Output, renewable energy consumption and trade in Africa

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Abstract: We use panel cointegration techniques to examine the relationship between renewable energy consumption, trade and output in a sample of 11 African countries covering the period 1980-2008. The results from panel error correction model reveal that there is evidence of bidirectional causality between output and exports and between output and imports in both the short-run and the long-run. However, in the short-run, there is no evidence of causality between output and renewable energy consumption and between trade (exports or imports) and renewable energy consumption. In the long-run, the FMOLS panel approach estimation shows that renewable energy consumption and trade (exports or imports) have a statistically significant and positive impact on output. Policies recommendations are that, in the long-run, international trade enables African countries to benefit from technology transfer and to build the human and physical capacities needed to produce more renewable energies, which in turn increases their output.

Keywords: Renewable energy consumption; International trade; Africa; Panel cointegration.
JEL Classification: C33, F14, Q43, O55

1. Introduction

The interaction between international trade and renewable energy consumption has not been previously studied, and it is the aim of the present paper by considering a panel of African countries. Nevertheless, it is accepted that the use of renewable energy is linked to the transfer of technology which is directly linked to international trade. It was recognized by both the Rio and Johannesburg conferences that trade helps achieving more efficient allocation of scarce resources, makes it easier for countries, rich and poor, to access environmental goods, services and technologies (World Trade Organization, 2011).

There are several empirical studies analyzing the causal relationship between economic growth and the consumption of renewable energy (e.g. Apergis and Payne, 2010a, 2010b, 2011, 2012; Sadorsky, 2009b). Other papers analyze the causal relationship between economic growth, renewable energy consumption and CO_2 emissions (e.g. Sadorsky, 2009a). All these studies approve that renewable energy consumption plays a vital role for increasing economic growth, and an energy policy planned to increase the share of renewable energy in total energy consumption is very effective in reducing greenhouse gas emissions. Capital, labor, and renewable energy consumption are not the only factors determining economic growth. Indeed, there are other factors that can be incorporated in the production function to explain the growth of gross domestic product (GDP) such as trade openness. This latter can be defined as exports, or imports, or the sum of both divided by the value of GDP.

Many papers study the relationship between energy consumption (total energy use), trade, and output. Lean and Smyth (2010a) examine the dynamic relationship between economic growth, electricity generation, exports and prices for Malaysia. The results from Granger causality tests show the existence of unidirectional causality running from economic growth to electricity generation. Lean and Smyth (2010b) examine the causal relationship between aggregate output, electricity consumption, exports, labor, and capital in a multivariate model for Malaysia. They find that there is bidirectional causality between aggregate output and electricity consumption. They conclude that Malaysia should adopt the dual strategy of increasing investment in electricity infrastructure and encouraging electricity conservation policies to reduce unnecessary wastage of electricity. Narayan and Smyth (2009) find the same conclusion for a panel of Middle East countries. Indeed, for the panel as a whole, they find feedback effects between electricity consumption, exports and GDP. Sadorsky (2011) uses panel cointegration techniques to show how trade can affect energy consumption for 8 Middle East countries. He finds Granger causality from exports to energy consumption, and bidirectional relationship between imports and energy consumption in the short-run. In the long-run, he achieves that an increase in both exports and imports affect the demand of energy. A similar study on a sample of 7 South American countries, Sadorsky (2012), confirms the long-run relationship between trade and energy consumption. One important consequence of these results is that environmental policies designed to reduce energy use will reduce trade.

To our knowledge, there is no study, in any country and particularly in Africa, trying to know the linkage between trade and renewable energy consumption. The aim of this paper is to explore the causal relationship between renewable energy consumption, trade, and output by considering a panel of 11 African countries.

The paper is structured as follows. Section 2 gives an idea about the renewable energy sector and trade in Africa. Section 3 describes the data. Section 4 is designated for descriptive statistics. Section 5 deals with the empirical models and results, and section 6 concludes.

2. Renewable energy and trade in Africa

Many studies underline the great potential of Africa regarding renewable energy production and consumption. Indeed, with their solar, wind, hydropower and geothermal capacities, among others, many African countries have set themselves ambitious strategic objectives and launched large-scale integrated energy programs from which they expect benefits involving reduction of greenhouse gas emissions, direct and indirect job creation, local industrial development and the improvement of human capital. Renewable energies also offer the opportunity to serve isolated regions remote from the national electricity grid and so improve the access to energy particularly for the poorest.

According to the United Nations Industrial Development Organization (2009), the most used renewable energy sources for large-scale applications in Africa are hydropower, modern biomass, geothermal, wind and solar. These sources are usually grid connected. Only about 5% of Africa's hydropower potential estimated to 1750 TWh has been exploited. The total hydropower potential for Africa is equivalent to the total electricity consumed in France, Germany, United Kingdom and Italy put together. The Inga River in the Democratic Republic of Congo (DRC) holds great potential for hydropower generation in Africa with an estimated potential of around 40,000 MW. The DRC alone accounts for over 50% of Africa's hydropower potential. Other countries with significant hydropower potential include Angola, Cameroon, Egypt, Ethiopia, Gabon, Madagascar, Mozambique, Niger and Zambia. Despite the low percentage use, large-scale hydropower so far provides over 50% of total power supply for 23 countries in Africa.

The use of wind energy for large-scale electricity production has been increasing faster than any other renewable energy technology over the past decade. In 2007, new installations were about 21GW, even more than hydropower. The development of wind energy projects is primarily limited by the lack of precise information about the wind potential. In terms of installed capacity at the beginning of 2008, Africa had about 476 MW of installed wind energy generation capacity compared to a global estimation of 93,900 MW. Many countries as Morocco, Egypt, Tunisia, South Africa, and Ethiopia are developing large-scale wind energy projects.

Large-scale solar energy projects are very limited in Africa because of their high cost. Many studies have established that Africa has great potential for concentrated solar thermal power generation from desert areas like the Sahara and Namibia. Egypt plans to install solar thermal plant of 300 MW by 2020. Several countries in North Africa are planning to install solar thermal plants in partnership with European countries. The United Nations Economic Commission for Africa (Office of North Africa, 2012) reports a number of current initiatives such as the Mediterranean Solar Plan (MSP), the Euro-Mediterranean partnership, the agreements that exist between the European Union and some countries of North Africa, the DESERTEC project. These partnerships aim to develop projects, increase investments, produce and distribute renewable energies, strengthen interconnections and create an expanding regional market for electricity.

Small-scale renewable energy systems are used to provide to communities energy services that are not accessed by existing conventional energy supply systems such as the electricity grid. Unfortunately, poor households have not benefited as much as high income households from solar photovoltaic (PV) systems because of their relatively high costs.

Countries in Africa can increase their energy efficiency without decreasing economic output or lowering the standards of living. Studies by the International Energy Agency show that in Africa energy intensity, i.e. total energy consumed per GDP, is at least twice the world average. Experiences so far show that the adoption of energy efficiency is inhibited by barriers including lack of appreciation of the benefits, initial capital requirements, resistance to change, absence of policy and regulatory frameworks. Africa can increase its energy efficiency by encouraging the use of renewables and more efficient technologies.

Recognizing that national energy markets are narrow (United Nations Industrial Development Organization, 2009), Africa is experiencing a shift towards regionally integrated energy markets. Regional Economic Communities (RECs) as Economic Community of West African States (ECOWAS), East African Community (EAC) and Southern African Development Community (SADC) are already working on regionally integrated policy planning, development and energy access programs. These efforts should strengthen the use of renewable energies. Indeed, RECs should play a more active role in promoting regionally integrated markets for renewable energy technologies that are commercially viable in order to realize economies of scale that attracts private sector investments. Moreover, RECs should encourage coherence and greater networking among their member states to promote sharing of experiences and best practices in renewable energy. This could be realized by establishing regional institutions that promote greater partnerships with similar institutions from other regions of the world in order to promote research and technology transfer, among other things.

3. Data

Annual data from 1980 to 2008 are collected for a sample of 11 African countries, namely: Algeria, Comoros, Egypt, Gabon, Ghana, Kenya, Mauritius, Morocco, Sudan, Swaziland and Tunisia. The criterion of selection of countries is based on the availability of data and on the interest of empirical results. The multivariate framework for the analysis includes real gross domestic product (GDP, output) measured in constant 2000 US dollars, renewable energy consumption (REC) defined as total renewable electricity consumption measured in billions of kilowatt hours, exports (imports) are measured using merchandise exports (imports) measured in current US dollars and are converted to real values by dividing them by the price level of consumption (PC). The capital stock is measured by the gross fixed capital formation in constant 2000 US dollars. Labor is measured as total number of labor force. Data on exports, imports, capital and labor are obtained from the World Bank (2010) World Development Indicators online data base. Data on renewable energy consumption are obtained from the U.S. Energy Information Administration (2012). Data on PC are obtained from the Penn World Tables version 7.1 (Heston *et al*., 2012). All estimations are done using Eviews 7.0.

4. Descriptive statistics

Figs (1-4) show the variation of each variable employed for the empirical analysis for the sample of 11 African countries over the period 1980-2008, and Table 1 reports some summary statistics (Mean, Median, Maximum, and Minimum).

Table.1 Summary statistics (output, capital, labor, renewable energy consumption, real exports, and real imports)

Description	*Output*	*Capital*	*Labor*	*REC*	*Exports*	*Imports*
Mean	19.71	4.45	6.29	2.12	73.60	93.67
Median	7.59	1.51	5.59	0.66	35.50	42.51
Maximum	145.59	34.90	26.31	16.18	1085.81	1139.72
Minimum	0.13	0.02	0.13	0.002	0.08	0.35
Cross sections	11	11	11	11	11	11

Source: World Bank (2010) online database and Energy Information Administration (2012). Output and capital are measured in billion of constant 2000 US dollars. Labor force is measured in millions. Renewable energy consumption (REC) is measured in billion kilowatt hours. Real merchandise exports and imports are measured in million US dollars.

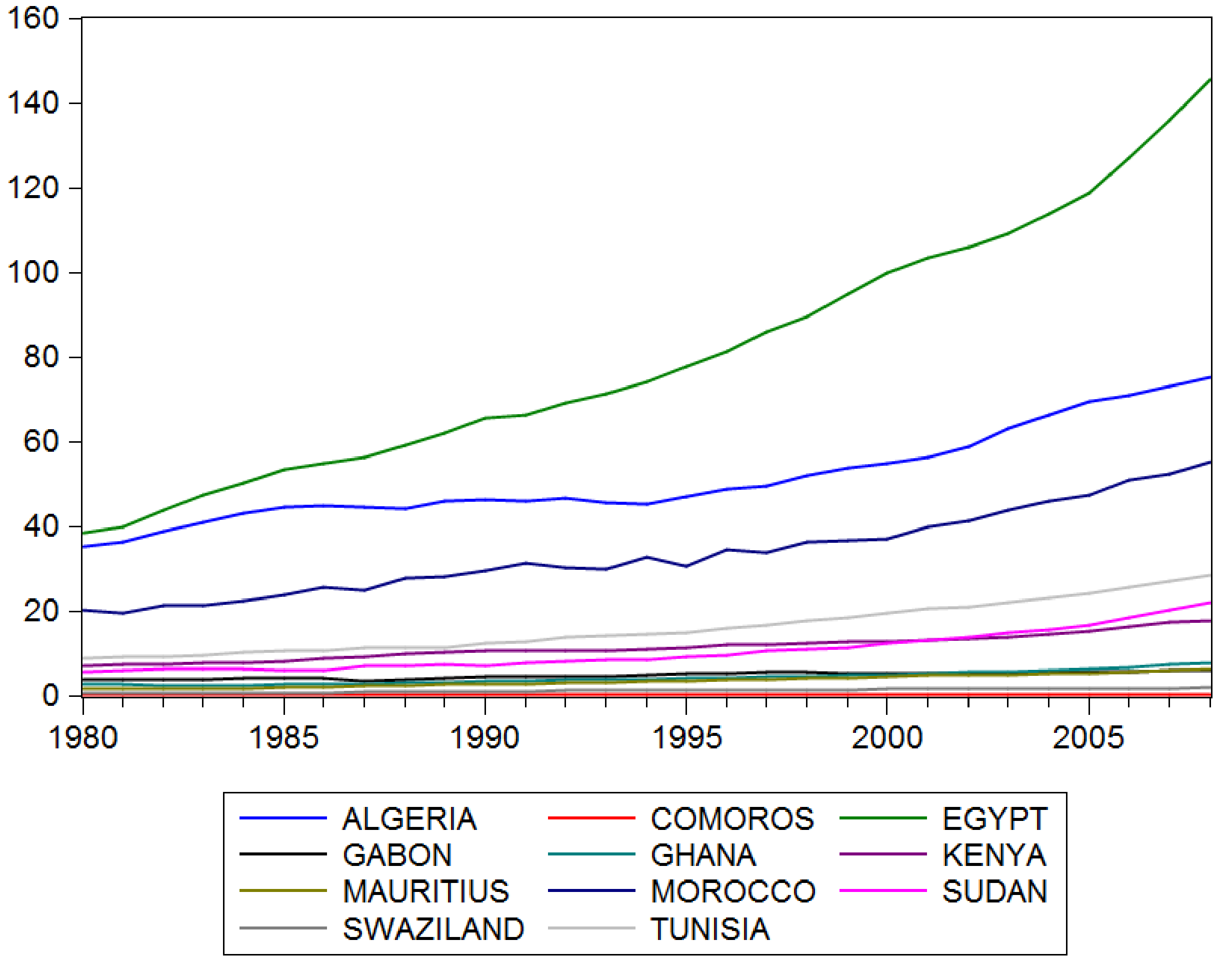

Fig.1. Real GDP (billion 2000 US dollars)

Fig. 1 presents the evolution of real GDP (measured in constant billion 2000 US dollars). Egypt has the biggest value of real GDP with 145.59 billion of constant 2000 US dollars in 2008 while Comoros has the smallest value with 0.13 billion of constant 2000 US dollars in 1980. According to Fig.1, we can see that Egypt takes the first place, then Algeria, Morocco and Tunisia in the fourth place. Comoros has the lowest level of real GDP.

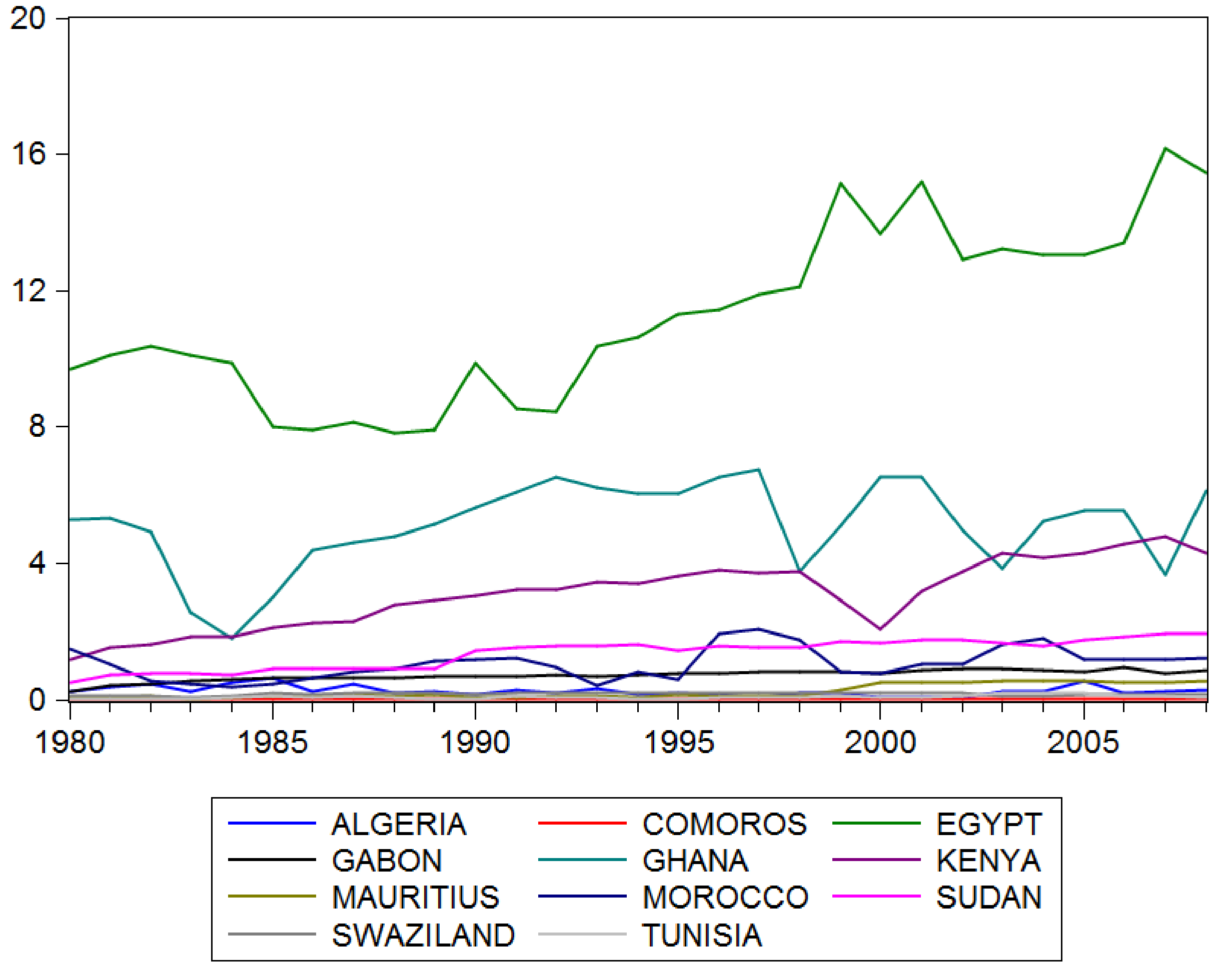

Fig.2. Renewable energy consumption (billion of kilowatt hours)

Fig.2 presents the evolution of the consumption of renewable energy (measured in billion of kilowatt hours) and shows that Egypt is the biggest consumer over all the period of observation with 16.18 billion of kilowatt hours in 2007, and then we have Ghana and Kenya with 6.78 billion of kilowatt hours in 1997 and 4.79 billion of kilowatt hours in 2007, respectively. The smallest consumer of renewable energy consumption is Comoros with 0.002 billion of kilowatt hours consumed each year during the period 1980 to 2001.

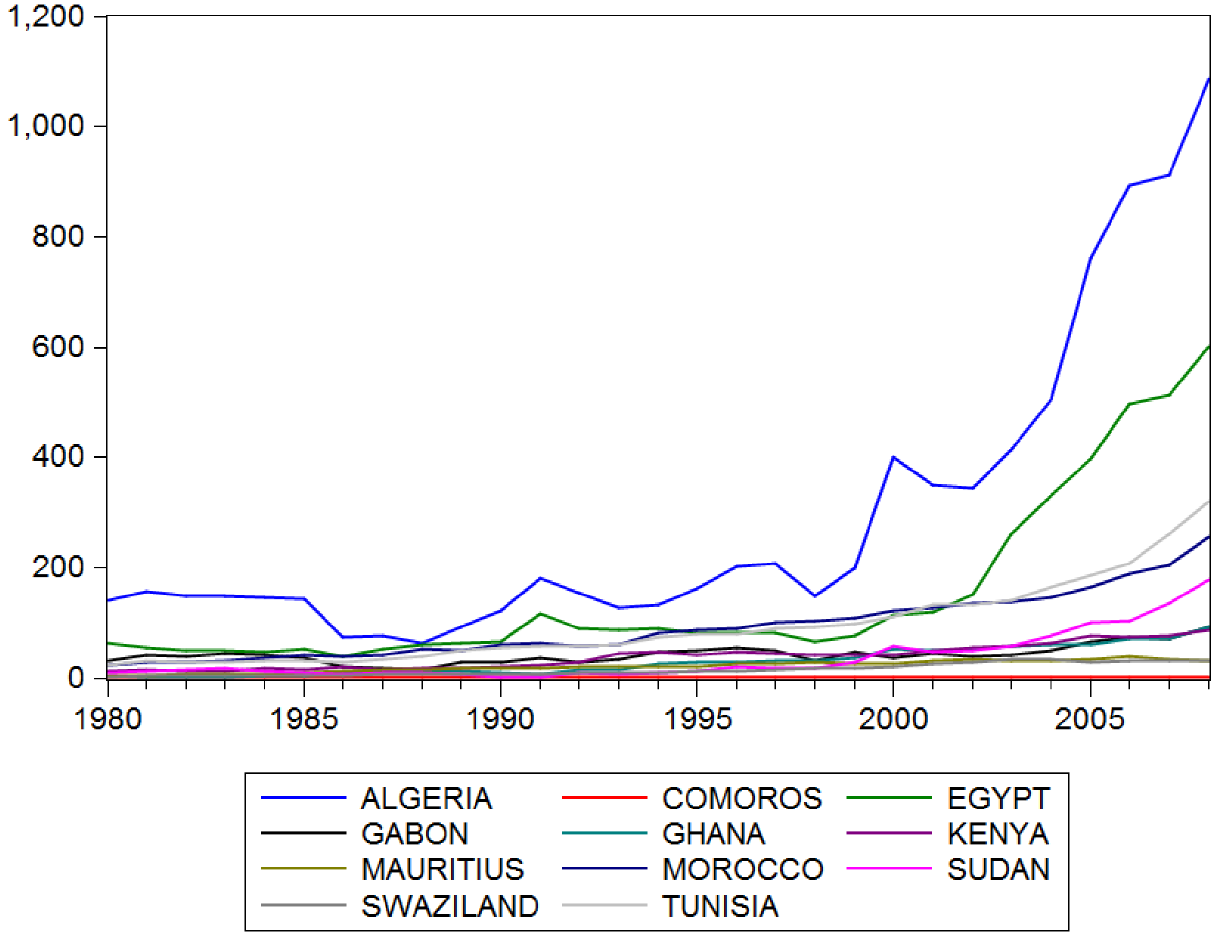

Fig.3. Real merchandises exports (million US dollars)

Fig. 3 reports the variation of real merchandises exports (million US dollars) and shows that Algeria is the biggest in exports of merchandises with 1085.81 million US dollars in 2008, and the smallest exporter is Comoros with 0.08 million US dollars in 1996.

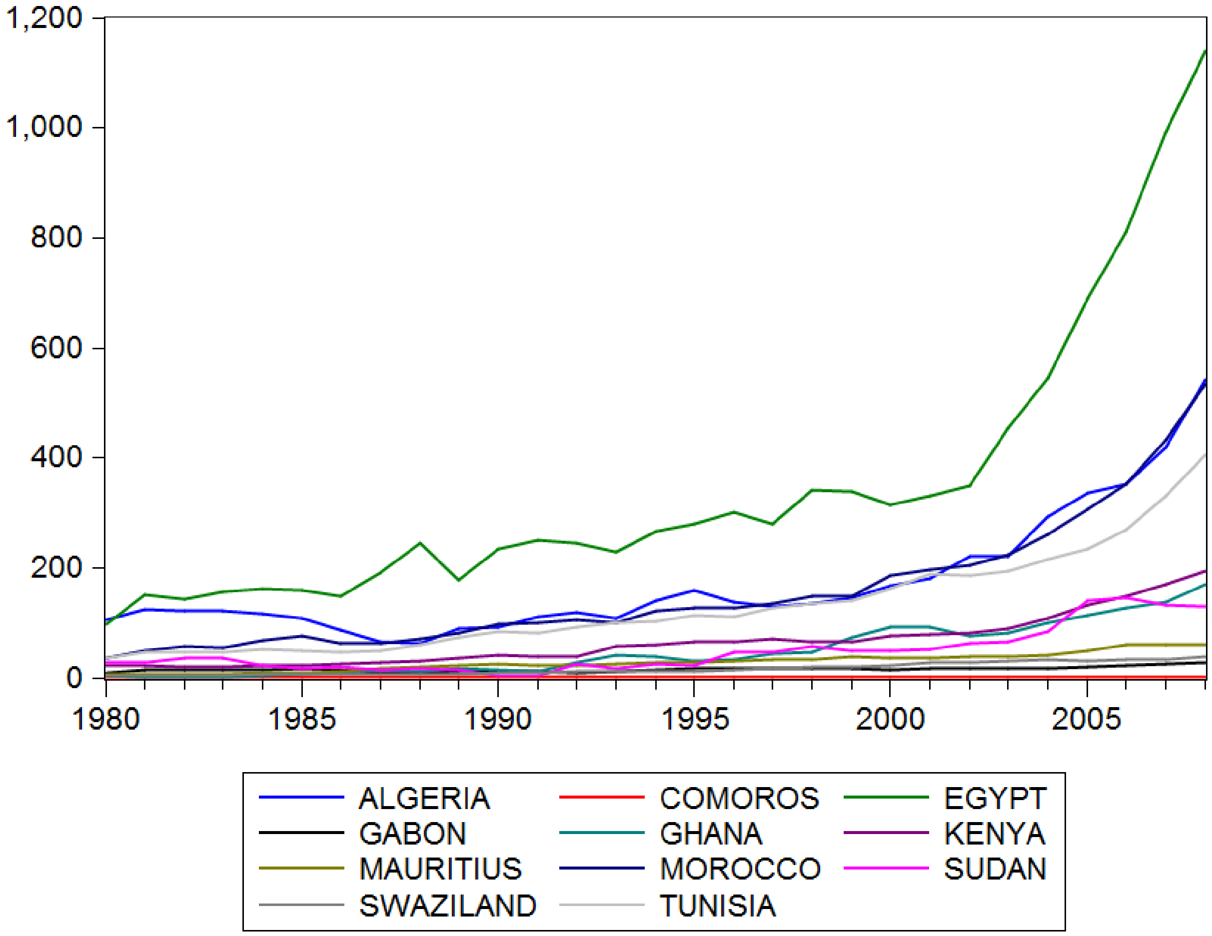

Fig.4. Real merchandises imports (million US dollars)

Fig. 4 reports real merchandises imports (million US dollars) and shows that Egypt is the biggest in imports of merchandises with 1139.72 million US dollars in 2008, while Comoros is the smallest importer with 0.35 million US dollars in 1980.

5. Empirical models and results

Following Lean and Smyth (2010a, 2010b) and Sadorsky (2012), the relationship between economic growth, energy consumption, and trade is modeled using the production function. The models in Lean and Smyth (2010a, 2010b) incorporate exports as trade variable, while the model in Sadorksy (2012) incorporates exports and imports in two separate specification models. The aim of this paper is to investigate the relationship between output, renewable energy consumption and trade using the same specification model as Sadorsky (2012). Output (Y) can be written as a function of renewable energy (REC), trade openness (O)[1], capital (K), and labor (L):

$$Y_{it} = f(REC_{it}, O_{it}, K_{it}, L_{it}) \tag{1}$$

The natural logarithm of Eq. (1) gives the following equation:

$$Y_{it} = \alpha_i + \delta_i t + \beta_{1i} REC_{it} + \beta_{2i} O_{it} + \beta_{3i} K_{it} + \beta_{4i} L_{it} + \varepsilon_{it} \tag{2}$$

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[1] Trade openness is incorporated into the production function by including real exports and real imports of merchandises in two separate specification models.

Where $i = 1, \ldots, N$ for each country in the panel, $t = 1, \ldots, T$ denotes the time period and (ε) denotes the stochastic error term. The parameters α_i and δ_i allow for the possibility of country-specific fixed effects and deterministic trends, respectively.

To examine the relationship between renewable energy consumption and trade for a sample of 11 African countries, we use panel cointegration techniques. These latter are interesting because models estimated from cross-sections of time series have more freedom degrees and are more efficient than models estimated from individual time series. Panel cointegration techniques are particularly useful when the time series dimension of each cross-section is short. We begin our empirical analysis with panel unit root test for cointegration, then we process the causality using Engle and Granger (1987), and we finish by the long-run estimates.

We start the analysis by testing the degree of integration and stationarity of each variable for panel cointegration tests. To check for panel unit root we use the test proposed by Breitung (2000) which is characterized by its great power and usually has smallest size distortions (Hlouskova and Wagner, 2006).

We use the following specification of Breitung (2000) panel unit root test:

$$\Delta y_{it} = \alpha y_{it-1} + \sum_{j=1}^{p_i} \Delta y_{it-j} + \delta_{0i} + \delta_{1i} t + \varepsilon_{it} \tag{3}$$

The null hypothesis assumes that panel series has unit root ($H_0 : \alpha = 0$), while the alternative hypothesis assumes that the process is stationary ($H_A : \alpha < 0$). The Schwarz Information Criterion (SIC) is used for selecting the number of lags (p_i).

Table.2 Panel unit root test

Panel unit root test method	Breitung t-stat
Y	3.18227(4) (0.9993)
ΔY	-6.56321(3) (0.0000)*
REC	-1.24424(2) (0.1067)
ΔREC	-5.09386(3) (0.0000)*
EX	0.71808(3) (0.7636)
ΔEX	-6.44933(5) (0.0000)*
IM	0.45409(2) (0.6751)
ΔIM	-6.24914(1) (0.0001)*
K	2.32248(2) (0.9899)

ΔK	-5.88532(5) (0.0000)*
L	3.11498(4) (0.9991)
ΔL	-3.03118(6) (0.0012)*

Null hypothesis: common unit root process.
Panel unit root test includes intercept and trend with lag lengths in parentheses.
Critical value at the 1 percent significance level denoted by "*".
Lag lengths selection is based on SIC.

Table 2 shows the result of the Breitung (2000) panel unit root test and indicates that variables are not stationary at level, while at the first difference all of them are stationary at the 1% significance level and the null hypothesis of a unit root can be rejected.

Given that the Breitung (2000)'s panel unit root test result suggests that all variables are stationary after first difference, we proceed testing for panel cointegration using two kinds of tests i.e. Pedroni (2004) and Kao (1999). To test the existence of cointegration within a heterogeneous panel, Pedroni (2004) proposes two categories of cointegration tests and seven statistics. The first category is based on four statistics (panel statistics) including v-statistic, rho-statistic, PP-statistic and ADF-statistic. These statistics are classified on the within-dimension and take into account common autoregressive coefficients across countries. The second category is based on three statistics (group statistics) including rho-statistic, PP-statistic and ADF statistic. These tests are classified on the between-dimension and based on the individual autoregressive coefficients for each country in the panel. The null hypothesis is that there is no cointegration, while the alternative hypothesis is that there is cointegration between variables. Panel cointegration tests of Pedroni (2004) are based on residuals of Eq. (2).

Table 3. Pedroni residual cointegration test results (Y, REC, EX, K, L)

Alternative hypothesis: common AR coefs. (within-dimension)				
			Weighted	
	Statistic	Prob.	Statistic	Prob.
Panel v-Statistic	1.691271	0.0454**	1.941998	0.0261**
Panel rho-Statistic	1.614396	0.9468	1.417284	0.9218
Panel PP-Statistic	-0.128617	0.4488	-0.805810	0.2102
Panel ADF-Statistic	-0.346780	0.3644	-1.362670	0.0865***
Alternative hypothesis: individual AR coefs. (between-dimension)				
	Statistic	Prob.		
Group rho-Statistic	2.369551	0.9911		
Group PP-Statistic	-0.936498	0.1745		
Group ADF-Statistic	-1.553027	0.0602***		

Null hypothesis: No cointegration.
Critical value at the 5 percent and 10 percent significance level denoted by "**" and "***", respectively.
Trend assumption: Deterministic intercept and trend.
Lag selection: Automatic SIC with a max lag of 5.

The results from these tests for the data set with exports are reported in Table 3 and suggest that there are two panel statistics (v-statistic and ADF statistic) of the within-dimension indicating cointegration at 5 and 10 percent significance, respectively. One group statistic of the between-dimension (group ADF-statistic) indicates cointegration at 10 percent significance.

Table.4 Pedroni residual cointegration test results (Y, REC, IM, K, L)

Alternative hypothesis: common AR coefs. (within-dimension)				
	Statistic	Prob.	Weighted Statistic	Prob.
Panel v-Statistic	1.421514	0.0776***	1.623290	0.0523***
Panel rho-Statistic	1.694911	0.9550	1.677025	0.9532
Panel PP-Statistic	0.050045	0.5200	-0.660107	0.2546
Panel ADF-Statistic	-0.387010	0.3494	-2.024870	0.0214**
Alternative hypothesis: individual AR coefs. (between-dimension)				
	Statistic	Prob.		
Group rho-Statistic	2.568598	0.9949		
Group PP-Statistic	-1.479789	0.0695***		
Group ADF-Statistic	-2.092685	0.0182**		

Null hypothesis: No cointegration.
Critical value at the 5 percent and 10 percent significance level denoted by "**" and "***", respectively.
Trend assumption: Deterministic intercept and trend.
Lag selection: Automatic SIC with a max lag of 5.

The results from these tests for the data set with imports are reported in Table 4 and suggest that there are two panel statistics (v-statistic and ADF statistic) of the within-dimension indicating cointegration at 10 and 5 percent significance, respectively. Two group statistics (PP-statistic and ADF-statistic) of the between-dimension indicate cointegration at 10 and 5 percent significance, respectively.

It is useful to confirm the existence of cointegration for the error correction model by using a second test for panel cointegration proposed by Kao (1999), which is based on ADF statistic.

Table 5. Kao cointegration test result (Y, REC, EX, K, L)

	t-Statistic	Prob.
ADF	-2.993029	0.0014*
Residual variance	0.001288	
HAC variance	0.001549	

Null hypothesis: No cointegration.
Trend assumption: No deterministic trend.
Automatic lag selection based on SIC with max lag of 7.
Critical value at the 1 percent significance level denoted by "*".

The result from Kao (1999) cointegration test for the data set with exports reported in Table 5 indicates that we can reject the null hypothesis of no cointegration at the 1 percent significance level. It means that there is evidence of cointegration between variables when *Y* (output) is defined as dependent variable.

Table 6. Kao cointegration test result (Y, REC, IM, K, L)

	t-Statistic	Prob.
ADF	-2.145063	0.0160**
Residual variance	0.001311	
HAC variance	0.001627	

Null hypothesis: No cointegration.
Trend assumption: No deterministic trend.
Automatic lag selection based on SIC with max lag of 7.
Critical value at the 5 percent significance level denoted by "**".

The result from Kao (1999) cointegration test for the data set with imports reported in Table 6 indicates that we can reject the null hypothesis of no cointegration at the 5 percent significance level. It means that there is evidence of cointegration between variables when *Y* (output) is defined as dependent variable.

The finding of cointegration between variables confirms the existence of long-run and short-run relationship between variables and the error correction model corresponding to each model can be estimated. To investigate the short-run dynamic and the long-run dynamic relationship between variables, Engle and Granger (1987) propose two-step procedure. The first step consists in estimating the long-run model specified in Eq. (2). The second step consists in defining the lagged residual obtained from Eq. (1) as the error correction term (*ECT*). The estimation of the dynamic vector error correction model is given as follows:

$$\Delta Y_{it} = \theta_{1i} + \sum_{j=1}^{q}\theta_{1,1ij}\Delta Y_{it-j} + \sum_{j=1}^{q}\theta_{1,2ij}\Delta REC_{it-j} + \sum_{j=1}^{q}\theta_{1,3ij}\Delta O_{it-j} + \sum_{j=1}^{q}\theta_{1,4ij}\Delta K_{it-j} + \sum_{j=1}^{q}\theta_{1,5ij}\Delta L_{it-j} + \lambda_{1j}ECT_{it-1} + \mu_{1it} \tag{4}$$

$$\Delta REC_{it} = \theta_{2i} + \sum_{j=1}^{q}\theta_{2,1ij}\Delta Y_{it-j} + \sum_{j=1}^{q}\theta_{2,2ij}\Delta REC_{it-j} + \sum_{j=1}^{q}\theta_{2,3ij}\Delta O_{it-j} + \sum_{j=1}^{q}\theta_{2,4ij}\Delta K_{it-j} + \sum_{j=1}^{q}\theta_{2,5ij}\Delta L_{it-j} + \lambda_{2j}ECT_{it-1} + \mu_{2it} \tag{5}$$

$$\Delta O_{it} = \theta_{3i} + \sum_{j=1}^{q}\theta_{3,1ij}\Delta Y_{it-j} + \sum_{j=1}^{q}\theta_{3,2ij}\Delta REC_{it-j} + \sum_{j=1}^{q}\theta_{3,3ij}\Delta O_{it-j} + \sum_{j=1}^{q}\theta_{3,4ij}\Delta K_{it-j} + \sum_{j=1}^{q}\theta_{3,5ij}\Delta L_{it-j} + \lambda_{3j}ECT_{it-1} + \mu_{3it} \tag{6}$$

$$\Delta K_{it} = \theta_{4i} + \sum_{j=1}^{q}\theta_{4,1ij}\Delta Y_{it-j} + \sum_{j=1}^{q}\theta_{4,2ij}\Delta REC_{it-j} + \sum_{j=1}^{q}\theta_{4,3ij}\Delta O_{it-j} + \sum_{j=1}^{q}\theta_{4,4ij}\Delta K_{it-j} + \sum_{j=1}^{q}\theta_{4,5ij}\Delta L_{it-j} + \lambda_{4j}ECT_{it-1} + \mu_{4it} \tag{7}$$

$$\Delta L_{it} = \theta_{5i} + \sum_{j=1}^{q}\theta_{5,1ij}\Delta Y_{it-j} + \sum_{j=1}^{q}\theta_{5,2ij}\Delta REC_{it-j} + \sum_{j=1}^{q}\theta_{5,3ij}\Delta O_{it-j} + \sum_{j=1}^{q}\theta_{5,4ij}\Delta K_{it-j} + \sum_{j=1}^{q}\theta_{5,5ij}\Delta L_{it-j} + \lambda_{5j}ECT_{it-1} + \mu_{5it} \tag{8}$$

$$ECT_{it} = Y_{it} - \hat{\beta}_{1i}REC_{it} - \hat{\beta}_{2i}O_{it} - \hat{\beta}_{3i}K_{it} - \hat{\beta}_{4i}L_{it} \tag{9}$$

where Δ is the first difference operator; the autoregression lag length, *q*, is set at 2 and determined automatically by the Schwarz Information Criterion (SIC); μ is a random error term; *ECT* is the error correction term derived from the long-run relationship of Eq. (2). The significance of the error correction term and the short-run dynamics can be tested using t-statistic tests and Granger causality F-statistic tests, respectively.

Table 7. Granger causality tests (model with exports)

Dependent variable	Sources of causation (independent variables)					
	Short-run					**Long-run**
	ΔY	***ΔREC***	***ΔEX***	***ΔK***	***ΔL***	***ECT***
ΔY	-	0.35791 (0.6994)	2.67662 (0.0704)***	1.46351 (0.2330)	0.04431 (0.9567)	-0.040860 [-2.80796]*
ΔREC	0.32509 (0.7227)	-	1.33274 (0.2653)	0.57230 (0.5648)	0.27011 (0.7635)	0.006379 [0.89085]
ΔEX	2.92869 (0.0549)***	0.23770 (0.7886)	-	0.69971 (0.4975)	0.62006 (0.5386)	-0.209228 [-3.56748]*
ΔK	0.43421 (0.6482)	0.63494 (0.5306)	2.06257 (0.1289)	-	0.16158 (0.8509)	0.071416 [1.48251]
ΔL	0.61034 (0.5438)	0.56512 (0.5689)	1.35445 (0.2596)	1.08832 (0.3381)	-	-0.003168 [-1.65966]

"*" and "***" indicate statistical significance at the 1 and 10 percent level.
Lag lengths: 2.
P-value listed in parentheses and t-statistic listed in brackets.

Table 7 reports short-run and long-run causality results of Granger tests for exports specific model and indicates that there is evidence of bidirectional causality between output and exports at 10 percent level of significance in the short-run. However, there is no evidence of short-run causality between renewable energy and exports (or exports and renewable energy) and between output and renewable energy (or renewable energy and output). The error correction term is statistically significant for output and exports equations at 1 percent level indicating that there is evidence of *i)* long-run causality from renewable energy consumption, exports, capital and labor to output, and *ii)* long-run causality from output, renewable energy consumption, capital and labor to exports.

Table 8. Granger causality tests (model with imports)

Dependant variable	**Sources of causation (independent variables)**					
	Short-run					**Long-run**
	ΔY	***ΔREC***	***ΔIM***	***ΔK***	***ΔL***	***ECT***
ΔY	-	0.35791 (0.6994)	4.47685 (0.0121)**	1.46351 (0.2330)	0.04431 (0.9567)	-0.008055 [-2.98395]*
ΔREC	0.32509 (0.7227)	-	1.54622 (0.2147)	0.57230 (0.5648)	0.27011 (0.7635)	0.006933 [1.63208]
ΔIM	3.32819 (0.0371)**	0.62773 (0.5345)	-	0.25045 (0.7786)	1.95937 (0.1427)	-0.246238 [-3.84318]*
ΔK	0.43421 (0.6482)	0.63494 (0.5306)	1.95271 (0.1436)	-	0.16158 (0.8509)	0.066622 [1.71941]
ΔL	0.61034 (0.5438)	0.56512 (0.5689)	2.85333 (0.0592)***	1.08832 (0.3381)	-	0.015146 [3.45757]

"*", "**", and "***" indicate statistical significance at the 1, 5 and 10 percent level.
Lag lengths: 2.
P-value listed in parentheses and t-statistic listed in brackets.

Table 8 reports short-run and long-run causality results of Granger tests for imports specific model. In the short-run, there is evidence of bidirectional causality between output and imports at 5 percent level of significance, and a unidirectional causality running from imports to labor at 10 percent level of significance. However, there is no evidence of short-run causality between renewable energy and imports (or imports and renewable energy), and between output and renewable energy (or renewable energy and output). The error correction term is statistically significant for output and imports equations at 1 percent level indicating that there is evidence of *i)* long-run causality from renewable energy consumption, imports, capital and labor to output, and *ii)* long-run causality from output, renewable energy consumption, capital and labor to imports.

The last step consists in the long-run estimation of Eq. (2) where the dependent variable is real GDP or output, and the independent variables are renewable energy consumption, real exports (or imports), capital stock and labor force. The long-run structural coefficients are estimated using ordinary least square (OLS) and the fully modified OLS (FMOLS) panel approach (Pedroni, 2001, 2004). The estimation technique FMOLS is more efficient than OLS because it resolves the problem of endogeneity between independent variables.

Table 9. Panel OLS-FMOLS long-run estimates (model with exports)

Variables	***REC***	***EX***	***K***	***L***
OLS	0.032927 (0.0051)*	0.195382 (0.0000)*	0.468869 (0.0000)*	0.244243 (0.0000)*
FMOLS	0.034133 (0.1736)	0.195467 (0.0001)*	0.479936 (0.0000)*	0.236151 (0.0000)*

Cointegrating equation deterministics: intercept and trend.
Critical value at the 1 percent significance level denoted by "*".
All variables are measured in natural logarithms.

Table 9 reports the results for panel OLS and FMOLS long-run estimates for Eq. (2) with exports. It indicates that the coefficients of all variables are statistically significant at 1 percent level and have a positive impact on output, except the coefficient of renewable energy consumption, which is not statistically significant under FMOLS**.** For the FMOLS results, a 1 percent increase in exports increases output by 0.19 percent, a 1 percent increase in capital increases output by 0.48 percent, and 1 percent increase in labor increases output by 0.24 percent. The OLS long-run estimates produce almost similar and very close results than those estimated with FMOLS. However, with OLS, the coefficient of renewable energy consumption is statistically significant at 1 percent level, and indicates that a 1 percent increase in renewable energy consumption increases output by 0.03 percent.

Table 10. Panel OLS-FMOLS long-run estimates (model with imports)

Variables	***REC***	***IM***	***K***	***L***
OLS	0.052444 (0.0001)*	0.208838 (0.0000)*	0.508536 (0.0000)*	0.175659 (0.0000)*
FMOLS	0.053928 (0.0500)**	0.214332 (0.0012)*	0.515070 (0.0000)*	0.163482 (0.0008)*

Cointegrating equation deterministics: intercept and trend.
Critical values at the 1 and 5 percent significance level are denoted by "*" and "**", respectively.
All the variables are measured in natural logarithms.

Table 10 gives the results for panel OLS and FMOLS long-run estimates for Eq. (2) with imports. It indicates that the estimated coefficients of all variables are statistically significant at 1 percent level, excepted the FMOLS coefficient of renewable energy consumption, which is statistically significant at 5 percent level. The results estimated by OLS and FMOLS are similar and very close and show that each dependent variable has a positive impact on output. For the FMOLS results, a 1 percent increase in renewable energy consumption increases output by 0.05 percent, a 1 percent increase in imports increases output by 0.21 percent, a 1 percent increase in capital increases output by 0.51 percent, and a 1 percent increase in labor increases output by 0.16 percent.

6. Conclusion

This paper is an attempt to explore the relationship between renewable energy consumption, trade and output for 11 African countries during the period 1980-2008. Exploring renewable energy and trade in Africa is interesting because many studies underline the great potential of Africa regarding renewable energy production and consumption, and because the use of renewable energy is linked to the transfer of technology which is directly linked to international trade. The aim of this study is to determine whether international trade in African countries has an impact on renewable energy consumption. Our specific model is similar to that developed by Sadorsky (2012) in which he estimates the impact of trade on energy consumption in a sample of 7 South American countries.

In this way, our analysis starts by proving the stationarity of variables from Breitung (2000) unit root test. Given that all variables are stationary and integrated at order one, I(1), we run Pedroni (2004) and Kao (1999) for panel cointegration test to know whether variables are cointegrated or not. Then, we investigate the short-run and the long-run dynamic relationship between variables by employing the Engle and Granger (1987) test. Lastly, long-run structural coefficients are estimated using OLS and the FMOLS panel approach (Pedroni, 2001, 2004).

The Granger causality test indicates that there is evidence of bidirectional causality between output and trade (exports or imports) in the short and in the long-run relationship. Also, in the short-run, there is a one way causality running from imports to labor force. However, there is no evidence of causality between renewable energy consumption and trade or between renewable energy consumption and output, in the short-term. These empirical results mean that, in the short-term, international trade has a positive impact on the real GDP of the sample of 11 African countries studied. They confirm previous studies and international organizations' recommendations that international trade is beneficial for developing countries because of, among other things, the technology transfer gained through trade. Also, it seems that international trade helps the transfer of technologies, but a relatively long time is needed for African countries to build the human and physical capacities needed to produce renewable energies.

Long-run elasticities estimated show that renewable energy consumption and trade (exports or imports) have a positive impact statistically significant on real GDP. A 1 percent increase in renewable energy consumption or in exports increases real GDP by 0.03 percent or 0.19 percent, respectively. A 1 percent increase in renewable energy consumption or in imports increases output by 0.05 and 0.20 percent, respectively. It seems evident that, in the long-term, international trade enables African countries to benefit from technology transfer and to build the human and physical capacities needed to produce renewable energies, which in turn increases their real GDP.

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