The environmental Kuznets curve, economic growth, renewable and non-renewable energy, and trade in Tunisia

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Abstract: We use the autoregressive distributed lag (ARDL) bounds testing approach for cointegration with structural breaks and the vector error correction model (VECM) Granger causality approach in order to investigate relationships between per capita CO_2 emissions, GDP, renewable and non-renewable energy consumption and international trade (exports or imports) for Tunisia during the period 1980-2009. We show the existence of a short-run unidirectional causality running from trade, GDP, CO_2 emission and non-renewable energy to renewable energy. Our long-run estimates show that non-renewable energy and trade have a positive impact on CO_2 emissions, whereas renewable energy impacts weakly and negatively CO_2 emission when using the model with exports and this impact is statistically insignificant when using the model with imports. The inverted U-shaped environmental Kuznets curve (EKC) hypothesis is not supported graphically and analytically in the long-run. This means that Tunisia has not yet reached the required level of per capita GDP to get an inverted U-shaped EKC. Our main policy recommendations for Tunisia are the following: *(i)* to radically reform the subsidies system granted by the Tunisian government for fossil fuels consumption; *(ii)* to encourage the use of renewable energy and energy efficiency by reinforcing actual projects and regulatory framework; *(iii)* to locate ports near exporting industrial zones (or vice versa) to reduce emission of pollution caused by the transport of merchandise; *(iv)* to elaborate a strategy for maximizing its benefit from renewable energy technology transfer occurring when importing capital goods; *(v)* to encourage the creation of renewable energy projects for export to the EU with a proportion of production for national consumption.

Keywords: Environmental Kuznets curve; Renewable and non-renewable energy; International trade; Autoregressive distributed lag; Tunisia.

JEL Classification: C22, F14, Q42, Q43, Q54

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1. Introduction

To our knowledge, there is no cross-sectional study on the causal relationship between renewable and non-renewable energy consumption, international trade, output and CO_2 emissions. This study tries to test the validity of the so-called environmental Kuznets curve (EKC) hypothesis and studies the causal relationships between per capita CO_2 emissions, renewable and non-renewable energy consumption, international trade (exports or imports) and output in Tunisia.

Tunisia made many important decisions to reinforce its international exchanges such as the economic liberalization and a structural adjustment plan which has been launched in 1986, the adherence to the general agreement on tariffs and trade (GATT) in 1989, the adherence to the world trade organization (WTO) in 1994 and the ratification of a free trade agreement with the European Union (EU) in 1995. By removing all trade barriers, Tunisia became the first Mediterranean country to enter into a free trade area with the EU in 2008. Tunisia international exchanges have considerably increased. Indeed, imports of goods and services as percentage of gross domestic product (GDP) have increased from 45.6% in 1980 to 48.3% in 2009, while the proportion of exports has increased from 40.2% to 45.7% in the same period. This gives a rise in the trade openness ratio from 85.8% to 94% between 1980 and 2009. In the same time, the GDP per capita (in constant 2005 US$) has increased from 1802 US$ to 3735 US$ (World Bank [56]).

This expansion in Tunisian international exchanges and GDP is accompanied by an increase in pollution emissions. Indeed, per capita emissions of CO_2 has increased from 1.5 metric tons in 1980 to 2.4 in 2009 (World Bank [56]), which is mainly due to an important increase in the use of fossil fuels. The Tunisian socio-economic development, combined with policies based on the government subsidization of nearly all types of energy, has led to the strong growth of energy demand in Tunisia over the last 30 years. In 2010, the industrial sector accounts for the largest share of energy consumption at 36% of overall final consumption, followed by the transportation sector at 31%, buildings at 27% and agriculture at 6% (Gestore dei Servizi Energetici - GSE S.p.A [29]). The energy situation in Tunisia is also characterized by a heavy dependence on natural gas with a share of 46.1% in the country's primary energy consumption in 2009, followed by oil (39.5%), biofuels and waste (14.1%), hydro (0.1%) and geothermal/solar/wind (0.1%) (Gestore dei Servizi Energetici - GSE S.p.A [29]). Tunisia receives natural gas from a pipeline between Algeria and Italy that runs across its territory. Compared to its neighboring countries, domestic fossil energy sources in Tunisia are limited. The Tunisian energy independence is around 87.6% in 2011(Gestore dei Servizi Energetici - GSE S.p.A [29]). Since 2001 the status of Tunisia has changed from an energy exporter country to a net importer. In order to become less dependent on energy imports and the volatile prices of oil and gas, Tunisia decided to develop many programs of energy efficiency and renewable energy production.

However, the increase in income can lead to a demand for better environmental quality and contributes to a reduction in greenhouse gas (GHG) emissions. The EKC hypothesis supposes an inverted U-shaped curb for per capita emissions in function of per capita GDP. Indeed, per capita emissions are supposed to increase with GDP for developing countries having low income, and from a threshold point, per capita emissions decrease with GDP for developed countries with high income. It is well known that international trade has an impact on pollution through four principal effects, which are the scale, composition, technique and technological effects. The scale effect links pollution to production, and it is expected that international trade increases production and, therefore, pollution. The composition effect stipulates that certain dirty industries could move to countries with less severe environmental regulations. The technique effect enables pollution reduction by using the available technology, and the technological effect refers to the possibility that international exchanges might encourage R&D activities on cleaner technologies to reduce the pollution intensity. Thus, more international commercial exchanges may increase the availability of goods and services that are more energy efficient, and can be used as a channel for diffusing cleaner technologies, among which those using renewable energy, especially from developed countries. In fact, the net effect of more trade on the environment is ambiguous and needs to be tested empirically (Copeland and Taylor [22]; Antweiler et al. [6]). In Tunisia, the production of electricity from renewable sources has considerably increased passing from 24 giga watt hour (GWH) in 1980 to 176 GWH in 2009. In addition, Tunisia has established since more than 20 years a policy of energy conservation and promotion of renewable energies and has planned many important renewable energy projects. Therefore, explaining the relationship between renewable energy consumption and international trade is particularly interesting for the Tunisian case.

International trade and renewable energy consumption are linked. Indeed, international trade can induce more renewable energy use because more trade in goods necessitates more energy and renewable energy to produce, consume and transport these traded goods to or from foreign countries. Moreover, international trade can play a significant role in greening the energy sector because 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. Domestic 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 (United Nations Environment Program [55]). In the other side, more renewable energy production can stimulate international trade because the use of more renewable energy implies more production of goods and the excess of production is exported. In addition, there may exist a surplus in renewable energy production in a country, and the excess of production is exported to countries having a deficiency in renewable energy production.

In conclusion, during the last three decades, Tunisia made an important increase in international commercial exchanges, economic growth, CO_2 emissions, non-renewable and renewable energy consumption and studying the relationship between these economic variables could be of great interest. Fig. 1 reports the graphs representations of per capita CO_2 emissions, real GDP, renewable and non-renewable energy consumption, real exports, and real imports. It shows that throughout the selected period 1980-2009, the movement of all series has a trend upward across time, with renewable and non-renewable energy consumption having an unstable evolution across time. Globally, excluding energy consumption plots, the other variables are characterized by similar tendencies and have nearly the same magnitude of growth.

The objectives of our empirical estimates are to investigate the dynamic causal relationships between per capita CO_2 emissions, real GDP, renewable and non-renewable energy consumption and international trade for the case of Tunisia. Also, we test whether the inverted U-shaped EKC hypothesis is verified or not for Tunisia during the considered period 1980-2009.

This paper has the following structure. Section 2 is a literature review and Section 3 gives an idea about renewable energy in Tunisia. Section 4 is concerned by the used data and methodology. Section 5 is devoted to the empirical analysis, and Section 6 concludes with policy recommendations.

Insert Fig.1 here

2. Literature review

Some recent empirical papers study the causal relationship between CO_2 emissions and other variables for the Tunisian case. Fodha and Zaghdoud [28] investigate the relationships between per capita economic growth and pollutant emissions (CO_2, SO_2) for Tunisia, using time series data and cointegration analysis. They show the existence of an inverted U-shaped relationship between SO_2 emissions and GDP, and a monotonically increasing relationship between CO_2 emissions and GDP. Moreover, they show the existence of a short and long-run unidirectional causality running from GDP to CO_2 and SO_2 emissions. Chebbi [20] provides some insights into the linkages between energy consumption, carbon emissions and the sector components of output growth (agriculture, industry and services) using Tunisian data. Long–run analysis suggests that there is bidirectional causality between energy consumption and output growth, and between energy consumption and CO_2 emissions. Short–run results indicate that the linkages between GDP and energy consumption, and between GDP and CO_2 emissions are not uniform across sectors. Chebbi et al. [21] use cointegration techniques to examine the causality between trade openness, per capita GDP and per capita CO_2 emissions for Tunisia. They show the existence of long-run bidirectional causality between the three variables per capita CO_2 emissions, per capita GDP and trade openness, and a one way short-run causality running from trade openness to CO_2 emissions. Their results suggest that the direct effect of trade openness on CO_2 emissions is positive in both the short and long-run, but the indirect effect is negative at least in the long-run. The overall effect is positive in both the short and long run. Shahbaz et al. [51] investigate the EKC hypothesis and the causal relationships between per capita CO_2 emissions, GDP, energy consumption and trade openness for Tunisia. They find long-run relationships between these variables, and an inverted U-shaped EKC was analytically proved.

With respect to the literature treating the Tunisian case, we add at least two contributions. First, we add renewable energy consumption, and this will enables us to evaluate its impact on CO_2 emissions and to assess its causal relationships with the other considered variables. Second, and contrary to Chebbi et al. [21] and Shahbaz et al. [51] where trade openness is measured by the ratio imports plus exports divided by GDP, in our paper international trade is measured by per capita imports or per capita exports variables into two different specification models, to have the proper impact of each variable.

Several other empirical studies, not concerned only by the Tunisian case, test the validity of the EKC hypothesis for a single country and/or a balanced panel. Many of these studies examine the dynamic relationship between economic growth and environmental pollutants (Akbostanci et al. [3]; Jaunky [36]; Narayan and Narayan [40]) or between economic growth, energy consumption and environmental pollutants (Ang [4], [5]; Soytas et al. [53]; Sadorsky [46]; Apergis and Payne [7]; Apergis et al. [12]; Menyah and Wolde-Rufael [38], [39]; Acaravci and Ozturk [1]; Ozturk and Acaravci [42]; Arouri et al. [13]; Hamit-Haggar [31]; Ozcan [41]). Another group of papers introduce international trade as an important variable and evaluate its dynamic relationship with output, non-renewable energy consumption and pollutant emissions (Jalil and Mahmud [35]; Halicioglu [30]; Jayanthakumaran et al. [37]; Shahbaz et al. [49], [50]; Sbia et al. [48]). Recently, Ben Jebli et al. [17] introduce renewable energy consumption as an important variable and study its dynamic relationships with international trade, output, non-renewable energy consumption and pollutant emissions, for a panel of OECD countries.

Ang [4] examines the dynamic causal relationships between per capita CO_2 emissions, energy consumption and output for France. His results show the existence of long-run causality running from economic growth to the growth of energy use and the growth of pollution. He also shows a unidirectional short-run causality running from energy use growth to output growth. The inverted U-shaped EKC hypothesis is verified graphically and analytically. Arouri et al. [13] examine the relationships between per capita CO_2 emissions, energy consumption, and real GDP for 12 Middle East and North African (MENA) countries. Their results reveal that, in the long-run, energy consumption has a positive significant impact on CO_2 emissions. Real GDP exhibits a quadratic relationship with CO_2 emissions for the region as a whole. The long-run elasticity of income and its square satisfy the EKC hypothesis in most studied countries, but is not satisfied for United Arab Emirates (UAE), Morocco and Tunisia. Halicioglu [30] examines the dynamic causal relationships between per capita CO_2 emissions, energy consumption, output, and foreign trade in the case of Turkey by using the autoregressive distributed lag (ARDL) bounds testing to cointegration procedure. The bounds test results show the existence of two forms of long-run relationships between variables. The first form long-run relationships indicate that CO_2 emissions are determined by energy consumption, income and foreign trade. The second form long-run relationships indicate that income is determined by CO_2 emissions, energy consumption and foreign trade. Moreover, income is the most significant variable in explaining CO_2 emissions in Turkey, followed by energy consumption and foreign trade. Ben Jebli et al. [17] use panel cointegration techniques to investigate the causal relationships between per capita CO_2 emissions, renewable and non-renewable energy consumption, and trade (exports or imports) for a panel of twenty five OECD countries. Long-run Granger causality tests show the existence of a unidirectional causality running from per capita output, renewable and non-renewable energy consumption, exports and imports to per capita CO_2 emissions. Long-run estimates suggest that per capita renewable energy consumption, exports and imports have negative impacts on per capita CO_2 emissions, and the inverted U-shaped EKC hypothesis is verified.

With respect to the literature not concerned only by the Tunisian case, this paper is closely related to Ben Jebli et al. [17]. While Ben Jebli et al. [17] use dynamic panel cointegration technique, the present paper is a cross-section study using ARDL bounds testing to cointegration procedure.

3. Renewable energy in Tunisia

From 2001 the status of Tunisia has changed from an energy exporter country to a net importer. In order to become less dependent on energy imports and the volatile prices of oil and gas, Tunisia decided to develop many programs of energy efficiency and renewable energy production. Saidi and Fnaiech [47] relate Tunisia’s experience and future opportunities in renewable energy and energy efficiency.

The key players for energy generation in Tunisia are: *(i)* ministry of industry, energy and mines: has the mission of developing and implementing government policy in topics related to industry, industrial services, energy, mining, industrial cooperation and industrial safety. Within the ministry, the department of electricity, gas and energy efficiency is responsible for the coordination and implementation of energy policies in coordination with the national agency for energy conservation (agence nationale pour la maîtrise de l'énergie-ANME) regarding renewable energy and energy efficiency. Moreover, the ministry supervises the Tunisian company for electricity and gas (société Tunisienne de l’électricité et du gaz-STEG) in the production, transport and distribution of electricity and gas; *(ii)* STEG: has been created in 1962 with the mission to produce, distribute, import and export of electricity and gas. The monopoly of production was ended in 1996 by opening to independent power producers while leaving to STEG the role of single buyer and the activities of distribution; *(iii)* ANME: was established in 2004 (Law No. 72 of August 2nd 2004) under the supervision of ministry of industry, energy and mines with the mission of implementing the energy policy of the Tunisian government related to the fields of energy efficiency and renewable energies. The area of intervention of ANME includes all initiatives and actions to improve the energy efficiency and diversify energy sources such as: conducting studies on mitigation of GHG emissions related to energy consumption, administration of a national fund for energy management (fonds national de maîtrise de l'énergie-FNME) by granting its implementation and sustainability, proposing legal and regulatory framework related to energy management, granting tax and financial incentives, giving support to research and development (R&D) demonstration projects, supporting the development of industry by encouraging investments in this sector,...etc.

Tunisia has established since more than 20 years a policy of energy conservation and promotion of renewable energies and has a specific regulatory energy framework. Tunisia has ratified the Kyoto protocol in 22 January 2003 even though, as a developing country, it is not committed to any GHG emissions under this protocol.[1] The main laws concerning energy efficiency and renewable energy are: *(i)* the Law No. 72 of August 2nd 2004, concerning the energy management was expected to strongly support the actions of mastering energy, and was amended by Law No. 7 of February 9th 2009, which has introduced important elements of promotion of renewable energies, in particular on electricity production, by allowing large industrial consumers to self-produce electricity from renewable energy sources and to sell their surpluses to STEG. Moreover, these self-producers are authorized to use the national grid to transport the electricity generated up to the consumption point, through the payment of transport fees. By this law, STEG is obliged to purchase the electricity surplus and the self-producers shall pay the costs of the connection to the grid and those of strengthening the grid if needed; *(ii)* the Law No. 82 of August 5th 2005, enabling to create the FNME with the mission of financing and subsidizing energy efficiency operations, promoting renewable energy and energy substitution. FNME is fed by taxes due on the first registration of tourism cars in Tunisian series, taxes due on the importation or local production of equipment for air conditioning, donations and grants from individuals and legal persons, and any other resources that can be assigned to the fund under the legislation. In 2010, the FNME financed up to 21 million TND (1 TND≅ 0.56 US$ in October 2014).

In addition to a specific regulatory framework in order to strengthen national renewable energy policy, a Tunisian solar plan (TSP) was established and incorporates in a simple concept the whole renewable technologies and the energy effectiveness, from the point of view of the Mediterranean solar plan (MSP). It covers the period 2010 to 2016 and includes 40 different projects, including solar, wind and energy efficiency projects. The estimated cost of the program is 3 369 millions TND, which is envisaged to be financed by private and public sources (private sector, STEG, FNME, technical cooperation). An important part of this project (2 500 millions TND) is financed by the private sector, 1 074 millions TND being affected to projects exporting to Europe. When the totality of the projects will be implemented, the main result of the TSP should be a reduction of fossil fuel consumption of 660 kilo tons of oil equivalent (ktoe) per annum, which is equivalent to 22% of the national energy consumption in 2016. These projects are expected to reduce importantly GHG emissions and their negative environmental impacts are marginal consisting mainly in ground occupation, water consumption and, in the case of wind farms, the negative impact on birds and bats. They are expected to have an impact on the increase on GDP by 0.4% and on investments by 1.4%. Although imports will increase, the overall effect will be positive, with an increase in exports by 0.1% and in employment by 0.2% (Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH [23]).

The TSP attests the will of the Tunisian state to promote concrete actions in the field of energy efficiency and renewable energies. Besides, it confirms Tunisia ambitions to become an international hub for industrial production and exportation of renewable energies.

[1] The Kyoto protocol was adopted in Kyoto, Japan, on 11 December 1997, entered into force on 16 February 2005 and amended in Doha, Qatar, on 8 December 2012.

Combined with political willingness, the potential for renewable energy sources in Tunisia enables it to reach such an objective: *(i)* wind energy: the development of wind energy is expanding fast. In 2012, the Tunisian renewable generation fleet consists principally in a 54 mega watt (MW) wind farm in Sidi Daoud in the north-east of the country, a 120 MW wind farm in the Bizerte region and scheduled extension to reach 190 MW (Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, 2013). Studies indicate that Tunisia could eventually generate 1 000 MW from wind energy. Several sites have been identified showing good potential for the use of wind power, with average wind speeds of 5.9-7.5 m/s at 80m high; *(ii)* solar energy: Tunisia has a very high solar potential with more than 3 200 hours of sunshine per year, and an average daily of 5-5.5 kilo watt hour (kwh)/m^2. However, until recently solar energy was not considered cost competitive enough, and is largely limited to use in domestic water heating systems and in certain community projects. Recently, the private sector is beginning to explore the commercial applications for solar power; *(iii)* hydropower: in 2012 six hydraulic power plants with a total capacity of 66 MW were installed (Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH [24]). Tunisia's gross theoretical hydropower potential was estimated at 1 000 GWH/year in the mid-1990s, with a technically feasible potential of 250 GWH/year; *(iv)* biomass energy: traditional wood and charcoal fuels are still used in some rural households. Projects are in place to disseminate more efficient biomass stoves. The potential for biomass gasification has been identified and pilot projects involving gasification through poultry waste has been launched; *(v)* geothermal energy: Tunisia has a substantial geothermal potential, primarily thermal waters. Its use currently extends to the heating of greenhouses, spas, resorts and other heat-dependent activities as well as being used in ice production. Geothermal resources are taken from the ‘‘Continental Intercalaire’’ aquifer: the deep aquifer is characterized by relatively hot water (between 30 and 80°C) and depths reaching 2 800 m. The resources are located in a reservoir of 1 000 000 km² which covers the regions of Kebili, Tozeur, Gabes and the extreme south, and extends to Algeria and Libya.

The great renewable energy potential of Tunisia is confirmed by the interest of foreign investors. Indeed, the European industrial initiative Desertec industrial initiative (Dii) plans to promote the implementation of several large-scale renewable energy projects in the MENA region. These projects are intended to produce electricity for national consumptions as well as for export to the EU. Dii intends to carry out a prefeasibility study for the implementation of a 1 000 MW (400 MW concentrated solar power (CSP), 300 MW photovoltaic (PV) and 300 MW wind) renewable energy pilot project in Tunisia (Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH [24]), over the period 2014-2020, with some projects that may be included in the TSP. A trans-Mediterranean cable is previewed for exporting electricity. By 2016, export capacity to the EU is expected to reach 1 000 MW, including 800 MW from fossil fuels and 200 MW from renewable energy (Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH [23]).

The current EU regulatory framework encourages the development of renewable energy. The EU also supports the development of renewable energy in the southern basin of the Mediterranean by the commitment of partnership within the EU for the MSP. Directive 2009/28/EC for the promotion of renewable energies can contribute to the development of renewable energy projects outside the EU borders. Article 9 of this directive provides that the energy produced in a third country may be recognized on account of a member state in order to achieve its renewable energy goals for 2020.

In addition to encouraging renewable energy use, Tunisia established a program in 2000 for the rational use of energy. The ANME developed a strategic plan, which covers several fields, including: *(i)* the development of a lawful framework relating to energy efficiency; *(ii)* the granting of the tax and financial incentives for energy efficiency; *(iii)* the set-up of training, education courses, and information dissemination; *(iv)* the support of R&D and the realization of demonstration projects; *(v)* the encouragement of private investments in this sector. These programs enabled Tunisia to save 9% of the energy consumed in 2011 (Agence Nationale pour la Maîtrise de l'Energie [2]).

As a result of this policy, the production of electricity from renewable sources has considerably increased passing from 24 GWH in 1980 to 176 GWH in 2009, and the proportion of electricity production from renewable sources with respect to total electricity produced has increased from 0.82% in 1980 to 1.15% in 2009 (World Bank [56]). Besides, primary energy intensity has clearly improved. Indeed, over the last twenty years, primary energy intensity has been decreasing at an average annual rate of 2.6%, followed by a decrease in carbon intensity (Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH [23]). Moreover, between 2005 and 2008, clean energy plans enabled the government to save nearly 900 millions € in energy bills (equivalent to 10 per cent of primary energy consumption), with an initial investment in clean energy infrastructure of only 260 millions € (United Nations Environment Program [54]).

In addition, there is an important growth in the solar water heater sector where the visibility provided by support programs for the solar thermal market made it possible to encourage industrial and partnership initiatives, which led to a significant solar water heater manufacturing and assembly capacity. Six industrial firms are already in operation: SOFTEN, SINES, SIER, BSI, Tech-Sol and Soltech. Furthermore, nearly forty firms are importing solar water heaters from different countries including Greece, Turkey, Italy and China, and distributing them on the Tunisian market. There are more than a thousand of small businesses, present throughout all Tunisia, involved in installing individual solar water heaters (Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH [23]). A dozen specialized companies are qualified to assemble and install collective systems. Several new companies have been established in the assembly sector for the installation of photovoltaic systems and they import modules from various countries among which Japan, Germany, Spain, France and China.

Finally, to achieve the ambitious objectives set in the TSP and to pave the way to foreign investment, Gestore dei Servizi Energetici - GSE S.p.A [29] recommends that it is necessary to realize a series of reforms and actions regarding: *(i)* energy strategy: define a long-term national development objectives for renewable energy resources in terms of power, production and/or consumption, identify the potential development of each renewable source at national level, define incentives for the promotion of the production of electricity from renewable with medium-large size plants, reduce fossil fuel subsidies; *(ii)* regulatory and administrative framework: the establishment of an appropriate regulatory and administrative framework should be implemented taking into account the current energy context (such as the monopoly of STEG for transmission and distribution, the fragmented regulatory framework for energy management,…etc.). In particular, the review of the existing laws governing renewable energy resources in Tunisia could be realized in a unique ‘‘code for renewable energy’’, focusing on the following two key elements: market access opportunities and the right and conditions of access to the grid.

4. Material and methods

Our database on Tunisia covers the period 1980-2009 and is selected to get the maximum number of observations depending on the availability of data. It includes annual data on an environmental indicator defined as per capita CO_2 emissions in metric tons, per capita real GDP or output in constant 2005 US dollars, per capita renewable electricity consumption in billion kilowatt hours and comprises geothermal, solar, wind, tide and wave, biomass and waste, and hydroelectric. Per capita non-renewable energy consumption in billion kilowatt hours and comprises oil, natural gas and coal. International trade variable is defined as per capita real merchandise exports or merchandise imports in US dollars. These variables 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 the population number to get the per capita unit. Data on per capita real GDP, per capita CO_2 emissions, population, merchandise exports, and merchandise imports are obtained from the World Bank [56].[2] Renewable and non-renewable energy data are obtained from the U.S. Energy Information Administration [26] online database, and are divided by population number to get per capita units. Data on (pc) are obtained from the Penn World Table version 7.1 (Heston et al. [34]).

The aim of this study is to verify the EKC hypothesis and to investigate the causal linkages between per capita CO_2 emissions (*E*), renewable and non-renewable energy consumption (*RE*, *NRE*), real GDP or output (*Y*) and international trade (*O*) for the case of Tunisia. Following the methodology developed by Ang [4], Holicioglu [30] and Jayanthakumaran et al. [37], among others, we develop a model based on the EKC hypothesis:

$$E_t = f(Y_t, Y_t^2, RE_t, NRE_t, O_t) \quad (1)$$

Because of the high correlation (0.99) between exports and imports, trade variable will be incorporated by including per capita real exports (*EX*) and per capita real imports (*IM*) into two separate models. The log linear quadratic EKC equation specified to examine the long-run relationship between variables is given as follow:

$$e_t = \alpha_0 + \alpha_1.y_t + \alpha_2.y_t^2 + \alpha_3.re_t + \alpha_4.nre_t + \alpha_5.o_t + \varepsilon_t \quad (2)$$

where *t*, α_0, and ε denote the time, the fixed country effect and the white noise stochastic disturbance term, respectively.

Since all variables presented in Eq. (2) are in natural logarithms, the coefficients $\alpha_{i(i=1,2,3,4,5)}$ are the long-run elasticities corresponding to each explanatory variable. Under the EKC hypothesis, the sign of α_1 is expected to be positive, whereas α_2 is expected to be negative. The expected sign of α_3 is negative because an increase in per capita renewable energy consumption would decrease per capita emissions. The sign of α_4 is expected to be positive given that emissions increase if the consumption of non-renewable energy is higher. The expected sign of α_5 is mixed depending on the stage of economic development of the considered country. It may be negative in the case of developed countries, because these latter can export or import less pollution intensive goods. However, α_5 may be positive in the case of developing countries, because they tend to have dirty industries due to their less restrictive environmental protection laws.

5. Results and discussions

Our statistical analysis follows four steps: (*i)* examines the stationary proprieties of each variable using traditional unit root tests and Zivot-Andrews structural break unit root test; *(ii)* tests the existence of long-run relationship among variables using the ARDL bounds testing approach; (*iii)* estimates the short and long-run parameters and tests the stability of the model;

[2] Our sample is quite limited to 30 observations because of renewable energy consumption data which start from 1980.

and *(iv)* establishes the direction causality between variables by using the Granger causality test.

5.1. Stationary tests

To check for integration order of each variable, we use traditional unit root tests. All variables are tested at level and after the first difference using a test of Fisher based on the augmented Dickey and Fuller [25] (ADF Fisher) and Phillips and Perron [45] (P-P Fisher). These two tests assume that the null hypothesis is that there is a unit root, whereas the alternative hypothesis is that variables are stationary. Unit root tests are done in the cases of intercept, and intercept and trend.

Insert Table 1 here

Table 1 reports the results of the ADF and P-P unit root tests, which show that all variables are non-stationary at level, whereas after first difference they become stationary at the 1% significance level. These two tests ensure that none of the variables is integrated with an upper order than 1 and approve that all series are integrated of order one, I(1)[3].

Traditional unit root tests used to check for the integration order do not take into account structural break points in series and provide biased and spurious results. Indeed, Baum [14] study forced to apply structural break unit root tests. We use Zivot and Andrews [57] test to get the information about the integration order and structural break proprieties. By considering the structural break information, this could be interesting for policy recommendations. Three models have been developed in this test: the first model allows that, at level form, there is one-time change in variables; the second model allows for one-time change in the trend coefficient; and the last model allows one-time change both in intercept and trend functions. The null hypothesis of unit root break reveals that the variable is non-stationary, while the alternative hypothesis indicates that the variable is stationary with one-time break point.

Insert Table 2 here

The results from Zivot-Andrews unit root test with intercept and trend are reported in Table 2. The results indicate that, at level, all the variables have a unit root with a structural break but, after first difference, all the variables are stationary.

5.2. ARDL cointegration tests

A number of cointegration techniques can be used for testing the existence of a long-run relationship between analysis variables. One of these cointegration techniques named autoregressive distributed lag (ARDL) or bounds testing approach has been developed by Pesaran et al. [44] is very used by researchers because it is considered as superior to traditional cointegration approaches. The ARDL approach has several econometric advantages in comparison to other single cointegration procedures: *(i)* long and short-run parameters are estimated simultaneously; *(ii)* endogeneity problems are avoided; *(iii)* it examines the long-run relationship between variables whether regressors are purely I(0), purely I(1) or fractionally integrated; and *(iv)* provides better results with small sample than other cointegration techniques. Thus, we find this technique convenient to our empirical study comprising 30 observations.

The ARDL representation of Eq. (2) is formulated as follows:

[3] The ARDL bounds technique can be applied irrespective of whether variables are I(0), I(1) or fractionally cointegrated (Pesaran and Pesaran [43]).

$$\Delta e_t = \theta_0 + \sum_{i=1}^{p} \theta_{1i} \Delta e_{t-i} + \sum_{i=1}^{p} \theta_{2i} \Delta y_{t-i} + \sum_{i=1}^{p} \theta_{3i} \Delta y_{t-i}^2 + \sum_{i=1}^{p} \theta_{4i} \Delta re_{t-i} + \sum_{i=1}^{p} \theta_{5i} \Delta nre_{t-i} + \sum_{i=1}^{p} \theta_{6i} \Delta o_{t-i} + \theta_7 e_{t-1} + \theta_8 y_{t-1} + \theta_9 y_{t-1}^2 + \theta_{10} re_{t-1} + \theta_{11} nre_{t-1} + \theta_{12} o_{t-1} + \pi_t \quad (3)$$

Where Δ and π_t are the first difference and the error terms, respectively. According to Pesaran et al. [44], the long-run linkage between variables is tested for the joint significance of estimated coefficients of the lagged level. This test can be done after determining the number of optimal lag length for regression which is selected by the Schwarz information criteria (SIC). Based on the Wald tests, the Fisher-statistic is calculated in order to test the existence of cointegration among variables. Pesaran et al. [44] have developed this approach for cointegration established on the null hypothesis of no long-run association between variables ($H_0 : \theta_7 = \theta_8 = \theta_9 = \theta_{10} = \theta_{11} = \theta_{12} = 0$), against the alternative hypothesis of long-run relationship ($H_1 : \theta_7 \neq \theta_8 \neq \theta_9 \neq \theta_{10} \neq \theta_{11} \neq \theta_{12} \neq 0$). The calculated value is compared with two terminal critical values provided by Pesaran et al. [44]. The first terminal critical value assumes that all variables are I(0) and corresponds to the lower critical bound value, whereas the second terminal critical value assumes that all variables are I(1) and corresponds to the upper bound value. In this case, three assumptions are possible to interpret Fisher-statistic value: if the computed F-statistic exceeds the upper critical value, then we reject the null hypothesis of no cointegration. If the computed Fisher-statistic falls behind the lower critical value, then we cannot reject the null hypothesis of no cointegration between variables. Finally, if the calculated value falls within lower and upper critical values, then the result is inconclusive. In this case, the existence of cointegration can be tested using the significance of the error correction term (ECT). Diagnostic tests are computed to assess the robustness of the empirical model based on the serial correlation, residual heteroskedasticity, and normality tests.

Our previous results reveal that all variables are stationary after first difference. Two steps have been recommended for the ARDL cointegration test. The first step consists in checking for the optimal number of lags for the vector autoregressive (VAR) model. Thereby, the number of lags on the first difference of variables is obtained via the unrestricted VAR by means of Log likelihood (LogL), Log likelihood ratio (LR), final prediction error (FPE), Akaike information criterion (AIC), SIC, and Hannan-Quinn information criterion (HQ), which are employed to determinate the optimal number of lags.

For the model with exports (resp. imports) the lag selection criteria results for VAR models are established. For the model with exports, with two as a maximum number of lags, the estimated results of most criteria suggest that the optimal number of lags is equal to two (VAR (p=2)), and SIC suggests a maximum lag of one (VAR (p=1)). However, with a number of lag 2, the adjustment to the long-run equilibrium is not proved, whereas with a number of lag 1 the adjustment is significant.[4] For the model with imports, the estimated results of LR, SIC, and HQ criteria suggest that the optimal number of lags is equal to one (VAR (p=1)), and the rest of criteria estimations suggest VAR (p=2))[5]. In the light of these statistics, we decide to use (VAR (p=1)).

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[4] With VAR (p=2) the error correction model (ECM), for the model with exports, is statistically not significant because the t-statistic is equal to -1.63. However, the ECM is statistically significant for VAR (p=1) because the t-statistic is equal to -2.56.

[5] With VAR (p=1) or VAR (p=2), the ECM for the model with imports is statistically significant given that the t-statistics are equal to -2.39 and -3.38, respectively.

The second step of the ARDL bounds approach consists in the estimation of Eq. (3) using ordinary least squares (OLS) estimation method and the Wald test (Fisher-statistic) for the joint significance of the long-run coefficients of lagged levels of variables in order to test the existence of long-run association using bounds test (coitegration test). This study employs the critical values of Pesaran et al. [44] for the F-test to check for cointegration. For the choice of lag length, we use AIC and SIC criteria. A maximum of three lags is appropriate for our test.

Insert Table 3 here

For the model with exports (resp. imports), the computed value of the Fisher-statistic is equal to 206.275 (resp. 29.512). This value is higher than the lower and the upper bounds values (see Table 3). This result confirms that there is a long-run relationship among variables when the emissions of CO_2 are defined as a dependent variable. We use two lag length criteria to calculate F-statistics of each model which are AIC and SIC. The results from these criteria suggest that lag 3 (resp. lag 2) is sufficient for the selected sample for the model with exports (resp. imports). Thus, the number of lags reveals an ARDL (3, 3, 3, 3, 3, 3) (resp. ARDL(2, 2, 2, 2, 2, 2)) for the model with exports (resp. imports).

5.3. Parameters estimates

In this subsection, we run the ARDL representation of Eq. (2) for the model with exports and the one with imports. Estimated coefficients are computed for short and long-run terms. In addition, diagnostic tests for residuals have been examined and are based on tests of serial correlation, heteroskedasticity and normality.

Insert Tables 4 and 5 here

Estimated long-run elasticities are reported in Tables 4 and 5 for the models with exports and imports, respectively. All estimated long-run coefficients are statistically significant at the 1% level, exception the coefficient of per capita renewable energy consumption in the model with imports is not statistically significant. The diagnostic test results show that, for the long-run estimates, there is no serial correlation, no problem of white heteroskedasticity, and the residual is normally distributed.

Insert Fig. 2 here

Long-run elasticity of CO_2 emissions with respect to income is $3.17y$-25.24 for the model with exports, and is $1.52y$-12.34 for the model with imports. Both analytical results do not support the EKC hypothesis stipulating an inverted U-shaped curb of per capita emissions as a function of per capita GDP, and are also confirmed graphically. Indeed, Fig. 2 shows that per capita CO_2 emissions have a positive trend with per capita GDP. This result is similar to that of Fodha and Zaghdoud [28] and Arouri et al. [13] for the Tunisian case. However, our result is contrary to that of Shahbaz et al. [51] who show analytically that the EKC hypothesis is verified for CO_2 emissions in Tunisia. This difference in results may be due to the difference in variables and data used. In fact, Tunisia has experienced an important economic development in the last three decades which has increased the use of energy and subsequently increased pollution. Even though many actions have been taken for renewable energy and energy efficiency (TSP, Laws 72-2004, 7-2009, 82-2005), the important increase in fossil energy use led to a continuous increase in per capita CO_2 emissions.

For both models, non-renewable energy consumption is an important contributor to carbon dioxide emissions in Tunisia. In the export (resp. import) model, a 1% increase in the consumption of non-renewable energy increases emissions by 0.90% (resp. 0.51%), in the long-run. For the model with exports, a 1% increase in the consumption of renewable energy leads to a slightly decrease in emissions by 0.08%, in the long-run. However, for the model with imports, the long-run impact of renewable energy on emissions is weak and statistically insignificant. Therefore, per capita CO_2 emissions are nearly unaffected by the consumption of renewable energy because the proportion of renewable energy consumed with respect to the total energy consumed is very weak as it is equal to approximately 0.20% in 2009 (Energy Information Administration [26]). This result is interesting because this is the first econometric study evaluating the impact of renewable energy consumption on CO_2 emissions in Tunisia.

For the model with exports (resp. imports), a 1% increase in per capita exports (resp. imports), increases per capita emissions in the long-run by 0.35% (resp. 0.37%). These results are expected because more traded goods need more non-renewable energy to be produced (or used), and to be transported to (or from) ports leading to an increase in CO_2 emissions. These results are similar to those of Chebbi et al. [21] and Shahbaz et al. [51] who show that trade openness increases per capita CO_2 emissions in Tunisia. However, our results are not consistent with those of Shahbaz et al. [52] because these authors find that increasing per capita exports in UAE reduces per capita CO_2 emissions. They attribute this result to the fact that UAE uses energy efficient technologies and also because free zones served by their own ports reduce considerably CO_2 emissions caused by transport.

The lower parts of Tables 4 and 5 provide short-run estimates for both models and reveal that all coefficients of the differentiated lagged variables are statistically significant, exception for renewable energy variable for the model with exports, and renewable energy and import variables for the model with imports. The short-run coefficients of per capita real GDP and the square of real GDP are positive and negative, respectively. Thus, in the short-run, the inverted U-shaped EKC hypothesis is supported. The lagged error correction term (ECT) is negative and statistically significant at the 5% level with a coefficient equal to -0.25 and -0.5 for the models with exports and imports, respectively. The statistical significance of the ECT confirms that the deviation of variables from the short to the long-run equilibrium is adjusted by 25% (resp. 50%) per year for the model with exports (resp. imports). The residual diagnostic tests applied to the two specification models show that there are no serial correlation, no autoregressive heteroskedasticity, and residuals are normally distributed.

Insert Fig. 3-4 here

The existence of a long-run association between variables does not mean that the estimated coefficients are stable. The stability of coefficients is tested by using the cumulative sum (CUSUM) and the cumulative sum of squares (CUSUMSQ) techniques developed by Brown et al. [19]. These tests are based on the recursive regression residuals and incorporate the short-run dynamics to the long-run through residuals. CUSUM and CUSUMSQ tests are more powerful than other kinds of stability tests such as Hansen [32] and Hansen and Johansen [33] because these latter require that variables are integrated of order one and do not incorporate short-run estimated coefficients of the model. The CUSUM and CUSUMSQ statistics are updated recursively and plotted against model's break points. When the plots of these statistics fall inside the critical bounds of 5% significance, we can assume that the estimated coefficients of a given regression are stable. Our CUSUM and CUSUMSQ are based on the ECM of Eq. (3) and are presented graphically in Fig. 3-4 which show that estimated coefficients are well within the 5% critical bounds, meaning that they are stable. Therefore, our model where CO_2 emissions is a an explanatory variable can be used for policy decision purposes.

5.4. Granger causality tests

After establishing the existence of long-run relationship between variables using ARDL bounds technique, we run the Granger causality test to check for the direction causality between them. Given the existence of long-run association among variables, it is required to rely on the significance of the ECT. Engle and Granger [27] techniques are employed to examine short and long-run associations among variables in two steps. Firstly, we estimate the long-run coefficients of Eq. (2) in order to obtain the residuals. Secondly, we estimate the coefficients related to the short-run adjustment of Eq. (4). Short-run causality is determined by the significance of F-statistics and long-run causality corresponding to ECT is determined by the significance of t-statistics.[6] The ECM of the long-run equation is given as follows:

$$\Delta e_t = \lambda_0 + \sum_{i=1}^{p} \lambda_{1i} \Delta e_{t-i} + \sum_{i=1}^{p} \lambda_{2i} \Delta y_{t-i} + \sum_{i=1}^{p} \lambda_{3i} \Delta y_{t-i}^2 + \sum_{i=1}^{p} \lambda_{4i} \Delta re_{t-i} + \sum_{i=1}^{p} \lambda_{5i} \Delta nre_{t-i} + \sum_{i=1}^{p} \lambda_{6i} \Delta o_{t-i} + \alpha ECT_{t-1} + \eta_t \quad (4)$$

where Δ indicates the first difference, η_t denotes the standard error term, ECT_{t-1} is the lagged error correction term generated from Eq. (2), *p* indicates the VAR lag length which is set to 1, and α indicates the speed of adjustment coefficients.

Insert Tables 6 and 7 here

Short and long-run Granger causality tests for the models with exports and imports are reported in Tables 6 and 7, respectively. For the model with exports, long-run dynamics results reveal that the ECT coefficients of emissions, renewable and non-renewable energy consumption are comprised between -1 and 0 and are statistically significant with a moderate speed of adjustment from short to long-run equilibrium. For the model with imports, long-run dynamics results reveal that the ECT coefficients of emissions and non-renewable energy consumption are both comprised between -1 and 0, are statistically significant and have a moderate speed of adjustment from short to long-run equilibrium. Fig. 5 sums up short-run Granger causalities between variables for both models. By looking to the short-run causalities in Fig. 5, and the long-run causalities in Tables 6 and 7, we can highlight our main causal relationships. These results are interesting because this is the first study interested in the causal relationships of renewable energy consumption in Tunisia.

Insert Fig. 5 here

In the short-run, there is a unidirectional causality running from non-renewable energy to renewable energy. This result is not consistent with the finding of Apergis and Payne [11] who conduct a study on a panel of 80 countries and show the existence of a bidirectional causality in both the short and long-run indicative of substitutability between the two energy sources. Our results mean that, in the short-run, changes in non-renewable energy consumption impact the consumption of renewable energy in Tunisia. Indeed, the Tunisian socio-economic development, combined with subsidy's policy for almost all forms of fossil

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

energy, have led to the strong growth of energy demand in Tunisia over the last 30 years. From 2001 the status of Tunisia has changed from an energy exporter to a net importer country. In order to become less dependent on energy imports and on the volatile prices of oil and gas, Tunisia decided to develop many programs of energy efficiency and renewable energy production which have increased renewable energy consumption. In the long-run, renewable energy Granger causes non-renewable energy consumption. This may explain a substitutability that may occur in the long-run between renewable and non-renewable energy. Indeed, we may expect that, in the long-run, the proportion of renewable energy consumption with respect to total energy consumed increases. This is likely to happen because the production of electricity from renewable sources has considerably increased passing from 24 GWH in 1980 to 176 GWH in 2009, and the proportion of electricity production from renewable sources with respect to total electricity produced has increased from 0.82% in 1980 to 1.15% in 2009 (World Bank [56]).

Our Granger causality analysis shows the existence of a unidirectional causality running from trade (exports or imports) to renewable energy in the short-run, and a unidirectional causality running from exports to renewable energy in the long-run. In the long-run, there is also an indirect causality running from exports to renewable energy occurring through non-renewable energy consumption. Indeed, more imports necessitate more renewable energy to use and to transport these goods from ports to consumers. Moreover, increasing imports may promote renewable energy consumption in Tunisia because of the renewable energy technology transfer occurring when importing capital goods, such as machines and equipment to produce renewable energy. Nearly forty firms are importing solar water heaters from different countries including Greece, Turkey, Italy and China, and distributing them on the Tunisian market. Moreover, several new companies have been established in the assembly sector for the installation of photovoltaic systems. These companies import modules from various countries such as Japan, Germany, Spain, France and China (Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH [23]). More exports necessitate more renewable energy to produce and transport these goods to ports. In Tunisia, the impact of exports on renewable energy is evident. Indeed, the European industrial initiative Dii plans to promote the implementation of several large-scale renewable energy projects in Tunisia intended to produce electricity for national consumption as well as for export to the EU. A trans-Mediterranean cable is previewed for exporting renewable electricity to the EU which is expected to reach 200 MW in 2016 (Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH [23]). This finding is not in accordance with that of Ben Aïssa et al. [16] who report the absence of causality between trade and renewable energy in a panel of 11 African countries.

There is a unidirectional short-run causality running from CO_2 emissions to renewable energy consumption. This means that pollution emission incites the use of clean energy. This is confirmed by the ratification of the Kyoto protocol by Tunisia in 2003 proving its willingness to take serious actions for GHG reductions, including the increasing use of renewable energy sources. In the long-run, renewable energy consumption Granger causes CO_2 emissions. This is confirmed by our long-run estimates in the model with exports showing that increasing renewable energy consumption reduces CO_2 emissions. Although per capita CO_2 emissions have steadily increased during the last 30 years mainly because of GDP increase, primary energy intensity has decreased at an average annual rate of 2.6%, followed by a decrease in carbon intensity. This signifies that actions taken to encourage renewable energy use (TSP, Laws 72-2004, 7-2009, 82-2005) were fruitful in terms of CO_2 emissions.[7]

[7] Recently a new law encouraging the private sector to invest in the production of renewable energy has been voted by the constitutional assembly. This law has not been yet published in the journal officiel de la république Tunisienne (JORT).

Our results differ from those of Menyah and Wolde-Rufael [38] who report only a unidirectional causality running from CO_2 emissions to renewable energy in the case of US, and from those of Apergis et al. [12] who study 19 developed and developing countries and show short and long-run bidirectional causalities.

In the short-run and the long-run for the model with exports, there is a unidirectional causality running from output to renewable energy. This means that economic growth affects the use of renewable energy in Tunisia. Indeed, more production needs more renewable energy consumption. Moreover, the estimated cost of the TSP is 3 369 millions TND meaning that such costly investments are made possible mainly due to economic growth. Our results are consistent with those of Menyah and Wolde-Rufael [38] but they differ from those of Apergis and Payne [8], [9], [10], [11] and Apergis et al. [12] who find a bidirectional causality between economic growth and renewable energy in both the short and long-run.

In both the short and long-run, there is a unidirectional causality running from trade to pollution emission. This result means that trade policy has a vital role in explaining emissions. Our results differ from those of Chebbi et al. [21] and Shahbaz et al. [51] who show long-run bidirectional causality between trade openness ratio and CO_2 emissions. This difference in results may be attributed to the difference in variables and data used. In the short-run, we find a unidirectional relationship running from output to imports, and there is no causality between exports and output. This can be explained by the fact that economic growth needs to import industrial products (machines, cars, etc.) necessary for production. In the long-run, there is a unidirectional causality running from trade to non-renewable energy consumption. Thus, in the long-run, an increase in commercial exchanges increases non-renewable energy consumption. Indeed, more trade needs more non-renewable energy to produce, to consume and to transport these traded goods.

In the long-run, there is a bidirectional causality between non-renewable energy consumption and emissions. This means that, in the long-run, the increase in per capita CO_2 emissions pushes authorities to take measures for reducing non-renewable energy consumption, and an increase in non-renewable energy consumption increases emissions. In the long-run, output Granger causes non-renewable energy consumption. Thus, economic growth implies more fossil fuels consumption in the long-run. Belloumi [15] and Chebbi [20] find long-run bidirectional causality between output and energy consumption. Let us notice that Boufateh et al. [18] use a structural vector error correction model (SVECM) to investigate the impact of income shocks on energy consumption and the impact of energy consumption shocks on income for Tunisia. They show that the effect of short-run shocks on production is negative, whereas the effect of a long-term shock on energy consumption is positive. We show that, in both the short and long-run, there is a unidirectional causality running from output to CO_2 emissions. Thus, any increase in economic growth affects pollution, but any effort that may reduce emissions will not affect Tunisia's economic growth.

5. Conclusion and policy implications

In this paper, we incorporate per capita renewable energy consumption and international trade as interesting variables to study their causal relationship with per capita CO_2 emissions, non-renewable energy consumption and GDP, and to verify the EKC hypothesis for Tunisia using data over the period 1980-2009. We estimate two separate specification models where in the first model, trade variable is per capita real exports, and in the second model, trade variable is per capita real imports. We apply the Zivot-Andrews structural break unit root test, the ARDL bounds testing approach to cointegration, and the VECM Granger causality approach.

Analytical results, which are confirmed graphically, do not support the EKC hypothesis stipulating an inverted U-shaped curb of per capita emissions as a function of per capita GDP.

This result is not surprising as the EKC hypothesis is usually verified by developed countries. In the short-run for both models and in the long-run only for the model with exports, we show that GDP Granger causes renewable energy consumption. In the short-run, there is a unidirectional causality running from non-renewable energy to renewable energy, and renewable energy Granger causes non-renewable energy in the long-run. Therefore, because of the substitutability that may occur between renewable and non-renewable energy, we may expect that a continuous economic growth will encourage the use of renewable energy leading to a reduction in per capita CO_2 emissions and an inverted U-shaped EKC.

In both the short and long-run, trade Granger causes CO_2 emissions. Moreover, our long-run estimates show that both per capita exports and imports have a positive impact on per capita CO_2 emissions. In addition, trade Granger causes renewable energy consumption in the short-run, and exports Granger causes renewable energy consumption in the long-run. To reduce the impact of trade on pollution, Tunisia should continue encouraging the use of renewable energy and energy efficiency to reduce the emission of pollution caused by the production or consumption of exported or imported goods. It can also locate ports near exporting industrial zones (or vice versa) to reduce emission of pollution caused by the transport of merchandise. Moreover, Tunisia should encourage the creation of renewable energy projects for export to the EU with a proportion of production for Tunisians. This will at the same time stimulate technology transfer. Moreover, Tunisia should establish a strategy for maximizing its benefits from renewable energy technology transfer occurring when importing capital goods such as machines and equipment in order to promote renewable energy consumption.

In the long-run, there is bidirectional causality between CO_2 emissions and non-renewable energy consumption. Moreover, our long-run estimates show that non-renewable energy consumption is an important contributor to CO_2 emissions in Tunisia. Thus, Tunisia has to reinforce its policy of promoting renewable energy and energy efficiency in order to reduce CO_2 emissions as a result of fossil energy use. A radical reform of the subsidies system granted by the Tunisian government to fossil fuels consumption can play an important role in reducing fossil fuels consumption and GHG emissions, while saving much money that can be invested in renewable energy projects.

In the short-run, there is a unidirectional causality running from emissions to renewable energy. In the long-run, renewable energy Granger causes CO_2 emissions. Our long-run estimates show that, for the model with exports, the consumption of renewable energy leads to a slightly decrease in emissions. However, for the model with imports, the impact of renewable energy on emissions is low and statistically insignificant. Therefore, per capita CO_2 emissions are nearly unaffected by the consumption of renewable energy because the proportion of per capita renewable energy consumed with respect to the per capita total energy consumed is very low (approximately 0.20% for the year 2009). Thus, Tunisia must continue to encourage the use of renewable energy and energy efficiency by reinforcing its actual projects and its incentive regulatory framework (TSP, Laws 72-2004, 7-2009, 82-2005) in order to get a higher share of renewable energy consumption enabling it to have an important and beneficial impact on CO_2 emissions in the future. Collaborative and partnership projects with the EU are particularly interesting for Tunisia because of its great potential in renewable energy production, its neighborhood and the important commercial and cultural exchanges with the EU, the possible technology transfer, and because it is certainly a win-win collaboration.

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Tables

Table 1. Unit root tests without structural break

	Variables	ADF test statistic				P-P test statistic			
		Level	k	1st difference	k	Level	k	1st difference	k
Intercept	*e*	-0.6322	0	-8.2294***	0	-0.1550	5	-13.4415***	8
	y	1.9779	0	-5.2105***	0	3.1119	5	-5.2189***	2
	y2	2.1538	0	-5.0487***	0	3.3515	5	-5.0906***	3
	re	-3.1041	0	-6.1946***	0	-3.0091	3	-12.4596***	18
	nre	-1.7203	0	-6.1394***	0	-1.6865	1	-6.2961***	2
	ex	-0.1089	0	-5.4510***	0	0.1897	5	-5.4692***	1
	im	-0.1023	0	-4.2199***	1	0.1735	5	-4.4833***	5
Intercept and trend	*e*	-4.0217	0	-4.7076***	6	-4.0001	1	-14.3516***	9
	y	-3.4242	6	-6.8602***	0	-1.5217	5	-8.9042***	12
	y2	-3.2842	6	-6.8540***	0	-1.4286	6	-9.7347***	14
	re	-3.3369	1	-5.0813***	4	-3.4940	5	-10.9412***	19
	nre	-2.1245	0	-5.3004***	1	-2.0365	2	-6.3965***	3
	ex	-2.5775	0	-5.7505***	0	-2.4631	3	-5.8689***	5
	im	-3.5675	1	-4.7198***	0	-2.3478	3	-4.9879***	10

Notes: ADF and P-P denote augmented Dickey-Fuller and Phillips-Perron, respectively. k is the lag length that is determined automatically and based on the Schwarz Information Criterion (SIC). Statistical significance at the 1% level is denoted by the superscript ***.

Table 2. Zivot-Andrews structural break unit root test

Variables	Level		1st difference	
	T-statistic	time break	T-statistic	Time break
e	-4.9890 (3)	2000	-5.5476 (6)**	1999
re	-2.9424 (5)	1993	-5.7233 (4)**	2002
nre	-2.8101 (5)	1991	-5.7233 (4)**	2002
y	-3.9801 (0)	1988	-7.5176 (0)**	1989
y^2	-3.6860 (0)	1988	-7.4341 (0)**	1989
ex	-4.0037 (1)	2000	-5.2771(4)**	1994
im	-3.9700 (1)	1987	-5.3777 (1)**	1987

Notes: ** indicates statistical significance at 5% level. Lag order is shown in parenthesis.

Table 3. F-test for cointegration

Models	*e=f(y,y2,re,nre,ex)*	*e=f(y,y2,re,nre,im)*
F-statictic	206.275*	29.512***
Critical values	10%	1%
Lower bounds I(0)	2.262	4.011
Upper bounds I(1)	3.367	5.331

Notes: * and *** indicate statistical significance at the 10 % and 1% levels, respectively. For the model with exports (resp. imports), critical values are provided by Pesaran et al. (2001) for the case II with intercept and no trend (resp. case III with intercept and trend).

Table 4. Long and short-run estimates: ARDL model with exports

Dependent variable: ***e=f(y,y2,re,nre,ex)***		
Regressors	**Coefficient**	**T-statistic**
Long-run estimates		
y	-25.2350	[-6.4087]***
y2	1.5841	[6.4694]***
re	-0.0851	[-3.0221]***
nre	0.9031	[7.5471]***
ex	0.3468	[4.1103]***
Constant	109.2655	[6.3692]***
Short-run estimates		
Δ (y)	19.6846	[1.8111]*
Δ (y2)	-1.2270	[-1.7529]*
Δ (re)	-0.0172	[-0.8485]
Δ (nre)	-0.2839	[-2.4207]**
Δ (ex)	-0.2881	[-3.0279]***
Constant	0.0373	[3.0142]***
ECT	-0.2455	[-2.5610]**
R^2*=0.57*	*F-stat=3.85*	*P(F-stat)=0.008*
Norm test= 3.05 (0.5720)		*Hetero test=1.38 (0.2515)*
LM test=0.84 (0.4461)		*DW= 1.90*

Notes: *, **, *** indicate statistical significance at the 10%, 5% and 1% levels, respectively.

Table 5. Long and short-run estimates: ARDL model with imports

Dependent variable: ***e=f(y,y2,re,nre,im)***		
Regressors	**Coefficient**	**T-statistic**
Long-run estimates		
y	-12.3394	[-4.4109]***
y2	0.7627	[4.3961]***
re	0.0324	[1.4481]
nre	0.5112	[5.9080]***
im	0.3744	[5.0859]***
Constant	56.0775	[3.7371]***
Short-run estimates		
Δ (y)	24.0272	[1.9045]*
Δ (y2)	-1.5322	[-1.8859]*
Δ (re)	-0.0315	[-1.2003]
Δ (nre)	-0.3553	[-2.8024]***
Δ (im)	-0.1224	[-0.9855]
Constant	0.0346	[2.4738]**
ECT	-0.5049	[-2.3956]**
R^2*=0.49*	*F-stat=2.74*	*P(F-stat)=0.036*
Norm test= 2.72 (0.468)		*Hetero test=0.76 (0.3916)*
LM test=0.19 (0.8288)		*DW= 1.93*

Notes: *, **, *** indicate statistical significance at the 10%, 5% and 1% levels, respectively.

Table 6. Granger causality tests (model with exports)

Dependent variable	Short-run						Long-run
	Δe	***Δy***	***Δy2***	***Δre***	***Δnre***	***Δex***	***ECT***
Δe	-	11.5977 (0.0022)***	10.9076 (0.0028)***	0.07934 (0.7804)	0.53993 (0.4690)	9.00307 (0.0059)***	-0.245502 [-2.56104]**
Δy	2.50563 (0.1255)	-	0.63570 (0.4325)	0.82962 (0.3707)	1.49591 (0.2323)	1.47237 (0.2359)	-3.265472 [-2.30455]
Δy2	2.45813 (0.1290)	0.67732 (0.4180)	-	0.72562 (0.4021)	1.54532 (0.2249)	1.49294 (0.2327)	3.172411 [2.32219]
Δre	4.45976 (0.0445)**	3.71442 (0.0649)*	3.71566 (0.0649)*	-	8.72536 (0.0066)***	2.99431 (0.0954)*	-0.337112 [-4.19423]***
Δnre	1.05278 (0.3143)	0.98038 (0.3312)	0.88758 (0.3548)	0.43092 (0.5173)	-	0.30592 (0.5849)	-0.326662 [-1.84811]*
Δex	1.42402 (0.2435)	2.64627 (0.1159)	2.48735 (0.1269)	0.37026 (0.5481)	0.57033 (0.4569)	-	-0.137690 [-1.48903]

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

Table 7. Granger causality tests (model with imports)

Dependent variable	Short-run						Long-run
	Δe	***Δy***	***Δy2***	***Δre***	***Δnre***	***Δim***	***ECT***
Δe	-	11.5977 (0.0022)***	10.9076 (0.0028)***	0.07934 (0.7804)	0.53993 (0.4690)	14.1019 (0.0009)***	-0.504980 [-2.39564]**
Δy	2.50563 (0.1255)	-	0.63570 (0.4325)	0.82962 (0.3707)	1.49591 (0.2323)	1.71039 (0.2024)	-2.615209 [-1.72953]
Δy2	2.45813 (0.1290)	0.67732 (0.4180)	-	0.72562 (0.4021)	1.54532 (0.2249)	1.68288 (0.2059)	2.519834 [1.75939]
Δre	4.45976 (0.0445)**	3.71442 (0.0649)*	3.71566 (0.0649)*	-	8.72536 (0.0066)***	3.56904 (0.0701)*	0.181750 [2.39568]
Δnre	1.05278 (0.3143)	0.98038 (0.3312)	0.88758 (0.3548)	0.43092 (0.5173)	-	0.54270 (0.4679)	-0.411122 [-2.01252]**
Δim	1.48440 (0.2340)	4.00694 (0.0559)*	3.84175 (0.0608)*	0.78193 (0.3847)	0.27521 (0.6043)	-	-0.162334 [-0.82061]

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

Figures

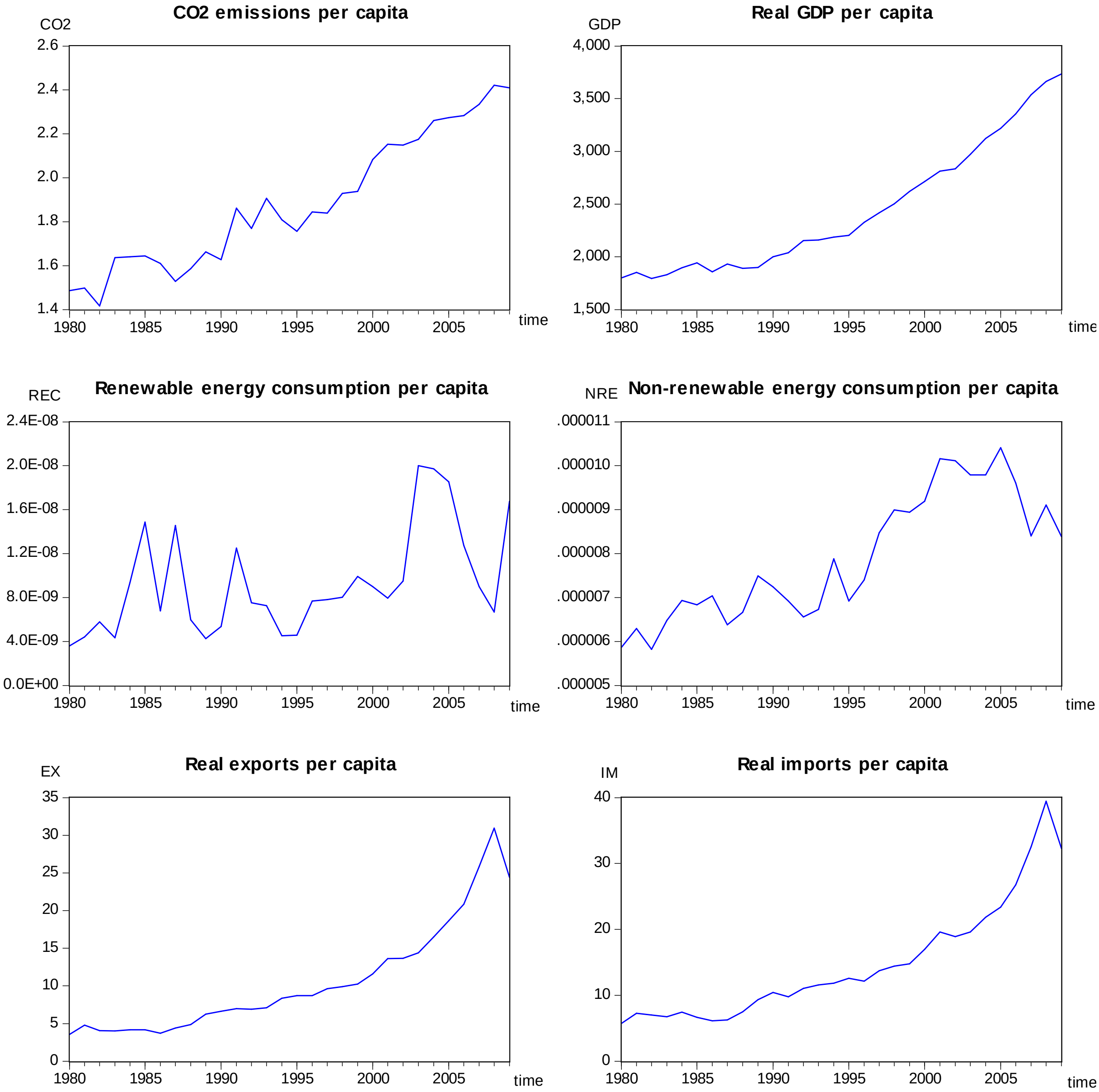

Fig. 1. Graphs representations of analysis variables

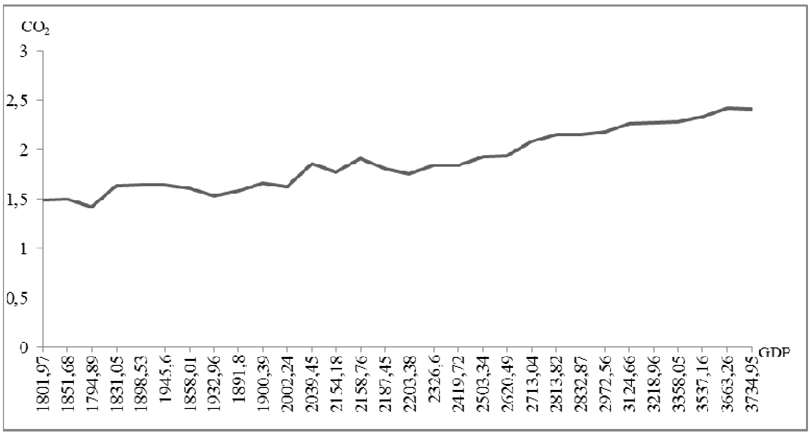

Fig. 2. Plot of per capita CO_2 emissions and GDP

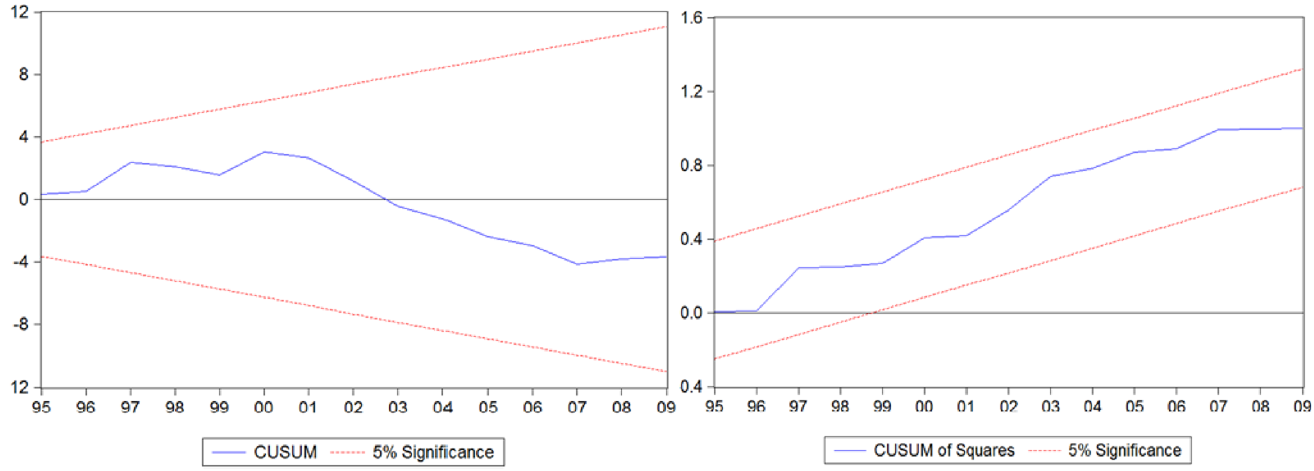

Fig. 3. CUSUM and CUSUM of squares plots of recursive residual (model with exports)

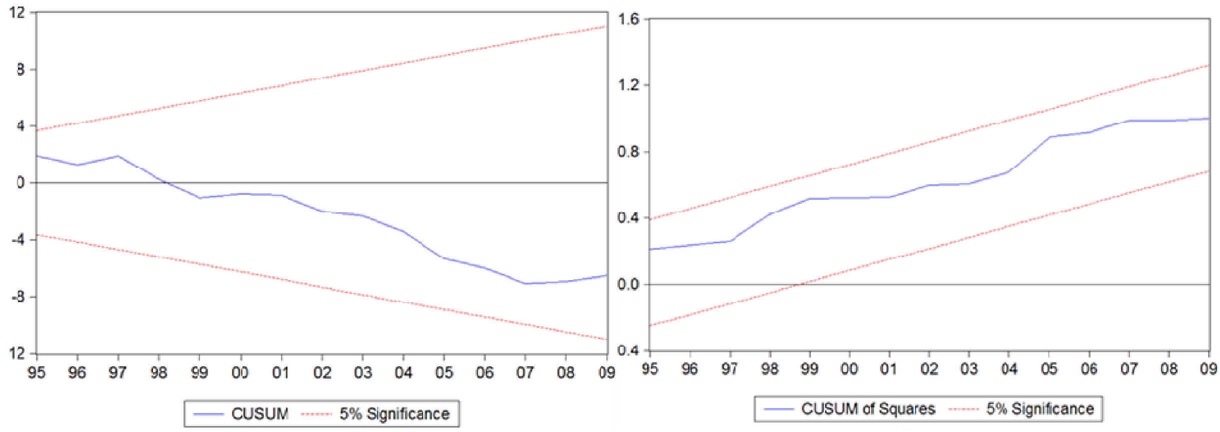

Fig. 4. CUSUM and CUSUM of squares plots of recursive residual (model with imports)

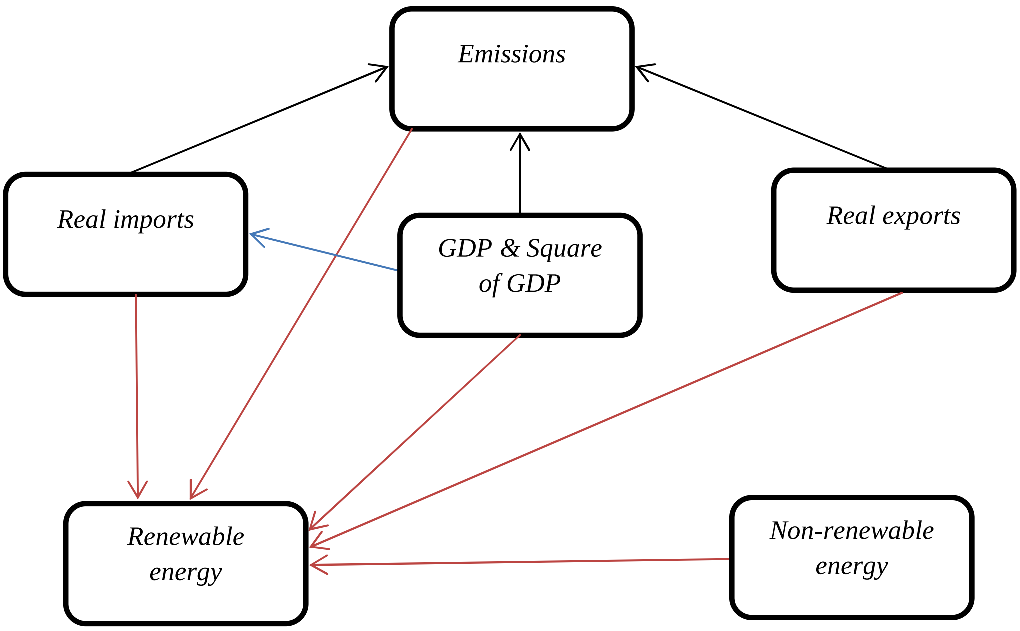

Fig. 5. Pairwise Granger causality results