The role of renewable energy and agriculture in reducing CO2 emissions: evidence for North Africa countries

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Abstract: this paper uses panel cointegration techniques and Granger causality tests to investigate the dynamic causal links between per capita renewable energy consumption, agricultural value added (AVA), carbon dioxide (CO_2) emissions, and real gross domestic product (GDP) for a panel of five North Africa countries spanning the period 1980-2011. In the short-run, the Granger causality tests show the existence of a bidirectional causality between CO_2 emissions and agriculture, a unidirectional causality running from agriculture to GDP, a unidirectional causality running from GDP to renewable energy consumption, and a unidirectional causality running from renewable energy consumption to agriculture. In the long-run, there is bidirectional causality between agriculture and CO_2 emissions, a unidirectional causality running from renewable energy to both agriculture and emissions, and a unidirectional causality running from output to both agriculture and emissions. Long-run parameter estimates show that an increase in GDP and in renewable energy consumption increase CO_2 emissions, whereas an increase in agricultural value added reduces CO_2 emissions. As policy recommendation, North African authorities should encourage renewable energy consumption, and especially clean renewable energy such as solar or wind, as this improves agricultural production and help to combat global warming.

Keywords: Renewable energy; Agriculture; CO_2 emissions; Panel cointegration; North Africa.

JEL Classification: C33; Q15; Q42 ; Q54.

1. Introduction

During several decades, developed and developing countries have used fossil energy intensively for growth purposes in the various economic sectors such as manufacturing industry, tourism, transport, and agriculture. This led to important carbon dioxide (CO_2) emissions in almost all the world regions. The agricultural sector contributes between 14 and 30% of the world greenhouse gas (GHG) emissions because of its heavy fossil energy use. Indeed, running fuel-powered farm equipment, pumping water for irrigation, raising dense populations of livestock in indoor facilities, and applying nitrogen-rich fertilizers all contribute to agriculture's high GHG. However, the United Nations food and agriculture organization (FAO) believes that the agricultural sector has a substantial potential to decrease its emissions, including removing 80 to 88% of the CO_2 emissions that it currently produces (Reynolds and Wenzlau, 2012). Indeed, many agricultural activities, such as irrigation, could be powered by renewable energy sources.

There are a number of commercial renewable technologies that could be used in agriculture. These technologies are at different points in their technology advance because some are commercially obtainable and others have a potential in the future. For the agricultural sector, renewable technologies could economically provide several advantages. Indeed, the operations related to the livestock and dairy require air and water heating because commercial dairy farms use a large quantities of water heating for cleaning machines and associated materials. The system of solar water heating can be used for all farming processes especially for dairy farmhouse. Besides, there are some other solar systems used for drying the crops. Small wind system is another source of energy that can serve agriculture to pump water or grind grain. Moreover, there are many agricultural advantages with geothermal energy. Indeed, vegetables, flowers, ornamentals, and tree seedlings are raised in 43 greenhouse operations heated by geothermal energy. Agri-industrial applications comprise food dehydration, grain drying, and mushroom culture (Fischer et al., 2006).

The North Africa region is facing an important increasing energy demand between 6% and 8% per year and fossil fuels dominate the energy mix with a greater share for natural gas (United Nations Economic Commission for Africa, 2012). Because of the high volatility of oil and gas prices, North Africa countries are reviewing their energy policies by diversifying their energy mix and giving greater importance to energy efficiency and renewable energies. The potential for energy efficiency and renewable energy in this region is still largely under-exploited. Indeed, there is real energy efficiency potential as a 10% gain in this region's energy consumption could be made by 2030 via improved energy efficiency measures.

Renewable energies' contribution to the energy mix is still weak since it represented only 8% in 2006, while the contributions of gas, oil and coil are 67%, 19% and 6%, respectively. Many reforms concerning the regulatory frameworks have been made in order to encourage more participation by the private sector in renewable energy production. In addition, these countries have elaborated ambitious strategic objectives and launched large-scale integrated programs with the main objectives of GHG emissions, creation of direct and indirect jobs, industrial development and human capital improvement. Current initiatives such as the Mediterranean solar plan (MSP) or the agreements signed between the European Union (EU) and some North Africa countries are expected to improve technical and financial cooperation and expand renewable energies' regional markets.

In the present paper, we investigate the dynamic causal links between per capita renewable energy consumption, agricultural value added, CO_2 emissions, and real GDP for a panel of five North Africa countries spanning the period 1980-2011. We also evaluate the long-run impact of renewable energy consumption, agricultural value added, and economic growth on CO_2 emissions. The present paper differs from that of Ben Jebli and Ben Youssef (2015b) mainly by the fact that we consider a panel of countries and we use panel cointegration techniques.

This paper is organized as follows: Section 2 is a literature review. Section 3 presents the data and some descriptive statistics and Section 4 reports the empirical results and their discussion. Finally, Section 5 concludes with policy recommendation.

2. Literature review

There are a several strategic factors explaining the evolution of carbon dioxide emissions such as economic growth, energy consumption, renewable energy consumption, international trade, tourism, and urbanization. Many econometric studies have investigated the causal relationships of CO_2 emissions and concluded various recommendations related to the progression of pollution in developed and developing countries (e.g. Ang, 2007; Apergis and Ozturk, 2015; Ben Jebli and Ben Youssef, 2015a; Ben Jebli et al., 2015; Chebbi, 2010b; Chebbi et al., 2011; Fodha and Zaghdoud, 2010; Halicioglu, 2009; Sadorsky, 2009; Shahbaz et al., 2014). Among these studies, certain variables affect CO_2 emissions positively and lead to their increase, whereas other variables contribute to CO_2 emissions reduction, depending on the integrated variables, selected time period and empirical methodology. Halicioglu (2009) uses the ARDL approach and cointegration techniques to investigate the dynamic causal links between CO_2 emissions, energy consumption, output, and foreign trade in the case of Turkey.

The results reveal the existence of two forms of long-run relationships between the variables. The first form suggests that CO_2 emissions are determined by energy consumption, income and foreign trade. The second form suggests that income is determined by CO_2 emissions, energy consumption and foreign trade. Sadorsky (2009) uses panel cointegration techniques to estimate an empirical model of renewable energy consumption for the G7 countries. The empirical results show that in the long-run real GDP and CO_2 emissions are both two major drivers behind renewable energy consumption. For the case of Tunisia, Chebbi (2010b) provides some insights into the relationships between energy consumption, carbon emissions and the sector components of output growth (agriculture, industry and services). The results of the long-run estimates reveal the existence of bidirectional causality between energy consumption and output growth, and between energy consumption and CO_2 emissions. However, the short-run results suggest that the interaction between GDP and energy consumption and between GDP and CO_2 emissions are not uniform across sectors.

Shahbaz et al. (2014) examine the validity of the EKC hypothesis and investigate the causal links between CO_2 emissions, GDP, energy consumption, and trade openness for the case of Tunisia. The results reveal that the inversed U-shaped EKC is supported and that a long-run cointegration between variables is established. Using the autoregressive distributed lag (ARDL) approach and Granger causality tests, Ben Jebli and Ben Youssef (2015a) examine the dynamic causal links between per capita CO_2 emissions, real GDP, square of real GDP, renewable and non-renewable energy consumption and trade (exports or imports) for the case of Tunisia in two specification models. They show that non-renewable energy consumption and trade affect positively emissions while renewable energy consumption affects negatively and weakly the emissions of CO_2. Besides, these authors suggest that the inversed U-shaped environmental Kuznets curve (EKC) hypothesis has not been supported. Apergis and Ozturk (2015) use the GMM methodology to study the EKC hypothesis for a panel of 14 Asian countries. Their multivariate framework comprises carbon dioxide emissions, economic growth, population density, land, industry shares in growth, and four indicators indicating institutions' quality. Their results validate the inverted U-shaped EKC hypothesis.

Our study is concerned by the relationship between energy consumption and agriculture. Karkacier et al. (2006) investigate the energy use effects on agricultural productivity in Turkey. Strong relationship between energy use and agricultural productivity is proved and increasing energy use increases agricultural productivity. Politicians support to the use of energy in the agricultural sector is recommended and a per hectare fuel subsidy is proposed.

Turkful and Unakitan (2011) study the relationship between per capita agricultural energy consumption (diesel, electricity), agricultural output, and energy prices in Turkey. A unidirectional causality running from diesel and electricity consumption to agricultural output is found. Increasing agricultural GDP increases the consumption of diesel and electricity in the long-run. These authors recommend continuing the support for energy use in Turkish agriculture in order to increase international market competitiveness, and balance the income of farmers.

Mushtaq et al. (2007) investigate the causal relationships between per capita agricultural energy consumption (oil, electricity, and gas), real agricultural output, and energy prices for Pakistan. A unidirectional causality running from agricultural output to oil consumption and from electricity consumption to agricultural output is proved. These authors recommend that governments should improve the infrastructure and subsidize rural and agricultural electricity in order to significantly enhance agricultural output. The causal relationships between agricultural output, energy consumption (oil, electricity), and trade openness in Tunisia is investigated by Sebri and Abid (2012). They show the existence of short and long-run unidirectional causality running from the total energy consumed and from the oil energy consumed to agricultural output. A long-run unidirectional causality running from agricultural output to oil consumption is also found. They conclude that energy can be considered as a limiting factor to agriculture and that shocks to energy supply should be handled carefully.

To our knowledge, the first econometric study dealing with renewable energy and agriculture is Ben Jebli and Ben Youssef (2015b). These authors investigate short and long-run relationships between per capita CO_2 emissions, GDP, renewable and non-renewable energy consumption, trade openness and agricultural value added (AVA) in Tunisia. Their short-run Granger causality tests show the existence of bidirectional causalities between AVA and CO_2 emissions, and between AVA and trade openness. In addition, there are long-run bidirectional causalities between all considered variables. Long-run estimates highlight that non-renewable energy, trade and AVA increase CO_2 emissions, whereas renewable energy consumption reduces CO_2 emissions. They recommend that subsidizing renewable energy use in the agricultural sector helps it to become more competitive on the international markets while polluting less. The present paper differs from that of Ben Jebli and Ben Youssef (2015b) mainly by the fact that we consider a panel of countries and we use panel cointegration techniques.

3. Data and descriptive statistics

To explore the dynamic causal link between per capita carbon dioxide emissions, economic growth, renewable energy consumption and agriculture, we consider a panel of five North Africa countries (Algeria, Egypt, Morocco, Sudan,[1] and Tunisia) studied over the period 1980-2011. The multivariate framework for the analysis includes per capita CO_2 emissions measured in metric tons, per capita real GDP in constant 2005 US dollars, per capita agricultural value added (AVA, AGR) in US dollars, and per capita renewable energy consumption (RE) in billion kilowatt hours. Renewable energy comprises all types of renewable electricity consumption and comprises geothermal, solar, wind, tide and wave, biomass and waste, and hydroelectric. The annual data concerning emissions, GDP and agriculture are collected from the World Bank (2015), and those concerning renewable energy are collected from the US Energy Information Administration (2015). To assess the moving of analysis time series of North Africa selected countries, we have illustrated some graphical presentations of per capita CO_2 emissions, GDP, renewable energy consumption, and agricultural value added.

Insert Fig.1-4 Here

Figure 1 shows the tendency of per capita CO_2 emissions measured in metric tons during the selected period across countries. The illustrated curves show that Algeria is the most polluting country during the period 1980- 2011 and reached 3.47 metric tons per capita of CO_2 emissions in 1998. Egypt and Tunisia are ranked second and third in 2011 and reached a level of 2.62 and 2.45 metric tons per capita of CO_2 emissions, respectively. Sudan takes the last rank with a maximum level of 0.31 metric tons per capita of CO_2 emissions reached in 2009. Figure 2 shows that the evolution of per capita real GDP measured in constant 2005 US dollars for the North Africa countries is in positive growing during the selected period, but with different ranges. Tunisia has reached in 2010 the highest level of per capita real GDP of 3848.14 US dollars, while Sudan has the lowest level with 406.39 US dollars. Figure 3 presents a graphical illustration showing the evolution of renewable energy consumption per capita (billion kilowatt hours) over time across countries. The representation shows that the process behaves in an unstable way for the entire sample. Egypt has the largest part of renewable energy consumption while Algeria is the smallest consumer during the last 15 years. Sudan has realized a significant increase during the last three years, while Morocco has

[1] This research concerns both Sudan and South Sudan due to lack of data concerning each country taken separately.

experienced a small drop in 2011. In Tunisia, the level of renewable energy consumption is relatively low and has also realized some drops in 1986, 1989, and 2008. Figure 4 reports the evolution of per capita agricultural value added (in constant US dollars) for each country over the selected period of time. These preliminary statistics show that, only in Algeria and Egypt, the growth level of agriculture is encouraging and is characterized by a stable long-run tendency. Agricultural value added changes in Tunisia and Morocco reveal somewhat disturbances during the selected period, while overall there is a significant increasing tendency. Serious disturbances are observed for the case of Sudan due to the drop in agricultural growth realized since 1998.

4. Empirical results

We consider the following log-linear equation exploring the long-run relationship between analysis variables:

$$LNCO_{2it} = \alpha_i + \theta_i t + \beta_i LNGDP_{it} + \delta_i LNRE_{it} + \lambda_i LNAGR_{it} + \varepsilon_{it} \quad (1)$$

where $i = 1,...,5$ denotes the country and $t = 1980,...,2011$ denotes the time period; ε_{it} indicates the estimated residuals which characterize deviations from the long-run relationship; α_i and θ_i allow for the possibility of country-specific fixed effect and deterministic trend, respectively; *LN* indicates the natural logarithms transformation.

4.1. Stationary tests

Insert Table 1 Here

We use four panel unit root tests to check for stationary proprieties of each variable. These tests are classified in two sets. The first set includes Levin et al. (2002, LLC test) which assumes a common unit root process across the cross-section. The second set includes Im et al. (2003, IPS test), Dickey and Fuller (1979, Fisher-ADF test) and Phillips and Perron (1988, Fisher-PP test) which assume an individual unit root process across the cross-section. For the two sets of panel unit root tests, the null hypothesis argues that there is a unit root, while the alternative hypothesis suggests that the variable is stationary. These tests will be applied for analysis variables at level and after first difference. Stationary tests are based on the Schwarz information criterion (SIC) to get the number of lags. The results from panel unit root tests are reported in Table 1 and suggest that all variables contain a unit root at level, but they become stationary after first difference, at the 1% significance level. Thus, all variables are integrated of order one.

4.2. Cointegration tests

The existence of long-run relationship between variables is established using the seven cointegration tests proposed by Pedroni (2001, 2004). These tests are divided in two sets. The first set contains four panel statistics (v-statistic, rho-statistic, PP-statistic and ADF-statistic) and assumes common autoregressive coefficients (within-dimension). The second set contains three group statistics (rho-statistic, PP-statistic and ADF-statistic) and assumes individual autoregressive coefficients (between-dimension). For all these tests, the null hypothesis assumes no cointegration among analysis variables, while the alternative hypothesis suggests that variables are cointegrated. All statistic tests have been applied for the case of intercept and deterministic trend. Deviations from the long-run equilibrium relationship are represented by the estimated residuals ε_{it}. The null hypothesis of no cointegration ($\rho_i = 1$) is tested via the following unit root test on the residuals:

$$\varepsilon_{it} = \rho_i \varepsilon_{it-1} + \omega_{it} \quad (2)$$

Insert Table 2 Here

Table 2 reports the results of Pedroni cointegration tests and indicates that there is a long-run relationship between per capita CO_2 emissions, GDP, renewable energy, and agriculture. Indeed, three statistics among four for the within dimension reject the null of no cointegration and accept the alternative of cointegration between variables. For the between dimension, the group statistics suggest that two statistics among three reject the null of no cointegration and accept the alternative hypothesis confirming the existence of long-run association between variables. Thus, there is five statistics among seven that approve the long-run cointegration when per capita CO_2 emissions is the dependent variable.

4.3. Granger causality

The pairwise Granger causality test and the vector error correction model (VECM) are used to check for the short and long-run interaction among variables, respectively. Engle and Granger (1987) consider two stages to establish causality relationship: the first step consists in estimating the residuals from Eq. (1), while the second step estimates the coefficients related to the short-run adjustment.

The VECM estimate is given as follows:

$$\begin{bmatrix} \Delta LNCO_{2it} \\ \Delta LNGDP_{it} \\ \Delta LNRE_{it} \\ \Delta LNAGR_{it} \end{bmatrix} = \begin{bmatrix} \delta_1 \\ \delta_2 \\ \delta_3 \\ \delta_4 \end{bmatrix} + \sum_{p-1}^{q} \begin{bmatrix} \theta_{11p} & \theta_{12p} & \theta_{13p} & \theta_{14p} \\ \theta_{21p} & \theta_{22p} & \theta_{23p} & \theta_{24p} \\ \theta_{31p} & \theta_{32p} & \theta_{33p} & \theta_{34p} \\ \theta_{41p} & \theta_{42p} & \theta_{43p} & \theta_{44p} \end{bmatrix} \times \begin{bmatrix} \Delta LNCO_{2it-1} \\ \Delta LNGDP_{it-1} \\ \Delta LNRE_{it-1} \\ \Delta LNAGR_{it-1} \end{bmatrix} + \begin{bmatrix} \alpha_1 \\ \alpha_2 \\ \alpha_3 \\ \alpha_4 \end{bmatrix} ect_{it-1} + \begin{bmatrix} \mu_{1it} \\ \mu_{2it} \\ \mu_{3it} \\ \mu_{4it} \end{bmatrix} \quad (3)$$

where Δ is the first difference operator; the autoregression lag length, *p*, is determined by the Schwarz information criterion (SIC), Akaike information criterion (AIC) and Hannan-Quinn (HQ) criterion and is set equal to 1; μ is a random error term; *ect* is the error correction term derived from the long-run relationship of Eq. (1).

Insert Table 3 Here

Granger causality test results are reported in Table 3. It shows that the error correction term is statistically significant at the 1% significance level only for the equations of CO_2 emissions and agricultural value added. We have short and long-run bidirectional causality between AVA and emissions. Thus, any change in agricultural production has an immediate effect on CO_2 emissions because the agricultural sector uses intensively fossil energy. This result is similar to that of Ben Jebli and Ben Youssef (2015b). There is short and long-run unidirectional causality running from renewable energy consumption to agriculture. This means that renewable energy use can stimulate agricultural value added even in the short-run. This result is different from that of Ben Jebli and Ben Youssef (2015b) as they show the absence of short-run causality between renewable energy and agriculture for the case of Tunisia, while in the long-run they find bidirectional causality.

In addition, there is a short-run causality running from AVA to GDP, and a long-run causality running from output to agriculture. This means that an increase in agricultural production has an immediate impact on economic growth and that, in the long-run, economic growth can help the development of the agricultural sector through increasing investment possibilities for instance. This result is different from that of Chebbi (2010a) showing a short-run unidirectional causality running from the non-manufacturing sector to agricultural GDP in Tunisia. A long-run causality running from renewable energy to emissions is also found meaning that, for this panel of countries any change in renewable energy consumption will affect CO_2 emissions in the long-run. Lastly, we find a short-run causality running from output to renewable energy meaning that economic growth needs renewable energy for producing goods and services.

4.4. Long-run estimates

The long-run estimates of Eq. (1) have been computed using ordinary least squares (OLS), fully modified OLS (FMOLS), and dynamic OLS (DOLS) techniques. It has been proved that the FMOLS and DOLS techniques, developed by Pedroni (2001, 2004), are more powerful than the OLS technique because they correct for endogeneity and serial correlation problems.

Insert Table 4 Here

Table 4 reports the results from OLS, FMOLS and DOLS long-run estimates. We observe that the estimated coefficients are statistically significant at the 1%. The three techniques provide very similar results in terms of sign, magnitude, and statistical significance. With the FMOLS approach: a 1% increase in GDP increases emissions by 1.55%, a 1% increase in renewable energy increases emissions by 0.19%, and a 1% increase in AVA reduces emissions by 0.93%. Therefore, increasing output increases CO_2 emissions in the long-run because economic growth still needs intensively fossil energy for producing goods and services. This result is similar to that of Apergis et al. (2010). We show that increasing renewable energy consumption increases CO_2 emissions in the long-run for this panel of countries. This is due to the fact that the renewable energy we have considered in our data contains all types of renewable sources among which combustible renewable and waste which are not ‘‘clean’’ resources but nevertheless pollute less than fossil energy. This result is similar to those of Apergis et al. (2010) and Ben Jebli et al. (2015). However, it differs from that of Ben Jebli and Ben Youssef (2015b) for the case of Tunisia.

Interestingly, increasing agricultural value added reduces CO_2 emissions in the long-run. This may be due to the fact that the agricultural sector for this panel of countries is less polluting that the other sectors such as manufacturing and transport. This result is similar to that reached by Rafiq et al. (2015) for a panel of 53 countries, and differs from that of Ben Jebli and Ben Youssef (2015b) for the case of Tunisia.

5. Conclusion and policy implication

This investigation examines the dynamic causal links between per capita CO_2 emissions, real GDP, renewable energy consumption, and agricultural value added for a panel of five North Africa countries (Algeria, Egypt, Morocco, Sudan, Tunisia) spanning the period 1980-2011. We use panel cointegration techniques and Granger causality tests to check for the existence of long-run association and to examine the direction of causalities between variables. The OLS technique and the panel FMOLS and DOLS techniques are used to estimate the long-run parameters when per capita emission is the dependent variable.

Our Granger causality results show the existence of a short and long-run unidirectional causality running from renewable energy to agriculture indicating the important role played by renewable energy in improving agricultural production. This finding is interesting because this study is the first that tries to investigate the dynamic linkages between renewable energy consumption and agriculture in North Africa. In addition, we have short and long-run bidirectional causalities between agricultural value added and CO_2 emissions implying that agriculture has an impact on emissions. The existence of a short-run unidirectional causality running from agriculture to GDP explains the important role played by the agricultural sector in pushing economic growth in this region. Moreover, GDP increase has an impact on agricultural value added in the long-run through increasing investment possibilities in the agricultural sector generated by economic growth. In the short-run, there is a unidirectional causality running from economic growth to renewable energy consumption, and there is a long-run unidirectional causality from renewable energy to emissions. Thus, encouraging renewable energy use has an impact on CO_2 emissions in the long-run.

Our long-run parameter estimates show that economic growth increases carbon dioxide emissions because economic growth still uses intensively fossil energy for goods and services production. The increase in renewable energy consumption also increase emissions in the long-run because the renewable energy we have considered in our data comprises all types of renewable sources among which combustible renewable and waste which are not ‘‘clean’’ resources but nevertheless pollute less than fossil energy. In addition, combustible renewable and waste represent an important proportion[2] with respect to renewable energy for this panel of countries. In the long-run, the increase in agricultural value added reduces CO_2 emissions for this panel of countries. This interesting result may be due to the fact that the agricultural sector in this region is less polluting that the other sectors such as manufacturing and transport. Given our econometric results, we recommend that encouraging renewable energy using in North Africa region, and particularly the use of clean renewable energy such as solar or wind, can stimulate agricultural production and at the same time contribute to combat global warming by reducing carbon dioxide emissions.

[2] According to the World Bank (2015), combustible renewables and waste percentage of total energy in 2011 for Algeria, Egypt, Morocco, Sudan, and Tunisia are 0.04, 2.05, 7.5, 65.81, and 14.63, respectively.

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Figures

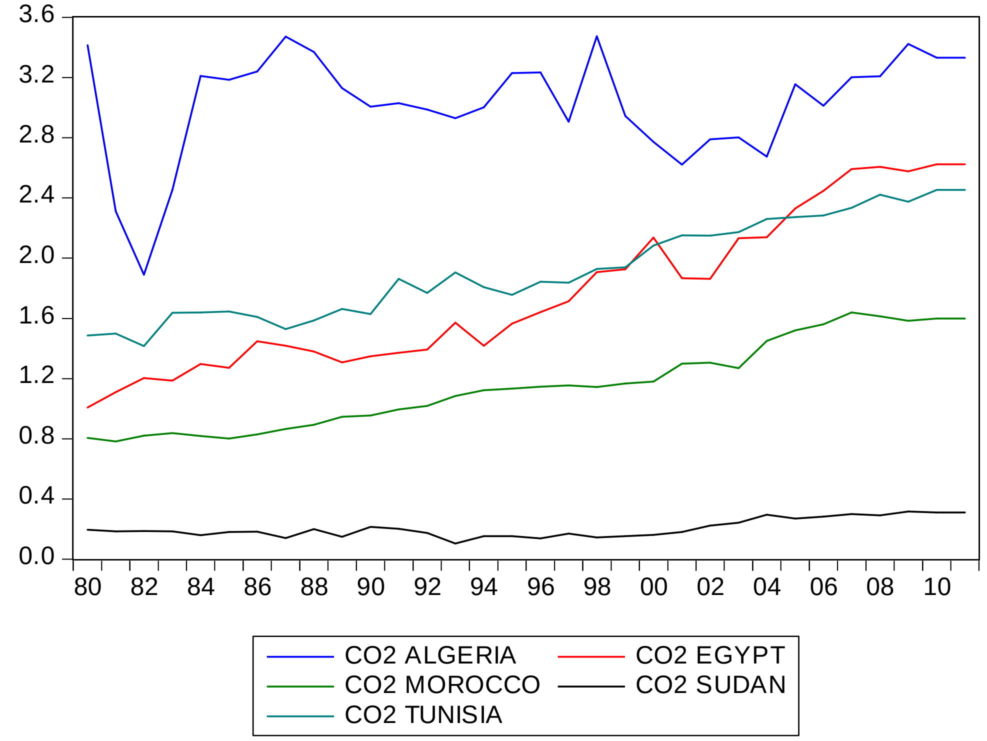

Fig.1. Per capita CO_2 emissions plots

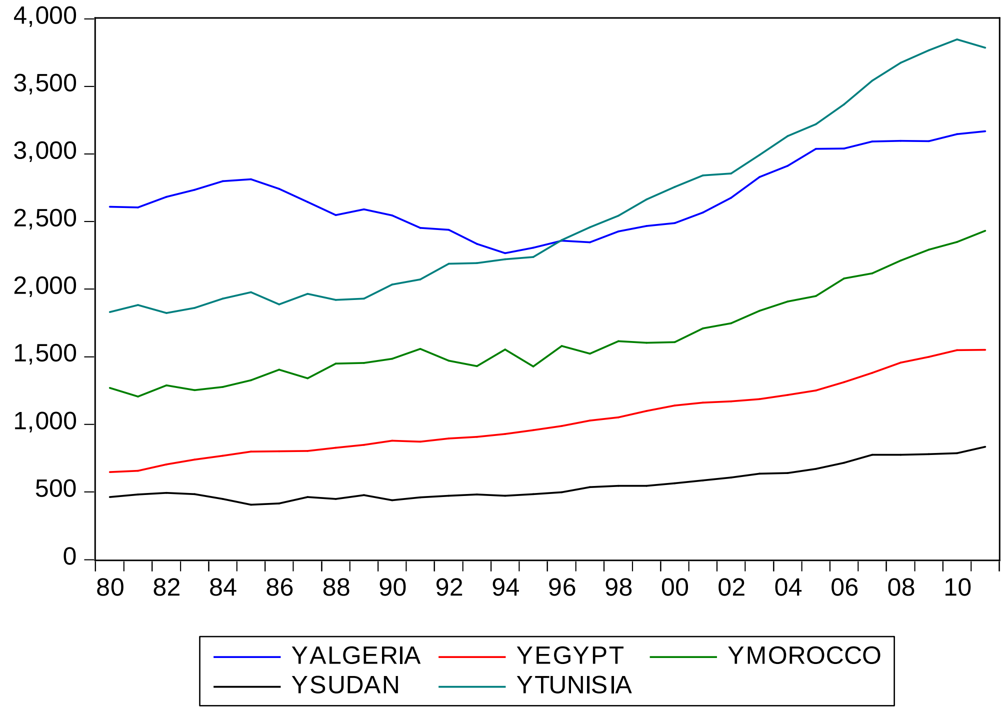

Fig.2. Per capita real GDP plots

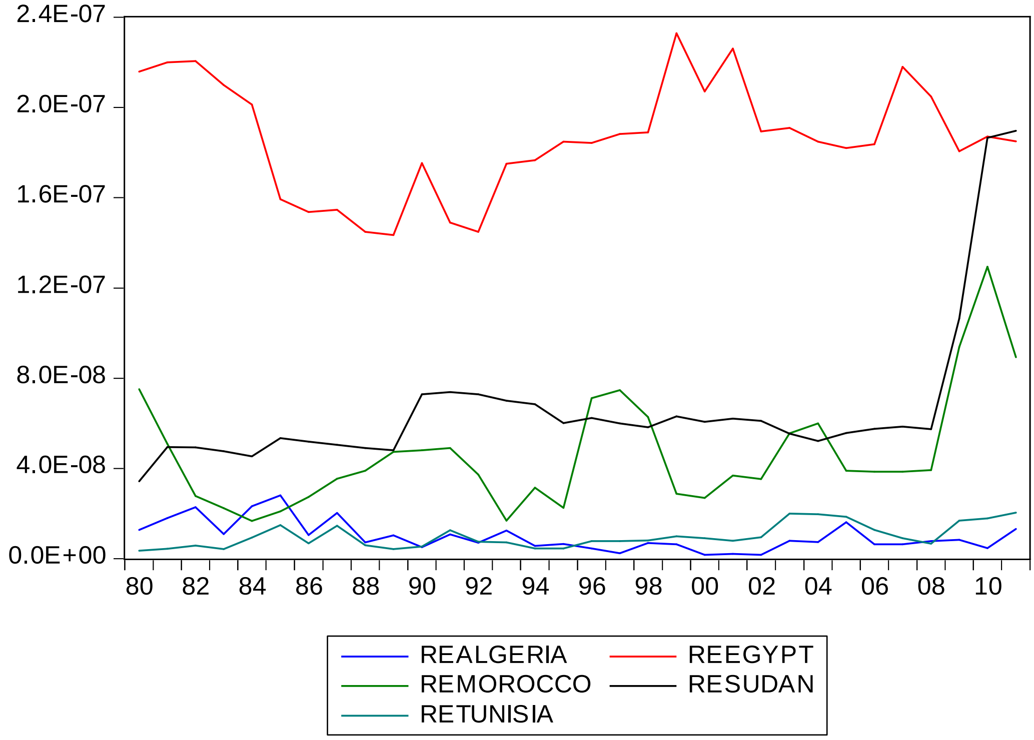

Fig.3. Per capita renewable energy consumption plots

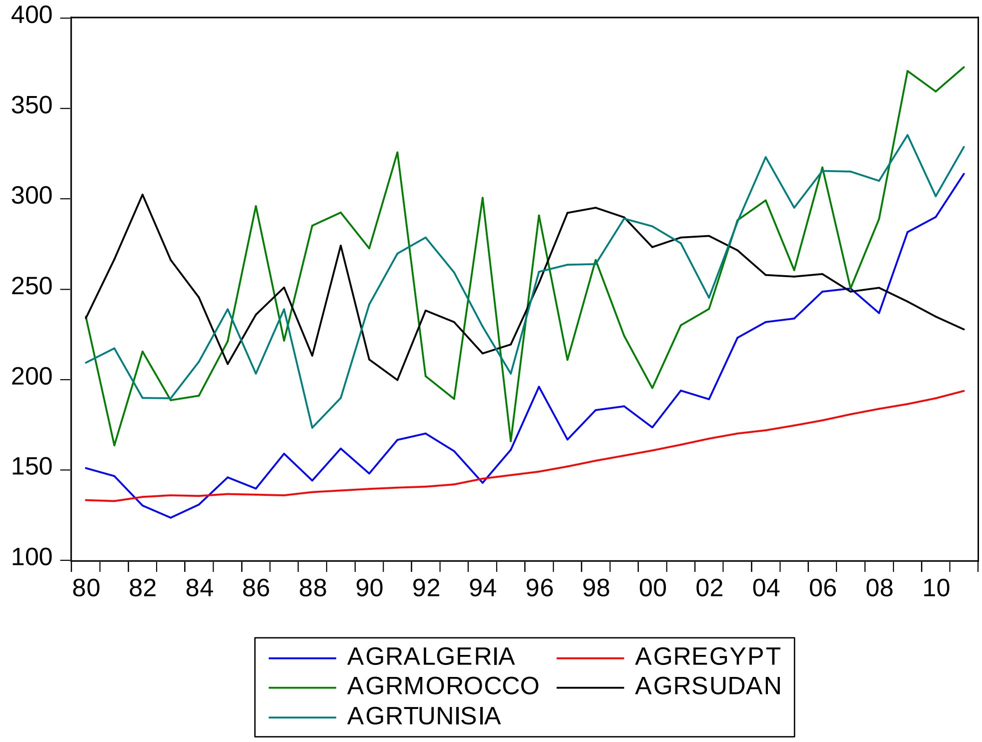

Fig.4. Per capita agricultural value added plots

Tables

Table 1. Panel unit root tests

Panel unit root test method	LLC	IPS	Fisher-ADF	Fisher-PP
$LNCO_2$	-0.89938	1.20518	21.7207	9.14912
	(0.1842)	(0.8859)	(0.0166)	(0.5180)
$\Delta LNCO_2$	-6.29775	-13.3678	125.343	378.280
	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***
LNGDP	-0.59747	0.60228	10.6339	4.54348
	(0.2751)	(0.7265)	(0.3867)	(0.9195)
ΔLNGDP	-8.34048	-10.0774	145.461	150.085
	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***
LNRE	-2.22717	-1.82375	19.6430	17.5655
	(0.0130)	(0.0341)	(0.0328)	(0.0628)
ΔLNRE	-10.1400	-10.1602	94.0340	489.001
	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***
LNAGR	-1.61870	2.09227	9.67492	17.4446
	(0.0528)	(0.9818)	(0.4695)	(0.0651)
ΔLNAGR	-6.62371	-10.6682	95.7954	668.447
	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***

Null hypothesis: Unit root. *** indicates statistical significance at the 1% significance level.

Table 2. Pedroni cointegration tests

Alternative hypothesis: common AR coefs. (within-dimension)				
			Weighted	
	Statistic	Prob.	Statistic	Prob.
Panel v-Statistic	-0.571759	0.7163	-0.973002	0.8347
Panel rho-Statistic	-1.503338	0.0664*	-1.292564	0.0981*
Panel PP-Statistic	-3.633726	0.0001***	-3.219746	0.0006***
Panel ADF-Statistic	-3.476328	0.0003***	-2.563942	0.0052***
Alternative hypothesis: individual AR coefs. (between-dimension)				
	Statistic	Prob.		
Group rho-Statistic	-0.702614	0.2411		
Group PP-Statistic	-3.564675	0.0002***		
Group ADF-Statistic	-3.164946	0.0008***		

Null hypothesis: No cointegration. All cointegration test regressions are run with intercept and deterministic trend. *** and * indicate statistical significance at the 1% and 10% levels, respectively.

Table 3. Granger causality tests

Dependent variable	Short-run				Long-run
	ΔLNCO2	*ΔLNGDP*	*ΔLNRE*	*ΔLNAGR*	*ECT*
ΔLNCO2	-	0.75957	0.11391	4.47613	-0.067352
		(0.3848)	(0.7362)	(0.0360)**	[-3.87846]***
ΔLNGDP	1.08889	-	1.01830	4.80365	0.109790
	(0.2983)		(0.3145)	(0.0299)**	[1.27896]
ΔLNRE	0.97554	3.25328	-	0.60664	0.000144
	(0.3248)	(0.0732)*		(0.4372)	[0.01268]
ΔLNAGR	2.51016	0.02471	3.44727	-	-0.239517
	(0.0846)*	(0.8753)	(0.0652)*		[-3.08835]***

Notes: ***, **, * indicate statistical significance at the 1%, 5%, and 10% levels, respectively. P-values are listed in parenthesis and t-statistics are presented in brackets.

Table 4. Long-run estimates

Variables	***LNGDP***	***LNRE***	***LNAGR***
OLS	1.479456	0.167916	-0.823870
	(0.0000)***	(0.0000)***	(0.0000)***
FMOLS	1.548605	0.188752	-0.929775
	(0.0000)***	(0.0000)***	(0.0000)***
DOLS	1.479456	0.167916	-0.823870
	(0.0000)***	(0.0000)***	(0.0003)***

Notes: *** indicates statistical significance at the 1% level. P-value listed in parentheses.