Output, renewable and non-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 and non-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 a bidirectional causality between output and trade (exports or imports), a bidirectional causality between non-renewable energy and trade, and a one way causality running from renewable energy to trade. In the long-run, a bidirectional causality between renewable energy and imports and a unidirectional causality running from renewable energy to exports, are noticed. Our long-run OLS, FMOLS and DOLS estimates suggest that renewable, non-renewable energy consumption and trade have a positive impact on economic growth. Our energy policy recommendations are the following: *i)* any non-renewable energy policy should take into account the importance of international trade, *ii)* more renewable energy use should be encouraged by national and international competent

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authorities in order to increase international economic exchanges and promote economic growth without harming the environment, and *iii)* increasing imports, particularly by developing countries, is a good vehicle for renewable energy technology transfer and contributes to increase renewable energy consumption in the long-run, thus contributing to reducing greenhouse gas emissions.

Keywords: Renewable and non-renewable electricity consumption; Trade; Panel cointegration.

JEL Classification: C33, F14, Q43

1. Introduction

This paper investigates the interaction between international trade and renewable and non-renewable energy consumption by considering a panel of 69 countries. This investigation is interesting because the causal relationship between renewable and non-renewable energy and international trade has not been previously studied. Nevertheless, it is admitted that the use of renewable energy, particularly by developing countries, is greatly influenced by technology transfer, which mainly operates through international economic exchanges. The Rio and Johannesburg conferences recognize that trade helps to achieve more efficient allocation of scarce resources and facilitates the access of rich and poor countries to environmental goods, services and technologies (World Trade Organization, 2011).

Several empirical studies analyze the causal relationship between economic growth and consumption of renewable energy (Apergis and Payne, 2010a, 2010b, 2011, 2012, Sadorsky, 2009b). Other research papers analyze the causal relationship between economic growth, renewable energy consumption and carbon dioxide (CO_2) emissions (Sadorsky, 2009a). All these studies agree that renewable energy consumption plays an important role in increasing economic growth. Moreover, an energy policy 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 international trade can be incorporated into the production function to explain the growth of gross domestic product (GDP).

Many studies investigate 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 a bidirectional causality between output and electricity consumption. They conclude that Malaysia should adopt the strategy of increasing investment in electricity infrastructure and encouraging electricity conservation policies to reduce unnecessary use of electricity. Similarly, Narayan and Smyth (2009) find feedback effects between electricity consumption, exports and GDP, for a sample of Middle East countries. Sadorsky (2011) uses panel cointegration techniques for 8 Middle East countries to study how trade can affect energy consumption. He finds a Granger causality running from exports to energy consumption and a bidirectional causality between imports and energy consumption in the short-run. In the long-run, he notices that an increase in both exports and imports affect the energy demand. In another paper, Sadorsky (2012) confirms the long-run causality between trade and energy consumption using a sample of 7 South American countries. He concludes that environmental policies made to reduce energy consumption will reduce trade.

Ben Aïssa et al. (2014) explore the relationship between renewable energy consumption, trade and output for 11 African countries. They show that there is a bidirectional causality between output and trade (exports or imports) in both the short and long-run. However, in the short-run, these authors find that there is no causality between output and renewable energy consumption and between trade and renewable energy consumption. The present paper differs from that of Ben Aïssa et al. (2014) by the inclusion of non-renewable energy consumption as a dependent variable, and by considering another panel of countries.

To our knowledge, no research has been reported on the causal relationship between international trade, renewable and non-renewable energy consumption. The aim of this paper is to explore the causal relationship between renewable energy consumption, non-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 methods used. Section 4 deals with the results and their discussions. Finally, Section 5 presents the main conclusions and policy implications.

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 CO_2 emissions 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 1684 million tons of oil equivalent (Mtoe) in 2010 representing 13% of total primary energy use (International Energy Agency, 2012). This share has remained stable since 2000, but the contributions of 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 renewable sector has been affected by the international economic crisis. However, weaker performances in some regions in Europe and United States for example, have been largely offset by an important increase in the rest of the world, notably in Asia.

Because of governments support, decreasing costs, CO_2 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 PV 7.5%. Solar PV production will increase 26-fold from 2010 to 2035. The use of renewables is expected to reduce CO_2 emissions by over than 4.1 Gt in 2035, contribute to the diversification of the energy sources, reduce oil and gas import bills, and decrease 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% in 1950 to 21% 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 countries' use 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 better environmental quality and a reduction in greenhouse gas emissions.

It is admitted that international trade and renewable energy consumption are linked. International trade can induce more renewable energy use, for many reasons: *i)* more trade in goods necessitates more energy and renewable energy use to produce and transport these goods from one country to another, *ii)* because of economies of scale and technology progress, the price of equipments (for instance solar PV and onshore wind power) used to produce renewable energy have considerably reduced pushing companies to explore new markets. This makes renewables more affordable for a larger range of consumers throughout the world (United Nations Environment Program 2013a), and *iii)* international trade can play a significant role in greening the energy sector as it is an important vehicle for renewable energy technology transfer. Indeed, international technology transfer through trade occurs when a country imports capital goods, such as machines and equipment to produce renewable energy. Local firms of the importing country can copy the technology of the imported goods, or acquire knowledge, through training sessions for engineers and technicians operating the production line, as customer or distributor, or through business relationships with the source company. As an example, China has mainly acquired foreign technologies to create a domestic PV industry mostly through the international trade of manufacturing equipments (De la Tour et al., 2011). Consequently, China is the largest solar PV cell producer in the world, with more than one third of worldwide production in 2008, exporting more than 95 percent of what it produces.

More renewable energy production can stimulate international trade for many reasons: *i)* the use of more renewable energy implies more production of goods and the excess of production in some countries is exported to importing countries, *ii)* according to the United Nations Environment Program (2013a), there is a surplus in renewable energy production in some regions in the world, whereas a deficiency in renewable energy production is noticed in other regions. This has established international commercial exchanges in renewable energy goods. For instance, in some regions of the world, available biomass is insufficient to meet growing demand for bioenergy, whereas other regions produce biomass in excess. This situation has created important international trade in solid and liquid biomass fuels. Another example is the Lesotho highlands power project which will generate 6 GW of wind power and 4 GW of hydropower, mainly for export to South Africa. This is equivalent to nearly one quarter of South Africa’s total current energy supply (United Nations Environment Program 2013b), and *iii)* increasing renewable energy production has a significant impact on international trade in rare earth minerals or metals, which are important inputs for the manufacture of several renewable energy supply products such as wind turbines and energy efficient lighting.

In conclusion, the production and consumption of renewable energies and international economic exchanges are increasing in all parts of the world. It is accepted that renewable energy consumption and international trade are linked, however few researches have empirically studied this relationship.

3. Material and methods

The data set is a panel of 69 countries followed over the years 1980-2007 and includes annual data on output, renewable and non-renewable electricity consumption, capital, labor, exports, and imports. The Appendix lists the 69 countries included in the analysis which 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 (output) measured in constant 2000 US dollars. Renewable energy consumption is the total renewable electricity consumption measured in millions of kilowatt hours. It comprises the electricity produced from geothermal, solar, wind, tide and wave, biomass and waste, and hydroelectric. Non-renewable energy consumption is the total non-renewable electricity produced using oil, natural gas and coal, and is 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 and non-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 using Eviews 8.0.

Following Apergis and Payne (2011, 2012), Lean and Smith (2010a, 2010b), and Sadorsky (2012), we estimate the relationship between renewable and non-renewable energy consumption, output and trade by using the production function. The model presented by Apergis and Payne (2012) includes renewable and non-renewable energy in the production function in order to investigate the relation between energy and output. The model used by Sadorsky (2012) includes exports and imports in two separate empirical models, whereas the models used by Lean and Smith (2010a, 2010b) include only exports. In the present paper, we follow the same model specification as Sadorsky (2012) to investigate the relationship between renewable and non-renewable energy consumption, output and trade.

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

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

Eq. (1) can be written as follow:

$$Y_{it} = RE_{it}^{\beta_{1i}} NRE_{it}^{\beta_{2i}} O_{it}^{\beta_{3i}} K_{it}^{\beta_{4i}} L_{it}^{\beta_{5i}} \tag{2}$$

The natural log of Eq. (2) gives the following equation:

$$y_{it} = \alpha_i + \delta_i t + \beta_{1i} re_{it} + \beta_{2i} nre_{it} + \beta_{3i} o_{it} + \beta_{4i} k_{it} + \beta_{5i} l_{it} + \varepsilon_{it} \tag{3}$$

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 trend, respectively.

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[1] International trade is incorporated into the production function by including real exports or real imports of merchandises in two separate specification models because of the high correlation value (0.97) between exports (*ex*) and imports (*im*).

To examine the relationship between renewable and non-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.

4. Results and discussions

Our empirical analysis follows four steps: *i)* we proceed panel unit root tests for stationary, *ii)* we look for long-term cointegration between variables, *iii)* we estimate the long-run relationships between variables, and *iv)* we study the causality between variables using Engle and Granger (1987) approach.

4.1. Stationary tests

In this study four types of unit root tests are computed in order to examine the order of integration of variables at level and at first difference, namely Levin et al. (2002), Im et al. (2003), test of Fisher using augmented Dickey and Fuller (ADF) (1979), and Phillips and Perron (1988). These tests are divided in two groups. The first group of tests includes LLC's test (Levin et al., 2002) assuming a common unit root process across the cross-section. The second group of tests comprises IPS-W-statistic (Im et al., 2003), Fisher-ADF Chi-square (Dickey and Fuller, 1979) and Fisher-PP Chi-square (Phillips and Perron, 1988) which assume individual unit root process across the cross-section. For all these 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 the test regressions contain an intercept and no deterministic trend. The numbers of lags are selected automatically using Schwarz information criterion (SIC). The results of unit root tests are reported in Table 1.

Insert Table 1 here

Table 1 indicates that, at level, there is a unit root for *y, nrec, k, ex,* and *im* panel data series, whereas after first difference, all our variables are integrated of order one, I(1). For (*re*) data series, the result from the IPS test reports the presence of a unit root at level, whereas after first difference it confirms that renewable energy consumption is integrated of order one at the 1% significance level. Using IPS and ADF tests, labor force (*l*) contains a unit root at level but becomes stationary after first difference. Finally, we can conclude that the stationary of each variable is established and our results confirm that the integration order is one.

4.2. Cointegration tests

To check for long-run association in a heterogeneous panel, we use the cointegration tests of Pedroni (1999, 2004). Pedroni (2004) proposes seven statistics distributed on two sets of cointegration tests. The first set comprises four panel statistics and includes v-statistic, rho-statistic, PP-statistic and ADF-statistic. These statistics are classified by the within-dimension and take into account common autoregressive coefficients across countries. The second set comprises three group statistics and includes rho-statistic, PP-statistic, and ADF statistic. These tests are classified by 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 ($H_0 : \rho_i = 1$), whereas the alternative hypothesis is that there is cointegration between variables. Panel cointegration tests of Pedroni (2004) are based on the residual of Eq. (3). The estimated residuals are defined as follows:

$$\hat{\varepsilon}_{it} = \rho_i \hat{\varepsilon}_{it-1} + w_{it} \tag{4}$$

We assume that the 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.

Insert Table 2 here

Table 2 indicates that, for the model with exports, three panel statistics (v-statistic, PP-statistic and ADF-statistic) among the four statistics used for the within-dimension, reject the null hypothesis of no cointegration at the 1% significance level and approve that there is evidence of cointegration between variables. Two group statistics (PP-statistic and ADF-statistic) among the three statistics used for the between-dimension reject the null hypothesis of no cointegration at the 1% significance level and approve the existence of cointegration between variables. Therefore, five tests among seven confirm the existence of long-term cointegration between the variables.

Insert Table 3 here

For the model with imports, Table 3 indicates that, among the four used statistics of the within-dimension, three panel statistics (v-statistic, PP-statistic and ADF-statistic) reject the null hypothesis of no cointegration at the 1% significance level. Two group statistics (PP-statistic and ADF-statistic) among the three statistics used of the between-dimension reject the null hypothesis of no cointegration at the 1% significance level. Thus, the tests of Pedroni (2004) confirm the existence of long-term cointegration between the variables.

4.3. Long-run estimations

This step consists in the long-run estimation of Eq. (3) where the dependent variable is real GDP or output, and the independent variables are renewable energy consumption, non-renewable energy consumption, real exports (or imports), capital stock and labor force. The ordinary least squares (OLS) estimator is asymptotically biased and its distribution depends on nuisance parameters, in the context of a panel estimate. To correct this bias, we estimate the long-run structural coefficients of Eq. (3) by using the fully modified OLS (FMOLS) and the dynamic OLS (DOLS) panel approaches proposed by Pedroni (2001, 2004). To correct the problems of endogeneity and serial correlation, FMOLS uses a non-parametric approach, whereas DOLS uses a parametric approach. As our variables are measured in natural logarithms, the coefficients estimated from the long-run cointegration relationship can be considered as long-run elasticities. The results of long-run estimates for the model with exports and that with imports are reported in Tables 4 and 5, respectively.

Insert Table 4 here

Table 4 reports the results for panel OLS, FMOLS and DOLS long-run estimates for Eq. (3) with exports. For the renewable energy, non-renewable energy, capital and labor variables, the three approaches produce very close results in terms of sign, magnitude and statistical significance.[2] Indeed, their estimated coefficients are statistically significant at the 1% level and indicate a positive impact on output. The estimated coefficient of exports is not statistically significant under FMOLS and DOLS approaches, but is statistically significant at the 1% level under the OLS approach with a positive impact on output**.**

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[2] Even though Kao and Chiang (2001) show, by using Monte Carlo experiments, that the DOLS estimator outperforms the OLS and FMOLS estimators, some authors prefer the DOLS and others the FMOLS, whereas some other authors use both of them as, in most cases, they give very close results. For instance and for heterogeneous panels, Apergis and Payne (2012) use the FMOLS estimator, whereas Sadorsky (2009b) uses the FMOLS, DOLS and OLS estimators.

By using the FMOLS approach, a 1% increase in renewable energy, non-renewable energy consumption, capital and labor increase output by 0.04%, 0.09%, 0.79%, and 0.06%, respectively. By using the OLS approach, a 1% increase in exports increases output by 0.03%.

Insert Table 5 here

Table 5 reports the results for panel OLS, FMOLS and DOLS long-run estimates for Eq. (3) with imports. For all variables, except for the import variable, the three approaches produce very close results in terms of sign, magnitude and statistical significance. Indeed, their estimated coefficients are statistically significant at the 1% level and indicate a positive impact on output. The estimated coefficients of imports are very close and indicate a positive impact on output with a statistical significance at the 1%, 10% and 5% levels with the OLS, FMOLS and DOLS approaches, respectively.

In the long-run, FMOLS estimate results suggest that a 1% increase in renewable energy, non-renewable energy consumption, imports, capital and labor increase output by 0.04%, 0.08%, 0.04%, 0.77%, and 0.06%, respectively.

For all variables except for the export and import variables, the computed coefficients for the model with exports and that with imports are very similar in terms of sign, magnitude and statistical significance, and lead to the same conclusions. These long-run estimates are very different from those found by Apergis and Payne (2012) because our estimated coefficients are relatively very small for the renewable energy, non-renewable energy, and labor variables. We think that this difference is due to the integration of international trade as a dependent variable in our specified model.

4.4. Causality tests

Given that the residual cointegration tests of Pedroni (1999, 2004) show the existence of a long-run relationship between variables in the two specific models (exports or imports), then the approach of Engle and Granger (1987) can be used to estimate the error correction model. Our analysis will focus principally on the output, renewable energy consumption, non-renewable energy consumption, exports, and imports variables.

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

$$\Delta y_{it} = \theta_{1i} + \sum_{j=1}^{q}\theta_{1,1ij}\Delta y_{it-j} + \sum_{j=1}^{q}\theta_{1,2ij}\Delta re_{it-j} + \sum_{j=1}^{q}\theta_{1,3ij}\Delta nre_{it-j} + \sum_{j=1}^{q}\theta_{1,4ij}\Delta o_{it-j} + \sum_{j=1}^{q}\theta_{1,5ij}\Delta k_{it-j}$$

$$+\sum_{j=1}^{q}\theta_{1,6ij}\Delta l_{it-j} + \lambda_{1i}ECT_{it-1} + \mu_{1it} \qquad (5)$$

$$\Delta re_{it} = \theta_{2i} + \sum_{j=1}^{q}\theta_{2,1ij}\Delta y_{it-j} + \sum_{j=1}^{q}\theta_{2,2ij}\Delta re_{it-j} + \sum_{j=1}^{q}\theta_{2,3ij}\Delta nre_{it-j} + \sum_{j=1}^{q}\theta_{2,4ij}\Delta o_{it-j} + \sum_{j=1}^{q}\theta_{2,5ij}\Delta k_{it-j}$$

$$\sum_{j=1}^{q}\theta_{2,6ij}\Delta l_{it-j} + \lambda_{2i}ECT_{it-1} + \mu_{2it} \tag{6}$$

$$\Delta nre_{it} = \theta_{3i} + \sum_{j=1}^{q}\theta_{3,1ij}\Delta y_{it-j} + \sum_{j=1}^{q}\theta_{3,2ij}\Delta re_{it-j} + \sum_{j=1}^{q}\theta_{3,3ij}\Delta nre_{it-j} + \sum_{j=1}^{q}\theta_{3,4ij}\Delta o_{it-j} + \sum_{j=1}^{q}\theta_{3,5ij}\Delta k_{it-j}$$

$$\sum_{j=1}^{q}\theta_{3,6ij}\Delta l_{it-j} + \lambda_{3i}ECT_{it-1} + \mu_{3it} \tag{7}$$

$$\Delta o_{it} = \theta_{4i} + \sum_{j=1}^{q}\theta_{4,1ij}\Delta y_{it-j} + \sum_{j=1}^{q}\theta_{4,2ij}\Delta re_{it-j} + \sum_{j=1}^{q}\theta_{4,3ij}\Delta nre_{it-j} + \sum_{j=1}^{q}\theta_{4,4ij}\Delta o_{it-j} + \sum_{j=1}^{q}\theta_{4,5ij}\Delta k_{it-j}$$

$$\sum_{j=1}^{q}\theta_{4,6ij}\Delta l_{it-j} + \lambda_{4i}ECT_{it-1} + \mu_{4it} \tag{8}$$

$$\Delta k_{it} = \theta_{5i} + \sum_{j=1}^{q}\theta_{5,1ij}\Delta y_{it-j} + \sum_{j=1}^{q}\theta_{5,2ij}\Delta re_{it-j} + \sum_{j=1}^{q}\theta_{5,3ij}\Delta nre_{it-j} + \sum_{j=1}^{q}\theta_{5,4ij}\Delta o_{it-j} + \sum_{j=1}^{q}\theta_{5,5ij}\Delta k_{it-j}$$

$$\sum_{j=1}^{q}\theta_{5,6ij}\Delta l_{it-j} + \lambda_{5i}ECT_{it-1} + \mu_{5it} \tag{9}$$

$$\Delta l_{it} = \theta_{6i} + \sum_{j=1}^{q}\theta_{6,1ij}\Delta y_{it-j} + \sum_{j=1}^{q}\theta_{6,2ij}\Delta re_{it-j} + \sum_{j=1}^{q}\theta_{6,3ij}\Delta nre_{it-j} + \sum_{j=1}^{q}\theta_{6,4ij}\Delta o_{it-j} + \sum_{j=1}^{q}\theta_{6,5ij}\Delta k_{it-j}$$

$$\sum_{j=1}^{q}\theta_{6,6ij}\Delta l_{it-j} + \lambda_{6i}ECT_{it-1} + \mu_{6it} \tag{10}$$

$$ECT_{it} = y_{it} - \hat{\beta}_{1i}re_{it} - \hat{\beta}_{2i}nre_{it} - \hat{\beta}_{3i}o_{it} - \hat{\beta}_{4i}k_{it} - \hat{\beta}_{5i}l_{it} \tag{11}$$

where Δ is the first difference operator; the autoregression lag length, q, is set at one and determined automatically by SIC; μ is a random error term; *ECT* is the error correction term derived from the long-run relationship of Eq. (3).

To investigate the short and long-run dynamic relations between variables, we follow the two steps approach of Engle and Granger (1987). First, we estimate the long-run parameters in Eq. (3) 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. (5) - (10). The 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.[3] The Granger causality tests are reported in Tables 6 and 7, and Fig.1 resumes short-run causalities for our main variables.

Insert Table 6 here

For the panel VECM with exports, short-run Granger causality tests, reported in Table 6, show that there is evidence of a bidirectional causality between exports and output at the 1% significance level. There is also a bidirectional short-run causality between exports and non-renewable energy consumption, which is statistically significant at the 1% and 5% levels when the causality runs from non-renewable energy and exports, respectively. A unidirectional short-run causality running from renewable energy consumption to exports is validated at the 5% significance level. However, there is no evidence of a short-run causality between output and renewable energy consumption, output and non-renewable energy consumption, and renewable and non-renewable energy consumption.

The long-run test results reported in Table 6, show that the error correction term is statistically significant at the 1% level for Eqs. (5), (8) and (10). Let us notice that the computed error correction terms corresponding to the renewable energy and non-renewable energy equations are statistically significant with a slow speed of adjustment whereas their

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[3] The error correction term estimates the speed at which the dependent variable converges to the long-run equilibrium after variations of independent variables. The value of lagged ECT should be between -1 and 0, and statistically significant.

signs are not negative.[4] This means that there is evidence of a long-run causality running: *i)* from renewable and non-renewable energy, exports, capital, and labor to output, *ii)* from output, renewable and non-renewable energy, capital and labor to exports, and *iii)* from output, renewable and non-renewable energy, exports and capital to labor. We can also deduce that there is a long-run bidirectional causality between output and exports.

Insert Table 7 here

For the panel VECM with imports, short-run Granger causality tests, reported in Table 7, show that there is evidence of a bidirectional causality between imports and output at the 1% significance level. There is a bidirectional short-run causality between imports and non-renewable energy consumption, which is statistically significant at the 1% and 10% levels when the causality runs from non-renewable energy and imports, respectively. A unidirectional short-run causality running from renewable energy consumption to imports is validated at the 5% significance level. However, there is no evidence of a short-run causality between renewable energy consumption and output, non-renewable energy consumption and output, and renewable and non-renewable energy consumption.

Table 7 reports the long-run test results which show that the error correction term is statistically significant at the 1% level for Eqs. (5), (6), (8) and (10). Notice that the estimated error correction terms concerning the non-renewable energy and capital equations are statistically significant with a slow speed of adjustment but their signs are not negative. This means that there is a long-run causality running: *i)* from renewable and non-renewable energy, imports, capital, and labor to output, *ii)* from output, non-renewable energy, imports, capital and labor to renewable energy, *iii)* from output, renewable and non-renewable energy,

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[4] To be significant, the estimated error correction term should be between -1 and 0 and statistically significant. Our estimated error correction terms for the non-renewable energy equation are not comprised between -1 and 0 for both the exports and imports models. The referee suggested this result may be due to multicolinearity between renewable and non-renewable energy variables which may affect the Granger causal results. Upon the recommendation of the referee the following two models were estimated: (1) renewable energy consumption, output, trade (exports or imports), capital and labor, and (2) non-renewable energy consumption, output, trade (exports or imports), capital and labor. We find no difference in the Granger causal results, both in the short and long-run, between the present model and these two models. Moreover, the estimated error correction terms for the non-renewable energy consumption are not significant because they are not comprised between -1 and 0 as in the present model. These results are available upon request.

capital and labor to imports, and *iv)* from output, renewable and non-renewable energy, imports and capital to labor. Also, we deduce that there is a long-run bidirectional causality between output and imports, output and renewable energy, and renewable energy and imports.

Insert Fig 1 here

Fig.1 sums up the short-run Granger causality between our main variables. By looking to the short-run causalities in Fig. 1, and the long-run causalities in Tables 6 and 7, we can highlight our main causal relationships.

Indeed, there are both short and long-run bidirectional causalities between trade (exports or imports) and output. This signifies that any variation in trade affects output, and any variation in output affects trade. This suggests that economic growth cannot be achieved without more international trade. These results are in agreement with the findings of Ben Aïssa et al. (2014) who consider a panel of 11 African countries, and those of Sadorsky (2012) who is concerned by a panel of 7 South American countries.

Our short-run Granger causality tests suggest the existence of a unidirectional causality running from renewable energy consumption to trade. In the long-run, there is a unidirectional causality running from renewable energy consumption to exports, and a bidirectional causality between renewable energy and imports. These results suggest that any variation in renewable energy consumption affects both exports and imports. Moreover, any increase in imports, increases renewable energy consumption. These results are different from those obtained by Ben Aïssa et al. (2014) who show that there is no short-run causality between renewable energy consumption and international trade for the considered panel of African countries mainly because the consumed renewable energy in most African countries considered in the panel is much lower than the consumed non-renewable energy. Sadorsky (2012) finds a short-run Granger causality running from energy consumption to imports, a long-run bidirectional causality between energy consumption and imports, and short and long-run bidirectional causalities between renewable energy and exports.

The Granger causality tests show the existence of a bidirectional causality between non-renewable energy consumption and trade in the short-run, and a one way causality running from non-renewable energy to trade in the long-run. This signifies that any variation in trade affects non-renewable energy consumption, and any variation in non-renewable energy consumption affects trade. Thus, trade expansion cannot be achieved without affecting non-renewable energy consumption. Sadorsky (2012) finds similar results by showing the existence of short and long-run bidirectional relationship between energy consumption and exports, and a long-run bidirectional relationship between energy consumption and imports.

In the short-run, there is no causality between renewable energy consumption and non-renewable energy consumption. However, there is a short-run indirect and unidirectional causality running from renewable energy consumption to non-renewable energy consumption through trade (exports or imports). This means that, in the short-run, any variation in renewable energy consumption indirectly affects non-renewable energy consumption. These results are new and interesting because this study is the first attempt to empirically investigate the causal relationship between renewable energy consumption, non-renewable energy consumption and international trade. In the long-run and for the model with imports, we find a unidirectional causality running from non-renewable energy consumption to renewable energy, meaning that any changes in non-renewable energy affect renewable energy consumption. However, Apergis and Payne (2012) show the existence of a short-run bidirectional causality between renewable and non-renewable energy consumption indicative of substitutability between the two energy sources. We think that this causality obtained by these authors may be due to the omission of the trade variable.

Our Granger causality tests show that there is no short-run causality between non-renewable energy consumption and output, supporting the neutrality hypothesis. However, there is an indirect short-run bidirectional causality between non-renewable energy and output, which occurs through trade (exports or imports). Therefore, in the short-run, policies targeted to reduce non-renewable energy consumption will indirectly reduce economic growth through the impact of non-renewable energy reduction on exports and imports. However, in the long-run, there is a one way causality running from non-renewable energy consumption to output. Conversely, Apergis and Payne (2012) demonstrate a bidirectional relationship between non-renewable energy consumption and output in both the short and long-run. These differences can be explained on the basis of the differences in used data and variables. Indeed, in our study, the integration of exports and imports in the production function as explanatory variables can divert the direction of short-run causality between variables. Our short-run Granger causality results confirm those of Sadorsky (2012) who shows that the causality between output and energy consumption is indirect. Indeed, in the short-run, he shows the existence of an indirect bidirectional causality between energy consumption and output through exports, and an indirect unidirectional causality from energy consumption to output through imports. Many other papers show the absence of a short-run causal relationship between energy consumption and output, and the existence of an indirect causality. Indeed, Halicioglu (2009) show the existence of an indirect and bidirectional short-run causality between energy consumption and output that runs through CO_2 emissions. Ozturk and

Acaravci (2010) report the absence of short-run causal relationship between energy consumption and output. In fact, the debate on the causal relationship between energy consumption and growth has been treated by different studies and the direction of causality depends on the selected countries, the period considered, the empirical methodologies, and included variables. Al-mulali et al. (2013) resume the findings of 81 studies concerned by the causal relationship between energy consumption and economic growth. They conclude that 45% of these studies find a bidirectional causality (feedback hypothesis), 10% find no causal relationship (neutrality hypothesis), 25% find a one way causal relationship running from energy consumption to output (growth hypothesis), and 20% find a one way causal relationship running from output to energy consumption (conservation hypothesis).

Our Granger causality tests show that there is no short-run causality between renewable energy consumption and output, and this supports the neutrality hypothesis. However, there is an indirect short-run unidirectional causality from renewable energy to output through trade (exports or imports). Thus, in the short-run, policies targeted to increase renewable energy consumption will indirectly increase economic growth through the impact of renewable energy increase on exports and imports. In the long-run, we show the existence of a unidirectional causality running from renewable energy to output in the model with exports, and a bidirectional causality between renewable energy and output in the model with imports. Thus, in the long-run, increasing renewable energy consumption is beneficial for economic growth. Our results are not in agreement with those of Apergis and Payne (2010a, 2011, 2012) who show the existence of a bidirectional relationship between renewable energy consumption and output in both the short and long-run. These differences can be explained on the basis of the differences in used data and variables. Indeed, in our study, the integration of exports and imports in the production function as explanatory variables can divert the direction of short-run causality between variables. Al-mulali et al. (2013) investigate the long-run relationship between renewable energy consumption and GDP growth for 108 countries categorized as high income, upper middle income, lower middle income, and low income countries. The results reveal that for 79% of the countries this causality is bidirectional, for 19% of the countries there is no causality, and for 2% of the countries there is a one way long-run relationship from output to renewable energy or from renewable energy to output.

5. Conclusions and policy implications

This research studies the causal relationship between output, renewable and non-renewable energy consumption and trade for a panel of 69 countries over the period 1980-2007. This study is interesting because no research has been reported on the causal relationship between output, international trade, renewable and non-renewable energy consumption.

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

Granger causality tests show that there is evidence of a bidirectional causality between output and trade (exports or imports) in both the short and long-run. These results indicate that any changes in trade affect output and any changes in output affect trade. They suggest that economic growth cannot be achieved without expanding international economic exchanges.

Even though there is no short-run causality between output and renewable energy consumption, there is a long-run and bidirectional causality between output and renewable energy consumption in the model with imports. Indeed, economic growth makes people more aware of environmental protection leading to an increase in renewable energy consumption. We provide this reason because we don’t find a causality running from output to non-renewable energy consumption. However, we find a long-run causality running from non-renewable energy consumption to output. Thus, more non-renewable energy consumption boosts economic growth in the long-run.

Also, there is evidence of a one way short-run causality without feedback running from renewable energy consumption to trade. These results suggest that increasing renewable energy consumption increases imports and exports, in the short-run. Thus, any policy designed to increase renewable energy consumption, will increase trade and its benefits. Policies designed to increase renewable energy consumption encourage international trade and promote economic growth. We think that this short-run unidirectional causality is due to at least one of the two following reasons: *i)* there are great disparities in the production of renewable energy between countries encouraging their international exchanges, which are becoming more and more important; *ii)* the increase in renewable energy production has a significant and positive impact on international exchanges in rare earth minerals or metals, which are becoming increasingly important. Our short-run Granger causality tests suggest that neither exports nor imports affect renewable energy consumption. However, in the long-run, there is a bidirectional causality between renewable energy and imports. This means that, in the long-run, increasing imports leads to an increase in renewable energy consumption. We think that this long-run causality is due to the renewable energy technology transfer occurring when countries import capital goods, such as machines and equipment to produce renewable energy. This causality from imports to renewable energy consumption occurs only in the long-run because, when renewable energy technology transfer occurs through imports, a relatively long time is needed for importing countries to build the necessary human and physical capacities for producing renewable energies. We also show the absence of causality running from exports to renewable energy consumption in both the short and long-run. This means that increasing exports has no impact on renewable energy consumption. This absence of causality can be attributed to at least one of the two following reasons which should be considered for all our panel of 69 countries: *i)* the proportion of renewable energy used to produce and to transport exported goods is not significant, *ii)* the exports of equipment needed to produce renewable energy are not important.

We show the existence of a short-run feedback causality between non-renewable energy consumption and trade, and a long-run unidirectional causality running from non-renewable energy to trade. These results suggest that trade expansion necessitates more non-renewable energy consumption. Moreover, any reduction in non-renewable energy consumption, for instance due to non-renewable energy conservation policies decided to reduce CO_2 emissions, will reduce international trade and its benefits.

In our long-run estimates, output is the dependent variable. Long-run elasticities are estimated using OLS, FMOLS and DOLS panel approaches. The results of estimates show that all coefficients are positive and statistically significant at mixed level, except for exports coefficients which are statistically significant only with the OLS panel approach. Therefore, in the long-run, any increase in capital, labor force, renewable energy consumption, non-renewable energy consumption and trade (exports or imports) will increase economic growth.

Our energy policy recommendations are the following. Firstly, we show the existence of a feedback short-run causal relationship between non-renewable energy consumption and trade, and a long-run causality running from non-renewable energy to trade. Thus, and as proposed by Sadorsky (2012), any non-renewable energy policy should take into account the importance of international trade. Secondly, we show that renewable energy consumption

Granger causes trade in both the short and long-run. Thus, the use of more renewable energy should be encouraged by national and international competent authorities because it increases international economic exchanges and promotes economic growth. This result is very interesting as it shows that more renewable energy stimulates trade, thus promoting economic growth without harming the environment. Thirdly, we demonstrate a long-run bidirectional causality between renewable energy consumption and imports. Therefore, increasing imports, especially by developing countries, is a good vehicle for renewable energy technology transfer and contributes to increase renewable energy consumption in the long-run. Thus, more imports do not mean systematically more pollution.

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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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Tables

Table 1. Panel unit root tests

Panel unit root test method	LLC	IPS	Fisher-ADF	Fisher-PP
y	6.53103	16.9322	27.9805	29.1039
	(1.0000)	(1.0000)	(1.0000)	(1.0000)
Δy	-19.9102	-20.7862	664.983	669.754
	(0.0000)[a]	(0.0000)[a]	(0.0000)[a]	(0.0000)[a]
re	-3.88498	-2.04254	217.292	262.121
	(0.0000)[a]	(0.0205)	(0.0000)[a]	(0.0000)[a]
Δre	-34.7766	-37.1259	1239.34	1396.95
	(0.0000)[a]	(0.0000)[a]	(0.0000)[a]	(0.0000)[a]
nre	-1.45649	6.16964	94.1782	103.004
	(0.0726)	(1.0000)	(0.9984)	(0.9886)
Δnre	-31.1550	-32.8946	1109.17	1338.54
	(0.0000)[a]	(0.0000)[a]	(0.0000)[a]	(0.0000)[a]
k	4.11696	8.83988	55.9864	37.5331
	(1.0000)	(1.0000)	(1.0000)	(1.0000)
Δk	-22.5516	-23.0878	752.298	737.308
	(0.0000)[a]	(0.0000)[a]	(0.0000)[a]	(0.0000)[a]
l	-11.9254	3.47584	177.046	267.188
	(0.0000)[a]	(0.9997)	(0.0140)	(0.0000)[a]
Δl	-9.00573	-12.7521	486.933	492.611
	(0.0000)[a]	(0.0000)[a]	(0.0000)[a]	(0.0000)[a]
ex	0.39704	9.92898	44.2421	40.1834
	(0.6543)	(1.0000)	(1.0000)	(1.0000)
Δex	-30.1456	-30.3572	1014.52	1135.34
	(0.0000)[a]	(0.0000)[a]	(0.0000)[a]	(0.0000)[a]
im	4.60742	14.2231	18.0246	17.5201
	(1.0000)	(1.0000)	(1.0000)	(1.0000)
Δim	-31.5097	-29.9565	997.782	1085.92
	(0.0000)[a]	(0.0000)[a]	(0.0000)[a]	(0.0000)[a]

Null hypothesis: Unit root.

All unit root tests regressions are run with intercept.

P-value listed in parentheses.

Automatic lag length selection based on SIC (Schwarz information criteria).

[a] Critical values at the 1% significance level.

Table 2. Pedroni cointegration tests (with exports)

Alternative hypothesis: common AR coefs. (within-dimension)				
			Weighted	
	Statistic	Prob.	Statistic	Prob.
Panel v-Statistic	3.000609	0.0000***	2.956833	0.0000***
Panel rho-Statistic	2.998403	0.9986	2.793275	0.9974
Panel PP-Statistic	-2.981728	0.0014***	-2.849749	0.0022***
Panel ADF-Statistic	-3.271644	0.0000***	-3.192934	0.0007***
Alternative hypothesis: individual AR coefs. (between-dimension)				
	Statistic	Prob.		
Group rho-Statistic	5.459964	1.0000		
Group PP-Statistic	-3.660259	0.0001***		
Group ADF-Statistic	-3.927177	0.0000***		

Null hypothesis: No cointegration

Trend assumption: Deterministic intercept and trend.

Automatic lag length selection based on SIC with a max lag of 5.

Newey-West automatic bandwidth selection and Bartlett kernel.

*** Critical values at the 1% significance level.

Table 3. Pedroni cointegration tests (with imports)

Alternative hypothesis: common AR coefs. (within-dimension)				
			Weighted	
	Statistic	Prob.	Statistic	Prob.
Panel v-Statistic	3.085872	0.0012***	3.047974	0.0012***
Panel rho-Statistic	3.652326	0.9999	3.489442	0.9998
Panel PP-Statistic	-2.708324	0.0034***	-2.076545	0.0189**
Panel ADF-Statistic	-3.022099	0.0013***	-2.504795	0.0061***
Alternative hypothesis: individual AR coefs. (between-dimension)				
	Statistic	Prob.		
Group rho-Statistic	6.203968	1.0000		
Group PP-Statistic	-2.493555	0.0063***		
Group ADF-Statistic	-2.450293	0.0071***		

Null Hypothesis: No cointegration

Trend assumption: Deterministic intercept and trend.

Automatic lag length selection based on SIC with a max lag of 5.

Newey-West automatic bandwidth selection and Bartlett kernel.

*** Critical values at the 1% significance level.

** Critical values at the 5% significance level.

Table 4. Panel OLS-FMOLS-DOLS long-run estimates (model with exports)

Variables	*re*	*nre*	*ex*	*k*	*l*
	0.040250	0.113815	0.033148	0.725328	0.076066
OLS	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***
	0.040625	0.089270	0.011540	0.788769	0.058852
FMOLS	(0.0000)***	(0.0002)***	(0.5694)	(0.0000)***	(0.0000)***
	0.040250	0.113815	0.033148	0.725328	0.076066
DOLS	(0.0002)***	(0.0000)***	(0.1059)	(0.0000)***	(0.0000)***

Cointegrating equation deterministics: intercept and trend.

All variables are measured in natural logarithms.

*** Critical values at the 1% significance level.

Table 5. Panel OLS-FMOLS-DOLS long-run estimates (model with imports)

Variables	*re*	*nre*	*im*	*k*	*l*
	0.041878	0.112659	0.048148	0.717723	0.072206
OLS	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***
	0.042188	0.082159	0.042819	0.770815	0.057262
FMOLS	(0.0000)***	(0.0005)***	(0.0708)*	(0.0000)***	(0.0016)***
	0.041878	0.112659	0.048148	0.717723	0.072206
DOLS	(0.0000)***	(0.0000)***	(0.0446)**	(0.0000)***	(0.0001)***

Cointegrating equation deterministics: intercept and trend.

All variables are measured in natural logarithms.

*** Critical values at the 1% significance level.

** Critical values at the 5% significance level.

* Critical values at the 10% significance level.

Table 6. Granger causality tests (model with exports)

Dependent variable	Short-run						Long-run
	Δy	Δre	Δnre	Δex	Δk	Δl	ECT
Δy	-	0.27709	0.09175	14.9943	0.70006	6.15837	-0.075582
		(0.5987)	(0.7620)	(0.0001)***	(0.4029)	(0.0132)**	(0.0034)***
Δre	2.05523	-	0.88021	0.27543	1.07893	0.37766	0.000726
	(0.1518)		(0.3483)	(0.5998)	(0.2991)	(0.5389)	(0.0543)
Δnre	0.87644	0.70423	-	5.20133	0.35917	2.99523	0.005314
	(0.3493)	(0.4015)		(0.0227)**	(0.5490)	(0.0837)*	(0.0029)
Δex	34.2832	6.52984	26.5075	-	30.3576	1.38140	-0.082826
	(0.0000)***	(0.0107)**	(0.0000)***		(0.0000)*	(0.2400)	(0.0000)***
Δk	7.83140	1.33448	1.11353	4.35998	-	2.38113	0.014184
	(0.0052)***	(0.2482)	(0.2914)	(0.0369)**		(0.1230)	(0.9040)
Δl	0.03283	0.04612	0.01208	3.62611	0.10699	-	-0.004447
	(0.8562)	(0.8300)	(0.9125)	(0.0570)*	(0.7436)		(0.0013)***

Lag lengths selected is 1 based on the Schwarz information criterion.

P-value listed in parentheses.

*** Critical values at the 1% significance level.

** Critical values at the 5% significance level.

* Critical values at the 10% significance level.

Table.7 Granger causality tests (model with imports)

Dependent variable	**Short-run**						**Long-run**
	Δy	*Δre*	*Δnre*	*Δim*	*Δk*	*Δl*	*ECT*
Δy	-	0.27709	0.09175	13.2892	0.70006	6.15837	-0.037834
		(0.5987)	(0.7620)	(0.0003)***	(0.4029)	(0.0132)**	(0.0000)***
Δre	2.05523	-	0.88021	0.31788	1.07893	0.37766	-0.004406
	(0.1518)		(0.3483)	(0.5730)	(0.2991)	(0.5389)	(0.0002)***
Δnre	0.87644	0.70423	-	3.43358	0.35917	2.99523	0.011976
	(0.3493)	(0.4015)		(0.0640)*	(0.5490)	(0.0837)*	(0.0017)
Δim	36.1896	5.65292	30.4427	-	26.6078	1.64869	-0.142364
	(0.0000)***	(0.0175)**	(0.0000)***		(0.0000)***	(0.1993)	(0.0000)***
Δk	7.83140	1.33448	1.11353	4.05661	-	2.38113	0.042607
	(0.0052)***	(0.2482)	(0.2914)	(0.0441)**		(0.1230)	(0.0348)
Δl	0.03283	0.04612	0.01208	2.55519	0.10699	-	-0.000430
	(0.8562)	(0.8300)	(0.9125)	(0.1101)	(0.7436)		(0.0002)***

Lag lengths selected is 1 based on the Schwarz information criterion.

P-value listed in parentheses.

*** Critical values at the 1% significance level.

** Critical values at the 5% significance level.

* Critical values at the 10% significance level.

Figures

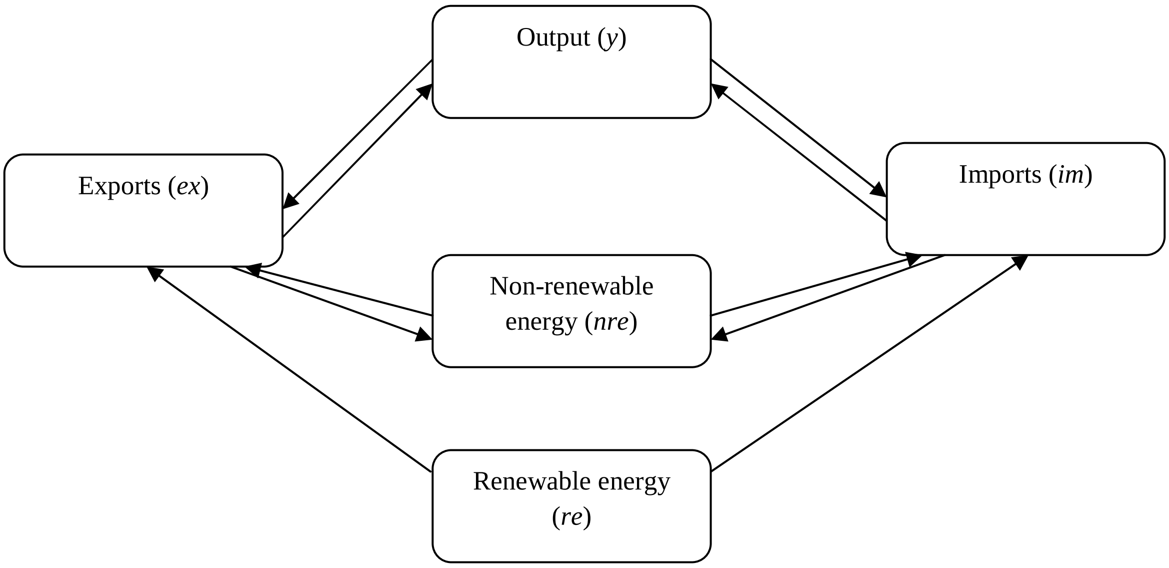

Fig.1. Short-run causality between output, renewable and non-renewable energy and trade