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# The Impact of Combustible Renewables and Waste Consumption and Transport on the Environmental Degradation: The case of Tunisia

**Abstract:** This study investigates the dynamic causal links between carbon dioxide ($CO_2$) emissions, real Gross Domestic Product (GDP), combustible renewables and waste consumption, and maritime and rail transport in Tunisia spanning the period 1980-2011. The autoregressive distributed lag (ARDL) approach and Granger causality tests are employed to examine the short- and long-run relationships between variables. The empirical results suggest a bidirectional short-run causality between $CO_2$ emissions and maritime transport, and a unidirectional causality running from real GDP, combustible renewables and waste consumption, rail transport to $CO_2$ emissions. The long-run estimates reveal that real GDP contributes to the decrease of $CO_2$ emissions, while combustible renewables and waste consumption and maritime and rail transport have a positive impact on emissions. Our policy recommendation is that Tunisia should use more combustible renewables and waste energy and increase the number of passenger's rail and maritime transport in order to motivate economic activities. However, the level of renewables energy required to reduce emissions caused by transport sector still very weak.

*Keywords*: Combustible renewables and waste; Transport; Autoregressive distributed lag model; Cointegration; Granger causality; Tunisia.

*JEL Classification*: C32; O55; Q53

## 1. Introduction

The transport sector presents real trials as humanity tries to ensure a more environmentally sustainable future. Over the last decades, the $CO_2$ emissions caused by the transport sector keep on growing while emissions of many other sectors stabilized or even decreased. In the European Union (EU), the transport is the only sector in which greenhouse gas (GHG) emissions have consistently raised since 1990, and current transport patterns are clearly unsustainable. Moreover, this sector contributes rapidly to climate change and air pollution, which lead to important costs that are supported by people, business, and society (International Union of Railways, 2008). The GHG emissions are dominated by the $CO_2$ emissions from burning fossil fuels. These are strongly related to transport energy use. Transport has also other severe impacts on society. Every year hundred-thousands of people are killed and injured in accidents and in various densely populated areas, high congestion levels result in time losses. However, rail transport is the most emissions-efficient major mode of transport, and electric train powered by renewable energy. This sector contributes less than 1.5% of the EU transport sector's total $CO_2$ emissions even though it has over 8.5% of total market share (International Union of Railways, 2015).

Maritime transport has been growing rapidly because of the globalization of business process and the increase of global-scale trade. Nevertheless, $CO_2$ emissions caused by maritime transport contribute significantly to air pollution. Oceangoing ships contribute by 15% of global anthropogenic oxides of nitrogen (NOx) and 5-8% of global sulfur oxides (SOx) emissions. The emissions level caused by ships affects not only major ports, but also medium and small-scale ones. Besides, emissions are generated while vessels are at berth, given that the main engines are not always switched off by all types of vessel (Viana, 2014). Thus, international regulations on ship emissions are needed, as those active in the EU, where land based emissions of Sulfur have been successfully reduced since 1980's (EEA, 2011).

Because of the assessment of rail and maritime transport on the global scale, human health, climate and ecosystems, urgent effort should be made in order to decrease emissions level coming from the transport sector. The increase of emissions level from transport may be explained by the extensive use of the non-renewable energy (oil, coal, and natural gas) which leads to increase air pollution quality. Thus, if this state continues to increase emissions, the environmental situation will be more and more catastrophic. The solution to this problem is to look for other sources of energy alternatives to fossil fuels one such as renewable energies.

The relationship between transportation and energy consumption seems to be very strong. In fact, passengers and merchandise can be transported by fast but energy intensive modes since the time factor of their mobility tends to have a high value, which carries the willingness to use more energy. Economies of scale, mainly those attained by maritime transportation, are linked to low levels of energy consumption per unit of mass being transported, but at a lower speed. There are massive reserves of energy able to meet the future needs. Solar energy is one of the main contemporary issues that many of these reserves cannot be exploited at reasonable costs (Jean-Paul Rodrigue, 2013). Renewable energy sources can transform the global shipping fleet and in varying scales, including: international and national transport of goods, people, and services; fishing; tourism and other maritime pursuits. Applications of renewable power in ships of all sizes include options for primary, hybrid and auxiliary propulsion, as well as on-board and shore-side energy use. The potential renewable energy sources for shipping applications comprise wind (e.g. wind turbines), solar photovoltaics, biofuels, wave energy and the use of super capacitors charged with renewables. These renewable energy sources can be integrated through retrofits to the existing fleet or incorporated into new shipbuilding and design, with a small number of new ships striving for 100% renewable energy or zero emissions technology for primary propulsion (International Renewable Energy Agency, 2015).

In Germany, rail transport accounts for 2.9% for energy consumption in the transport sector. 75% of their energy comes from fossil, while 25% come from green. German Railway Company named Deutsche Bahn (DB) is the largest single consumer of electricity in Germany with almost 12 billion kWh per year consumed by their trains. Approximately 3.6% of the total numbers of passengers are served by rail-based modes of transport. However, almost 7.5% of the total passenger mileage is carried out on rail. If the energy supply is substituted to green sources, then within the rail sector zero emission transport might be possible. The DB is now planning to purchase the equipment amount of electricity from renewable sources and feed them into their electricity mix (Internationale Zusammenarbeit (GIZ, 2014).

The present paper tries to examine the dynamic short- and long-run interrelationships between $CO_2$ emissions, real GDP, combustible renewables and waste consumption and rail and maritime transport for the case of Tunisian economy. We think this topic is interesting and has not been previously treated in the econometric literature. In fact, to mitigate climate change and decrease energy dependencies, many countries have adopted efficient policies to increase the use of renewable energy sources in comparison to total energy. Moreover, it is essential to highlight the strong dynamic causal links between renewable energy consumption and economic growth which is examined in several empirical studies either for the case of cross-sectional time series or the case of panel (e.g. Chang et al., 2015; Bilgili and Ozturk, 2015; Ozturk and Bilgili, 2015…). From these cited papers, the directions of causalities are investigated for the short- and the long-run relationship using several methodologies (Granger causality, panel coitegration, VAR, VECM, ARDL…). The directions of causalities between renewable energy-growth are varied from one study to another (no causal links, unidirectional or bidirectional causal links). This difference is due to the choice of the selected sample (for the case of panel) or country, empirical technique of estimation, period of time.

In other side, there is much consideration on how renewable energy consumption leads to reduce the pollution level. Several analyses have demonstrated empirically this involvement. Based on the environmental Kuznets curve hypothesis, Bilgili et al. (2016) consider a panel data for a panel composed by 17 OECD countries in order to investigate the relationship between, renewable energy consumption and $CO_2$ emissions. The authors confirm the existence of negative causality from renewables to $CO_2$ emissions. The panel FMOLS and panel DOLS long-run estimates suggest that renewable energy consumption yields to affect negatively $CO_2$ emissions. Shafiei and Salim (2014) use STIRPART econometric model to investigate the relationship between disaggregated energy consumption and $CO_2$ emission for OECD countries. The results reveal that non-renewable energy consumption increases $CO_2$ emissions, while renewable energy consumption decreases $CO_2$ emissions. For the case of Tunisia, Ben Jebli and Ben Youssef (2015a) use ARDL bounds approach, VECM and Granger causality tests to investigate the dynamic causal links between $CO_2$ emissions, output (GDP), renewable and non-renewable energy consumption and trade (exports or imports). The authors show that $CO_2$ emissions and non-renewable energy consumption cause renewable energy in the short-run. Long-run estimates suggest that non-renewable energy consumption and trade contribute to increase emissions, while renewable energy consumption leads to decrease emissions. Sebri and Salha (2014) use the ARDL bounds approach to cointegration and VECM to investigate the causal links between economic growth, renewable energy consumption, $CO_2$ emissions and trade openness for the case of BRICS. The results from the empirical analysis show that the significant effect of trade and $CO_2$ emissions in promoting the renewable energy consumption.

Furthermore, numerous empirical studies have mentioned the role that renewable energy consumption can play in the development of economic activity sectors such as tourism, trade openness, and many other economic sectors…, and in the reduction of $CO_2$ emissions (e.g.

Apergis et al., 2010; Ben Aïssa et al., 2014; Shafiei and Salim, 2014; Ben Jebli and Ben Youssef, 2015b,c; Ben Jebli et al., 2015; Al-Mulali and Che Sab, 2015…). From these cited papers, there is much consideration on how trade and tourism sectors could contribute to the motivation of growth and in the control of the environmental situation in the long-run.

The present study tries to evaluate the role that maritime and rail transport sector can gives to the development of Tunisian economy (GDP, output) and investigate its impact on climate change conditions ($CO_2$ emissions). Moreover, this study examines the dynamic short- and long-run causalities between $CO_2$ emissions, economic growth, combustible renewables and waste consumption and transport in Tunisia using various empirical methodologies. To do that, it is interesting to examine the evolution of these factors across time and to observe the degree of correlation between them. Figure 1 reports the evolution of per capita real GDP, per capita $CO_2$ emissions, combustible renewables and waste consumption, and rail and maritime transport in Tunisia over the period 1990-2011.

**Insert Fig. 1 Here**

According to Figure 1, the evolution of all the series have a tendency to raise across time with a slight decrease at the end of the selected period. Per capita combustible renewables and waste consumption have a tendency to increase with approximately the same portion as per capita real GDP. For rail and maritime transport, their progresses record an increase across time with a sharp fall in the last year (in 2011). For the maritime transport, the number of travelers has recorded a decrease of 599929 to reaches 685295 in 2011 instead of 1285224 in 2010. For the rail transport, the number of travelers has recorded a decrease of 7412 to reaches 32741 in 2011 instead of 40153 in 2010. This scenario has a strong and negative effect on the expansion of the economic activities of the nation which is due to the instability of the political situation.

Before debating the empirical analysis of the present study, let's discuss some examinations related to the transport-energy interaction. Lund and Kempton (2008) recommends large-scale sustainable energy systems in order to increase the use of renewable electricity (wind power) and reduce $CO_2$ emissions. The authors suggest that the integration of new technology systems (electric vehicles and vehicle-to-grid) lead to replace oil in the transportation sector by renewable energy resources which may protect the environmental condition and maintain a balance between demand and supply.

Liddle (2009) examine the long-run relationship between transport demands, income and gasoline price for the case of US. The results mentioned that the variables move together with transport system in the short-run. However, estimating a long-run association for motor fuel use is difficult because of the combination of the efficacy of the CAFE standards to influence fleet fuel economy and the short period for which those standards existed and were increased.

Liddle (2012) investigates the relationships between gasoline consumption per capita, income, gasoline price, and car ownership for a panel of OECD countries. The author revealed that short- and long-run income elasticities are smaller than typically found. Moreover, Granger causality results suggest that gasoline consumption is caused by gasoline price, while caused by car ownership. Car ownership is Granger-caused by income and by gasoline consumption, but not by gasoline price.

Zhang et al. (2015) examine a dynamic panel quantile regression in order to estimate the direct energy rebound effect for road passenger transport in the whole country, eastern, central and western China over the period 2003-2012. The empirical findings suggest that the direct rebound effect does exist for road passenger transport and on the whole country. Moreover, the direct rebound effect for road passenger transport in central and eastern China tends to decrease, increase and then decrease again, whereas that in western China decreases and then increases, with the increasing passenger kilometers.

## 2. Rail and maritime transport in Tunisia

It is fairly essential to state the role played by Tunisian transport services of passengers and merchandise in the development of economic activities, and in the growing of pollution level of the country, especially rail and maritime transport. According to La Société Nationale des Chemins de Fer Tunisiens (SNCFT, 2015), rail transport accounts for over a third of the national movement through a domestic network of 2.167 kilometers train tracks including 471 km of standard gauge lines (1437 mm); 1688 kilometers of meter gauge lines (1000 mm) of which 65 km are electrified; 8 km line spacing mixed (standard and metric). The first railway line in the country (Tunis - La Marsa) was installed in August 1872 (nine years before the establishment of the French protectorate). The first major line (192 km) linking Tunis to Ghardimaou, is commissioned between 1878 and 1880 in order to transport raw materials from western countries to ports and then to France. These two lines are built according to international standards (standard gauge of 1437 mm).

Regarding the maritime transport, Tunisia has seven commercial ports installed in Radès, Sfax, Bizerte, Gabès, Sousse, Zarzis and La Goulette. Besides, a deep water port will be installed at Enfidha. The Office of Shipping and ports of Tunisia provides for 96% of foreign trade. The port of Radès has a significant share of its specialization in container traffic and rolling units. This latter provides 22% of global traffic, 90% of the tonnage of containerized goods, 90% of the tonnage of goods loaded on rolling units, 92% in twenty-foot equivalent of container traffic, 91% of the traffic of rolling units and 23% of ship traffic registered in all Tunisian commercial ports. With 550,000 passengers and 415,000 cruise passengers recorded in 2004, the port of La Goulette is one of the most popular destinations in the western Mediterranean (National Institute for Statistics, 2015).

This paper investigates the short- and long-run dynamic relationships between $CO_2$ emissions, real GDP, combustible renewables and waste consumption and rail and maritime transport for the case of Tunisia over the period 1990-2011. The main goal of this study is to evaluate the role of rail and maritime transport in simulating emissions, when combustible renewables and waste is considered as an energy source. To our knowledge, this research is original, and the econometric literature review has not yet examined the dynamic causal links between these variables.

This investigation is organized as follows: section 3 presents the data and methodology. Section 4 reports the results and discussion. Section 5 concludes.

## 3. Data and methodology

For the empirical analysis, annual data are collected over the period 1990-2011 for the case of Tunisia. Data include $CO_2$ emissions per capita (metric tons), real GDP ($y$) per capita (constant 2005 US$), combustible renewables and waste ($crw$) consumption per capita (metric tons of oil equivalent), rail transport ($rt$) and maritime transport ($mt$) are measured by the number of travelers. $CO_2$ emissions per capita, real GDP per capita and per capita combustible renewables and waste are collected from the World Bank (2015), whereas the rail and maritime transport are collected from the National Institute for Statistics of Tunisia (2015). All the empirical tests are computed after natural logarithmic transformation. Eviews 8.0 is used for estimation.

The main goal of this study is to investigate the dynamic short and long-run interaction between emissions, real GDP, combustible renewables and waste and rail and maritime transport for the case of Tunisia. The empirical analysis start through testing the integration order proprieties of each variable using the Zivot and Andrews (1992) unit root test with structural break; then, the ARDL bounds approach of Pesaran et al. (2001) is used to check for cointegration among variables. The short- and long-run coefficients corresponding to each cointegrated equation are estimated using the Ordinary Least Square (OLS) technique, and finally, the direction of causalities between the analysis variables are examined by using Granger causality tests.

## 4. Results and discussion

### *4.1. Zivot and Andrews's unit root test with structural break*

The empirical analysis begins by testing the integration order of the variable used in this study. All of the statistic tests are computed at level and after first difference. The stationary proprieties are tested using Zivot and Andrews (1992) unit root test. This unit root test seems to be more powerful than traditional statistics tests (e.g. Augmented Dickey Fuller; Phillips and Perron…) of the integration order because it takes into account the structural break proprieties. Besides, Zivot and Andrews test may be a motivating investigation for policymakers to improve economic recommendations. The null hypothesis suggests that series is non-stationary with one time break-point, while the alternative hypothesis suggests that the series is stationary with one-time break point. This test is developed in three models: 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 unit root test with structural break is estimated with intercept and deterministic trend.

**Insert Table 1 Here**

The Zivot and Andrews's unit root test results with structural break are reported in Table 1. The estimated statistics show that, at level, real GDP, combustible renewables and waste consumption, rail and maritime transport are non-stationary, whereas they become stationary after first difference. For $CO_2$ emissions, the result shows that the computed statistics confirm the stationary of the variable at level and after first difference. Thus, all the variables are integrated of order one, I(1).

### *4.2. ARDL bounds test to cointegration*

Following the same methodological approach used by Ben Jebli et al. (2015) and Ben Jebli and Ben Youssef (2015a), the present paper tries to the short- and long-run dynamic interdependence between $CO_2$ emissions, real GDP, combustible renewables and waste consumption, rail and maritime transport using the ARDL bound approach and Granger causality tests. The ARDL bounds approach is one of the recent and powerful techniques of cointegration developed by Pesaran and Pesaran (1997), Pesaran and Smith (1998), Pesaran and Shin (1999), and Pesaran et al. (2001). Over alternative cointegration procedures, there are several econometric advantages for the ARDL approach: (i) the short and long-run parameters are estimated in the same model; (ii) the endogeneity problems are resolved; (iii) the long-run association among variables can be tested for the case where regressors are integrated of order zero, I (0), or integrated of order one, I (1), or fractionally integrated; and (iv) provides better regression results for small samples. Our sample contains 22 observations. The ARDL presentation is given by the following equations:

$$\Delta co_{2t} = \alpha + \sum_{i=1}^{q} \alpha_{1i} \Delta co_{2t-i} + \sum_{i=1}^{q} \alpha_{2i} \Delta y_{t-i} + \sum_{i=1}^{q} \alpha_{3i} \Delta crw_{t-i} + \sum_{i=1}^{q} \alpha_{4i} \Delta rt_{t-i} + \sum_{i=1}^{q} \alpha_{5i} \Delta mt_{t-i} \\ \alpha_6 co_{2t-1} + \alpha_7 y_{t-1} + \alpha_8 crw_{t-1} + \alpha_9 rt_{t-1} + \alpha_{10} mt_{t-1} + \varepsilon_{1t} \tag{1}$$

$$\Delta y_t = \beta + \sum_{i=1}^{q} \beta_{1i} \Delta co_{2t-i} + \sum_{i=1}^{q} \beta_{2i} \Delta y_{t-i} + \sum_{i=1}^{q} \beta_{3i} \Delta crw_{t-i} + \sum_{i=1}^{q} \beta_{4i} \Delta rt_{t-i} + \sum_{i=1}^{q} \beta_{5i} \Delta mt_{t-i} \\ \beta_6 co_{2t-1} + \beta_7 y_{t-1} + \beta_8 crw_{t-1} + \beta_9 rt_{t-1} + \beta_{10} mt_{t-1} + \varepsilon_{2t} \tag{2}$$

$$\Delta crw_t = \theta + \sum_{i=1}^{q} \theta_{1i} \Delta co_{2t-i} + \sum_{i=1}^{q} \theta_{2i} \Delta y_{t-i} + \sum_{i=1}^{q} \theta_{3i} \Delta crw_{t-i} + \sum_{i=1}^{q} \theta_{4i} \Delta rt_{t-i} + \sum_{i=1}^{q} \theta_{5i} \Delta mt_{t-i} \\ \theta_6 co_{2t-1} + \theta_7 y_{t-1} + \theta_8 crw_{t-1} + \theta_9 rt_{t-1} + \theta_{10} mt_{t-1} + \varepsilon_{3t} \tag{3}$$

$$\Delta rt_t = \lambda + \sum_{i=1}^{q} \lambda_{1i} \Delta co_{2t-i} + \sum_{i=1}^{q} \lambda_{2i} \Delta y_{t-i} + \sum_{i=1}^{q} \lambda_{3i} \Delta crw_{t-i} + \sum_{i=1}^{q} \lambda_{4i} \Delta rt_{t-i} + \sum_{i=1}^{q} \lambda_{5i} \Delta mt_{t-i} \\ \lambda_6 co_{2t-1} + \lambda_7 y_{t-1} + \lambda_8 crw_{t-1} + \lambda_9 rt_{t-1} + \lambda_{10} mt_{t-1} + \varepsilon_{4t} \tag{4}$$

$$\Delta mt_t = \phi + \sum_{i=1}^{q} \phi_{1i} \Delta co_{2t-i} + \sum_{i=1}^{q} \phi_{2i} \Delta y_{t-i} + \sum_{i=1}^{q} \phi_{3i} \Delta crw_{t-i} + \sum_{i=1}^{q} \phi_{4i} \Delta rt_{t-i} + \sum_{i=1}^{q} \phi_{5i} \Delta mt_{t-i} \\ \phi_6 co_{2t-1} + \phi_7 y_{t-1} + \phi_8 crw_{t-1} + \phi_9 rt_{t-1} + \phi_{10} mt_{t-1} + \varepsilon_{5t} \tag{5}$$

where $\Delta$ and $\varepsilon$ are the first differences and error terms, respectively. $q$ denotes the number of lags. To check for the long-run dynamic relationships between $CO_2$ emissions, real GDP, combustible renewables and waste consumption, rail and maritime transport, the joint significance test of long-run estimated coefficients must be tested. The joint significance of the long-run estimated coefficients is based on the Fisher statistic of the Wald test. The null hypothesis is that the long-run estimated coefficients of the lagged variables are not jointly significant, while the alternative hypothesis suggests that the estimated coefficients of the lagged variables are jointly significant. The Schwarz Information Criterion (SIC) and Akaike Information Criterion (AIC) are used to get the optimal number of lags lengths.

To test the long-run interaction between the variables, Pesaran et al (2001) have advanced the ARDL bound approach to cointegration. This statistical approach is established on the test of the joint significance of long-run estimated coefficients. The null hypothesis of no long-run cointegration for each equation ($\alpha_6 = \alpha_7 = \alpha_8 = \alpha_9 = \alpha_{10}$; $\beta_6 = \beta_7 = \beta_8 = \beta_9 = \beta_{10}$; $\theta_6 = \theta_7 = \theta_8 = \theta_9 = \theta_{10}$; $\lambda_6 = \lambda_7 = \lambda_8 = \lambda_9 = \lambda_{10}$; $\phi_6 = \phi_7 = \phi_8 = \phi_9 = \phi_{10}$), against the alternative hypothesis of long-run cointegration ($\alpha_6 \neq \alpha_7 \neq \alpha_8 \neq \alpha_9 \neq \alpha_{10}$; $\beta_6 \neq \beta_7 \neq \beta_8 \neq \beta_9 \neq \beta_{10}$; $\theta_6 \neq \theta_7 \neq \theta_8 \neq \theta_9 \neq \theta_{10}$; $\lambda_6 \neq \lambda_7 \neq \lambda_8 \neq \lambda_9 \neq \lambda_{10}$; $\phi_6 \neq \phi_7 \neq \phi_8 \neq \phi_9 \neq \phi_{10}$). According to Pesaran et al. (2001), the estimated F-statistic of the Wald test will be compared to two terminal critical values: the lower critical value assumes that series are integrated of order zero, I(0), and the upper critical value assumes that series are integrated of order one, I(1). Thereby, three assumptions can be considered to conclude this investigation. If the computed value of F-statistic is more than the upper critical value, then the null hypothesis of no cointegration is rejected. If the computed F-statistic falls between the lower and upper critical values, then the result is inconclusive. In this case, we run the vector error correction model (VECM) to test the significance of the error correction term (ECT) for the long-run cointegration. Finally, if the computed value of F-statistic is less than the lower critical value, then the null hypothesis of no cointegration is not rejected.

**Insert Table 2 Here**

The ARDL bound approach suggests two steps for the long-run relationship between variables. The first step consists in checking for the optimal number of lags obtained by the unrestricted Vector Autoregressive (VAR) model. Based on the AIC and SIC criteria, the number of lags length selected for the VAR model is equal to the maximum of one (VAR (q=1)). In the second step, the ARDL model will be estimated using the OLS estimation approach in order to get the long-run coefficients. Then, the joint significance tests of the long-run estimated coefficients are computed using the Fisher statistics of the Wald test. Thus, to test for the long-run equilibrium (cointegration) relationship, the empirical study considers the AIC criterion[1] to get the required number of lags. For our cases, we have considered a maximum number of lag two.

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[1] To get the maximum number of lags, we chose the AIC criterion because of its performance, in comparison to other criteria, for the small simples.

The ARDL bound test to cointegration results are reported in Table 2. The outcomes indicate that all Fisher statistics of the Wald tests corresponding to each equation are statistically significant at mixed levels. With respect to equations 1 and 4, the null hypothesis of no long-run cointegration is rejected at the 1% significance level. However, for the equations 2 and 3, the null of no long-run cointegration can be rejected at the 5% significance level. Finally, when maritime transport is the dependent, the null of no cointegration is rejected at the 10% significance level. Thus, the ARDL bound tests confirm the existence of long-run cointegration between the variables.

It is worth interesting to test the validity of our model using further diagnostic tests (serial correlation, heteroscedasticity and normality). According to the estimated statistics tests, LM-test, ARCH test and normality test indicate that there is no serial correlation, no white heteroscedasticity, and residuals are normally distributed, respectively. Thus, all these tests confirm the validity of our results.

*4.3. Granger causality tests*

Engle and Granger (1987) procedure is used to investigate the short and long-run dynamic interrelationships between $CO_2$ emissions, economic growth, combustible renewables and waste consumption, and rail and maritime transport. Granger causality tests recommended by Engle and Granger (1987) are used in two steps. The first step starts by the estimation of long-run coefficients. The second step estimates the parameters related to the short-run adjustment. Fisher statistics test the significance of the short-run causality and the t-student statistics test the significance of the long-run causality (the significance of the error correction term). The VECM of the long-run equations is given as follows:

$$\Delta e_t = \chi_0 + \sum_{i=1}^{p} \chi_{1i} \Delta e_{t-i} + \sum_{i=1}^{p} \chi_{2i} \Delta y_{t-i} + \sum_{i=1}^{p} \chi_{3i} crw_{t-i} + \sum_{i=1}^{p} \chi_{4i} \Delta rt_{t-i} + \sum_{i=1}^{p} \chi_{5i} \Delta mt_{t-i} + \tau_1 ECT_{t-1} + \zeta_{1t} \quad (6)$$

$$\Delta y_t = \chi_0 + \sum_{i=1}^{p} \chi_{1i} \Delta e_{t-i} + \sum_{i=1}^{p} \chi_{2i} \Delta y_{t-i} + \sum_{i=1}^{p} \chi_{3i} crw_{t-i} + \sum_{i=1}^{p} \chi_{4i} \Delta rt_{t-i} + \sum_{i=1}^{p} \chi_{5i} \Delta mt_{t-i} + \tau_2 ECT_{t-1} + \zeta_{2t} \quad (7)$$

$$\Delta crw_t = \chi_0 + \sum_{i=1}^{p} \chi_{1i} \Delta e_{t-i} + \sum_{i=1}^{p} \chi_{2i} \Delta y_{t-i} + \sum_{i=1}^{p} \chi_{3i} crw_{t-i} + \sum_{i=1}^{p} \chi_{4i} \Delta rt_{t-i} + \sum_{i=1}^{p} \chi_{5i} \Delta mt_{t-i} + \tau_3 ECT_{t-1} + \zeta_{2t} \quad (8)$$

$$\Delta rt_t = \chi_0 + \sum_{i=1}^{p} \chi_{1i} \Delta e_{t-i} + \sum_{i=1}^{p} \chi_{2i} \Delta y_{t-i} + \sum_{i=1}^{p} \chi_{3i} crw_{t-i} + \sum_{i=1}^{p} \chi_{4i} \Delta rt_{t-i} + \sum_{i=1}^{p} \chi_{5i} \Delta mt_{t-i} + \tau_4 ECT_{t-1} + \zeta_{4t} \quad (9)$$

$$\Delta mt_t = \chi_0 + \sum_{i=1}^{p} \chi_{1i} \Delta e_{t-i} + \sum_{i=1}^{p} \chi_{2i} \Delta y_{t-i} + \sum_{i=1}^{p} \chi_{3i} crw_{t-i} + \sum_{i=1}^{p} \chi_{4i} \Delta rt_{t-i} + \sum_{i=1}^{p} \chi_{5i} \Delta mt_{t-i} + \tau_5 ECT_{t-1} + \zeta_{5t} \quad (10)$$

where $\Delta$ presents the first difference of the variables. $p$ denotes the VAR lag length; $ECT_{t-1}$ indicates the lagged error correction term corresponding to each equation, and $\tau$ measures the speed of adjustment from the short to the long-run equilibrium.

**Insert Table 3 Here**

The dynamic short- and long-run causalities between $CO_2$ emissions, real GDP, combustible renewables and waste consumption, rail and maritime transport are reported in Table 3. Figure 1 highlights our short-run causalities investigation. Granger causality results suggest that, in the short-run, there is evidence of unidirectional causality running from real GDP, combustible renewables and waste consumption and rail transport to $CO_2$ emissions at the 1% significance level, and a bidirectional causality between $CO_2$ emissions and maritime transport at a mixed levels. In the long-run, Granger causality results reveal that the lagged ECT corresponding to each equation is statistically significant. This result indicates that there is a long-run interaction between $CO_2$ emissions, economic growth, combustible renewables and waste consumption, and rail and maritime transport. Thus, we can conclude that there is a long-run relationship running from i) real GDP, combustible renewables and waste consumption, rail and maritime transport to $CO_2$ emissions; ii) combustible renewables and waste consumption, $CO_2$ emissions, rail and maritime transport to real GDP; iii) $CO_2$ emissions, real GDP, rail and maritime transport to combustible renewables and waste consumption; iv) $CO_2$ emissions, real GDP, combustible renewables and waste consumption, rail transport to maritime transport; and from v) $CO_2$ emissions, real GDP, combustible renewables and waste consumption, rail transport to maritime transport.

The resumed short-run dynamic interdependence between variables reported in Figure 1 can help us to interpret the economic aspect of the directions of causalities.

**Insert Figure 2 Here**

According to Figure 2 and Table 3, Granger causality results reveal the existence of a unidirectional short-run causality running from real GDP to $CO_2$ emissions without feedback, whereas, in the long-run, the interdependence between them is founded to be bidirectional. These results indicate that a short-run expansion of the economic activities of the nation can play an important role in the simulation of environmental quality. Our short-run findings are consistent with those by Ben Jebli and Ben Youssef (2015a) and Ben Jebli et al. (2015a) for the case of Tunisia. The bidirectional long-run interaction between $CO_2$ emissions and economic growth shows that the spread of pollution is in real dependence with economic sector's growth. It means that any changes in the degree of pollution are due to country's economic development and vis-versa.

A dynamic short-run interconnection running from combustible renewables and waste consumption to $CO_2$ emissions is established at the 1% significance level. However, in the long-run, the relationship between them is bidirectional at the 1% significance level. This finding is not online with those by Apergis et al. (2010) for developing and developed countries, Ben Jebli and Ben Youssef (2015b) for the case of North Africa countries, and Ben Jebli et al. (2015b) for sub-Saharan countries, but consistent to the findings by Ben Jebli et al. (2015a) for the case of Tunisia. It seems that the correlation between the share of combustible renewables and waste and the degree of pollution is very strong. It means that any increase in the level of combustible renewables and waste will affect the environmental degradation and any variation in the pollution degree will have an impact on combustible renewables energy conservation.

Granger causality results show that there is no short-run causal links between economic growth and combustible renewables and waste consumption. This finding supports the neutrality hypothesis which assumes that, in the short-run, the expansion of economic growth do not affect the share of combustible renewables and waste energy consumed for production and vice versa. However, in the long-run, the causality result is quite the contrary, given that their interrelationship is found to be bidirectional. Thus, the long-run interdependence between energy and economic growth supports the feedback hypothesis. Our direction results is on line with the long-run findings of Apergis and Payne (2010a) for the case of panel of OECD countries and Apergis and Payne (2010b) for the case of Eustria and Apergis and Payne (2011) for the case of Central America.

Interestingly, rail and maritime transport both contribute to cause pollution growth in Tunisia. This result is explained by the existence of a unidirectional short-run Granger causality running from rail transport to $CO_2$ emissions, a bidirectional short-run causality between maritime transport and emissions, and by the existence a bidirectional long-run causality between emissions $CO_2$ and rail and maritime transport. We think that this result is new and substantial because it takes into account the role of transport in the degradation of environmental quality. According to the United Nations Environment Programme (UNEP, 2015), the Tunisian transport sector is among the major contributors to air pollution and lead

$CO_2$ emissions at 30%. Besides, between 1994 and 2002, greenhouse gas (GHG) emissions of $CO_2$ from transport sector rose from 3.4 million tonnes to 5.8 million tonnes (annual increase rate of 9%). Thus, it is necessary that Tunisian policymakers should control the pollution condition caused by transport sector. One may think to pick up animals and industrial wastes and turn it into combustible renewables energy to power transport machineries and equipment.

*4.4. ARDL coefficients estimates*

After establishing the direction causalities between the variables, in this subsection the short- and long-run coefficients corresponding to each ARDL equation are estimated. Table 4 documents the short- and long-run coefficients estimates which are based on the OLS approach.

**Insert Table 4 Here**

The results reported in Table 4 show that all long-run estimated parameters are statistically significant. When $CO_2$ emissions are the dependent variable, only economic growth affects negatively pollution growth, while combustible renewables and waste consumption and transport both affects positively the expansion of emissions. It means that a 1% increase in the real GDP contributes to decrease $CO_2$ emissions by 0.57%, while a 1% increase in the consumption of combustible renewables and waste consumption and rail and maritime transport lead to increase emissions by 0.65%, 0.22% and 0.16%, respectively. This finding is similar to those provided by Ben Jebli et al. (2015) for the case of Tunisia, i.e. the authors' show that any increase in economic growth leads to decrease pollution levels, while any increase in combustible renewables and waste consumption and tourism, both contribute to increase emissions.

For the case where real GDP is the dependent variable, the results affirm that, in the long-run, any increase in the level of $CO_2$ emissions leads to decrease economic growth, while any increase in combustible renewables and waste consumption and transport leads to increase economic growth. This finding implies that a 1% increase in the use of combustible renewables and waste and rail and maritime transport increases economic growth by 1.14%, 0.38%, and 0.28%, respectively.

When combustible renewables and waste consumption is the dependent variable, the impact of economic growth and $CO_2$ emissions are positive and statistically significant at the 1% level. However, the impact of transport (rail and maritime) is negative and statistically significant at the 1% level. The results reveal that, in the long-run, a 1% increase in real GDP and emissions increases combustible renewables and waste consumption by 1.55% and 0.88%, respectively. A 1% increase in rail and maritime transport decreases the use of combustible renewables and waste by 0.38% and 0.24%, respectively.

When rail transport is the dependent variable, the ARDL long-run estimates reveal that $CO_2$ emissions and economic growth both affect positively rail transport at the 1% significance level, while combustible renewables and waste and maritime transport affect negatively rail transport at the 1% significance level. The results show that, in the long-run, a 1% increase in $CO_2$ emissions and real GDP increases rail transport by 4.58% and 2.61%, respectively. However, a 1% increase in combustible renewables and waste consumption and maritime transport decreases rail transport by 2.96% and 0.72%, respectively.

By considering maritime transport as a dependent variable, the long-run estimates reveal that, economic growth and $CO_2$ emissions have a positive and statistically significant impact on maritime transport at the 1% significance level. However, combustible renewables and waste consumption and rail transport have a negative and statistically significant impact on maritime transport at the 1% significance level. In other terms, a 1% increase in $CO_2$ emissions and real GDP increases maritime transport by 6.34% and 3.61%, respectively. In other hand, a 1% increase in the consumption of combustible renewables and waste and rail transport decreases maritime transport by 4.1% and 1.38%, respectively. We have considerably tested the validity of the estimated model. The diagnostic tested are based on the serial correlation, heteroscedasticity and normality tests. All these computed tests confirm the robustness of our short and long-run estimated model. These tests are available upon request.

Given that our ARDL estimated model is valid and confirms the strength of short and long-run computed parameters, it is required to check for the their stability using CUSUM and CUSUMSQ statistical tests developed by Brown et al. (1975). These statistical tests are more powerful than any other tests (e.g. Hansen and Johansen, 1993) because they do not require that the integration order should be equal to one, (I(1)). Moreover, based on the recursive residuals, the CUSUM and CUSUMSQ include the short-run dynamics to the long-run through residuals. The stability tests results are reported in Figs. 3, 4, 5, 6 and 7.

**Insert Figs. 3-7 Here**

The results reported in these figures indicate that, when $CO_2$ emissions are the dependent variable (Fig. 3), all the short- and long-run estimated coefficients are stable because these latter are well within the critical bounds of 5% significance. For the other figures (Figs. 4, 5, 6 and 7), CUSUMSQ plots indicate that estimated coefficients are unstable because the calculated statistic is not well inside the critical bounds. Thus, it is required to test the break point properties using Chow forecasting tests for each equation.

For the case where real GDP is dependent variable (Fig. 4), the instability of the estimated coefficients is around the period 2008-2011, while when combustible renewables and waste consumption is the dependent variable (Fig. 5), the instability of the estimated parameters is around the period 2008-2010. For the case where rail transport (resp. maritime transport) is defined as a dependent variable, (Fig. 6 resp. (Fig. 7)), the instability of the computed coefficients is around the period 2007-2011.

**Insert Table 5 Here**

Table 5 reports the results of the Chow forecasting tests for each instable model. According the estimated statistics, the results confirm that there is no significant structural break point in these models.

## 5. Conclusions and policy implications

This study uses the ARDL bound approach and Granger causality tests to investigate the short and long-run interrelationship between $CO_2$ emissions, real GDP, combustible renewables and waste consumption, and rail and maritime transport for the case of Tunisia spanning the period 1990-2011. The long-run cointegration among variables has been established using the Wald test.

Granger causality tests reveal that, in the short-run, there is a unidirectional causality running from real GDP, combustible renewables and waste consumption, and rail transport to $CO_2$ emissions. Indeed, there is a bidirectional short-run causality between $CO_2$ emissions and maritime transport. In the long-run, all estimated error correction terms are statistically significant, indicating the existence of long-run relationships between variables.

Long-run estimates suggest that combustible renewables and waste consumption and rail and maritime transport, both lead to increase $CO_2$ emissions, while any increase in rail and maritime transport decrease the use of combustible renewables and waste consumption. Moreover, any increase in the consumption of combustible renewables and waste consumption and rail transport (resp. maritime transport) lead to decrease maritime transport (resp. rail transport).

Tunisian authorities should change their transport technologies by adopting clean technology using renewables energies to transport passengers. Thereby, this strategy could be a good plan to eliminate wastes, to decrease air pollution degree, to control the environmental situation and to stimulate economic growth.

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# Tables

**Table.1. Zivot-Andrews unit root test with structural break**

| Variables | Levels | | 1st differences | |
|---|---|---|---|---|
| | t-statitic | Time break | t-statitic | Time break |
| *y* | -5.418456 (1) | 1996 | -5.178057 (0)** | 1995 |
| *e* | -5.693173 (0)*** | 1994 | -10.27862 (0)*** | 1995 |
| *crw* | -7.557180 (4) | 2001 | -6.306236 (1)*** | 1996 |
| *rt* | -2.188578 (4) | 2006 | 4.170320 (0)** | 1998 |
| *mt* | 1.245271 (4) | 2008 | 5.980402 (0)*** | 2006 |

Notes: ***, ** denote statistical significance at the 1% and 5% levels, respectively. Lag order is presented in parenthesis.

**Table 2. ARDL bound test to cointegration**

| Estimated model | Bounds testing to cointegration | | F-statistics | Prob (F.stat) |
|---|---|---|---|---|
| | optimal lag length | | | |
| F(e/y,crw,tt,tm) | (1,1,1,1,1) | | 6.582185 | 0.007600*** |
| F(y/e,crw,tt,tm) | (1,2,2,2,1) | | 10.39532 | 0.011200** |
| F(crw/e,y,tt,tm) | (2,2,1,2,1) | | 10.61170 | 0.010800** |
| F(rt/e,y,crw,tm) | (1,2,1,1,1) | | 10.49005 | 0.003800*** |
| F(mt/e,y,crw,tt) | (1,2,2,1,1) | | 3.658848 | 0.072800* |
| Critical values | Lower bounds I(0) | | | Upper bounds I(1) |
| 1% | 3.817 | | | 5.122 |
| 5% | 2.850 | | | 4.049 |
| 10% | 2.425 | | | 3.574 |
| | Diagnostic tests | | | |
| | LM-test | ARCH test | Normality test | |
| F(e/y,crw,tt,tm) | 3.093543 | 1.231807 | 1.587951 | |
| F(y/e,crw,tt,tm) | 1.952046 | 0.878593 | 0.160470 | |
| F(crw/e,y,tt,tm) | 4.279490 | 0.353776 | 1.260719 | |
| F(rt/e,y,crw,tm) | 3.081450 | 0.343803 | 0.470655 | |
| F(mt/e,y,crw,tt) | 1.881236 | 0.166744 | 1.011788 | |

Notes: ***,**, and * indicate statistical significance at the 1%, 5% and 10% levels, respectively. F(.) denotes the computed value of Fisher statistic for the case with intercept and no trend. Terminal critical values are provided by Pesaran et al. (2001). LM-test, ARCH test and Normality test refer to serial correlation test, the heteroskedasticity test, and the Jarque-Bera normality test, respectively.

**Table 3. Granger causality tests**

| Variables | Short-run | | | | | Long-run |
|---|---|---|---|---|---|---|
| | ***Δe*** | ***Δy*** | ***Δcrw*** | ***Δtt*** | ***Δtm*** | **ECT** |
| ***Δe*** | - | 24.0867 (0.0001)*** | 21.3931 (0.0002)*** | 31.1257 (0.0000)*** | 26.9360 (0.0000)*** | -0.892791 [-2.74516]*** |
| ***Δy*** | 0.08291 (0.7767) | - | 1.53646 (0.2311) | 0.02673 (0.8719) | 2.09195 (0.1580) | -0.504730 [-4.13979]*** |
| ***Δcrw*** | 0.21536 (0.6482) | 1.74186 (0.2034) | - | 0.40368 (0.5332) | 0.00312 (0.9560) | -0.625985 [-2.55572]*** |
| ***Δrt*** | 0.15601 (0.6975) | 0.00916 (0.9248) | 0.01529 (0.9030) | - | 0.00928 (0.9243) | -0.265826 [-2.79733]*** |
| ***Δmt*** | 5.45194 (0.0313)** | 0.31630 (0.7336) | 0.82212 (0.3765) | 1.74305 (0.2033) | - | -0.242559 [-2.19891]** |

Notes: ***, ** indicate statistical significance at the 1% and 5% levels of significance, respectively. P-value are listed in parenthesis and t-statistics are presented in brackets.

**Table 4. ARDL coefficients estimates**

| | | | | | | |
|---|---|---|---|---|---|---|
| | Dependent variable: *e* | *y* | *crw* | *rt* | *mt* | *c* |
| | ARDL estimates | -0.569083 | 0.646639 | 0.218413 | 0.157813 | 6.861082 |
| | p-value | 0.0000*** | 0.0000*** | 0.0000*** | 0.0000*** | 0.0000*** |
| | Dependent variable: *y* | *e* | *crw* | *rt* | *mt* | *c* |
| | ARDL estimates | -1.757213 | 1.136283 | 0.383798 | 0.277311 | 12.05638 |
| | p-value | 0.0000*** | 0.0000*** | 0.0000*** | 0.0000*** | 0.0000*** |
| *Long-run* | Dependent variable: *crw* | *e* | *y* | *rt* | *mt* | *c* |
| *Estimates* | ARDL estimates | 1.546457 | 0.880062 | -0.337766 | -0.244051 | -10.61037 |
| | p-value | 0.0000*** | 0.0000*** | 0.0000*** | 0.0000*** | 0.0000*** |
| | Dependent variable: *rt* | *e* | *y* | *crw* | *mt* | *c* |
| | ARDL estimates | 4.578483 | 2.605537 | -2.960628 | -0.722545 | -31.41335 |
| | p-value | 0.0000*** | 0.0000*** | 0.0000*** | 0.0000*** | 0.0000*** |
| | Dependent variable: *mt* | *e* | *y* | *crw* | *tt* | *c* |
| | ARDL estimates | 6.336603 | 3.606054 | -4.097498 | -1.383996 | -43.47596 |
| | p-value | 0.0000*** | 0.0000*** | 0.0000*** | 0.0000*** | 0.0000*** |
| | Dependent variable: *d(e)* | *d(y)* | *d(crw)* | *d(rt)* | *d(mt)* | *c* |
| | | 0.812738 | -2.012327 | -0.274506 | 0.021073 | 0.028012 |
| | p-value | [2.49774]*** | [-3.61020]*** | [-1.54334] | [0.38588] | [0.38361] |
| | Dependent variable: *d(y)* | *d(e)* | *d(crw)* | *d(rt)* | *d(mt)* | *c* |
| | | 0.235666 | -0.826855 | -0.081787 | -0.407076 | 0.049304 |
| *Short-run* | p-value | [2.12575]** | [-2.11772]** | [-2.54980]*** | [-2.95985]*** | [3.55457]*** |
| *Estimates* | Dependent variable: *d(crw)* | *d(e)* | *d(y)* | *d(rt)* | *d(mt)* | *c* |
| | | -0.063098 | 0.107278 | -0.179440 | 0.012722 | 0.011821 |
| | p-value | [-0.53808] | [0.33059] | [-1.78164]* | [0.37496] | [0.80566] |
| | Dependent variable: *d(rt)* | *d(e)* | *d(y)* | *d(crw)* | *d(mt)* | *c* |
| | | 1.104809 | 0.679332 | -0.036238 | -0.128282 | 0.010518 |

| | | | | | |
|---|---|---|---|---|---|
| p-value | [2.20747]** | [0.51638] | [-0.01608] | [-0.85665] | [0.16242] |
| Dependent variable: *d(mt)* | *d(e)* | *d(y)* | *d(crw)* | *d(mt)* | *c* |
| | 0.589308 | 9.222779 | -5.647762 | -5.429838 | 0.084901 |
| p-value | [1.13860] | [1.75178]* | [-1.19156] | [-1.93053]* | [0.43001] |

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

**Table 5. Tests of Chow forecasting**

| Model | | Value | Probability |
|---|---|---|---|
| y=f(e,crw,rt,mt) | Test predictions for observations from 2008 to 2011 | | |
| | F-statistic | 71.59195 | 0.0884 |
| | Likelihood ratio | 107.5545 | 0.0000*** |
| crw=f(y,e,rt,mt) | Test predictions for observations from 2008 to 2010 | | |
| | F-statistic | 119.4167 | 0.0671 |
| | Likelihood ratio | 111.7964 | 0.0000*** |
| rt=f(y,e,crw,mt) | Test predictions for observations from 2007 to 2011 | | |
| | F-statistic | 12.13194 | 0.0776 |
| | Likelihood ratio | 61.35814 | 0.0000*** |
| mt=f(y,e,crw,rt) | Test predictions for observations from 2007 to 2011 | | |
| | F-statistic | 4.672737 | 0.1813 |
| | Likelihood ratio | 39.53100 | 0.0000*** |

Notes: *** indicates statistical significance at the 1% significance level.

# Figures

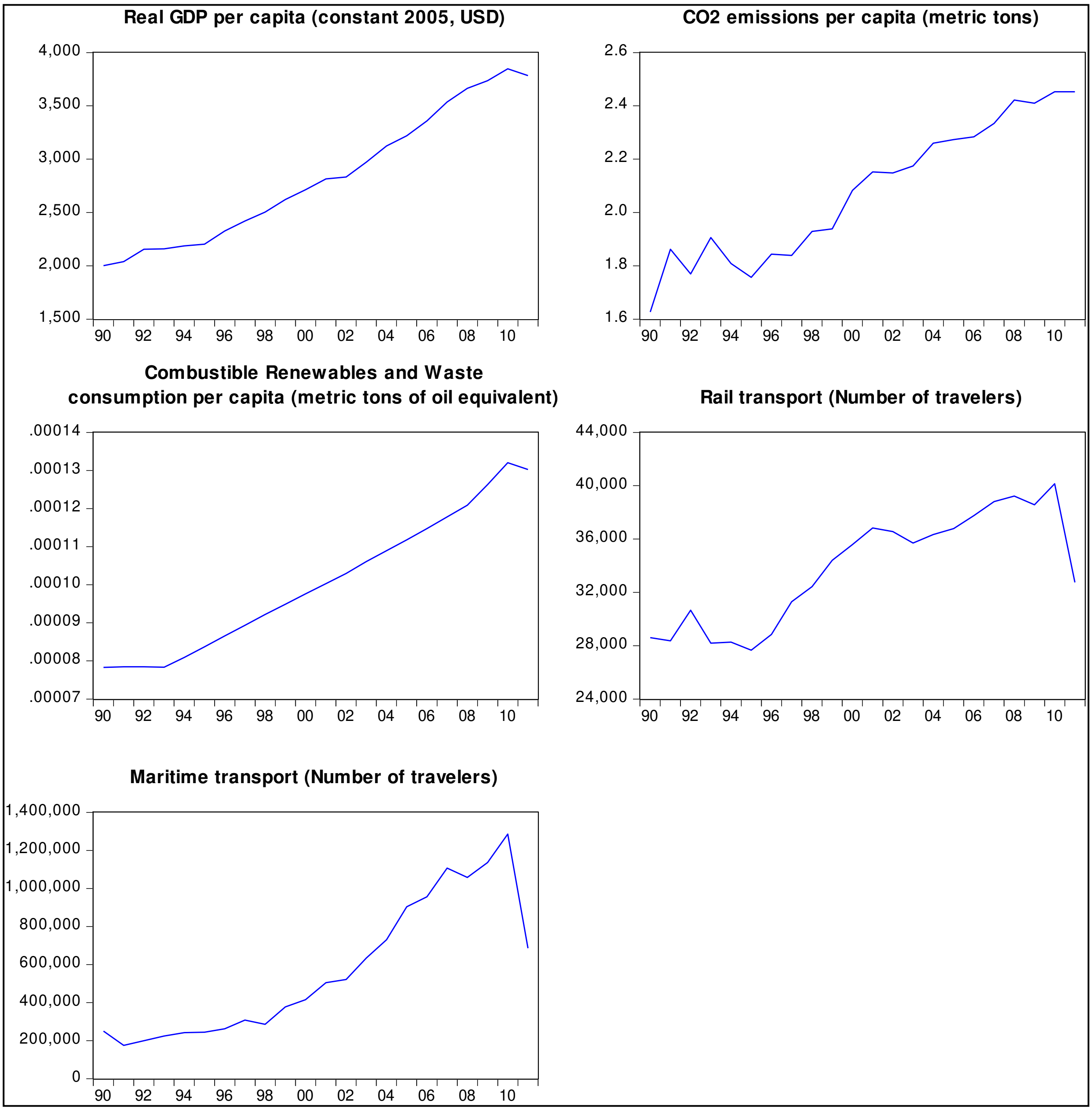


**Fig.1. plots presentation of real GDP, $CO_2$ emissions, combustible renewables and waste consumption and transport in Tunisia**

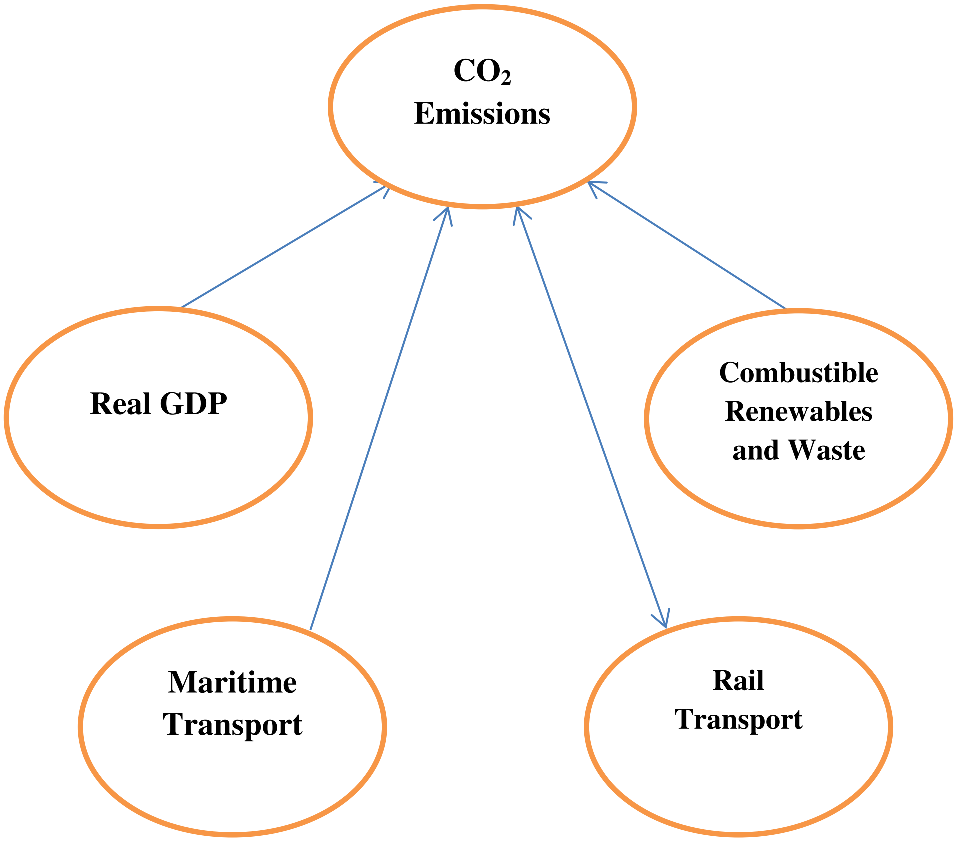


**Fig.2. Short-run Granger causality results**

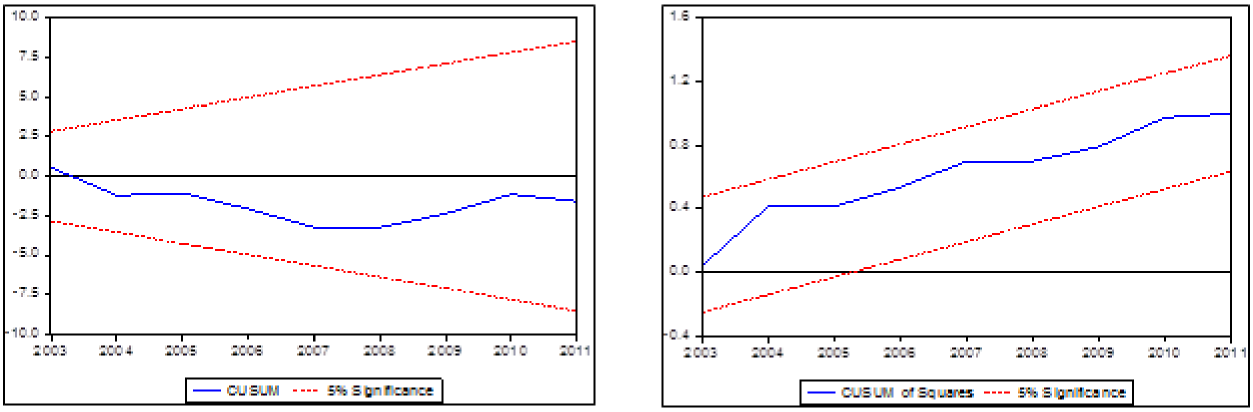


**Fig.3. CUSUM and CUSUM of Squares plots of recursive residuals (for $CO_2$ emissions model)**

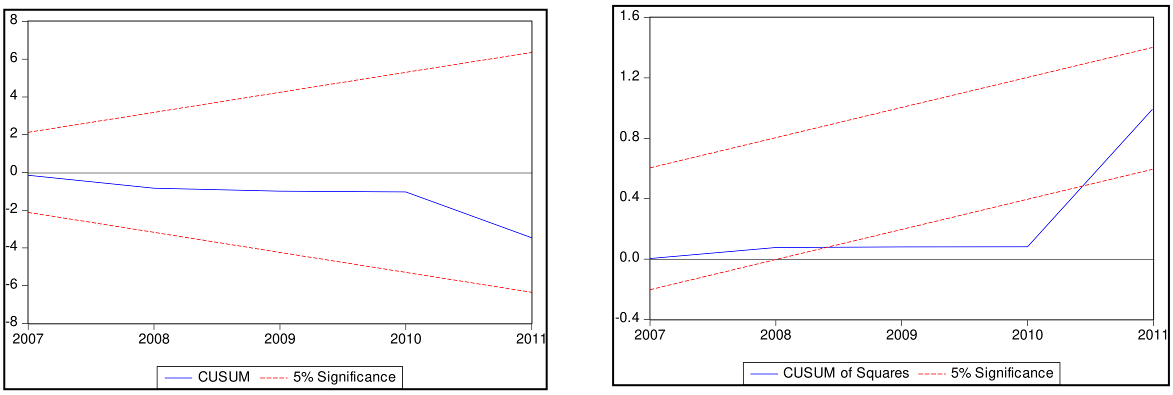


**Fig.4. CUSUM and CUSUM of Squares plots of recursive residuals (for real GDP model)**

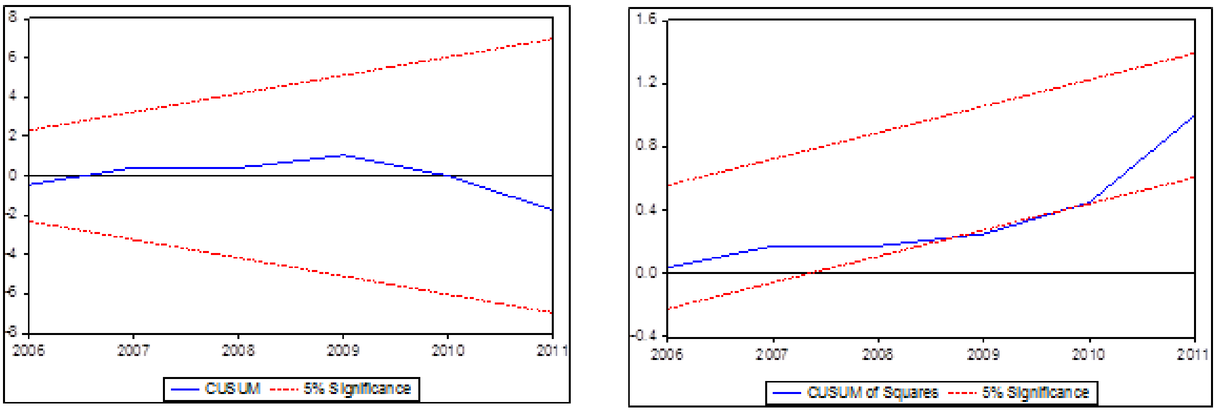


**Fig.5. CUSUM and CUSUM of Squares plots of recursive residuals (for CRW consumption model)**

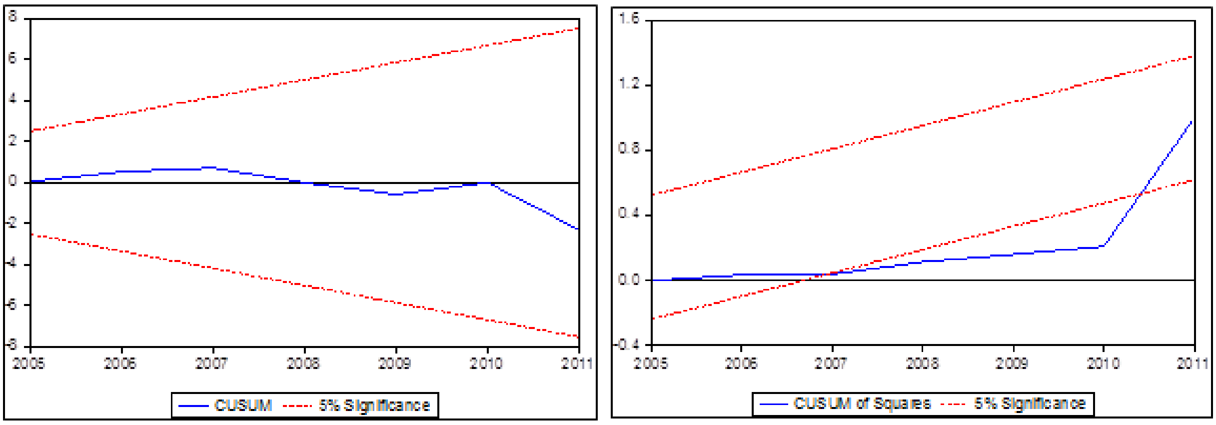


**Fig.6. CUSUM and CUSUM of Squares plots of recursive residuals (for rail transport model)**

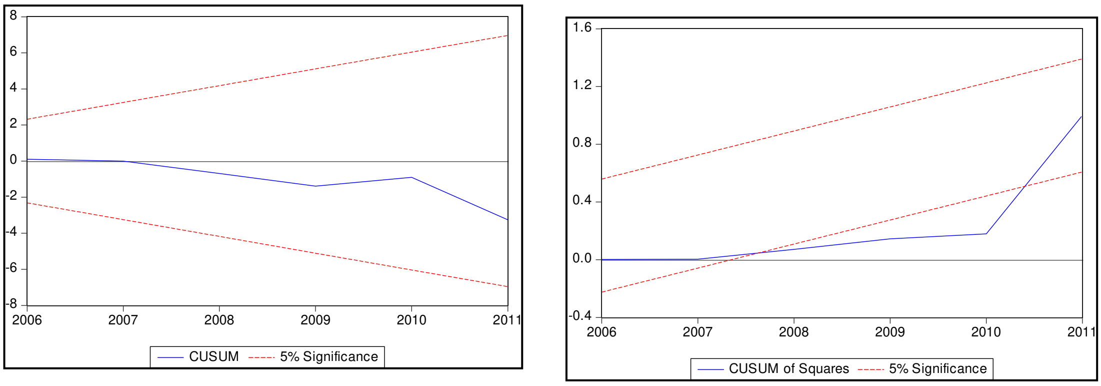


**Fig.7. CUSUM and CUSUM of Squares plots of recursive residuals (for maritime transport model)**