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RESEARCH ARTICLE

Factors influencing CO_2 emissions in the MENA countries: the roles of renewable and non-renewable energy

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Abstract

This article seeks to examine the impacts of renewable and non-renewable energy on carbon dioxide emissions for 14 Middle East and North Africa economies using fully modified least-squares and vector error correction model techniques. Different sectoral outputs (agricultural, industry, and services) are considered in the analysis to find the influence of each sector on carbon emissions and to validate the environmental Kuznets curve model at both aggregate and disaggregate levels. The fully modified least-squares estimates show that renewable energy enhances environmental quality, whereas non-renewable energy deteriorates it. We also find that the industry sector has the highest contribution to environmental degradation. The results of the vector error correction model technique show a two-way linkage between CO_2 emissions and renewable energy and between CO_2 emissions and non-renewable energy in both short and long runs. At the sectoral level, we also find a two-way linkage between agricultural value added and CO_2 emissions, a unidirectional relationship running from emissions to industry value added, and a unidirectional linkage running from services value added to CO_2 emissions in both short and long runs. Therefore, governments must focus their actions on environmental policies of a green and inclusive economy that combine tools of environmental economics with those of the ecological economy. This can be considered a call for policymakers to take relevant and quick policies and actions towards low-carbon energy to reach these dual objectives.

Keywords CO_2 emissions · Sectoral outputs · Renewable energy · Non-renewable energy

Introduction

Concerns about the planet's sustainability have become a growingly influential topic in policy and academic circles, and more recently with the publication of the United Nations' report "The Future We Want" in 2012 (Dhahri and Omri, 2018). To deal with these concerns, Zhai and Chang (2019) argue that a set of decisions must be made fairly, considering an interesting aspect of sustainability, such as mitigating climate change and environmental damage. For that reason, the Paris Climate Change Agreement was signed in 2015 by 196 countries who have agreed to change their growth model by moving towards a more "ecologically sustainable" growth model (Bouyghrissi et al. 2021; Dhahri et al., 2021; Hamid et al. 2021; Murshed et al. 2021a,b). The representatives of these countries have committed to curbing their respective greenhouse gas and other types of emissions for limiting global temperature rise to less than 2 °C over the pre-industrial temperature level (Omri et al. 2021). Reducing CO_2 emissions is, therefore, relevant for these countries to meet the commitments. Therefore, they should follow a transition from the use of non-renewable to renewable energies, keeping in mind CO_2 emission reductions. The conventional dependence on the use of non-renewable energy resources to meet the world's energy demand has ultimately generated consensus among the worldwide economies for achieving both socio-economic and environmental sustainability, particularly through the efficient use of cleaner renewable energies (Murshed 2020).

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Recently, with the growing interest in achieving sustainable development goals (SDGs), scholars, policymakers, and international organizations have been interested more and more on the role of renewable energy as a pathway to low-carbon economies. For instance, the new SDGs' agenda considers renewable energy resources as a way to achieve some SDGs, such as ensuring healthy lives through reducing air pollution, enhancing energy-use efficiency levels, equitable quality education, and sustainable growth for all (Murshed et al. 2021a, 2021b; Omri et al. 2022). SDGs 7 and 13 of this agenda highlight the significance of renewable energy in mitigating climate change and environmental impacts. They call for substantially increasing the share of renewable energy in the total energy mix by the end of 2030 (Murshed and Tanha 2021), which potentially support economic development without increasing CO_2 emissions and related risks, and therefore any effort to achieve the SDGs will augment the demand for renewable energy resources (Omri and Belaïd 2021). In this context, Murshed et al. (2020) argue that the transition from non-renewable energy to cleaner and environmentally friendly renewable energy use helps reverse worsening trends in greenhouse gas emissions. Some other scholars, such as Luderer et al. (2012) and Rockström et al. (2017), also argue that increasing the share of renewables in the global energy mix must be aligned with policies aimed at decarbonizing the global atmosphere.

In light of the above discussion, the main objective of this study is to examine the role of renewable and non-renewable energy use in reducing CO_2 emissions for 14 Middle East and African countries (2014). To our knowledge, none of the existing studies on the determinants of CO_2 emissions in the MENA region has been interested in investigating the short- and long-run impacts of both types of energy on CO_2 emissions. We choose the MENA region because its characteristics are very well adapted to the case of this study. In addition, two main reasons allow us to focus on this region: (i) despite progress and development over the past decade, the MENA countries face a series of challenges for their long-term security and prosperity in the twenty-first century. Although many of the economic challenges in the region have been widely analyzed, environmental challenges are little taken into account in the process of formulating economic policies in these countries (Sakmar et al., 2011). However, it has the highest CO_2 emissions per dollar of production in the world and is ranked as the second greatest polluted region in the world, after South Asia (Omri, 2013); (ii) the region has developed rapidly in recent years the market for renewable energy with increased investment and an expanding pipeline of projects to take advantages of the abundance of energy resources renewable sources. Despite the short- and long-run impacts of renewable and non-renewable energy, this study also extends previous studies on determinants of CO_2 emissions by integrating different sectoral GDP (agriculture, industry, and services) to the environmental function to show the contribution of each sector on increasing emissions in the MENA region and to validate the presence of the EKC hypothesis at aggregate and disaggregated levels.

The rest of the article is as such: the "Determinants of CO_2 emissions" section reviews the existing literature on the determinants of CO_2 emissions. The "Data and model specification" section describes the used data and empirical model. The "Empirical results" section discusses the results, and finally the fifth concludes and provides recommendations for the policymakers in the MENA region.

Determinants of CO_2 emissions

Economic growth and CO_2 emissions

Most of the empirical debates on the environment-growth nexus have focused on validating the EKC model. As mentioned above, the existing studies on the EKC are however inconclusive and contradictory. For instance, by using two non-linear parametric functional forms (Gamma and Weibull functions) as alternatives to the standard specification (polynomial function), Galeotti and Lanza (2005) examine the impact of economic growth on CO_2 emissions for three groups of countries (OECD, non-OECD, and the two groups together) over the period 1960–1995. They show an inverted U-shaped relationship for the three groups with turning points around 15,000 US$ for the first group, 17,000 US$ for the second, and 13,000 US$ for the third group. In the same spirit, Richmond and Kaufmann (2006) examine the same relationship for 36 countries (20 OECD countries and 16 developing countries) over the period 1973–1997 using three different models, namely fixed-effects model, random-effect model, and random coefficient model; the latter model was favored. The authors validate the EKC hypothesis only for the OECD panel of countries and for the global panel. Using data for six Central American countries over the period 1971–2004, Apergis and Payne (2009) examine the links among CO_2 emissions, energy usage, and output using a VECM technique. Their findings show that there exists an inverted U-shaped running from income growth to CO_2 emissions, validating, therefore, the EKC hypothesis. Using data for 43 developing economies, Narayan and Narayan (2010) also validate the EKC hypothesis in the case of Middle Eastern and South Asian countries by using a panel cointegration approach. In Saudi Arabia, examine the factors influencing environmental sustainability using panel FMOLS and DOLS estimators and they confirm the presence of the EKC hypothesis. Using data for six South Asian countries, Murshed (2020) also examines the validity of the EKC by taking into account liquefied petroleum gas

(LPG) consumption for the period 1980–2016 by employing an autoregressive distributed lag (ARDL) regression, which confirms the validity of this hypothesis only for Bangladesh, India, Sri Lanka, and Bhutan. In the same spirit, Murshed and Dao (2020) examine the validity of the EKC hypothesis controlling for the role of export quality on the relationship between growth and CO_2 emissions for five South Asian countries. Their findings validate this hypothesis for the group of countries, whereas the country-specific results show heterogeneity of these findings in this regard.

However, some other studies find no evidence of EKC. Among them, by applying the ordinary least squares (OLS) model, Roca et al. (2001) find no evidence of this hypothesis in Spain. In the case of Turkey and 19 European economies, Acaravci and Ozturk (2010) also find no evidence of the EKC. Jaunky (2010) tests the presence of the EKC for 36 high-income countries and their empirical findings show that the EKC hypothesis does not hold in these economies, but shows that carbon emissions decline in high-income economies over time. A similar result was found by Esteve and Tamarit (2012) in the case of Spain. Using a panel of OECD and emerging economies, Özokcu and Ozdemir (2017) also find no evidence of EKC. Isik et al. (2019) also investigate the EKC for 51 countries using the common correlated effects and the augmented mean group estimation procedures. Their findings reveal that only in 14 out of 51 countries the EKC hypothesis is validated. Some other studies, such as Friedl and Getzner (2003) and Martinez-Zarzoso and Bengochea-Maranco (2004), find N-shaped link between economic growth and environmental degradation. Recently, Badeeb et al. (2020) analyze the GDP-CO_2 emissions nexus in resource-based economies. Their empirical results suggest that the EKC mechanism does not explain the economic growth-environment nexus in these countries. In addition, Khan et al. (2020) study the linkage among energy, economic growth, and emissions for 51 countries of the "Belt & Road Initiative (BRI)." The results show that the EKC hypothesis validated between growth and the environment for BRI countries.

CO_2 emissions, and renewable and non-renewable energy

The impact of renewable and non-renewable energy on CO_2 emissions is a key subject in the environmental economics literature. For instance, Le et al. (2020) examine the energy consumption-economic growth-CO_2 emissions nexus for 102 countries. They show that both types of energy increase economic growth across countries, supporting the growth hypothesis. They also find that non-renewable energy sources increase emissions. In the same spirit, in Saudi Arabia, Alkhathlan and Javid (2013) find that economic development and energy use cause emissions in the short and long runs. Energy use increases economic development only in the long run. In the same context, Alshehry and Belloumi (2015) find a long-term linkage among growth, CO_2 emissions, and energy use and price. In Turkey, Bulut (2017) tests the impacts of renewable and non-renewable energies on CO_2 emissions and he shows that emissions are positively related to both types of energy. In the case of the USA, Twumasi (2017) also studies the linkage between CO_2 emissions and renewable energy, and their results indicate that rising the production of renewable energy does not necessarily lead to lessen emissions. Using data for 25 Euro Mediterranean economies, investigate the contributions of GDP per capita, and renewable and non-renewable energy on CO_2 emissions and show a positive impact of economic growth and non-renewable energy on CO_2 emissions; however, renewable energy negatively influences CO_2 emission. For Sub-Sahara Africa, show that both types of energy increase CO_2 emissions. In the case of Malaysia, Saudi (2019) analyzes the impacts of technological innovation, and renewable and non-renewable energies on the validity of the EKC model using the ARDL bound testing approach. They find that renewable energy significantly reduces emissions; however, non-renewable energy increases CO_2 emissions. Using data for Argentina, Brazil, Paraguay, Uruguay, and Venezuela, examine the causality among CO_2 emissions, economic growth, urbanization, and renewable and non-renewable energy. Their findings show bi-directional relationships among variables, except urbanization. Similarly, investigates the effects of economic complexity, renewable and non-renewable energy on CO_2 emissions, and ecological footprint in the USA. He finds that non-renewable energy increases both types of environmental degradation, while renewable energy reduces them. For BRICS countries, Wang and Zhang (2020) investigate the role of research and development on the relationship between economic growth and CO_2 emissions by employing the fully modified ordinary least squares (FMOLS) method for the period 1996–2014 and they find that industrialization, urbanization, and economic activity have negative impacts on the decoupling of economic growth from emissions, whereas renewable energy use helps the decoupling. Using data for 147 countries, Li et al. (2021) examine the impacts of economic, energy, social, and trade structural changes on per capita CO_2 emissions and they find that increasing the use of renewable energy helped to decrease CO_2 emissions. In the same direction, Wang and Zhang (2020) investigate the effect of trade openness on decoupling economic growth from CO_2 emissions using data for 182 countries and they find that high oil prices and renewable energy contribute to decoupling economic growth from CO_2 emissions.

Table 1 Summary statistics

	LnCO2	LnGDP	LnYA	LnYI	LnYS	LnRE	LnNRE	LnFD	LnTR
Mean	1.485919	8.630431	21.88724	22.94428	24.04014	0.591767	7.355392	3.936123	4.229813
Median	1.232297	8.312231	21.92295	23.17821	24.63661	0.735473	6.993235	4.108354	4.340857
Maximum	4.250431	11.19370	24.36629	25.60936	28.72352	3.859405	9.996952	5.707677	5.237096
Minimum	−0.837533	6.868325	17.84701	19.26691	1.055582	−4.795854	5.325443	−2.081613	−3.863269
Std. Dev	1.318310	1.296784	1.571178	1.513690	3.956943	2.137700	1.262385	0.927616	0.871228
Skewness	0.336746	0.647277	−0.606279	−0.514309	−4.364441	−0.669546	0.561789	−2.045874	−6.382781
Kurtosis	2.235939	2.211644	2.841728	2.508249	25.80224	2.909607	2.158380	10.72412	53.56576
Jarque–Bera	15.08522	33.40768	21.74486	18.90232	8668.804	26.19447	28.65799	1111.047	39,551.24
Probability	0.000530	0.000000	0.000019	0.000079	0.000000	0.000002	0.000001	0.000000	0.000000
Sum	518.5856	3012.021	7638.646	8007.553	8390.010	206.5268	2567.032	1373.707	1476.205
Sum Sq. Dev	604.8040	585.2135	859.0733	797.3580	5448.774	1590.277	554.5785	299.4443	264.1452
Observations	349	349	349	349	349	349	349	349	349

Table 2 Matrix of correlation between variables

	LnCO2	LnGDP	LnYA	LnYI	LnYS	LnRE	LnNRE	LnFD	LnTR
LnCO2	1.000000								
LnGDP	0.645958	1.000000							
LnYA	−0.181874	−0.181091	1.000000						
LnYI	0.537362	0.432571	0.359078	1.000000					
LnYS	0.396214	0.390104	0.058229	0.127630	1.000000				
LnRE	−0.443955	−0.394013	−0.408321	−0.475360	−0.116959	1.000000			
LnNRE	0.679074	0.658687	−0.210107	0.460893	0.411943	−0.411065	1.000000		
LnFD	0.010050	−0.017423	−0.168496	−0.172654	−0.006959	0.426488	−0.026670	1.000000	
LnTR	0.107068	0.179195	−0.240821	−0.017113	−0.027066	0.080965	0.092056	0.056968	1.000000

Data and model specification

Data

The study uses data for 14 selected MENA countries[1] over document that covers the period 1990–2014. The variables included in the analysis are CO_2 emissions per capita (in metric tons per capita), GDP per capita (constant 2010 US dollars), non-renewable energy consumption (in kg of oil equivalent per capita), renewable energy consumption (REC) defined as combustible renewable and waste % of total energy, foreign trade measured as the total of exports and imports as % of GDP, financial development measured as the ratio of money supply to GDP, per capita agricultural value added (Y_A) in constant 2010 US dollars, per capita industry value added (Y_I) in constant 2010 US dollars, and per capita services value added (Y_S) in constant 2010 US dollars. The dataset are sourced from the World Bank databases (WDI).

Tables 1 and 2 report the descriptive statistics and the pairwise correlations among the different variables, respectively. From the information reported in Table 1, we can see that, over the sample time, the logarithm of CO_2 emissions ranges from around − 0.84 to around 1.5 metric tons, logarithm of per capita GDP ranges from around 6.9 to around 11.2, logarithm of non-renewable energy consumption ranges from around 5.3 to around 10 kg of oil equivalent per capita, and logarithm of renewable energy consumption ranges from around − 4.8% to around 3.9%. Furthermore, the pairwise correlations reported in Table 2 show that non-renewable energy consumption has the highest correlation with per capita CO_2 emissions, while the lowest is for financial development. The renewable energy consumption variable is negatively correlated with per capita CO_2 emissions; however, non-renewable energy consumption is positively correlated with emissions, indicating that promoting renewables is able to mitigate the impact of non-renewable energy on CO_2 emissions in MENA countries. The assessed coefficients of the correlation matrix provide evidence that all estimations will not be seriously affected by the multicollinearity problem.

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[1] Namely Algeria, Egypt, Iran, Iraq, Jordan, Kuwait, Lebanon, Mauritania, Morocco, Qatar, Saudi Arabia, Tunisia, UAE, and Yemen.

Model specifications

This study employs the FMOLS and VECM techniques to extract the effect of renewable energy and non-renewable energy, and aggregated and disaggregated sectoral outputs (agriculture, industry, services). In this study, financial sector development and foreign trade are included in the model as control variables. Previous studies, such as Omri et al. (2015), Murshed (2020), Ben Youssef et al. (2020), Omri et al. (2021), among others, show that financial development and trade increase CO_2 emissions. The general specification of the model is as follows:

$$\mathrm{CO_2} = \mathrm{F}\left(\mathrm{GDP}, \mathrm{NRE}, \mathrm{RE}, \mathrm{Y_A}, \mathrm{Y_I}, \mathrm{Y_S}, \mathrm{FD}, \mathrm{TR}\right) \tag{1}$$

The model in Eq. (1) can be written in the following logarithmic form:

$$\begin{aligned} CO_{2i,t} = {} & \alpha_0 + \alpha_1 GDP_{i,t} + \alpha_2 YA_{i,t} \\ & + \alpha_3 YI_{i,t} + \alpha_4 YS_{i,t} + \alpha_5 RE_{i,t} \\ & + \alpha_6 NRE_{i,t} + \alpha_7 FD_{i,t} + \alpha_8 TR_{i,t} + \varepsilon_{i,t} \end{aligned} \tag{2}$$

To validate the EKC hypothesis at aggregate and disaggregate levels of output, Eq. (1) could be specified in the following multiple regression models:

$$\begin{aligned} CO_{2it} = {} & \alpha_0 + \alpha_1 GDP_{it} + \alpha_2 GDP_{it}^2 + \alpha_4 RE_{it} \\ & + \alpha_5 NRE_{it} + \alpha_6 FD_{it} + \alpha_7 TR_{it} + \varepsilon_{it} \end{aligned} \tag{3}$$

$$\begin{aligned} CO_{2it} = {} & \alpha_0 + \alpha_1 YA_{it} + \alpha_2 YA_{it}^2 + \alpha_4 RE_{it} \\ & + \alpha_5 NRE_{it} + \alpha_6 FD_{it} + \alpha_7 TR_{it} + \varepsilon_{it} \end{aligned} \tag{4}$$

$$\begin{aligned} CO_{2it} = {} & \alpha_0 + \alpha_1 YI_{it} + \alpha_2 YI_{it}^2 + \alpha_4 RE_{it} \\ & + \alpha_5 NRE_{it} + \alpha_6 FD_{it} + \alpha_7 TR_{it} + \varepsilon_{it} \end{aligned} \tag{5}$$

$$\begin{aligned} CO_{2it} = {} & \alpha_0 + \alpha_1 YS_{it} + \alpha_2 YS_{it}^2 + \alpha_4 RE_{it} \\ & + \alpha_5 NRE_{it} + \alpha_6 FD_{it} + \alpha_7 TR_{it} + \varepsilon_{it} \end{aligned} \tag{6}$$

where $i = 1, \ldots\ldots, 14$ designates countries and $t = 1990, \ldots\ldots, 2016$ designates the time period; $\varepsilon_{i,t}$ designates the estimated residuals; $\alpha_1, \ldots\ldots, \alpha_7$ denote the elasticity of environmental pollution using CO_2 emissions with respect to economic growth (GDP), squared GDP (GDP^2), renewable energy, non-renewable energy (NRE), sectoral outputs (Y_A, Y_I, and Y_S), financial development (FD), and trade openness, respectively.

The foundation of the EKC is that the level of pollution should increase at the same time as per capita income increases, up to a certain point, during which pollution should decrease as GDP per capita enters a different level. The link between emissions, economic growth, real agriculture, real service, and the real industry is explained as follows:

- If $\alpha_1 = \alpha_2 = 0$, the hypothesis of EKC can be rejected;
- If $\alpha_2 = 0$ and $\alpha_1 > 0$, there is a linear relationship;
- If $\alpha_1 > 0$ and $\alpha_2 < 0$, there exists an inverted U-shaped.

Table 3 Cross-sectional dependency and panel unit root tests

	Pesaran et al., (2004) CD test	LLC	IPS	Fisher-PP
$LnCO_2$	0.832 (3)	2.37828	−2.99950	12.8765
$D(LnCO_2)$	-	−21.7109*	−18.7421*	342.579*
LnY_A	0.450 (2)	33.4744	1.70156	5.55443
$D(LnY_A)$	-	−6.39759*	−17.1345*	262.149*
LnY_I	0.639 (2)	11.7768	−0.84749	9.62537
$D(LnY_I)$	-	−14.2383*	−13.0382*	218.853*
LnY_S	0.340 (3)	32.0782	−2.44115	3.65465
$D(LnY_S)$	-	−8.07603*	−11.0844*	144.535
LnRE	0.335 (1)	−1.84787	−1.52397	75.1975
D(LnRE)	-	−16.4930*	−12.2142*	272.297*
LnNRE	0.868 (1)	4.24718	−0.34544	7.37269
D(LnNRE)	-	−17.7709*	−16.7839*	283.865*
LnGDP	0.518 (2)	8.78806	0.29721	6.23335
D(LnGDP)	-	−13.9294*	−13.2962*	234.329*
LnFD	0.428 (3)	1.35264	0.06910	22.8822
D(LnFD)	-	−15.0379*	−9.90860*	226.568*
LnTR	0.368 (1)	2.50048	−1.30678	12.2965
D(LnTR)	-	−19.1955*	−14.3795*	305.072*

*$p < 0.01$

Empirical results

Tests of cross-sectional dependency and panel unit root

We begin our empirical research by examining the stationarity of the used variables. Before running the stationarity tests, we should check the existence of cross-sectional dependency in the panel to choose between the first- and second-generation panel unit root tests. Using the Pesaran et al., (2004) CD test, Table 3 shows that the null hypothesis of cross-sectional independence is accepted in the panel, implying that we cannot run the second-generation tests. Therefore, we will use three first-generation tests, namely the IPS test of Im et al. (2003), the LLC test of Levin et al. (2002), and the Fisher-PP test of Phillips and Perron (1988). Table 3 summarizes the findings of this testing and it indicates that all the variables are stationary first differences (I (1)). We can then suspect cointegration relationships between the different variables.

Table 4 Pedroni and Kao panel cointegration results

	14 MENA countries							
	Panel EKC							
	Model 1		Model 2		Model 3		Model 4	
	T-statistics	Prob	T-statistics	Prob	T-statistics	Prob	T-statistics	Prob
Within-dimension								
Panel v-stat	−1.882373	(0.9701)	−1.264604	(0.8970)	−1.277713	0.8993	−0.499422	(0.6913)
Panel rho-stat	2.218041	(0.9867)	0.533885	(0.7033)	0.730578	0.7675	0.424475	(0.6644)
Panel ADF-stat	−1.757453**	(0.0109)	−3.465642*	(0.0003)	−1.376024	(0.0844)**	−2.590641	(0.0048)**
Panel PP-stat	−1.276192**	(0.0253)	−3.471225*	(0.0003)	−2.486194	(0.0065)**	−2.908668	(0.0018)**
Between-dimension								
Group rho-stat	1.835658	(0.9668)	0.911163	(0.8189)	0.895321	(0.8147)	0.988291	0.8385
Group ADF-stat	0.332451*	(0.0000)	−2.115525*	(0.0172)	−0.328175	(0.3714)	−1.831591	(0.0335)**
Group PP-stat	−4.918016**	(0.0000)	−5.449859**	(0.0000)	−4.907728	(0.0000)*	−5.201353	(0.0000)*
Kao statistics	−7.244263*	(0.0000)	−6.040397*	(0.0000)	−5.593622*	(0.0000)	−5.630980*	(0.0000)

* and ** indicate the significance at 1% and 5% levels, respectively

Panel cointegration tests

Pedroni (1999, 2004) presents seven (7) tests based on the estimate of the residual of the long-term model in the scenario when the cointegration connections involve more than two variables. Pedroni tests accommodate for heterogeneity by using factors that might differ across individuals. According to the alternative hypothesis, each individual has a cointegration connection, but the parameters of this cointegration relationship are not definitely the same for each individual in the panel (Hurlin and Mignon 2007). In addition, Kao (1999) also proposed tests for the null hypothesis of absence of cointegration: Dickey-Fuller type test and Dickey-Fuller type augmented test. Unlike Pedroni tests, Kao considers the specific scenario when the cointegration vectors are assumed to be homogenous among individuals. Unlike Pedroni tests, Kao considers the specific scenario when the cointegration vectors are assumed to be homogenous among individuals. Table 4 summarizes the findings of the panel cointegration tests.

From the results of the cointegration tests of Pedroni, we can observe that the majority of the statistics allows us to accept the hypothesis of a cointegration relationship between renewable and non-renewable energy consumption, CO_2 emissions, real industry value added per capita, real agriculture value added per capita, economic growth, and real services value added per capita, trade openness, and financial development at 1% and 5%. According to the Pedroni cointegration test findings, the majority of these statistics demonstrate the existence of a long-term connection and therefore a cointegration relationship between CO_2 emissions and control variables. Thus, the results show that the probability associated with T-statistic is 0.00; as a result, the null hypothesis of no cointegration may be ruled out. We can therefore say that there is a cointegration linkage among CO_2 emissions, renewable and non-renewable energy, agriculture, trade openness, financial development, and economic growth.

FMOLS estimates

The results from the estimation of the FMOLS for EKC are given in Table 5. The FMOLS estimates confirm that CO_2 emissions tend to decrease with the increase of renewable energy consumption, ranging from −0.0187 to −0.0859%; however, non-renewable energy consumption increases CO_2 emissions in all the estimated models, ranging from 0.763 to 0.84%. This result is in line with Shafiei and Salim (2014) who investigate the impact of disaggregated energy consumption on CO_2 emissions for OECD countries and they show that renewable energy decreases CO_2 emissions whereas non-renewable energy increases emissions. They suggest that policymakers in OECD countries should focus on clean energy deployment to make a substantial contribution to both curbing CO_2 emissions and decreasing the use of non-renewable energy. Moreover, the FMOLS estimates indicate that the long-term influence of GDP on CO_2 emissions is significant.

Table 5 Panel FMOLS estimates

Independent variables	Dependent variabCO_2 emissions							
	Model 1		Model 2		Model 3		Model 4	
	Coef	Prob	Coef	Prob	Coef	Prob	Coef	Prob
LnGDP	1.3079*	(0.0001)	-	-	-	-	-	-
$LnGDP^2$	−0.0770*	(0.0000)	-	-	-	-	-	-
LnYA	-		0.2200	(0.0004)*	-	-	-	-
$LnYA^2$	-		0.0273	(0.0005)*	-	-	-	-
LnY_I	-		-	-	0.7160	(0.0952)***	-	-
LnY_I^2	-		-	-	0.0157	(0.0885)***	-	-
LnY_S	-		-	-	-	-	−0.0175	(0.6886)
LnY_S^2	-	-	-	-	-	-	0.0610	(0.8928)
LnRE	−0.0239**	(0.0372)	−0.0187**	(0.0386)	−0.0859**	(0.0572)	−0.0276*	(0.0002)
LnNRE	0.8392*	(0.0000)	0.7646	(0.0000)*	0.7626	(0.0000)*	0.7634	(0.0000)*
LnFD	0.0665**	(0.0379)	0.0216**	(0.0294)	0.0265	(0.0154)**	0.0127**	(0.1374)
LnTR	0.0444*	(0.0003)	0.0530	(0.0000)*	0.0534	(0.0000)*	0.0577*	(0.0000)

*, **, and *** indicate the significance at 1%, 5%, and 10% levels, respectively

The findings show that a 1% rise in economic growth corresponds to a 1.3079% increase in CO_2 emissions. This result confirms the findings of who investigate the determinant of CO_2 emissions in Saudi Arabia and they show that economic growth is a key factor that influences CO_2 emissions, suggesting that CO_2 emissions may be decreased at the costs of economic growth or encouraging the use of environmentally friendly technologies. This result is also confirmed by for 12 Western European countries, calling policymakers to make quick and relevant solutions to decrease CO_2 emissions without reducing economic growth. However, at the 1% threshold, squared GDP has a negative and statistically significant effect, implying that an increase in square GDP results in a reduction of 0.0770 in CO_2 emissions. Since the GDP coefficient is positive and significant, while the GDP^2 coefficient is negative and significant, the presence of an EKC is definitely confirmed by the results of model 1, indicating that CO_2 emissions increase with economic development at the initial stages of development, but decrease after the economy surpasses a certain threshold. This result is also confirmed by Choi et al (2010) for China and Korea, Torrini et al (2016) for Brazil and Japan, Fujii et al (2018) for 26 countries, Saucedo et al. (2017) for OECD countries, and Kong and Khan (2019) for developed and developing economies. The coefficients of financial development and trade openness are positive, while these two variables positively and significantly affect CO_2 emissions at the 5% and 1% levels. The impact of international commerce on emissions is captured by the degree of trade openness. Strong environmental laws in industrialized nations generally result in polluting offshoring companies to countries with less environmental controls (this is the "pollution haven" assumption). As a result, the coefficient sign of trade openness fluctuates depending on the nations' degree of development (Grossman and Krueger, 1996). In developed countries, trade openness reduces environmental degradation, while the opposite effect is observed in developing countries. In addition, according to the results in Table 5, we see that the coefficient of agriculture and square agriculture are positive and statistically significant at the 1% threshold, this means that an increase of 1% in these two variables increases CO_2 emissions by 0.2200 and 0.0273, respectively. Finally, a one-point increase in real industry value added per capita (Y_I) leads to a 0.7160-point increase in CO_2 emissions. However, an increase in the point of the real added value of services per inhabitant (Y_S) leads to a reduction of 0.0175 points in CO_2 emissions.

Results of VECM technique

We use VECM technique to examine if the short- and long-term connections between variables are causative. The causation relationship is established in two phases: the first stage is to estimate the residuals of Eq. (2) whereas the second step is to estimate the short-term adjustment coefficients. The VECM in the panel is as follows:

$$\begin{pmatrix} \Delta LnCO2_{i,t} \\ \Delta LnGDP_{i,t} \\ \Delta LnGDP2_{i,t} \\ \Delta LnYA_{i,t} \\ \Delta LnYI_{i,t} \\ \Delta LnYS_{i,t} \\ \Delta LnRE_{i,t} \\ \Delta LnNRE_{i,t} \\ \Delta LnFD_{i,t} \\ \Delta LnTR_{i,t} \end{pmatrix} = \begin{pmatrix} \alpha_{1,i} \\ \alpha_{2,i} \\ \alpha_{3,i} \\ \alpha_{4,i} \\ \alpha_{5,i} \\ \alpha_{6,i} \\ \alpha_{7,i} \\ \alpha_{8,i} \\ \alpha_{9i} \end{pmatrix} + \sum_{k=1}^{m} \begin{bmatrix} \beta_{11i}\beta_{12i}\beta_{13i}\beta_{14i}\beta_{15i}\beta_{16i}\beta_{17i}\beta_{18i}\beta_{19i} \\ \beta_{21i}\beta_{22i}\beta_{23i}\beta_{24i}\beta_{25i}\beta_{26i}\beta_{27i}\beta_{28i}\beta_{29i} \\ \beta_{31i}\beta_{32i}\beta_{33i}\beta_{34i}\beta_{35i}\beta_{36i}\beta_{37i}\beta_{38i}\beta_{39i} \\ \beta_{41i}\beta_{42i}\beta_{43i}\beta_{44i}\beta_{45i}\beta_{46i}\beta_{47i}\beta_{48i}\beta_{49i} \\ \beta_{51i}\beta_{52i}\beta_{53i}\beta_{54i}\beta_{55i}\beta_{56i}\beta_{57i}\beta_{58i}\beta_{59i} \\ \beta_{61i}\beta_{62i}\beta_{63i}\beta_{64i}\beta_{65i}\beta_{66i}\beta_{67i}\beta_{68i}\beta_{79i} \\ \beta_{71i}\beta_{72i}\beta_{73i}\beta_{74i}\beta_{75i}\beta_{76i}\beta_{77i}\beta_{78i}\beta_{79i} \\ \beta_{81i}\beta_{82i}\beta_{83i}\beta_{84i}\beta_{85i}\beta_{86i}\beta_{87i}\beta_{88i}\beta_{89i} \\ \beta_{91i}\beta_{92i}\beta_{93i}\beta_{94i}\beta_{95i}\beta_{96i}\beta_{97i}\beta_{98i}\beta_{99i} \end{bmatrix} \times \begin{pmatrix} LnCO2_{i,t-k} \\ LnGDP_{i,t-k} \\ LnGDP2_{i,t-k} \\ LnYA_{i,t-k} \\ LnYI_{i,t-k} \\ LnYS_{i,t-k} \\ LnRE_{i,t-k} \\ LnNRE_{i,t-k} \\ LnFD_{i,t-k} \\ LnTR_{i,t-k} \end{pmatrix} + \begin{pmatrix} \lambda_{1t} \\ \lambda_{2t} \\ \lambda_{3t} \\ \lambda_{4t} \\ \lambda_{5t} \\ \lambda_{6t} \\ \lambda_{7t} \\ \lambda_{8t} \\ \lambda_{9t} \end{pmatrix} ECT_{i,t-1}$$

$$+ \begin{pmatrix} \varepsilon_{1,i,t} \\ \varepsilon_{2,i,t} \\ \varepsilon_{3,i,t} \\ \varepsilon_{4,i,t} \\ \varepsilon_{5,i,t} \\ \varepsilon_{6,i,t} \\ \varepsilon_{7,it} \\ \varepsilon_{8,it} \\ \varepsilon_{9,it} \end{pmatrix}$$

where Δ is the first difference operator; m is the lag length, CO_2 is the natural log of CO_2 emissions, NRE is the natural log of non-renewable energy, RE is the natural log of renewable energy, Y_A is the natural log of agriculture, GDP is the natural log of economic growth, FD is the natural log of financial development, TR is the natural log of trade openness, Y_I is the natural log of real industry, and Y_S is the log of real services, respectively. μ is the random error term, and ECT is the error correction term. The parameter α reflects the movements in the equilibrium relationship between CO_2 emissions and other variables.

The results of the Granger causality tests are presented in Table 6. In model 1, we find that there is a two-way relationship between CO_2 emissions and GDP per capita and between CO_2 emissions and renewable energy in the short and long runs. This outcome differs from that of Menyah and Wolde-Rufael (2010) for the USA and Apergis et al. (2010a, b) for 19 developed and developing economies; however, it is similar to Lu (2017) for 24 Asian countries, Saidi and Mbarek (2016) for nine developed countries, and Khobai and Le Roux (2017) for South Africa. Likewise, there is a two-way association between non-renewable energy and CO_2 emissions in the short and long runs. The outcome is consistent with the findings of Saidi and Mbarek (2016). Furthermore, a unidirectional causal relationship ranging from trade openness and financial development to CO_2 emissions in both the short and long runs is found. In addition, renewable energy usage and economic growth have a bidirectional link and this finding strongly confirms the studies of in the case of G7 countries, in the case of six Latin American developing countries, Hung-Pin (2014) for nine OECD countries, and Khawlah (2016) for Jordan.

Regarding model 2, there is a two-way causal relationship between agricultural value added and CO_2 emissions and between renewable energy and CO_2 emissions. In addition, our results show a two-way relationship between non-renewable energy and CO_2 emissions in the short and long runs. We have short- and long-term unidirectional causality running from financial development and trade openness to CO_2 emissions. This outcome is in line with the findings of Omri et al. (2015). In addition, renewable energy and agriculture value added have a two-way causal connection in the short and long terms, but no causal link between agriculture and non-renewable energy. So, the production of agricultural goods in the MENA region depends on the use of renewable energy. Farmers and/or the government can get the required capital for the production and use of renewable energy by increasing agricultural value added. This finding contradicts that of Ben Youssef et al., (2016), who showed that increasing agricultural value added lowers renewable energy use in Brazil. As a result, there is a one-way link between agricultural and renewable energy usage.

Regarding model 3, in the short and long runs, we report that CO_2 emissions and industry value added have a unidirectional connection. In addition, a two-way relationship is found between non-renewable energy and CO_2 emissions in both the short and long runs. But in both the short and long terms, there is a one-way link between renewable energy and CO_2 emissions.

Finally, for model 4, in both the short and long runs, we reveal a one-way link between renewable energy use and CO_2 emissions. This result contradicts the results of Menyah and Wolde-Rufael (2010) for the USA and Shafiei and Salim (2014) for OECD countries. The findings also

Table 6 Panel Granger causality results

<u>Model 1</u>

Dependant variable	Sources of causation							
	Short-run							Long-run
	$\Delta LnCO_2$	$\Delta LnGDP$	$\Delta LnGDP^2$	$\Delta LnRE$	$\Delta LnNRE$	$\Delta LnFD$	$\Delta LnTR$	ECT (t-value)
$\Delta LnCO_2$		0.0243** (0.0192)	0.0420 (0.1337)	0.3148** (0.0141)	0.0393*** (0.0597)	0.1947 (0.2092)	0.0645 (0.2764)	-0.6987* (0.0056)
$\Delta LnGDP$	0.8543** (0.0412)		12.867 (0.1412)	0.8831** (0.0374)	-0.6785 (0.4907)	0.0931 (0.7180)	0.1353*** (0.0596)	-0.2654 (0.0096)*
$\Delta LnGDP^2$	0.0496** (0.0427)	0.4912*** (0.0725)		0.1437*** (0.0694)	0.0111** (0.0363)	0.0755* (0.0096)	0.1759 (0.1681)	-0.4120** (0.0172)
$\Delta LnRE$	0.0964** (0.0373)	0.1253*** (0.0633)	0.4907 (1.0556)		0.0109** (0.0295)	0.0634 (0.1112)	0.1930 (0.1367)	-1.1304* (0.0092)
$\Delta LnNRE$	0.0867*** (0.0906)	0.0205 (0.0344)	1.1160 (3.2055)	0.2984 (0.1715)		0.3533 (0.3143)	0.9621 (0.4153)	-1.8965* (0.0048)
$\Delta LnFD$	0.3088** (0.0203)	0.0205 (0.0344)	0.3431 (0.6172)	0.0361 (0.0330)**	0.5430** (0.0172)		0.0703*** (0.0799)	-0.1216** (0.0169)
$\Delta LnTR$	0.3161** (0.0138)	0.0237 (0.0234)	0.3622 (0.4196)	0.2533 (0.0224)**	0.0374** (0.0117)	0.0229** (0.0411)		-0.1540** (0.0223)

<u>Model 2</u>

Dependant variable	Short-run							Long-run
	$\Delta LnCO_2$	ΔLnY_A	ΔLnY_A^2	$\Delta LnRE$	$\Delta LnNRE$	$\Delta LnFD$	$\Delta LnTR$	ECT (t-value)
$\Delta LnCO_2$		0.1340** (0.0150)	6.2222 (5.0898)	0.3618** (0.0145)	0.0449*** (0.0601)	0.1995 (0.2081)	0.2316 (0.2522)	-1.2317* (0.0005)
ΔLnY_A	0.0192* (0.0080)		2.8108 (51.4061)	0.1809** (0.0572)	0.3776 (0.6075)	0.5481 (2.1019)	0.1828 (2.8008)	-0.7088* (0.0008)
ΔLnY_A^2	0.0548** (0.0159)	0.0453** (0.0262)		0.0889** (0.0261)	0.5564 (0.0137)	0.2532** (0.0474)	0.0813 (0.0632)	-0.7224** (0.0378)
$\Delta LnRE$	0.0995** (0.0361)	0.1264*** (0.0593)	5.5753 (2.6260)		0.0914** (0.0310)	0.0868 (0.1073)	0.0522 (0.1430)	-0.4282* (0.0008)
$\Delta LnNRE$	0.0280*** (0.0834)	0.2066 (0.1369)	9.3778 (6.0572)	0.1438 (0.1363)		0.2768 (0.2476)	0.5195 (0.3300)	-1.1621* (0.0004)
$\Delta LnFD$	0.3081** (0.0202)	0.0290** (0.0332)	1.2642 (1.4708)	0.0424** (0.0331)	0.5191** (0.0173)		0.2667*** (0.0601)	-0.7729* (0.0015)
$\Delta LnTR$	0.1661** (0.0138)	0.0152** (0.0227)	0.6905 (1.0045)	0.0126** (0.0226)	0.0365** (0.0118)	0.0147** (0.0410)		-7.2642* (0.0020)

<u>Model 3</u>

	Short-run							Long-run
Dependant variable	$\Delta LnCO_2$	ΔLnY_I	ΔLnY_I^2	$\Delta LnRE$	$\Delta LnNRE$	$\Delta LnFD$	$\Delta LnTR$	ECT (t-value)
$\Delta LnCO_2$		0.1061** (0.0479)	3.3157 (0.1790)	0.3300 (0.1151)	0.0589*** (0.0602)	0.1689 (0.2067)	-0.1132 (0.2811)	-1.7852* (0.0112)
ΔLnY_I	0.3668 (0.6061)		26.058 (0.8942)	0.9332 (0.8540)	0.1616 (0.4468)	0.2236 (0.5331)	0.2880*** (0.0526)	-1.3812** (0.0237)
ΔLnY_I^2	0.0901 (0.0359)	0.0395*** (0.0759)		0.0338*** (0.0591)	0.0932** (0.0309)	0.0801 (0.1060)	-0.0405 (0.1442)	-1.2033* (0.0001)
$\Delta LnRE$	0.0807** (0.0344)	0.0567*** (0.0728)	2.5885 (0.3760)		0.0194** (0.0296)	0.0176 (0.1017)	0.1663 (0.1382)	-0.0457** (0.0184)
$\Delta LnNRE$	0.0809*** (0.0762)	0.1464 (0.1756)	6.9366 (0.1456)	0.0975 (0.1367)		-0.2430 (0.2453)	-0.4077 (0.3336)	-0.5365* (0.0096)
$\Delta LnFD$	0.0074** (0.0204)	0.0229** (0.0432)	0.3954 (0.9762)	0.2574** (0.0331)	0.0325** (0.0173)		-0.0278** (0.0809)	-0.0330** (0.0331)
$\Delta LnTR$	0.0144** (0.0145)	0.0045** (0.0293)	0.1865 (0.3628)	0.0112** (0.0228)	0.0342** (0.0119)	-0.0104** (0.0410)		-0.2784** (0.0450)

<u>Model 4</u>

Dependant variable	Short-run							Long-run
	$\Delta LnCO_2$	ΔLnY_s	ΔLnY_s^2	$\Delta LnRE$	$\Delta LnNRE$	$\Delta LnFD$	$\Delta LnTR$	ECT (t-value)
$\Delta LnCO_2$		0.1153 (0.7106)	2.3994 (0.1782)	0.1650 (0.1039)	0.0426** (0.0545)	0.0806 (0.1881)	0.2038 (0.2557)	-0.0070* (0.0049)
ΔLnY_s	0.0696** (0.0266)		0.2113 (0.3038)	0.0041** (0.0435)	0.0123** (0.0228)	0.0278*** (0.0788)	0.0542 (0.1072)	-0.1917*** (0.0558)
ΔLnY_s^2	0.0025* (0.0010)	0.0077** (0.0113)		0.3072* (0.0016)	0.5118* (0.0008)	0.1163* (0.0030)	0.1906* (0.0040)	-4.4020** (0.0467)
$\Delta LnRE$	0.0953** (0.0354)	0.0812 (0.4043)	0.0281*** (0.0591)		0.0915** (0.0310)	0.0725 (0.1070)	0.2017 (0.1439)	-0.0105* (0.0081)
$\Delta LnNRE$	0.1000*** (0.0755)	0.7118 (0.9335)	2.4295 (0.1067)	0.1123 (0.1259)		0.1065 (0.2278)	0.6731 (0.3097)	-0.0003* (0.0042)
$\Delta LnFD$	0.0075** (0.0199)	0.0635 (0.2272)	2.4686* (0.0066)	0.0398** (0.0332)	0.0108** (0.0174)		0.0225** (0.0817)	-0.0112** (0.0147)
$\Delta LnTR$	0.0121** (0.0141)	0.1391 (0.1613)	0.2135*** (0.0559)	0.2611** (0.0227)	0.0324** (0.0119)	0.0140** (0.0427)		-0.1248** (0.0201)

*, **, and *** indicate the significance at 1%, 5%, and 10% levels, respectively

show that non-renewable energy and CO_2 emissions have a bidirectional causal connection. Our results also show that there is a one-way causal link from services value added to CO_2 emissions. In addition, they also reveal a one-way causality that runs from financial development and trade openness to CO_2 emissions.

Conclusion and policy implications

This inquiry examines the effects of renewable and non-renewable energy consumption, among other control variables, on CO_2 emissions for 14 MENA countries. We apply panel techniques of cointegration and Granger causality tests (VECM) to verify the existence of long-run associations and to examine the causality between the variables. The panel FMOLS technique is also used to estimate long-term relationships among variables. Empirical results show that renewable energy decreases CO_2 emissions, whereas non-renewable energy increases emissions. They also confirm the presence of a robust long-term relationship between per capita CO_2 emissions and per capita income. In addition, the positive and negative signs of the coefficients of GDP and its squared seem to validate the existence of the EKC. However, at the sectoral level, this hypothesis has not been validated and the industry sector has the highest contribution to environmental degradation. In addition, renewable energy contributes to improving environmental quality, whereas non-renewable energy deteriorates it. Granger's causality results show a two-way linkage between renewable energy and CO_2 emissions and between non-renewable energy and CO_2 emissions in both short and long runs. At the sectoral level, we also find a two-way causal relationship between agricultural value added and CO_2 emissions, a unidirectional causality running from CO_2 emissions to industry value added, and a unidirectional causality running from services value added to CO_2 emissions in both in short and long-terms.

To reduce the aggregate and disaggregate effects of outputs on environmental degradation, policymakers in MENA countries must focus their actions on environmental policies of a green and inclusive economy that combine tools of environmental economics with those of the ecological economy. This can be done by supporting the use of renewable energies that can significantly reduce carbon dioxide emissions, supporting the view that renewable energies offer many advantages, from mitigating emissions and cleaning the air, to lowering fossil fuel prices and creating more jobs than non-renewable energies. Private investors should participate more actively in the broad field of renewable energy by recognizing the barriers to increased investment in renewable energy and supporting more public–private partnerships (PPPs). Multilateral negotiations between public and private sectors, university, and non-governmental organizations are also essential to the transition towards low-carbon economies.

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Data availability The data are available upon demand by request to the corresponding author.

Declarations

Ethics approval and consent to participate Not applicable.

Consent for publication Not applicable.

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