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# Testing environmental Kuznets curve hypothesis: The role of renewable and non-renewable energy consumption and trade in OECD countries

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ABSTRACT

This paper investigates the causal relationships between per capita $CO_2$ emissions, gross domestic product (GDP), renewable and non-renewable energy consumption, and international trade for a panel of 25 OECD countries over the period 1980–2010. Short-run Granger causality tests show the existence of bidirectional causality between: renewable energy consumption and imports, renewable and non-renewable energy consumption, non-renewable energy and trade (exports or imports); and unidirectional causality running from: exports to renewable energy, trade to $CO_2$ emissions, output to renewable energy. There are also long-run bidirectional causalities between all our considered variables. Our long-run fully modified ordinary least squares (FMOLS) and dynamic ordinary least squares (DOLS) estimates show that the inverted U-shaped environmental Kuznets curve (EKC) hypothesis is verified for this sample of OECD countries. They also show that increasing non-renewable energy increases $CO_2$ emissions. Interestingly, increasing trade or renewable energy reduces $CO_2$ emissions. According to these results, more trade and more use of renewable energy are efficient strategies to combat global warming in these countries.


## 1. Introduction

International economic exchanges of the organization for economic cooperation and development (OECD) countries have considerably increased these last decades because many studies highlighted the positive effect of trade on economic growth, political will, and technological progress. This latter has considerably reduced the costs of transportation and communications. This expansion in international trade poses questions about its impact on greenhouse gas emissions, which can be explained by three principal effects: the scale, composition and technique effects. The Rio and Johannesburg conferences recognize that trade helps to realize 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).

For many decades, the demand of fossil fuel energy has reached an exponential growth rate which caused disasters and catastrophic damages on the environment. The big problem is that the consumption of non-renewable energy (oil, coal, natural gas) increases in general economic growth but increases also carbon dioxide ($CO_2$) emissions. These emissions are considered as the main cause of global warming. Therefore, it is necessary to increase the energy efficiency and to find a substitutable energy to the fossil one such as renewable energy. More than 70 countries are expected to use renewable energy technologies in the power sector by 2017 (International Energy Agency, 2012). One policy driver is environmental concerns which aim to reduce $CO_2$ emissions and local pollutants. Renewables may also be encouraged to stimulate economies, reinforce energy security and diversify energy consumption.

Many actions could be taken to encourage energy efficiency and renewable energy use. In most cases fiscal incentives and/or subsidies are needed because, compared to the use of conventional energy sources, the use of renewable energies necessitates an initial investment cost. However, several OECD countries have begun to reduce subsidies for renewable energy sources, due largely to individual domestic political and economic circumstances, lower technology prices, and a lack of long-term policy guidance for renewables (United Nations Environment Program, 2013a). Reforming the subsidies for fossil energy is crucial. Indeed,

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international fossil fuel subsidies amounted to 523 billion US$ in 2011 and thus exceeded subsidies to renewable energy resources sixfold (United Nations Environment Program, 2013b). OECD countries alone spend an annual amount of 400 billion US$ in subsidies, often supporting environmentally damaging technologies. Thus, to accelerate the growth of more sustainable methods and thereby encourage increased trade in green manufactured goods, countries should eliminate subsidies that benefit to carbon-intensive industries. The financial resources that thereby become available could be used to encourage the development and use of environmentally technologies. In addition, environmental laws and regulations enforcement is crucial to protect the environment and biodiversity worldwide. The OECD (2008) report indicates the effectiveness of long-term sustainable development through the promotion of sustainable growth instruments that aid to reduce environmental hazards and fulfill social needs to the region. Advances in the sustainable consumption are more pronounced to lessen environmental and social externalities that enable to provide sustainable products to the markets.

Many recent econometric studies explore the relationship between economic growth and renewable energy consumption (Apergis and Payne, 2010a, 2010b, 2011; Ben Jebli and Ben Youssef, 2015b; Sadorsky, 2009, 2011, 2012; Tugcu et al., 2012). The direction of causality between the considered variables vary from one study to another and the long-run association reveals the significant impact of renewable energy on emissions without deteriorating economic growth. Sadorsky (2009) shows the absence of short and long-run causal relationships between GDP and renewable energy consumption for 18 emerging countries. However, he shows that increasing output increases renewable energy consumption in the long-run for this sample of countries. Apergis and Payne (2011) show the existence of short and long-run bidirectional causality between renewable energy consumption and economic growth. Tugcu et al. (2012) make a comparison between renewable and non-renewable energy sources in order to decide which type of energy is more important for economic growth in the G7 countries. These authors find bidirectional causality between economic growth, renewable and non-renewable energy consumption for all countries in case of classical production function. Ben Jebli and Ben Youssef (2015b) show the existence of short-run unidirectional causality running from renewable energy consumption to trade (exports or imports), and long-run bidirectional causality between trade and renewable energy consumption. Their long-run estimates suggest that renewable, non-renewable energy consumption and trade have a positive and statistically significant impact on economic growth.

There is a growing literature interested in studying the environmental Kuznets curve (EKC) hypothesis which can be divided in two sets. The first set is related to cross-sectional studies (Ang, 2007; Ben Jebli and Ben Youssef, 2015a; Halicioglu, 2009; Jalil and Mahmud, 2009; Jayanthakumaran et al., 2012; Ozturk and Acaravci, 2010; Shahbaz et al., 2013). Ang (2007) shows that the inverted U-shaped EKC hypothesis is verified for France either graphically and analytically. The long-run association supports that economic growth exerts a causal influence on the growth of energy consumption and the growth of pollution. In the short-run, the results provide that there is a unidirectional causality running from the growth of energy consumption to economic growth. Halicioglu (2009) examines the causal relationships between carbon emissions, energy consumption, income, and the trade openness ratio for the case of Turkey during the period 1960–2005 by using the ARDL bounds testing to cointegration procedure. Granger causality results show the existence of short and long-run bidirectional causality between output and $CO_2$ emissions, and short-run bidirectional causality between energy consumption and $CO_2$ emissions. Long-run estimates show that the inverted U-shaped EKC hypothesis is verified for Turkey. Ozturk and Acaravci (2010) examine the causal relationships between economic growth, $CO_2$ emissions, energy consumption and the employment ratio in Turkey during the period 1968–2005. They show that the employment ratio Granger causes output in the short-run. In addition, the EKC hypothesis is not verified. Ben Jebli and Ben Youssef (2015a) show the existence of short-run unidirectional causality running from trade, GDP, $CO_2$ emission and non-renewable energy to renewable energy for Tunisia. The inverted U-shaped EKC hypothesis is not supported graphically and analytically in the long-run.

The second set is related to panel studies (Acaravci and Ozturk, 2010; Al-Mulali et al., 2015; Apergis and Ozturk, 2015; Arouri et al., 2012; Jaunky, 2011; Ozcan, 2013). Arouri et al. (2012) examine the causal relationships between per capita $CO_2$ emissions, energy consumption, and gross domestic product (GDP) for 12 Middle East and North African (MENA) countries. They show that, in the long-run, energy consumption has a positive significant impact on $CO_2$ emissions. The long-run elasticity of income and its square satisfy the inverted U-shaped EKC hypothesis in most studied countries, but is not satisfied for United Arab Emirates (UAE), Morocco and Tunisia. Ozcan (2013) discusses the empirical nexus between carbon emissions, energy consumption and economic growth in 12 MENA countries. This study shows the existence of a short-run unidirectional causality running from GDP to energy consumption, and a long-run unidirectional causality running from energy consumption and output to $CO_2$ emissions. The inverted U-shaped EKC hypothesis is verified by three countries which are Egypt, Lebanon and UAE. Apergis and Ozturk (2015) examine the EKC hypothesis for 14 Asian countries by using the GMM methodology for panel data. The multivariate framework includes $CO_2$ emissions, GDP, population density, land, industry shares in GDP, and four indicators measuring the quality of institutions. Their results support the inverted U-shaped EKC hypothesis.

The present paper tries to investigate the causal nexus between per capita $CO_2$ emissions, economic growth, renewable and non-renewable energy consumption and trade (exports or imports) and to verify the EKC hypothesis for a panel of 25 OECD countries. We use panel cointegration techniques and two specification models differing by the trade variable (exports or imports). Since there is no study which investigates the causal nexus between $CO_2$ emissions, economic growth, renewable and non-renewable energy consumption and trade for OECD countries, this paper aims to fulfill this gap and contributes to the empirical literature.

This paper is organized as follows: Section 2 provides data information, modeling and methodology; Section 3 gives empirical results and Section 4 deals with conclusion and policy implications.

## 2. Data, specification models and methodology

### 2.1. Data

Our data are in per capita and cover the period of 1980–2010 for a panel of 25 OECD countries.[1] Renewable and non-renewable energy are measured in billion kilowatt hours, $CO_2$ emissions are in metric tons, real GDP are in constant 2005 US dollars, real exports and real imports are in US dollars. The database is selected to get the maximum number of observations depending on the availability data. Renewable energy consumption comprises the electricity produced from geothermal, solar, wind, tide and wave,

[1] The sample countries are: Australia, Austria, Belgium, Canada, Chile, Denmark, Finland, France, Greece, Hungary, Iceland, Italy, Japan, Mexico, Netherlands, New Zealand, Norway, Portugal, South Korea, Spain, Sweden, Switzerland, Turkey, United Kingdom and United States.

biomass and waste, and hydro electric power consumption. The non-renewable energy consumption is that coming from the sum of electricity consumption from oil, gas, and coal. Renewable and non-renewable energy data are obtained from the U.S. Energy Information Administration (2015) online database. These data are obtained in billion kilowatt hours and we divide them by the population number to get the per capita unit. Data on per capita $CO_2$ emissions, per capita real GDP, merchandize exports and merchandize imports are obtained from the World Bank (2015) online database. The annual data on merchandize exports (imports) are transformed from the current value to the real one by dividing them by the consumer price index (pc) and then they are divided by population to get the per capita unit. Data on the consumer price index and population are obtained from the Penn World Tables version 7.1 (Heston et al., 2012). All variables are transformed to the natural logarithm form. Our estimates are done using Eviews 8.0 software.

Table 1 presents some descriptive statistics of the selected variables over the period 1980–2010. The summary common statistics contain the means, median, maximum and minimum of each series before transformation in logarithm form. We have also examined the pairwise correlation between our analysis variables.

According to these statistic results, the highest level of per capita $CO_2$ emissions was in the Unites States (20.78 metric tons in 1980) while the lowest level was in Turkey (1.73 metric tons in 1980). The real GDP per capita was highest in Norway (67,804.55 US dollars constant 2005 in 2007) and the lowest level was in Chile (2898.22 US dollars constant 2005 in 1983). Iceland was the biggest consumer of per capita renewable energy ($408.616 \times 10^{-6}$ billion kilowatt hours in 2006) and per capita non-renewable energy ($53.23 \times 10^{-6}$ billion kilowatt hours in 2010), and the smallest consumers of per capita renewable energy and per capita non-renewable energy are Turkey ($5.486 \times 10^{-6}$ billion kilowatt hours in 1981) and The Netherlands ($0.00139 \times 10^{-6}$ billion kilowatt hours in 1984), respectively. Regarding to the levels of per capita real exports and per capita real imports, Belgium has the highest levels with 347,073 US dollars 343,003.2 and US dollars in 2008, respectively, whereas Turkey has the lowest levels with 882.49 US dollars and 2398.78 US dollars in 1980, respectively. We find that the series are normally distributed as revealed by Jarque–Bera statistics. The matrix correlation between our analysis variables shows that $CO_2$ emissions are positively correlated with all the other variables.

### 2.2. Specification models

In this study, we follow the methodology developed by Ang (2007), Halicioglu (2009) and Jayanthakumaran et al. (2012) for time series and by Narayan and Narayan (2010) for heterogeneous panel. Based on the environmental Kuznets curve hypothesis, the multivariate framework is established to investigate the long-run causal relationships between per capita carbon dioxide emissions ($e$), per capita real GDP ($y$), square of per capita real GDP ($y^2$), per capita renewable energy consumption ($re$), per capita non-renewable energy consumption ($nre$) and trade ($ex$ or $im$). We estimate two models differing by the trade variable. In the first model, trade variable is measured by per capita real exports, and in the second model, it is measured by per capita real imports. This enables us to evaluate the proper impact of each variable separately. The log linear quadratic forms are specified as follows:

$$e_{it} = \delta_{0i} + \rho_i t + \delta_{1i} y_{it} + \delta_{2i} y_{it}^2 + \delta_{3i} re_{it} + \delta_{4i} nre_{it} + \delta_{5i} o_{it} + \pi_{it} \quad (1)$$

where $i = 1, \ldots, 25$ and $t = 1980, \ldots, 2010$ indicate the country and time, respectively. $\delta_{0i}$ and $\rho_i$ denote the country specific fixed effect and deterministic trends corresponding to each panel, respectively. $\pi_{it}$ indicates the estimated residuals which characterize deviations from the long-run equilibrium. The trade variable is referred by ($o$), and relates to exports or imports. The parameters $\left\langle (\delta_{1i}, \delta_{2i}, \delta_{3i}, \delta_{4i}, \delta_{5i}) \right\rangle$ are the long-run elasticities corresponding to each explanatory variable of the panel. With respect to the inverted U-shaped EKC hypothesis, the sign of $\delta_{1i}$ is expected to be positive, whereas the sign of $\delta_{2i}$ is expected to be negative. The sign corresponding to $\delta_{3i}$ is expected to be mixed and depending on the specific economic development of the selected panel. We expect that $\delta_{3i}$ is negative if the level of renewable energy used is high enough and the industrial sectors use the clean technology for production; but it could be positive if the level of renewable energy is low and the technology used for production is polluting. The sign of $\delta_{4i}$ is expected to be positive. The sign of $\delta_{5i}$ is expected to be mixed and depending on the economic development of the selected countries. Most of the studies exploring the relationship between $CO_2$ emissions, economic growth, energy use, and international trade (e.g. Grossman and Krueger, 1995; Halicioglu, 2009) reveal that the sign of trade parameter is positive if the dirty industries of developing economies are producing with high $CO_2$ emissions.

### 2.3. Methodology

We employ panel cointegration techniques to investigate the causal relationships among variables for a panel of 25 OECD countries during the period 1980–2010. Our empirical analysis consists in the following stages: (i) examination of the stationary proprieties using traditional panel unit root tests, (ii) testing the existence of long-run relationship among variables using Pedroni cointegration tests, (iii) running the Granger causality tests to check for the short and long-run causalities, and (iv) estimation of the long-run coefficients by using the fully modified ordinary least squares (FMOLS) and dynamic ordinary least squares (DOLS) panel techniques.

## 3. Empirical analysis

### 3.1. Unit root tests

We use five unit root tests to check for the integration order of each variable: Breitung (2000), Levin et al. (2002), Im et al. (2003), tests 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 $t$-statistic of the Breitung (2000) and LLC's test (Levin et al., 2002). These tests assume a common unit root process across the cross-sections for the null hypothesis of a unit root. The second group of tests includes IPS-W-statistic (Im et al., 2003), ADF-Fisher Chi-square (Dickey and Fuller, 1979) and PP-Fisher Chi-square (Phillips and Perron, 1988). These tests assume an individual unit root process across the cross-sections. 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. All panel unit root tests are estimated with intercept and deterministic trend.

All unit root statistics reported in Table 2 are calculated at level and after first difference. The results from these integration tests indicate that, for the $CO_2$ emissions variable, four tests among five cannot reject the null hypothesis of non-stationary at level, while after taking the first difference, the five tests reject the null hypothesis of non-stationary at the 1% level of significance. LLC's test, Breitung $t$-stat and IPS-W statistics confirm that renewable energy consumption variable has a unit root at level, whereas after the first difference all the five tests suggest the null hypothesis of non-stationary can be rejected at the 1% significance level. For GDP, square of GDP, non-renewable energy, exports and imports variables, the null hypothesis of no unit root cannot be rejected at level for all unit root statistic tests, whereas after first difference, all these tests confirm that our variables are stationary at the 1% significance level.

**Table 1**
Descriptive statistics and correlation matrix of the variables.

| Variables | *y* | *e* | *re* | *nre* | *ex* | *im* |
|---|---|---|---|---|---|---|
| Mean | 27,317.39 | 8.510183 | $49 \cdot 10^{-6}$ | $4.03 \cdot 10^{-6}$ | 53,743.54 | 54,579.03 |
| Median | 27,591.93 | 7.766497 | $36.2 \cdot 10^{-6}$ | $0.94 \cdot 10^{-6}$ | 39,433.79 | 42,078.59 |
| Maximum | 67,804.55 | 20.77751 | $408.616 \cdot 10^{-6}$ | $53.23 \cdot 10^{-6}$ | 347,073.0 | 343,003.2 |
| Minimum | 2898.221 | 1.725601 | $5.486 \cdot 10^{-6}$ | $0.00139 \cdot 10^{-6}$ | 882.4837 | 2398.779 |
| Std. dev. | 13,912.97 | 4.113691 | $55.3 \cdot 10^{-6}$ | $7.18 \cdot 10^{-6}$ | 51.98338 | 46.78907 |
| Skewness | 0.209241 | 1.034508 | 4.397323 | 3.038924 | 2.320152 | 2.320512 |
| Kurtosis | 2.693356 | 3.797644 | 24.26318 | 14.14281 | 10.12242 | 10.80641 |
| Jarque–Bera | 8.691554 | 158.7801 | 17,097.42 | 5202.268 | 2333.439 | 2663.387 |
| Probability | 0.012961 | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| *y* | 1 | | | | | |
| *e* | 0.68 | 1 | | | | |
| *re* | 0.46 | 0.08 | 1 | | | |
| *nre* | 0.06 | 0.43 | -0.29 | 1 | | |
| *ex* | 0.54 | 0.45 | 0.25 | -0.12 | 1 | |
| *im* | 0.53 | 0.45 | 0.20 | -0.11 | 0.95 | 1 |

*Notes*: per capita emissions (*e*) are measured in metric tons, per capita real GDP (*y*) are measured in US dollars constant 2005, per capita renewable (*re*) and non-renewable (*nre*) energy consumption in billion kilowatt hours, per capita real exports (*ex*) and imports (*im*) of merchandize are measured in US dollars.

### 3.2. Cointegration tests

The existence of long-run dynamic relationship between variables is tested by using Pedroni (1999, 2004) panel cointegration tests. Pedroni (1999, 2004) proposes two sets of cointegration tests. The first set is a panel group based on 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 group is based on 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. All these tests are based on the residuals of Eq. (1). For all these tests, the null hypothesis is that there is no cointegration, whereas the alternative hypothesis is that there is cointegration between variables. Compared to other cointegration techniques such as Kao (1999) homogeneous cointegration tests, the advantage of Pedroni tests is that they take into account the heterogeneity across countries.

For both models (model with exports and model with imports), the results of Pedroni cointegration tests are reported in Table 3. These tests confirm that the null hypothesis of no cointegration can be rejected at the 1% significance level because two tests of the within dimension (panel PP-statistic and panel ADF-statistic) and two tests of the between dimension (group PP-statistic and group ADF-statistic) approve this rejection. Thus, four tests among seven reveal that the variables move together in the long-run equilibrium. The non-weighted statistics of the within dimension for panels conserve approximately the same significance as the weighted statistics. In conclusion, the seven tests of Pedroni cointegration

**Table 2**
Panel unit root tests.

| Variables<br>Method/statistics | *e*<br>Level | $\Delta e$<br>First diff. | *y*<br>Level | $\Delta y$<br>First diff. | $y^2$<br>Level | $\Delta y^2$<br>First diff. |
|---|---|---|---|---|---|---|
| **Null: Unit root (assumes common unit root process)** | | | | | | |
| *Levin, Lin & Chu t* | 0.750 | −21.0641*** | 1.595 | −12.549*** | 1.556 | −12.753*** |
| *Breitung t-stat* | −0.813 | −8.17477*** | 2.765 | −4.557*** | 2.628 | −4.408*** |
| **Null: Unit root (assumes individual unit root process)** | | | | | | |
| *Im, Pesaran and Shin W-stat* | −0.342 | −20.9629*** | 0.356 | −11.258*** | 0.162 | −11.208*** |
| *ADF – Fisher Chi-square* | 75.478 | 432.584*** | 47.802 | 208.158*** | 49.407 | 207.358*** |
| *PP – Fisher Chi-square* | 78.191*** | 1074.52*** | 21.150 | 204.719*** | 21.885 | 232.931*** |

| Variables<br>Method/statistics | *re*<br>Level | $\Delta re$<br>First diff. | *nre*<br>Level | $\Delta nre$<br>First diff. | *ex*<br>Level | $\Delta ex$<br>First diff. |
|---|---|---|---|---|---|---|
| **Null: Unit root (assumes common unit root process)** | | | | | | |
| *Levin, Lin & Chu t* | −1.112 | −22.213*** | 1.222 | −14.542*** | −0.952 | −16.060*** |
| *Breitung t-stat* | −0.100 | −12.351*** | 2.602 | −2.90*** | −0.754 | −2.707*** |
| **Null: Unit root (assumes individual unit root process)** | | | | | | |
| *Im, Pesaran and Shin W-stat* | −2.317 | −23.809*** | 0.007 | −17.304*** | 3.534 | −12.921*** |
| *ADF – Fisher Chi-square* | 147.007*** | 481.562*** | 57.9716 | 378.401*** | 24.278 | 268.671*** |
| *PP – Fisher Chi-square* | 156.793*** | 2653.47*** | 51.5580 | 991.158*** | 46.094 | 1022.39*** |

| Variables<br>Method/statistics | *im*<br>Level | $\Delta im$<br>First diff. |
|---|---|---|
| **Null: Unit root (assumes common unit root process)** | | |
| *Levin, Lin & Chu t* | −1.272 | −21.527*** |
| *Breitung t-stat* | 1.630 | −7.284*** |
| **Null: Unit root (assumes individual unit root process)** | | |
| *Im, Pesaran and Shin W-stat* | 5.619 | −18.249*** |
| *ADF – Fisher Chi-square* | 10.410 | 346.256*** |
| *PP – Fisher Chi-square* | 12.084 | 1143.56*** |

*** Indicates statistical significance at the 1% level. All variables are tested with intercept and trend. Automatically lag length selection based on the Schwarz Information Criterion (SIC).

**Table 3**
Pedroni cointegratin tests.

| | Model with exports | | Model with imports | |
|---|---|---|---|---|
| | Statistic | Weighted statistic | Statistic | Weighted statistic |
| *Alternative hypothesis: common AR coefs. (within-dimension)* | | | | |
| Panel $v$-statistic | −1.216612 | −1.894982 | −0.211988 | −0.752206 |
| Panel rho-statistic | 2.065187 | 2.407397 | 0.958273 | 2.109624 |
| Panel PP-statistic | −5.468320*** | −7.963959*** | −7.549487*** | −6.936571*** |
| Panel ADF-statistic | −4.915303*** | −7.084281*** | −4.845646*** | −6.574396*** |
| *Alternative hypothesis: individual AR coefs. (between-dimension)* | | | | |
| Group rho-statistic | 3.979402 | | 3.455101 | |
| Group PP-statistic | −10.90011*** | | −10.71302*** | |
| Group ADF-statistic | −6.761471*** | | −6.515201*** | |

*** Indicates statistical significance at the 1% level. The null hypothesis is that there is no cointegration among variables, whereas the alternative hypothesis is that there is cointegration. Lag length selection is based on SIC and is determined automatically with a max lag of 5 for the panels with exports and with imports.

techniques confirm the existence of long-run links between the analysis variables and the direction of causality between them can be examined.

### 3.3. Granger causality tests

We examine the direction of causality between our variables by using the Engle and Granger (1987) two-steps procedure for cointegration analysis. The first step estimates the long-run equilibrium from Eq. (1) through FMOLS technique to recover the residuals considered as a lagged error correction term (ECT). The second step estimates the dynamic vector error correction model (VECM) corresponding to each panel (exports or imports). The formulation of the dynamic VECM is given as follows:

$$\Delta e_{it} = \gamma_{1i} + \sum_{j=1}^{p}\gamma_{11ij}\Delta e_{it-j} + \sum_{j=1}^{p}\gamma_{12ij}\Delta y_{it-j} + \sum_{j=1}^{p}\gamma_{13ij}\Delta y^2_{it-j} + \sum_{j=1}^{p}\gamma_{14ij}\Delta re_{it-j} + \sum_{j=1}^{p}\gamma_{15ij}\Delta nre_{it-j}\sum_{j=1}^{p}\gamma_{16ij}\Delta o_{it-j} + \theta_{1i}ect_{it-1} + \psi_{1it} \quad (2)$$

$$\Delta y_{it} = \gamma_{2i} + \sum_{j=1}^{p}\gamma_{21ij}\Delta e_{it-j} + \sum_{j=1}^{p}\gamma_{22ij}\Delta y_{it-j} + \sum_{j=1}^{p}\gamma_{23ij}\Delta y^2_{it-j} + \sum_{j=1}^{p}\gamma_{24ij}\Delta re_{it-j} + \sum_{j=1}^{p}\gamma_{25ij}\Delta nre_{it-j}\sum_{j=1}^{p}\gamma_{26ij}\Delta o_{it-j} + \theta_{2i}ect_{it-1} + \psi_{2it} \quad (3)$$

$$\Delta y^2_{it} = \gamma_{3i} + \sum_{j=1}^{p}\gamma_{31ij}\Delta e_{it-j} + \sum_{j=1}^{p}\gamma_{32ij}\Delta y_{it-j} + \sum_{j=1}^{p}\gamma_{33ij}\Delta y^2_{it-j} + \sum_{j=1}^{p}\gamma_{34ij}\Delta re_{it-j} + \sum_{j=1}^{p}\gamma_{35ij}\Delta nre_{it-j}\sum_{j=1}^{p}\gamma_{36ij}\Delta o_{it-j} + \theta_{3i}ect_{it-1} + \psi_{3it} \quad (4)$$

$$\Delta re_{it} = \gamma_{4i} + \sum_{j=1}^{p}\gamma_{41ij}\Delta e_{it-j} + \sum_{j=1}^{p}\gamma_{42ij}\Delta y_{it-j} + \sum_{j=1}^{p}\gamma_{43ij}\Delta y^2_{it-j} + \sum_{j=1}^{p}\gamma_{44ij}\Delta re_{it-j} + \sum_{j=1}^{p}\gamma_{45ij}\Delta nre_{it-j}\sum_{j=1}^{p}\gamma_{46ij}\Delta o_{it-j} + \theta_{4i}ect_{it-1} + \psi_{4it} \quad (5)$$

$$\Delta nre_{it} = \gamma_{5i} + \sum_{j=1}^{p}\gamma_{51ij}\Delta e_{it-j} + \sum_{j=1}^{p}\gamma_{52ij}\Delta y_{it-j} + \sum_{j=1}^{p}\gamma_{53ij}\Delta y^2_{it-j} + \sum_{j=1}^{p}\gamma_{54ij}\Delta re_{it-j} + \sum_{j=1}^{p}\gamma_{55ij}\Delta nre_{it-j}\sum_{j=1}^{p}\gamma_{56ij}\Delta o_{it-j} + \theta_{5i}ect_{it-1} + \psi_{5it} \quad (6)$$

$$\Delta o_{it} = \gamma_{6i} + \sum_{j=1}^{p}\gamma_{61ij}\Delta e_{it-j} + \sum_{j=1}^{p}\gamma_{62ij}\Delta y_{it-j} + \sum_{j=1}^{p}\gamma_{63ij}\Delta y^2_{it-j} + \sum_{j=1}^{p}\gamma_{64ij}\Delta re_{it-j} + \sum_{j=1}^{p}\gamma_{65ij}\Delta nre_{it-j}\sum_{j=1}^{p}\gamma_{66ij}\Delta o_{it-j} + \theta_{6i}ect_{it-1} + \psi_{6it} \quad (7)$$

where $\Delta$ indicates the first difference operator, $p$ denotes the lag length determined automatically by the Schwarz Information Criterion (SIC) and is set equal to 2, ($o$) refers to the trade variable (exports or imports), $\gamma_i$ denote the fixed country effect, $\psi_{it}$ is a random error term. The lagged error correction term ($ect$) is generated from Eq. (1), and $\theta_i$ denotes the country speed of adjustment coefficient.

Short-run causal relationships are investigated by lagged differences of variables specified in each equation using $F$-statistic. Long-run causal relationships are established when the lagged $ect$ is between −1 and 0 and the $t$-statistic is significant. The results from these tests are reported in Tables 4 and 5, for the model with exports and that with imports, respectively.

Table 4 suggests a short-run unidirectional causality running from exports to $CO_2$ emissions at the 10% significance level. We find also a short-run one way causality running from exports to renewable energy consumption at the 1% significance level, whereas short-run bidirectional causality is found between exports and non-renewable energy consumption at mixed levels of significance. In the long-run, the error correction terms estimated are statistically significant for all estimated equations (Eqs. (2)–(7)). Thus, there are bidirectional long-run relationships between $CO_2$ emissions, economic growth, renewable and non-renewable energy consumption and exports.

Short-run Granger causality tests reported in Table 5 reveal that there is a unidirectional causality running from imports to $CO_2$ emissions at the 5% significance level. Besides, there is a bidirectional short-run causality between renewable energy consumption and imports and between non-renewable energy consumption and imports at mixed levels of significance. In the long-run, the error correction terms estimated are statistically significant for all estimated equations (Eqs. (2)–(7)) indicating the existence of bidirectional long-run causal relationships between $CO_2$ emissions, economic growth, renewable and non-renewable energy consumption and imports.

Fig. 1 sums up the short-run causalities between all our considered variables. By looking to Fig. 1, Tables 4 and 5, we can highlight

**Table 4**
Granger causality tests (model with exports).

| Dependent variable | Short-run | | | | | | Long-run |
|---|---|---|---|---|---|---|---|
| | $\Delta e$ | $\Delta y$ | $\Delta y^2$ | $\Delta re$ | $\Delta nre$ | $\Delta ex$ | *ect* |
| $\Delta e$ | – | 8.17752 | 7.40352 | 0.31593 | 15.8378 | 2.35312 | −0.007762 |
| | | (0.0003)$^{***}$ | (0.0007)$^{***}$ | (0.7292) | (0.0000)$^{***}$ | (0.0958)$^{*}$ | [−5.18541]$^{***}$ |
| $\Delta y$ | 1.14451 | – | 0.34002 | 0.32990 | 2.55632 | 0.13245 | −0.044131 |
| | (0.3190) | | (0.7119) | (0.7191) | (0.0783)$^{*}$ | (0.8760) | [−2.17387]$^{**}$ |
| $\Delta y^2$ | 1.23329 | 0.48436 | – | 0.35969 | 2.69611 | 0.00247 | −0.001165 |
| | (0.2919) | (0.6163) | | (0.6980) | (0.0681)$^{*}$ | (0.9975) | [−2.71403]$^{***}$ |
| $\Delta re$ | 1.04898 | 3.86865 | 4.08590 | – | 4.13807 | 5.77154 | −0.031046 |
| | (0.3508) | (0.0213)$^{**}$ | (0.0172)$^{**}$ | | (0.0163)$^{**}$ | (0.0033)$^{***}$ | [−7.06016]$^{***}$ |
| $\Delta nre$ | 2.87229 | 10.1013 | 10.9082 | 2.34389 | – | 6.23900 | −0.005404 |
| | (0.0572)$^{*}$ | (0.0000)$^{***}$ | (0.0000)$^{***}$ | (0.0967)$^{*}$ | | (0.0021)$^{***}$ | [−2.07041]$^{**}$ |
| $\Delta ex$ | 1.03654 | 1.67278 | 1.38562 | 0.39890 | 2.50111 | – | −0.005244 |
| | (0.3552) | (0.1885) | (0.2508) | (0.6712) | (0.0827)$^{*}$ | | [−3.31770]$^{***}$ |

*Notes*: Lag lengths selected are equal to 2 based on the Schwarz information criterion. *P*-values are listed in parentheses and t-statistics are listed in brackets.
$^{***}$ Indicate statistical significance at the 1% level.
$^{**}$ Indicate statistical significance at the 5% level.
$^{*}$ Indicate statistical significance at the 10% level.

**Table 5**
Granger causality tests (model with imports).

| Dependent variable | Short-run | | | | | | Long-run |
|---|---|---|---|---|---|---|---|
| | $\Delta e$ | $\Delta y$ | $\Delta y^2$ | $\Delta re$ | $\Delta nre$ | $\Delta im$ | *ect* |
| $\Delta e$ | – | 8.17752 | 7.40352 | 0.31593 | 15.8378 | 3.40676 | −0.005509 |
| | | (0.0003)$^{***}$ | (0.0007)$^{***}$ | (0.7292) | (0.0000)$^{***}$ | (0.0337)$^{**}$ | [−5.39203]$^{***}$ |
| $\Delta y$ | 1.14451 | – | 0.34002 | 0.32990 | 2.55632 | 8.99567 | −0.058007 |
| | (0.3190) | | (0.7119) | (0.7191) | (0.0783)$^{*}$ | (0.0001)$^{***}$ | [−2.78825]$^{**}$ |
| $\Delta y^2$ | 1.23329 | 0.48436 | – | 0.35969 | 2.69611 | 9.64424 | −0.001484 |
| | (0.2919) | (0.6163) | | (0.6980) | (0.0681)$^{*}$ | (0.0000)$^{***}$ | [−3.46252]$^{***}$ |
| $\Delta re$ | 1.04898 | 3.86865 | 4.08590 | – | 4.13807 | 6.91345 | −0.030680 |
| | (0.3508) | (0.0213)$^{**}$ | (0.0172)$^{**}$ | | (0.0163)$^{**}$ | (0.0011)$^{***}$ | [−7.18584]$^{***}$ |
| $\Delta nre$ | 2.87229 | 10.1013 | 10.9082 | 2.34389 | – | 9.39626 | −0.002566 |
| | (0.0572)$^{*}$ | (0.0000)$^{***}$ | (0.0000)$^{***}$ | (0.0967)$^{*}$ | | (0.0000)$^{***}$ | [−2.25167]$^{**}$ |
| $\Delta im$ | 0.86507 | 7.75689 | 8.35070 | 2.49064 | 2.82109 | – | −0.005478 |
| | (0.4215) | (0.0005)$^{***}$ | (0.0003)$^{***}$ | (0.0836)$^{*}$ | (0.0602)$^{*}$ | | [−2.90005]$^{***}$ |

*Notes*: Lag lengths selected are equal to 2 based on the Schwarz information criterion. *P*-values are listed in parentheses and t-statistics are listed in brackets.
$^{***}$ Indicate statistical significance at the 1% level.
$^{**}$ Indicate statistical significance at the 5% level.
$^{*}$ Indicate statistical significance at the 10% level.

our main causal links. Indeed, there is some evidence of a one way short-run causal relationship running from economic growth to emissions. However, in the long-run, the relationship between emissions and economic growth is bidirectional. This finding is consistent with the short-run result of Ben Jebli and Ben Youssef (2015a) for the case of Tunisia, but is in contrast to their long-run result in which they suggest a unidirectional causality running from economic growth to emissions of $CO_2$.

The finding of a unidirectional short-run causal relationship running from economic growth to renewable energy consumption is not similar to the results of Apergis and Payne (2010a) for a panel of 20 OECD countries, and to the results of Apergis et al. (2010). However, their long-run outcome is consistent to our long-run Granger results in which they confirm that the relationship between renewable energy consumption and economic growth supports the feedback hypothesis. We think that this short-run

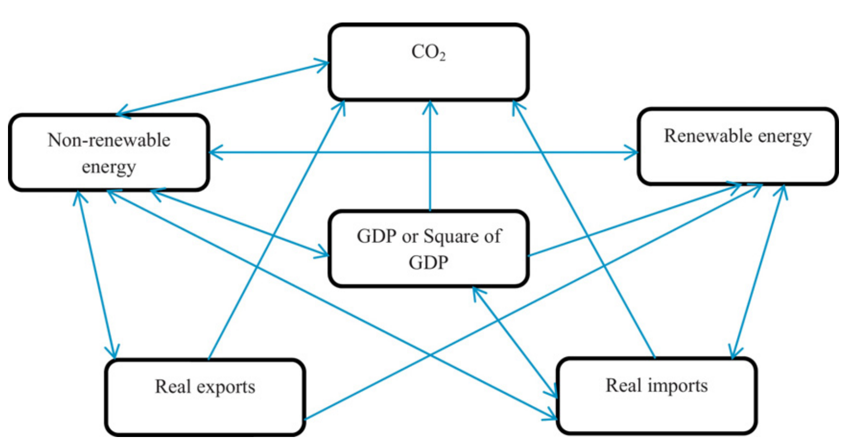


**Fig. 1.** Short-run causalities between $CO_2$ emissions, economic growth, renewable and non-renewable energy consumption and trade.

**Table 6**
FMOLS-DOLS long-run estimates.

| | FMOLS | | | DOLS | | |
|---|---|---|---|---|---|---|
| Variable | Coefficient | *t*-Statistic | Prob. | Coefficient | t-Statistic | Prob. |
| *Model with exports* | | | | | | |
| *y* | 2.347618 | 6.547627 | 0.0000*** | 2.555595 | 7.236842 | 0.0000*** |
| $y^2$ | −0.104916 | −5.856863 | 0.0000*** | −0.116317 | −6.582119 | 0.0000*** |
| *re* | −0.031822 | −3.165888 | 0.0016*** | −0.032684 | −3.266685 | 0.0011*** |
| *nre* | 0.465396 | 12.14432 | 0.0000*** | 0.422452 | 11.22010 | 0.0000*** |
| *ex* | −0.110665 | −4.946634 | 0.0000*** | −0.089855 | −4.139783 | 0.0000*** |
| *Model with imports* | | | | | | |
| *y* | 2.280273 | 6.590051 | 0.0000*** | 2.469702 | 7.206329 | 0.0000*** |
| $y^2$ | −0.099399 | −5.733568 | 0.0000*** | −0.109436 | −6.349100 | 0.0000*** |
| *re* | −0.029232 | −3.022719 | 0.0026*** | −0.031538 | −3.261061 | 0.0012*** |
| *nre* | 0.494040 | 13.30218 | 0.0000*** | 0.439273 | 11.95833 | 0.0000*** |
| *im* | −0.143910 | −6.457138 | 0.0000*** | −0.120931 | −5.475490 | 0.0000*** |

*** denotes statistical significance at the 1% level. Cointegrating equation deterministics: intercept and trend. All variables are estimated in natural logarithms.

divergence is due to the differences in both the variables used and the selected time period considered.

Besides, there is evidence of short and long-run bidirectional causality between emissions and non-renewable energy consumption. These results confirm that any changes in the degree of pollution can affect the trend in the fossil fuels consumed in this region. In addition, any non-renewable energy conservation policy leads to disturb the emissions tendency. The relationship between non-renewable energy consumption and economic growth is bidirectional either in the short or in the long-run. This feedback causality between these two variables means that economic growth in OECD countries has a strong influence on the use of fossil energy sources.

Granger causality tests reveal the existence of short and long-run bidirectional causality between non-renewable energy consumption and trade (exports or imports), short and long-run bidirectional causality between renewable energy consumption and imports, short-run unidirectional causality running from exports to renewable energy consumption, and long-run bidirectional causality between renewable energy consumption and exports.

### 3.4. Panel long-run estimates

We estimate the long-run coefficients by using the FMOLS and DOLS estimators. The FMOLS approach estimate has been proposed by Pedroni (2001, 2004), whereas the DOLS approach has been recommended by Kao and Chiang (2001), and Mark and Sul (2003) for the panel case. These two approaches are more powerful than the ordinary least square (OLS) approach. The advantage of the FMOLS non-parametric technique is that it corrects for both endogeneity bias and serial correlation, whereas DOLS is a parametric technique.

The results from FMOLS and DOLS long-run estimates corresponding to each model are reported in Table 6. All estimated coefficients can be interpreted as long-run elasticities given that variables are expressed in natural logarithms. The long-run coefficients estimated using the two techniques are very similar and are statistically significant at the 1% level. The EKC hypothesis that assumes an inverted U-shaped relationship between per capita emissions and per capita GDP is verified for both models.

Table 6 shows that, for the model with exports and for the FMOLS method, panel estimate results indicate that the long-run elasticity of $CO_2$ emissions with respect to GDP is approximately equal to $2.35 - 0.21y$; a 1% increase in renewable energy decreases emissions by approximately 0.03%; a 1% increase in non-renewable energy consumption increases emissions by 0.46%; a 1% increase in exports reduces $CO_2$ emissions by 0.11%. For the model with imports and using the FMOLS method: the long-run elasticity of per capita $CO_2$ emissions with respect to per capita GDP is approximately equal to $2.28 - 0.20y$; a 1% increase in renewable energy decreases emissions by 0.03%; a 1% increase in non-renewable energy consumption increases $CO_2$ emissions by 0.49%; a 1% increase in imports reduces $CO_2$ emissions by 0.14%.

For both models we show that increasing renewable energy consumption reduces $CO_2$ emissions in the long-run. Thus, encouraging renewable energy use by granting research and development (R&D) programs, reinforcing regulatory framework, etc. is a good policy for OECD countries to combat global warming. This result is consistent with that of Ben Jebli and Ben Youssef (2015a) for the export model. However, our result is not similar to that of Apergis et al. (2010) as they show that more renewable energy consumption increases $CO_2$ emissions for the panel of 19 developed and developing countries they consider.

We show that increasing exports or imports reduces $CO_2$ emissions. This result could be explained by the fact that most countries of our considered panel are developed countries. Since trade has a positive effect on per capita GDP and knowing that the inverted U-shaped EKC hypothesis is verified for this panel of OECD countries, the increase in per capita trade leads to a reduction in per capita $CO_2$ emissions in the long-run. This result is similar to that of Shahbaz et al. (2014) who show that the EKC hypothesis is verified in UAE and that increasing exports in UAE reduces $CO_2$ emissions in the long-run. This result is contrary to that found by Ben Jebli and Ben Youssef (2015a) as they show that increasing trade increases $CO_2$ emissions. Their result is due to the fact that the inverted U-shaped EKC hypothesis is not verified in Tunisia considered as a developing country. In addition, our result differs from that of Halicioglu (2009) showing that increasing the trade openness ratio in turkey increases per capita $CO_2$ emissions in the long-run, whereas the EKC hypothesis is verified analytically but not graphically. It is evident from these empirical studies that when the EKC hypothesis is verified, there is a great chance that trade has a beneficial and reducing impact on $CO_2$ emissions.

## 4. Conclusion and policy implications

In this paper, we use panel cointegration techniques to investigate the short and long-run causal nexus between per capita carbon dioxide emissions, economic growth, renewable and non-renewable energy consumption and trade (exports or imports) for a panel of 25 OECD countries over the period 1980–2010. We also try to test the validity of the inverted U-shaped EKC hypothesis for this panel of countries.

Our short-run Granger causality tests show the existence of a unidirectional causality running from trade to $CO_2$ emissions, a unidirectional causality running from exports to renewable energy consumption, bidirectional causality between imports and renewable energy consumption, and bidirectional causality between renewable and non-renewable energy consumption. This last causality is indicative of short-run substitutability between the two energy sources. In the long-run however, there is evidence of bidirectional causal relationships between per capita $CO_2$ emissions, real GDP, renewable and non-renewable energy consumption, real exports (or imports).

The FMOLS and DOLS long-run estimates support the inverted U-shaped EKC hypothesis between per capita $CO_2$ emissions and GDP. This result is not surprising as most of the considered countries in our panel are developed countries. As expected, increasing non-renewable energy consumption increases $CO_2$ emissions in the long-run. However, increasing renewable energy consumption reduces $CO_2$ emissions in the long-run. Therefore, and because of the substitutability between non-renewable and renewable energy, increasing the consumption of renewable energy leads to a reduction in $CO_2$ emissions and may reduce the dependency of these OECD countries on fossil energy. Long-run estimates show also that increasing trade reduces $CO_2$ emissions. Thus, increasing international commercial exchanges, which has been shown to be increasing economic growth in most empirical studies, is actually helping in combating global warming for this panel of OECD countries.

As a policy implication, OECD countries should increase their international economic exchanges and their renewable energy consumption in order to reduce their $CO_2$ emissions and to combat global warming. By increasing the use of renewable energy this will help them to reduce their energy dependency and promote the energy security of energy importing countries too.

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