Output, renewable energy consumption and international trade: Evidence from a panel of 69 countries

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Abstract: This paper uses panel cointegration techniques to examine the causal relationship between output, renewable energy consumption and international trade for a sample of 69 countries during the period 1980-2007. In the short-run, Granger causality tests show that there is evidence of bidirectional causality relationship between output and trade (exports or imports), and a unidirectional causality relationship running from renewable energy consumption to trade. However, in the short-run, there is evidence of no causality running from trade to renewable energy consumption. In the long-run, the error correction term provides that there is evidence of bidirectional causality relationship between output, trade and renewable energy consumption. Long-run estimations show that all coefficients are positive and statistically significant. Policies recommendations are that, in the long-run, international trade enables countries to benefit from technology transfer and to build the human and physical capacities needed to produce more renewable energies, while increasing their output. Therefore, more trade openness could be a good policy for combating global warming as it incites the use of renewable energies.

Keywords: Renewable electricity consumption; Trade openness; Panel cointegration.
JEL Classification: C33, F14, Q43

1. Introduction

This paper investigates the interaction between international trade and renewable energy consumption by considering a panel of 69 countries. This investigation is interesting because the causal relationship between renewable energy and international trade has not been previously studied. Nevertheless, it is admitted that the use of renewable energy is linked to technology transfer, which is directly linked to international trade. The Rio and Johannesburg conferences recognized that trade helps achieving more efficient allocation of scarce resources, makes it easier for rich and poor countries to access environmental goods, services and technologies (World Trade Organization, 2011).

Several empirical studies analyze the causal relationship between economic growth and the consumption of renewable energy (e.g. Apergis and Payne, 2010a, 2010b, 2011, 2012; Sadorsky, 2009b). Another group of papers analyze the causal relationship between economic growth, renewable energy consumption and CO_2 emissions (e.g. Sadorsky, 2009a). All these studies support that renewable energy consumption plays an important role in increasing economic growth. Moreover, an energy policy planned to increase the share of renewable energy in total energy consumption is very effective in reducing greenhouse gas emissions. In addition to capital, labor, and renewable energy consumption, other variables such as trade openness can be incorporated in the production function to explain the growth of gross domestic product (GDP). Trade openness can be defined as exports, or imports, or the sum of both divided by the value of GDP.

Several papers study the causal relationship between energy consumption (total energy use), international trade, and output. Lean and Smyth (2010a) study the dynamic relationship between economic growth, electricity production, exports and prices in Malaysia. Granger causality tests show the existence of a unidirectional causality running from economic growth to electricity production. Lean and Smyth (2010b) study the causal relationship, in Malaysia, between output, electricity consumption, exports, labor, and capital in a multivariate model. They show the existence of bidirectional causality between output and electricity consumption. They come to the conclusion that Malaysia should adopt the strategy of increasing investment in electricity infrastructure and encouraging electricity conservation policies to reduce unnecessary use of electricity. Narayan and Smyth (2009) come to the same conclusion for a sample of Middle East countries and find feedback effects between electricity consumption, exports and GDP. Sadorsky (2011) uses panel cointegration techniques for 8 Middle East countries to study how trade can affect energy consumption. He finds Granger causality running from exports to energy consumption and bidirectional causality between imports and energy consumption in the short-run. In the long-run, he finds that an increase in both exports and imports affect the demand of energy. Another study on a sample of 7 South American countries, Sadorsky (2012), confirms the long-run causality between trade and energy consumption. He concludes that environmental policies made to reduce energy consumption will reduce trade.

To the best of our knowledge, there is no study that tries to evaluate the causal relationship between international 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 69 countries.

This study has the following structure. Section 2 gives an idea about the renewable energy sector and international trade. Section 3 describes the data used. Section 4 deals with the methodology used and the empirical analysis. Finally, Section 5 concludes.

2. Renewable energy and international trade

According to the International Energy Agency (2012), more than 70 countries are expected to use renewable energy technologies in the power sector by 2017. One policy driver is environmental concerns which aim to reduce the emission of carbon dioxide (CO_2) and local pollutants. Renewables are also encouraged to stimulate economies, reinforce energy security and diversify energy consumption. Renewable energies have been used principally by the electricity sector, followed by biofuels. In most cases, subsidies are needed because renewables are still more expensive than conventional energy sources.

Renewable energy use, including traditional biomass, was 1 684 million tons of oil equivalent (Mtoe) in 2010 representing 13% of total primary energy use. This share has remained stable since 2000, but contributions of the different renewable sources have changed. The share of traditional biomass in total renewable energy decreased from 50% in 2000 to 45% in 2010, while biofuels made an increasing share in the transportation fuel needs. The share of hydropower, the largest source of renewable electricity, remained stable. The most important increases are those of electricity generation from wind which increased by 27% and solar photovoltaic (PV) which increased by 42% per year on average during the period 2000-2010. The renewables sector has been affected by the international economic crisis. However, weaker performances in some regions, for example, in some regions in Europe and the United States, have been largely offset by important increase in the rest of the world, notably in Asia.

Because of government support, decreasing costs, CO2 pricing in some regions, and rising fossil fuel prices in the long-term, the International Energy Agency (2012) estimates that the share of renewables in primary energy use will increase. Electricity generation from renewable will approximately triple from 2010 to 2035, attaining 31% of total production. In 2035, hydropower will provide half of renewable production, wind nearly one-quarter and solar photovoltaic 7.5%. Solar PV production will increase 26-fold from 2010 to 2035. The use of renewables is expected to reduce CO2 emissions by over than 4.1 Gt in 2035, contribute to the diversification of the energy sources, lower oil and gas import bills, and diminish air pollution.

The United Nations Environment Program and the World Trade Organization (2009) consider that the 60 years prior to 2008 have been marked by a considerable expansion of international trade. In terms of volume, world trade is approximately 32 times greater now than it was in 1950. The share in total GDP increased from 5.5 per cent in 1950 to 21 per cent in 2007. This considerable expansion in world trade has been encouraged by technological progress, which has considerably reduced the costs of transportation and communications, and by the use by countries of more open trade and investment policies. The number of countries participating in international trade has increased. For instance, developing countries have approximately doubled their share in international trade in the last 60 years. This expansion in international trade poses questions about its impact on greenhouse gas emissions. The impact of trade on pollution can be explained by three principal effects, which are the scale, composition and technique effects. International trade can be used as a channel for diffusing technologies, especially from developed to developing countries, to combat climate change. International trade can increase the availability of goods and services that are more energy efficient. The increase in income made possible by trade openness can lead to a demand for a better environmental quality and to a diminution of greenhouse gas emissions.

In conclusion, the production of renewable energies is increasing in all parties of the world and this is the same for international trade. It is admitted that international trade helps the use and diffusion of renewable technologies. However, this should be verified empirically.

3. Data

The data set is a panel of 69 countries followed over the years 1980-2007 and includes annual data on renewable electricity consumption, capital, labor, exports, and imports. The Appendix lists the 69 countries included in the analysis and they are distributed on the five continents. Annual time series data are chosen to include as many countries as possible by taking into account the availability of data over the selected period. The multivariate framework for the analysis includes real gross domestic product (GDP, output) measured in constant 2000 US dollars. Renewable energy consumption (RE) is the total renewable electricity consumption measured in millions of kilowatt hours. Exports (imports) are measured using merchandise exports (imports) 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 the total number of labor force. Data on exports, imports, capital and labor are obtained from the World Bank (2010). Data on renewable energy consumption are obtained from the U.S. Energy Information Administration (2012), and those on PC are obtained from the Penn World Table version 7.1 (Heston *et al.*, 2012). All estimations are made with Eviews 7.0.

4. Methodology and empirical analysis

Following Lean and Smith (2010a, 2010b) and Sadorsky (2012), we estimate the relationship between energy consumption, output and trade by using the production function. The model in Sadorsky (2012) includes exports and imports in two separate empirical models, while the models in Lean and Smith (2010a, 2010b) includes only exports. In the present paper, we follow the same specification model than Sadorsky (2012) to investigate the relationship between renewable energy consumption, output and trade.

The production modeling framework given below shows that output (Y) is written as a function of renewable energy (RE), trade openness (*O*)[1], capital (*K*), and labor (*L*):

$$Y_{it} = f(RE_{it}, O_{it}, K_{it}, L_{it}) \qquad (1)$$

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

$$Y_{it} = \alpha_i + \delta_i t + \beta_{1i} RE_{it} + \beta_{2i} O_{it} + \beta_{3i} K_{it} + \beta_{4i} L_{it} + \varepsilon_{it} \qquad (2)$$

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 effect and deterministic trends, respectively.

To examine the relationship between renewable energy consumption and trade for a sample of 69 countries, we use panel cointegration techniques. These techniques are interesting because estimations from cross-sections of time series have more freedom degrees and are more efficient than estimations from individual time series. Panel cointegration techniques are particularly useful when the time series dimension of each cross-section is short. Our empirical analysis follows four steps: i) we proceed panel unit root tests for stationarity, ii) we look for long-term cointegration between variables, iii) we study the causality between variables using Engle and Granger (1987) approach, iv) we estimate the long-run relationships between variables.

4.1. Stationarity tests

To check the stationarity properties of each variable, we will perform two types of panel unit root tests. The first test is proposed by Breitung (2000) and presumes that there is a common unit root process across the cross-section. The second test is proposed by Im *et al.* (2003) and presumes that there is an individual unit root process across the cross-section. For these two tests, the null hypothesis is that there is a unit root and the alternative hypothesis is that there is no unit root. We assume that all unit root tests regressions contain only intercept and no deterministic trend. The results of unit root tests are reported in Table 1.

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

Table 1. Panel unit root tests

Panel unit root test method	Breitung t-stat	Im, Pesaran and Shin W-stat
Y	2.00693	16.9322
	(0.9776)	(1.0000)
ΔY	-13.4559	-20.7862
	(0.0000)*	(0.0000)*
RE	-2.80676	-2.04254
	(0.0025) *	(0.0205)
ΔRE	-18.3052	-37.1259
	(0.0000)*	(0.0000)*
K	-0.52587	8.83988
	(0.2995)	(1.0000)
ΔK	-15.6482	-23.0878
	(0.0000)*	(0.0000)*
L	4.76046	3.47584
	(1.0000)	(0.9997)
ΔL	-3.67124	-12.7521
	(0.0001)*	(0.0000)*
EX	0.47128	9.92898
	(0.6813)	(1.0000)
ΔEX	-16.2233	-30.3572
	(0.0000)*	(0.0000)*
IM	-1.48515	14.2231
	(0.0688)	(1.0000)
ΔIM	-21.0201	-29.9565
	(0.0000)*	(0.0000)*

Null hypothesis: Unit root.
All unit root tests regressions are run with intercept.
P-value listed in parentheses. Critical value at the 1 percent level denoted by "*".
Automatic lag length selection based on SIC (Schwarz Information Criteria).

Table 1 indicates that, at level, there is a unit root for *Y*, *K*, *L*, *EX*, and *IM* panel data series, while after first difference, all these variables are integrated of order one. For *RE* data series, the result from the Breitung (2000) test provides that there is no evidence of a unit root at level, while the result from Im *et al.* (2003) test indicates the presence of unit root at 1 percent level significance. The two tests indicate that *RE* is stationary at the first difference. In summary, the Im et *al.* (2003) test indicates that all variables have a unit root at 1 percent level, and both the Breitung (2000) and Im et *al.* (2003) tests show that all variables are integrated of order one I(1).

4.2. Cointegration tests

To check for cointegration in a heterogeneous panel, we use the tests of Pedroni (1999, 2004) and Kao (1999). Pedroni (2004) proposes seven statistics distributed on two sets of cointegration tests. The first set comprises four statistics and includes 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 set comprises three statistics and includes rho-statistic, PP-statistic, and ADF statistic. These tests are classified on the between-dimension and are 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 the residual of Eq. (2). We assume that tests are running with individual intercept and deterministic trend. The results from the tests for the data set for the model with exports and the model with imports are reported in Tables 2 and 3, respectively.

Table2. Pedroni cointegration tests (with exports)

Alternative hypothesis: common AR coefs. (within-dimension)				
			Weighted	
	Statistic	Prob.	Statistic	Prob.
Panel v-Statistic	4.269584	0.0000*	4.556405	0.0000*
Panel rho-Statistic	2.998403	0.9986	2.793275	0.9974
Panel PP-Statistic	-3.824837	0.0001*	-4.582789	0.0000*
Panel ADF-Statistic	-4.298267	0.0000*	-5.125621	0.0000*
Alternative hypothesis: individual AR coefs. (between-dimension)				
	Statistic	Prob.		
Group rho-Statistic	5.459964	1.0000		
Group PP-Statistic	-5.053143	0.0000*		
Group ADF-Statistic	-6.203061	0.0000*		

Null Hypothesis: No cointegration
Trend assumption: Deterministic intercept and trend.
Critical value at the 1 percent significance level denoted by "*".
Automatic lag length selection based on SIC with a max lag of 5.
Newey-West automatic bandwidth selection and Bartlett kernel.

Table 2 indicates that, for the model with exports, three panel statistics among the four used of the within-dimension, reject the null hypothesis of no cointegration at the 1 percent level and approve that there is evidence of cointegration between variables. Two statistics among the three used of the between-dimension reject the null hypothesis of no cointegration at the 1 percent level and approve the existence of cointegration between variables. Therefore, the Pedroni (2004) tests confirm the existence of long-term cointegration between the variables of the model with exports.

Table 3. Pedroni cointegration tests (with imports)

Alternative hypothesis: common AR coefs. (within-dimension)				
			Weighted	
	Statistic	Prob.	Statistic	Prob.
Panel v-Statistic	4.991274	0.0000*	5.034122	0.0000*
Panel rho-Statistic	3.652326	0.9999	3.489442	0.9998
Panel PP-Statistic	-2.168519	0.0151**	-3.054140	0.0011*
Panel ADF-Statistic	-2.756677	0.0029*	-4.107505	0.0000*
Alternative hypothesis: individual AR coefs. (between-dimension)				
	Statistic	Prob.		
Group rho-Statistic	6.203968	1.0000		
Group PP-Statistic	-2.628138	0.0043*		
Group ADF-Statistic	-3.911402	0.0000*		

Null Hypothesis: No cointegration
Trend assumption: Deterministic intercept and trend.

Critical value at the 1 percent and 5 percent significance level denoted by "*" and "**", respectively.
Automatic lag length selection based on SIC with a max lag of 5.
Newey-West automatic bandwidth selection and Bartlett kernel.

For the model with imports, Table 3 indicates that, among the four used statistics of the within-dimension, two panel statistics reject the null hypothesis of no cointegration at the 1 percent level and one statistic rejects the null hypothesis of no cointegration at the 5 percent level. Two statistics among the three used from the between-dimension reject the null hypothesis of no cointegration at the 1 percent level. Thus, the Pedroni (2004) tests confirm the existence of long-term cointegration between the variables of the model with imports.

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

Table 4. Kao cointegration test (with exports)

	t-Statistic	Prob.
ADF	-6.661170	0.0000*

Null Hypothesis: No cointegration.
Trend assumption: No deterministic trend.
Automatic lag length selection based on SIC with a max lag of 6.
Critical value at the 1 percent significance level denoted by "*".
Newey-West automatic bandwidth selection and Bartlett kernel.

Table 5. Kao cointegration test (with imports)

	t-Statistic	Prob.
ADF	-6.579141	0.0000*

Null Hypothesis: No cointegration.
Trend assumption: No deterministic trend.
Automatic lag length selection based on SIC with a max lag of 6.
Critical value at the 1 percent significance level denoted by "*".
Newey-West automatic bandwidth selection and Bartlett kernel.

Tables 4 and 5 show that, for the model with exports and that with imports, the cointegration test of Kao (1999) rejects the null hypothesis of non cointegration at the 1 percent significance level. Thus, the Kao (1999) test approves that all variables are cointegrated in the long-run for both the models with exports and with imports.

4.3. Causality tests

Given that the residual cointegration tests of Pedroni (1999, 2004) and Kao (1999) show the existence of long-run relationship between variables for the two specific models (exports or imports), then the approach of Engle and Granger (1987) can be used to estimate the error correction model.

The estimation of the dynamic vector error correction model (VECM) is given as follows:

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

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

$$\Delta O_{it} = \theta_{3i} + \sum_{j=1}^{q}\theta_{3,1ij}\Delta Y_{it-j} + \sum_{j=1}^{q}\theta_{3,2ij}\Delta RE_{it-j} + \sum_{j=1}^{q}\theta_{3,3ij}\Delta O_{it-j} + \sum_{j=1}^{q}\theta_{3,4ij}\Delta K_{it-j} + \sum_{j=1}^{q}\theta_{3,5ij}\Delta L_{it-j}$$
$$+\lambda_{3i}ECT_{it-1} + \mu_{3it} \quad (5)$$
$$\Delta K_{it} = \theta_{4i} + \sum_{j=1}^{q}\theta_{4,1ij}\Delta Y_{it-j} + \sum_{j=1}^{q}\theta_{4,2ij}\Delta RE_{it-j} + \sum_{j=1}^{q}\theta_{4,3ij}\Delta O_{it-j} + \sum_{j=1}^{q}\theta_{4,4ij}\Delta K_{it-j} + \sum_{j=1}^{q}\theta_{4,5ij}\Delta L_{it-j}$$
$$+\lambda_{4i}ECT_{it-1} + \mu_{4it} \quad (6)$$
$$\Delta L_{it} = \theta_{5i} + \sum_{j=1}^{q}\theta_{5,1ij}\Delta Y_{it-j} + \sum_{j=1}^{q}\theta_{5,2ij}\Delta RE_{it-j} + \sum_{j=1}^{q}\theta_{5,3ij}\Delta O_{it-j} + \sum_{j=1}^{q}\theta_{5,4ij}\Delta K_{it-j} + \sum_{j=1}^{q}\theta_{5,5ij}\Delta L_{it-j}$$
$$+\lambda_{5i}ECT_{it-1} + \mu_{5it} \quad (7)$$
$$ECT_{it} = Y_{it} - \hat{\beta}_{1i}RE_{it} - \hat{\beta}_{2i}O_{it} - \hat{\beta}_{3i}K_{it} - \hat{\beta}_{4i}L_{it} \quad (8)$$

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).

To investigate the short-run and long-run dynamic relationships between variables, we follow the two steps of Engle and Granger (1987) approach. We first estimate the long-run parameters in Eq. (2) in order to get the residuals corresponding to the deviation from equilibrium. Second, we estimate the parameters related to the short-run adjustment of Eqs. (3)-(7). Short-run causality is determined by the significance of F-statistics and the long-run causality corresponding to the error correction term is determined by the significance of t-statistics. The Granger causality tests are reported in Tables 6 and 7.

Table 6. Granger causality tests (model with exports)

Dependent variable	**Sources of causation (independent variables)**					
	Short-run					**Long-run**
	ΔY	*ΔRE*	*ΔEX*	*ΔK*	*ΔL*	*ECT*
ΔY	-	0.24932	8.53160	0.48520	3.21340	-0.074078
		(0.7794)	(0.0002)*	(0.6157)	(0.0404)**	(0.0034)*
ΔRE	1.38652	-	1.16109	0.88437	0.60815	0.000474
	(0.2502)		(0.3134)	(0.4131)	(0.5445)	(0.0543)***
ΔEX	18.2503	3.31759	-	16.4526	0.71187	-0.060183
	(0.0000)*	(0.0364)**		(0.0000)*	(0.4909)	(0.0000)*
ΔK	4.87454	0.78289	2.58096	-	1.36636	-0.004324
	(0.0077)*	(0.4572)	(0.0760)***		(0.2553)	(0.9040)
ΔL	0.15877	0.04352	1.81553	0.10264	-	-0.002738
	(0.8532)	(0.9574)	(0.1630)	(0.9025)		(0.0088)*

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

For the panel VECM with exports, short-run Granger causality tests show for the principal variables (output, renewable energy consumption, exports) that there is evidence of bidirectional causality between output and exports at the 1 percent level, and unidirectional causality running from renewable energy consumption to exports at the 5 percent level. However, there is no evidence of short-run causality between output and renewable energy.

Given that renewable energy consumption Granger causes exports and exports Granger causes output, we can deduce that there is evidence of an indirect causality relationship from renewable energy consumption to output that runs through exports.

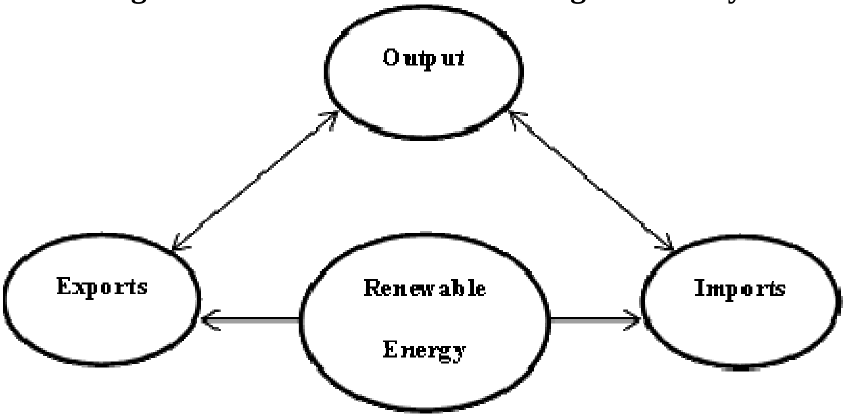
Table.7 Granger causality tests (model with imports)

Dependent variable	Sources of causation (independent variables)					
	Short-run					**Long-run**
	ΔY	*ΔRE*	*ΔIM*	*ΔK*	*ΔL*	*ECT*
ΔY	-	0.24932	7.13715	0.48520	3.21340	-0.063833
		(0.7794)	(0.0008)*	(0.6157)	(0.0404)**	(0.0036)*
ΔRE	1.38652	-	0.64795	0.88437	0.60815	-0.001608
	(0.2502)		(0.5232)	(0.4131)	(0.5445)	(0.0160)**
ΔIM	18.3334	2.91844	-	13.5292	1.36636	-0.065202
	(0.0000)*	(0.0543)***		(0.0000)*	(0.2553)	(0.0000)*
ΔK	4.87454	0.78289	2.28826	-	1.36636	0.008115
	(0.0077)*	(0.4572)	(0.1017)		(0.2553)	(0.8095)
ΔL	0.15877	0.04352	1.27866	0.10264	-	-0.000222
	(0.8532)	(0.9574)	(0.2786)	(0.9025)		(0.0079)*

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

For the panel VECM with imports, short-run Granger causality tests show that there is evidence of bidirectional causality between output and imports at the 1 percent level and unidirectional causality running from renewable energy consumption to imports at the 10 percent level. There is no evidence of short-run causality between output and renewable energy consumption. Given that renewable energy consumption Granger causes imports and imports Granger causes output, we can deduce that there is evidence of an indirect short-run causality relationship from renewable energy to output that runs through imports. In Fig. 1, we resume the short-run Granger causality for the two models (exports or imports).

Fig.1. Direction of short-run Granger causality



With his research focalized on the causal relationship between energy consumption (total energy used) and trade (exports or imports), Sadorsky (2012) find similar results than ours concerning the causal relationship between renewable energy consumption and trade. Indeed, in the short-run, the Granger causality tests in Sadorsky (2012) show the presence of bidirectional causality between output and trade (exports or imports) and between energy consumption and exports, and a one way relationship from energy consumption to imports. He also shows no evidence of a direct causality between output and energy consumption, but there is only an indirect causality between them through trade.

From the model with exports and that with imports, we do not find evidence of (direct) short-run causality between output and renewable energy. These results are not similar to those found by Apergis and Payne (2010a, 2012) as they show the existence of a short-run bidirectional relationship between renewable energy and output. These differences in results can be explained by two main reasons: the first is that the data used in our study differ from those used by Apergis and Payne (2010a, 2012), and the second is that we incorporate in our study trade as an explanatory variable.

In the short-run, Granger causality tests provide that there is evidence of an indirect and unidirectional causality running from renewable energy to output, which occurs through trade (exports or imports). This result is very interesting and shows that renewable energy consumption has an impact on both trade and output.

In the long-run, the error correction term is statistically significant at the 1 percent level for Eqs. (3), (5) and (7). For the model with exports and that with imports, it is statistically significant for Eq. (4) at levels 10 percent and 5 percent, respectively. Thus, there is evidence of long-run causality: *i)* from renewable energy, exports or imports, capital, and labor to output, *ii)* from exports or imports, output, capital, and labor to renewable energy, *iii)* from renewable energy, output, capital, and labor to exports or imports, and *iv)* from renewable energy, output, exports or imports, and capital to labor.

4.4. Long-run estimations

The final 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 squares (OLS), fully modified OLS (FMOLS) (Pedroni 2001, 2004), and Dynamic OLS (DOLS) reformed by Kao and Chiang (2000) and Mark and Sul (2003) to the case of panel data. While FMOLS estimation technique resolves the problem of endogeneity between independent variables and the problem of correlation between estimators, DOLS estimation technique eliminates the problem of correlation between independent variables and residuals. The results of long-run estimates for the model with exports and that with imports are reported in Table 8 and Table 9, respectively.

Table 8. Panel OLS-FMOLS-DOLS long-run estimates (model with exports)

Variables	*RE*	*EX*	*K*	*L*
OLS	0.038190 (0.0000)*	0.055065 (0.0000)*	0.802286 (0.0000)*	0.104571 (0.0000)*
FMOLS	0.038312 (0.0001)*	0.030624 (0.1307)	0.849781 (0.0000)*	0.080197 (0.0000)*
DOLS	0.038190 (0.0002)*	0.055065 (0.0072)*	0.802286 (0.0000)*	0.104571 (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 8 indicates that all coefficients are positive and statistically significant at the 1 percent level significance, exception for exports with FMOLS estimation. The long-run estimations with OLS and DOLS are the same, and the FMOLS long-run estimations produce almost similar and very close results than those estimated with OLS or DOLS. Using DOLS results, we can say that, in the long-run, a 1 percent increase in renewable energy consumption, increases output by 0.04 percent, and a 1 percent increase in exports, increases output by 0.05 percent.

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

Variables	*RE*	*IM*	*K*	*L*
OLS	0.040648 (0.0000)*	0.071702 (0.0000)*	0.794970 (0.0000)*	0.098109 (0.0000)*
FMOLS	0.040791 (0.0001)*	0.064964 (0.0061)*	0.825714 (0.0000)*	0.074405 (0.0000)*
DOLS	0.040648 (0.0001)*	0.071702 (0.0028)*	0.794970 (0.0000)*	0.098109 (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 indicates that all coefficients are positive and statistically significant at the 1 percent significance level. The long-run estimations with OLS and DOLS are identical, and the FMOLS long-run estimations produce almost similar and very close results than those obtained with OLS or DOLS. In the long-run, FMOLS results show that a 1 percent increase in renewable energy consumption increases output by 0.04 percent, and 1 percent increase in imports increases output by 0.06 percent. Using DOLS results, we can say that, in the long-run, a 1 percent increase in renewable energy consumption, increases output by 0.04 percent, and a 1 percent increase in imports, increases output by 0.07 percent. The estimations for the model with exports and that with imports are very close and lead to the same conclusions.

5. Concluding remarks

This study has extended research by studying the causal relationship between output, renewable energy consumption and trade for a panel data of 69 countries over the period 1980-2007. This study is interesting because there is no previous work that tried to understand the causal relationship between international trade and renewable energy consumption.

We consider two models, and in each model the dependant variable is GDP (output). Independent variables are renewable energy consumption, trade openness, stock of capital and labor force. In the first model, trade openness is measured by merchandise exports, and in the second model, it is measured by merchandise imports.

In the short-run, Granger causality tests show that there is evidence of bidirectional causality between output and trade (exports or imports). These results indicate that, in the short-run, any changes in trade affect output and any changes in output affect trade. Also, there is evidence of one way short-run causality running from renewable energy consumption to trade. This result means that, in the short-run, any change in the consumption of renewable energy affects exports and imports. There is no direct short-run causality between renewable energy consumption and output. However, there is an indirect short-run causality running from renewable energy to output running via trade. Thus, in the short-run, renewable energy consumption has an impact on output.

In the long-run, the error correction term provides that there is evidence of bidirectional causality relationship between output, trade and renewable energy consumption. In our long-run estimations, output is the dependant variable. Long-run elasticities are estimated using

OLS, FMOLS and DOLS panel approaches. The results of estimations show that all coefficients are positive and statistically significant at the 1 percent level, exception for exports coefficient which is not statistically significant with FMOLS panel approach. Therefore, in the long-run, any increase in one of the three variables: renewable energy consumption, trade (exports or imports) and output, increases the other two variables. For instance, more trade openness, results in an increase in renewable energy consumption and in growth.

Policies recommendations planned for the long-run should consider that trade openness enables countries to benefit from technology transfer and enables them to build the human and physical capacities needed to produce more renewable energies, while increasing their GDP. Therefore, more trade openness could be a good policy for combating global warming as it incites the use of renewable energies.

Appendix: 69 countries sample

Algeria, Argentina, Australia, Austria, Bangladesh, Belgium, Bolivia, Brazil, Bulgaria, Cameroon, Canada, Chile, China, Comoros, Costa Rica, Denmark, Dominican Republic, Ecuador, Egypt, El Salvador, Finland, France, Gabon, Ghana, Greece, Guatemala, Honduras Hungary, Iceland, India, Indonesia, Iran, Ireland, Italy, Japan, Kenya, Korea Rep, Malawi, Malaysia, Mali, Mauritius, Mexico, Morocco, Mozambique, Netherlands, New Zealand, Nicaragua, Norway, Pakistan, Panama, Paraguay, Peru, Philippines, Portugal, South Africa, Spain, Sri Lanka, Sudan, Swaziland, Sweden, Switzerland, Syria, Thailand, Tunisia, United Kingdom, United States, Uruguay, Venezuela, Zambia.

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