0.129	0.158	0.194	0.404
N	1,206	1,160	1,190	990

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

urbanization rate is not significant, the effect of agriculture and renewables remains robust. Following Le and Nguyen (2021), we control for tourism receipts per capita from the World Bank to account for the role of tourism industry in environmental sustainability. Our results suggest, tourism is negatively related to CO_2 emissions. In columns 3 and 4, we control for internet users as % of population and domestic credit to private sector as % of GDP from world bank to control for the ICT and financial development. Of these two variables only, financial development has positive effect on CO_2 emission. For example, 1% increase in financial development leads to a 0.16% increase in CO_2 emissions. The effect of agriculture and renewable energy remains robust across all specifications.

CONCLUSION AND POLICY IMPLICATIONS

The issue of curbing greenhouse gas emissions has been on the agenda of international organizations and policymakers in developing and developed countries. This has been particularly important in the middle-income countries group where per capita CO_2 emission levels have been rising rapidly over the past decades. Numerous studies attempted to identify the potential drivers and remedies for CO_2 emissions across countries. In this paper, we attempt to make a contribution to this research strand from several perspectives. First, we focus particularly on middle-income nations, thus, reducing the effect of GDP per capita, a catch-all variable. Second, in our study, to account for the problems of heteroskedasticity, autocorrelation and endogeneity, we use the two-step GMM estimator. Third, we focus on the effects of renewable energy and agriculture on CO_2 emissions controlling for other macroeconomic indicators.

The results in this study can be summarized as follows: 1) renewable energy and agriculture value added are negatively related to CO_2 emission; 2) accounting for the problems of simultaneity and endogeneity, we confirm the negative effect of renewables and agriculture sector on carbon emissions; 3) GDP growth and FDI increase CO_2 emissions, validating for the "pollution haven" hypothesis in the middle-income countries. While our results confirm the negative effect of renewables on CO_2 emissions, the extant research on the relationship between renewable energy and air pollution is mixed. For example, Jebli et al. (2020) finds that renewable energy does not decrease CO_2 emissions in lower middle-income countries. Nguyen and Kakinaka (2019) report that renewable energy is positively linked to CO_2 emissions in low-income countries and positively in high-income countries. In a similar vein, CO_2 emissions decrease with the adoption of renewable energy technologies in high-income countries.

Considering that renewable energy is instrumental in curbing carbon emissions, it is vital for middle-income countries to switch from its dependence on traditional sources of energy towards renewables. In addition, the positive effect of FDI on CO_2 emissions could be reduced by channeling foreign investment flows in the renewable energy industry. Moreover, it is possible to foster renewable energy penetration in the upcoming decade as the deployment costs are decreasing. For example, solar PV energy production decreased by 56% over the period 2010–2015 (Balakrishnan et al., 2020).

Turning to the agriculture sector, the introduction of efficient irrigation systems, the adoption of energy efficient technologies and shifting to the production of higher value-added products could contribute to the decrease in CO_2 emissions (Zornoza et al., 2016). As suggested by Sarkodie et al. (2019) (p. 149), "Agricultural sector reforms .... need to focus on climate-smart and sustainable agricultural production [which] ... can help increase productivity and income, adapt to climate change sensitivity and reduce greenhouse gas emissions.". For example, Guo et al. (2021), using hybrid computable general equilibrium model, shows that renewable energy subsidies were important policy instrument to foster renewable energy consumption in China to achieve national 2030 targets.

Our study has a number of limitations. First, due to the lack of robust and reliable data for all countries in our sample for longer time frame, we limited our study only to cover the years from 2000 to 2015. As a result, we did not use other methods such as cointegration or vector error correction models to assess the cointegrating relationship among the variables. Second, the existing data provided by World Bank does not allow us to explore the effect of various types of renewable energy (wind, solar etc.) on CO_2 emissions. Third, our approach does not take into account heterogeneity in the agriculture sector (productivity, quality of land etc) among middle-income countries. Taking into account all these aspects would require reliable and sufficient data for all countries in our sample. Finally, our study shows only the relationship between renewable energy, agriculture and CO_2 emissions. At the same time, a number of studies report that environmental policies (Shahzad, 2020; Shahzad et al., 2021), environmental taxes (Ghazouani et al., 2021), economic reforms (Shahzad et al., 2021) are linked to renewable energy and CO_2 emissions. This, we leave the inclusion of these variables as avenue for future research.

Prospective studies can explore this research study in a number of ways. First, it is important to assess the relationship between agriculture, renewable energy sector and CO_2 emissions across other income groups and geographical regions (Salahodjaev and Isaeva, 2021). For example, Sarkodie et al. (2019) find that agriculture value added and renewable energy reduced CO_2 emissions in 14 African countries over the period 1990–2013. In addition, future studies can explore the non-linear relationship between the renewable energy sector and CO_2 emissions to test whether the "critical mass" hypothesis exists in this area of environmental research. Moreover, the use of alternative data period and estimation methods such as cointegration or Geodector model can offer novel evidence on the link between renewables and CO_2 emissions in middle-income countries. Finally, following Obydenkova and Salahodjaev (2016), prospective studies should explore the role that institutions, real estate market, female empowerment and human capital play along with the renewable energy sector in explaining cross-national differences in CO_2 emissions (Eshchanov et al., 2021; Mirziyoyeva and Salahodjaev, 2021).

DATA AVAILABILITY STATEMENT

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

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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