ECONOMIC RESEARCH FORUM

منتدى البحوث الاقتصادية

2009

# working paper series

# LONG AND SHORT-RUN LINKAGES BETWEEN ECONOMIC GROWTH, ENERGY CONSUMPTION AND CO2 EMISSIONS IN TUNISIA

Houssem Eddine Chebbi

Working Paper No. 485

# LONG AND SHORT-RUN LINKAGES BETWEEN ECONOMIC GROWTH, ENERGY CONSUMPTION AND $CO_2$ EMISSIONS IN TUNISIA

Houssem Eddine Chebbi

**Working Paper 485**

**April 2009**

Send Correspondence to:

Houssem Eddine Chebbi, Faculty of Economic Sciences and Management of Nabeul (FSEGN), Nabeul. Tunisia.

E-mail : chebbihe@planet.tn

## Abstract

The aim of this country specific study is to understand long and short-run linkages between economic growth, energy consumption and carbon emission using Tunisian data. These linkages were largely under considered and unanswered for policy makers in Tunisia and this empirical research attempts to present some findings to better integrate the environment into economic development decisions. Cointegration procedure is used to analyze time series relationships and error-correction terms are considered to estimate generalized impulse response functions and to test for the direction of Granger causality. Statistical findings of Johansen's cointegration analysis detect the presence of two cointegrating vectors. The first reveals a positive linkage between output and energy use and the second indicates that carbon emission and energy consumption are positively related in the long-run. In addition, results of the long-run relationships provide some evidence of "inefficient use" of energy in Tunisia, since environmental degradation tends to rise more rapidly than economic growth. Moreover, empirical results provide support for causality running from $CO_2$ emissions growth to output growth, both in the short-run and the long-run. The results also provide some support of mutual causal and feedback relationship in the long-run. This pattern of development is consistent with the experiences of many developing countries. The results have important implications for policy makers in Tunisia who should be mindful that a persistent decline in environmental quality may exert negative externalities to the economy. Since statistical results confirm that an increase in pollution level induces economic expansion and in order not to adversely affect economic growth, more efforts must be made to encourage Tunisian industry to adopt technology that minimizes pollution, as a serious environmental policy. In Tunisia, the potential exists for the development of renewable energies and further efforts would require additional financing by policy makers and environmental awareness. In addition, the combined results of causality analysis and impulse response functions do not support the view that energy and output are neutral with respect to each other in Tunisia and the finding of a bi-directional causality between output growth and growth in energy consumption in the long-run implies that Tunisia is an energy dependent economy. The Tunisian economy may be vulnerable to energy shocks in which an energy shortage may adversely affect output growth. For this reason, it seems possible that energy conservation policies could be achieved through the rationalization of consumer and household demand and the reduction of Tunisian government consumption.



## ملخص

تهدف هذه الدراسة النوعية القطرية إلى فهم الروابط بعيدة وقصيرة المدى بين النمو الاقتصادي واستهلال الطاقة والانبعاثات الكربونية وذلك بالاعتماد على البيانات التونسية. ولم تحظ هذه الروابط إلى حد كبير بالقدر الكافي من الدراسة أو الردود الشافية (لما تطرقه من أسئلة) بالنسبة لصانعي السياسات في تونس ومن ثم جاء هذا البحث الخبروي ليعرض بعض النتائج بغرض رفع مستوى التكامل بين البيئة وبين القرارات المتعلقة بالتنمية الاقتصادية. ويستخدم إجراء التكامل المشترك لتحليل العلاقات المتسلسلة زمنيا، كما تؤخذ في الاعتبار العلاقات المتبادلة بين الخطأ والصواب لتقدير الوظائف المعممة للحوافز والاستجابات، وكذا إجراء اختبارات لتوخي اتجاه العليّة لدى جرانجر. وقد توصل تحليل التكامل المشترك الذي قال به جوهانسون توصل إلى نتائج إحصائية تدلنا على وجود عاملين متكاملين: العامل الأول يكشف لنا وجود ترابط موجب بين الإنتاج واستخدام الطاقة، كما يدلنا العامل الثاني على العلاقة الموجبة بين انبعاثات الكربون واستهلاك الطاقة على المدى البعيد ـ أضف إلى ذلك أن النتائج التي تتمخض عنها تلك العلاقات بعيدة المدى تتيح لنا قدراً من الأدلة على الاستخدام غير الكفء للطاقة في تونس إذ نجد أن التدهور البيئي يجنح إلى الارتفاع بصورة أسرع

عما هي الحال بالنسبة للنمو الاقتصادي. أضف إلى ذلك أن النتائج الخبروية تؤكد حدوث علاقة علية بين انبعاثات ثاني أكسيد الكربون ونمو الإنتاج على المدى القريب والمدى البعيد على حد سواء، كما تؤكد النتائج أيضاً وجود علاقة متبادلة بين السبب والمردود على المدى البعيد. ويتمشى هذا النموذج في التنمية مع خبرات كثير من الدول النامية. ولهذه النتائج تأثيرات مهمة بالنسبة لصناع السياسة في تونس الذين يجب عليهم الانتباه إلى أن التدهور المستمر في نوعية البيئة قد يكون له آثار سلبية خارجية على الاقتصاد. ونظراً لأن النتائج الإحصائية تؤكد لنا أن ارتفاع نسبة التلوث يستتبع حدوث توسع اقتصادي، فلابد من بذل مزيد من الجهد لتحاشي أية تأثيرات ضارة على النمو الاقتصادي، وذلك بتشجيع الصناعة التونسية على مراعاة استخدام التقانة التي تحد من التلوث باعتبارها سياسة بيئية جادة. ونجد أن تونس لديها الإمكانات لتنمية الطاقة المتجددة، كما نجد أن المزيد من الجهد في هذه السبيل تتطلب مزيداً من التمويل من جانب صناع السياسة، وكذا مزيد من الوعي البيئي. كما نجد بالإضافة إلى ذلك أن النتائج المشتركة للتحليل العلّي ووظائف الحوافز والاستجابات لا تؤيد الرأي القائل بأن ثمة انفصالا بين الطاقة والإنتاج في تونس، كما نجد أن وجود علاقة علية مزدوجة الاتجاه بين نمو الإنتاج والنمو في استهلاك الطاقة على المدى البعيد إنما يدل على أن الاقتصاد بتونس هو اقتصاد يعتمد على الطاقة، ومن ثم نجده عرضه للتأثر بصدمات الطاقة، حيث قد يؤدي نقص الطاقة إلى الإضرار بنمو الإنتاج. ولذا نجد أن سياسات صون الطاقة يمكن تحقيقها من خلال ترشيد الاستهلاك المنزلي، وكذا تخفيض استهلاك الدوائر الحكومية في تونس

## Introduction

The relationship between energy consumption and economic growth, as well as economic growth and environmental pollution, has been one of the most widely investigated topics in the economic literature during the three last decades. However, existing outcomes have varied considerably.

Whether energy consumption stimulates, delays or is neutral to economic activities has motivated curiosity and interest among economists and policy analysts to find out the direction of causality between energy consumption and economic variables.

The pioneering study by Kraft and Kraft (1978) found a unidirectional Granger causality running from output to energy consumption for the United States using data for the 1947–1974 time frame.

The empirical outcomes of the subsequent studies on this subject, which differ in terms of time period, country, econometric techniques, and proxy variables, have reported mixed results and are not conclusive to offer policy recommendations that can be applied across countries. Depending upon the direction of causality, the policy implications can be considerable with regards to energy conservation, emission reduction and economic performance viewpoints.

Most of the analyses on this topic have recently been conducted using Vector Autoregression (VAR) models. Earlier empirical works have used Granger (1969) or Sims (1972) tests to test whether energy use causes economic growth or whether energy use is determined by the level of output[1]. Their empirical findings are generally inconclusive. But when significant results are obtained, they indicate that causality runs from output to energy use. Erol and Yu (1987) tested the data of six industrialized countries and found some indications of a causal relationship between energy and output in a number of industrialized countries with the most significant relationship being for Japanese data between 1950 and 1982. However, when the sample was restricted to 1950-1973, the relationship was no longer significant. Yu and Choi (1985) also found a causal relationship running from energy to GDP in the Philippines economy, but causality is reversed in the case of South Korea. Ebohon (1996) examines the causal directions between energy consumption and economic growth for two African economies (Nigeria and Tanzania). The results show a simultaneous causal relationship between energy and economic growth for both countries.

With advances in time series econometric techniques, more recent studies have focused on the vector error correction model (VECM) and the cointegration approach. Masih and Masih (1996) used cointegration analysis to study this relationship in a group of six Asian countries and found that cointegration does exist between energy use and GDP in India, Pakistan, and Indonesia. No cointegration is found in the case of Malaysia, Singapore and the Philippines. The flow of causality is found to be running from energy to GDP in India and from GDP to energy in Pakistan and Indonesia. Using trivariate approach based on demand functions, Asafu-Adjaye (2000) tested the causal relationship between energy use and income in four Asian countries using cointegration and error-correction analysis. He found that causality runs from energy to income in India and Indonesia, and a bi-directional causality in Thailand and the Philippines.

Stern (2000) undertakes a cointegration analysis to conclude that energy is a limiting factor for growth, as a reduction in energy supply tends to reduce output. Yang (2000) considers the causal relationship between different types of energy consumption and GDP in Taiwan for the period 1954–1997. Using different types of energy consumption, he found a bi-directional

[1] See for example, Akarca and Long (1980) and Yu and Hwang (1984).

causality between energy and GDP. This result contradicts with Cheng and Lai (1997) who found that that there is a unidirectional causal relationship from GDP to energy use in Taiwan.

Soytas and Sari (2003) discovered bi-directional causality in Argentina, causality running from GDP to energy consumption in Italy and Korea, and from energy consumption to GDP in Turkey, France, Germany and Japan. Paul and Bhattacharya (2004) found bi-directional causality between energy consumption and economic growth in India. The empirical results by Oh and Lee (2004) for the case of Korea suggested the existence of a long-run bi-directional causal relationship between energy and GDP, and short-run unidirectional causality running from energy to GDP using VECM. Based on a production function approach, Ghali and El-Sakka (2004), develop a VECM model to test the existence and direction of causality between output growth and energy use in Canada. Their empirical findings indicate that the long-run movements of output, labor, capital and energy use in Canada are related by two cointegrating vectors and the short-run dynamics of the variables indicate that Granger-causality is running in both directions between output growth and energy use.

Wolde-Rufael (2005) investigated the long run and causal relationship between real GDP per capita and energy use per capita for 19 African countries for the period 1971–2001. This work provides evidence of a long run relationship between energy consumption and economic growth for only eight of the 19 countries and a causal relationship for only 10 countries. Using cointegration analysis, Wietze and Van Montfort (2007) showed that energy consumption and GDP are cointegrated in Turkey over the period 1970–2003 and found a unidirectional causality running from GDP to energy consumption indicating that energy saving would not have a negative impact on economic growth in Turkey.

On the other hand, the relationship between output growth and pollution level has also been well discussed in the literature of Environmental Kuznets Curve (EKC) where environmental degradation initially increases with the level of per capita income, reaches a turning point, and then declines with further increases in per capita income (Grossman and Krueger, 1991)[2].

Whether continued increase in national income brings more degradation to the environment is critical for the design of development strategies for an economy (Ang, 2007). Hence, a number of studies have attempted to assess the tie and to test for linear, as well as quadratic and cubic relationships between per capita income and $CO_2$ emissions. These studies deal with environmental degradation measure(s) as the dependent variable(s) and income as the independent variable and provide mixed results[3].

On the other hand, there are several studies that realize the problem of omitted variables bias and therefore include different explanatory variables ranging from macroeconomic variables such as prices, population, income distribution and trade balances to education, technology, and human development indicators (Soytas et al. 2007). Including labor and gross fixed capital formation in their model, Soytas et al. (2007) examined the effect of energy consumption and output on carbon emissions in the United States and explored the Granger

[2] Antweiler et al. (2001) and Coxhead (2003) postulate that this non-linear relationship between environmental pollution and income levels can be explained by three factors: scale, composition, and technique effects. The scale effect occurs as pollution increases with the size of the economy. The composition effect refers to the change in the production structure of an economy from agriculture-based to industry and service- based which results in the reallocation of resources. Finally, the pollution–income relationship also depends on techniques of production. An improvement in techniques of production, i.e., the technique effect, may reduce the amount of pollutant emissions per unit of production.

[3] For a review of the Environmental Kuznets Curve research see for example the works of Stagl (1999), Yandle et al. (2002), Dinda (2004) and Stern (2004).

causality relationship between income, energy consumption, and carbon emissions. They found that income does not Granger-cause carbon emissions in the US in the long run, but energy use does. Hence, income growth by itself may not become a solution to environmental problems.

The existing literature reveals that empirical finding studies differ substantially and are not conclusive enough to offer policy recommendations that can be applied across countries. In addition, few studies focus on testing the nexus of output-energy and output-environmental degradation under the same integrated framework.

Ang (2007 and 2008) attempted to investigate dynamic causal relationships between pollutant emissions, energy consumption, and output using cointegration and vector error-correction modeling techniques. Considering annual data for France for the period 1960–2000, Ang (2007) provided empirical evidence of the existence of a fairly robust long-run relationship between these variables. His causality results support the argument that economic growth exerts a causal influence on growth of energy use and growth of pollution in the long run. His results also point to a unidirectional causality running from growth of energy use to output growth in the short-run. In his other empirical work, Ang (2008) examined the relationship between output, pollutant emissions, and energy consumption in Malaysia during the period 1971–1999. His empirical results provide support for a robust long-run equilibrium relationship between the variables, indicating that carbon emissions and energy use are positively related to output in the long-run. The causality results support the argument that economic growth exerts a positive causal influence on energy consumption growth, both in the short-run as well as the long-run. The results also provide some support for a feedback relationship in the long-run. With regards to the output-pollution link, only a weak causality running from $CO_2$ emissions growth to economic growth was found in the long-run.

Following the idea of Ang (2007 and 2008) and given that energy consumption has a direct impact on the level of environmental pollution; the above discussion highlights the importance of linking these two strands of literatures together[4].

The aim of this country specific study is to understand long and short-run linkages between economic growth, energy consumption and carbon emission using Tunisian data. These linkages were largely under considered and unanswered for policy makers in Tunisia and this empirical research attempts to present some findings to better integrate the environment into economic development decisions.

Also, this case study for the Tunisian economy attempts to overcome the shortcomings in literature related with these linkages in developing economies. Tunisia is an interesting case study given that it is one of the highest growth economies in the MENA region and energy supply in this country is insufficient to meet the increasing demand.

This research may be useful to formulate policy recommendations from conservation, emission reduction and economic performance viewpoints. Conclusions for Tunisia may be applied to several countries, which have to go through a similar development path, increasing the pressure of the current energy resources scarcity. In fact, having a better view on the long-run equilibrium relationships and the short-run dynamics between GDP, energy consumption

[4] Without applying the cointegration techniques, Sari and Soytas (2007) explore the inter-temporal link between energy consumption and income in six developing countries, namely, Indonesia, Iran, Malaysia, Pakistan, Singapore, and Tunisia, within a multivariate framework that incorporates labor and capital as in a production function. These authors employ the generalized variance decompositions and generalized impulse response techniques to see if the growth of income and energy consumption contains considerable information to predict each other. In all countries, energy appears as an essential factor of production. Results indicate that energy may be a relatively more important input than labor and/or capital in some countries. Hence, neutrality of energy does not seem to hold.

and $CO_2$ emissions in Tunisia may provide an answer to the question: to which extent can economic development be sustained under various energy supply constraints and pollution scenarios?

The rest of this study is arranged as follows: Section 2 briefly describes the Tunisian energy context. Section 3 describes the datasets used in this study and their stochastic characteristics. Long-run equilibrium relationships are analyzed in Section 4. Section 5 depicts the empirical findings from the short-run dynamics using the generalized impulse response functions. Section 6 completes the investigation of the short-run linkages between economic growth, energy consumption and $CO_2$ emissions with the application of the analysis of causality. Finally, some concluding remarks and some policy implications are outlined in Section 7.

**Tunisian Economic and Energy Situations**

With its annual GDP growth rate exceeding 5% since 1995, Tunisia is among North African countries with the strongest growth potential. The improvement in Tunisian major macroeconomic indicators is the result of a series of economic reforms and prudent macroeconomic management (principally since the adoption and implementation of the structural adjustment program).

The Tunisian economy is now diversified and less vulnerable than in the past to external shocks such as climate hazards. Agriculture accounted for 12 percent of GDP in 2006. The manufacturing sector accounted for more than 60 percent of industrial production, about 20 percent of the working population and 18.2 percent of GDP. The services sector represents about 40 percent of GDP and half of the working population. It has expanded significantly in the past few years and has driven Tunisian growth upwards.

At the sectoral level, growth in the last years was driven by strong domestic and European demand. It was primarily stimulated by services (telecommunications in particular), machinery and electricity industries, and construction and civil engineering.

Over the years, the manufacturing and tourist sectors have gained a few percentage points of GDP to the detriment of the primary sector (agriculture, oil and phosphates).

In Tunisia, demand for energy, notably electricity, has risen sharply during the last years. Household consumption has been the main engine of growth; it represented 63.8 percent of GDP in 2006 (up 8.8 percent from 2005).

The increase of total primary energy consumption for the1990-2005 period was very strong due to the rapid economic growth caused by increased tourism, transportation and industrial activities, as well as the increase in the standard of living of the Tunisian population[5].

Table 1 shows the evolution of annual energy consumption and resources in Tunisia during the period 1990-2005.

Based on 2005 values, the consumption of primary energy exceeded 8.5 Mtoe (million tons oil equivalent) in Tunisia, supplied primarily by crude oil and petroleum products (50 percent) and natural gas which became the second source since the mid 1980s (38 percent) due to the switch of industrial and electricity sectors to it from oil. Biomass, essentially used in rural areas, represented 12 % of primary energy consumption.

Lastly, the contribution of renewable energies (hydropower, wind and solar water heating) of 46 ktoe (kilo tons of oil equivalent) represented only 0.6% of the primary energy balance for 2005.

[5] With population growth slowing down, GDP per capita in 2007 was USD 9401 in purchasing power parity, which placed Tunisia just behind Romania and well ahead of Morocco.

Energy consumption by sector in Tunisia has not changed since 2000. Household is the leading sector (29%), followed by transportation (25%), industry (16%) and agriculture (4%).

Although crude oil is the leading export product in terms of value, national production is still far from satisfying the country's needs. In fact, Tunisia is a hydrocarbon importer and will remain so in the absence of a significant discovery, and has already initiated a program to reduce the oil-deficiency[6]. This objective was expressed by the national energy plan 'Energy 21' based on energy saving and the increased utilization of renewable energy sources[7].

**Data and Stationarity Properties**

In this empirical study, annual data for per capita real gross domestic product (PGDP), per capita of carbon dioxide emissions ($PCO_2$) as proxy for the level of pollution and environmental degradation, and per capita energy (PENE) use in Tunisia is collected from the World Development Indicators (World Bank, 2008). The sample period covers data from 1971 to 2004[8], and series are transformed into logarithms so that they can be interpreted in growth terms after taking first difference.

Figure 1 suggests that the three selected variables tend to move together over time, and a long-run or cointegrating relationship is likely to be present in this case[9]. In addition, Figure 1 reveals that PGDP and $PCO_2$ emissions have a linear relationship so that a quadratic specification is not required.

The first step of this empirical work is to investigate the stationarity properties and establishing the order of integration of series (PGDP, $PCO_2$ and PENE).

When the number of observations is low, unit root tests have limited power (Blough, 1992). For this reason we have examined the results from two different tests: the Augmented Dickey-Fuller (ADF) (Dickey and Fuller, 1979, 1981), which tests the null of unit root, and KPSS (Kwiatkowski et al., 1992), which tests the null of stationarity. The results of both tests for the individual time series and their first differences are shown in Table 2.

The ADF statistics suggests that all variables in levels are non-stationary and are I(1) (integrated of order one), but stationary in the first difference I(0) (integrated of order zero). The KPSS test rejects the null hypothesis of level and trend stationarity for both lag truncation parameters. The KPSS statistics does not reject the I(0) hypothesis for the first-differenced series at conventional levels of statistical significance.

Therefore, the combination of the unit root tests results (see Table 2) suggests that the series involved in the estimation procedure are integrated of order one (i.e., I(1)). This implies the possibility of cointegrating relationships.

---

[6] Since the end of the 1960s, Tunisia has benefited from relatively secure energy balance surplus; but the 1980s saw the advent of the era of energy dependency. In 1994 for the first time, Tunisia recorded a deficit in its energy balance. Following the extension of the gas pipeline between Algeria and Italy and the start-up of operations in the Miskar gas mine in 1996, surplus was restored, but as of 2001, deficits appeared again as a result of increasing demand and stagnating supply.

[7] The 10th Tunisian Development Plan (2002-2006) contains specific provisions on sustainable development and is based on four pillars: (i) the integration of environmental dimension in the process of development, (ii) the protection of natural resources and the fight against desertification, (iii) the fight against pollution and the improvement of living standards, and (iv) the contribution of the environment to development.

[8] Per capita $CO_2$ emissions value for 2004 is from the Carbon Dioxide Information Analysis Center (CDIAC).

[9] The three variables in levels were indexed (basis 100=1986) in order to present the data series in the same scale.

**Long-run Relationships Study: A Cointegration Analysis**

The next step is to investigate whether the series are cointegrated since the three variables were I (1). In this work, cointegration analysis has been conducted using the general technique developed by Johansen (1988) and Johansen and Juselius (1990). They provide a methodology that allows the researcher to distinguish between the short and the long-run[10].

These authors proposed a maximum likelihood estimation procedure which allows researchers to estimate simultaneously the system involving two or more variables to circumvent the problems associated with the traditional regression methods. Further, this procedure is independent of the choice of the endogenous variable and allows researchers to estimate and test for the presence of more than one long-run structural relationship(s) in the multivariate system and how variables in the system adjust to deviations from such long-run equilibrium relationship(s).

The base-line econometric specification for multivariate cointegration is a VAR(p) representation of a k-dimensional time series vector $Y_t$ reparameterized as a VECM:

$$\Delta Y_t = \mu D_t + \Gamma_1 \Delta Y_{t-1} + ... + \Gamma_{p-1} \Delta Y_{t-p+1} - \Pi Y_{t-1} + e_t \qquad (3.1)$$

where, $Y_t$ is a (kx1) column vector of endogenous variables; $D_t$ is a vector of deterministic variables (intercepts, trend...); and $\mu$ is the matrix of parameters associated with $D_t$ ; $\Gamma_i$ are (k×k) matrices of short-run parameters (i=1,...,p-1), where p is the number of lags; $\Pi$ is a (k×k) matrix of long-run parameters and $e_t$ is the vector of disturbances niid(0,Σ).

In the I(1) system $Y_t$ is said to be cointegrated if the following rank conditions are satisfied: $H_r : \Pi = \alpha\beta'$ of rank 0<r<k, where $\alpha$ and $\beta$ are matrices of dimension (k×r). $\beta$ is a matrix representing the cointegrating vectors which are commonly interpreted as meaningful long-run equilibrium relations between the $Y_t$ variables, while $\alpha$ gives the weights of the cointegration relationships in the ECM equations.

The general procedure outlined above has been applied to the system including the three selected variables (PGDP; $PCO_2$ and PENE). However, in empirical applications, the choice of r is frequently sensitive to: i) the deterministic terms included in the system (such as a constant and/or a trend) and on the way in which such components interact with the error - correction term; and ii) the appropriate lag length to ensure that the residuals are Gaussian.

In the present work, the model is estimated including two lags and a constant term restricted to the cointegration space, implying that some equilibrium means are different from zero.

In this work, although the underlying variables are trended, they move together, and it seems unlikely that there will be a trend in cointegrating relation between variables[11].

Multivariate tests for autocorrelation (Godfrey, 1988) and normality (Doornik and Hansen, 1994) have been carried out to check for model statistical adequacy before applying the reduced rank tests. Results indicated that the model could be considered correctly specified[12].

[10] In general, this distinction is useful as economic restrictions are considered to be long-run in nature while it is also interesting, for policy analysis, to know how the system adjusts to disequilibrium.

[11] The lag length has been determined by the Akaike's information criterion. The maximum number of lags is set to be three given the reduced sample size.

[12] The result from multivariate first-order autocorrelation test was 6.792, which was well below the critical value at the 5% level of significance ($\chi^2_9 = 16.919$). Also, the result from multivariate normality test was 7.264, which was well below the critical value at the 5% level of significance ($\chi^2_6 = 12.591$).

Table 3 shows the results of Johansen's likelihood ratio tests for cointegration rank. As can be observed, for the 5 and 10% levels of significance, respectively, the trace statistics do not reject the null hypothesis that there are two cointegrating relations between the variables (r=2).

In all the following analyses we assume the presence of two cointegrating or stationary relations and one common stochastic trend in the system. The presence of two cointegrating vectors in our system suggests an inherent movement in the system to revert towards long-run equilibrium path of the Tunisian economy subsequent to a short-run shock.

The estimated $\beta$ and $\alpha$ parameters are presented in Table 4 (Panel A), where $\beta$ is presented in a normalized form. The two cointegrating vectors have been normalized by PGDP and $PCO_2$ respectively. As can be observed, all parameters of the long-run equilibrium relationships are statistically significant and have the expected signs.

The first cointegration vector reveals a positive linkage between PGDP and PENE. Interpreted as a long-run relation, a 1% rise in energy consumption will raise economic growth by 1.124%, in Tunisia. The second vector indicates that $CO_2$ emission and energy consumption are positively related and a 1% increase in PENE will originate an increase in $PCO_2$ by 1.352% in the long-run. These results may provide some evidence of "inefficient use" of energy in Tunisia since environmental pressure tends to rise faster than economic growth in the long-run.

On the other hand, in this type of analysis, it is also convenient to consider the estimated $\alpha_{i,j}$ (i indicates the row and j the column) parameters as they provide valuable information about the speed of adjustment of each variable towards the long-run equilibrium.

Moreover, in this empirical study, we have applied a sequential elimination strategy test to delete those regressors in the VECM (all the loading coefficients and $\Gamma_i$ parameters) with the smallest absolute values of t-ratios until all t-ratios (in absolute value) are greater than some specified threshold value (Brüggemann and Lütkepohl, 2001). The value of the statistic was 10.8742 under the critical value ($\chi^2_7 = 14.067$) at the 5% level of significance and this result indicates that it was not possible to reject the null hypothesis ($H_0$: restricted model). Table 4 (Panel B) shows the new loading coefficients for the reduced model.

In relation to the first cointegrating vector, the first comment is that parameters related with economic growth ($\alpha_{11}$) and with $PCO_2$ emission ($\alpha_{21}$) are not significant and that any shock in the long-run relationship between GDP and ENE generates only a significant adjustment of energy consumption. On the other hand, the $\alpha$ parameters corresponding to the second cointegrating relationship between PENE and $PCO_2$ indicate that energy use reacts quicker than economic growth and $CO_2$ emission ($\alpha_{32}>\alpha_{12}>\alpha_{22}$). This may indicate that energy policy in Tunisia seems to be more oriented towards supporting economic growth than towards encouraging the reduction of $CO_2$ emission.

However, simply considering the magnitude of the adjustments to long-run relationships is not enough. It is also important to look at the time path of the reactions. The impulse response functions provide relevant evidence. They are analyzed in the next section.

**Generalized Impulse Response Functions**

Once the VECM has been estimated, short-run dynamics can be examined by considering the impulse response functions (IRF). These functions show the response of each variable in the system to a shock in any of the other variables. The IRF are calculated from the Moving Average Representation of the VECM (Lütkepohl, 1993 and Pesaran and Shin, 1998):

$$Y_t = \sum_{i=0}^{\infty} B_i \varepsilon_t \qquad (5.1)$$

where matrices $B_i$ (i=2,…,n) are recursively calculated using the following expression: $B_n = \Phi_1 B_{n-1} + \Phi_2 B_{n-2} + ... + \Phi_k B_{n-p}$; $B_0=I_p$; $B_n=0$ for n<0; $\Phi_1 = I + \Pi + \Gamma_1$; and $\Phi_i = \Gamma_i - \Gamma_{i-1}$ (i=2,…,p).

Following Pesaran and Shin (1998) the scaled generalized impulse response functions (GIRF) of variable $Y_i$ with respect to a standard error shock in the $j^{th}$ equation can be defined as:

$$\text{GIRF}\ (Y_{it}, Y_{jt}, h) = \frac{e_i' B_h \Sigma e_j}{\sqrt{\sigma_{jj}}};\ h = 0, \dots, n \qquad (5.2)$$

Where $e_{ls}$(s=i, j) is the $s^{th}$ column of the identity matrix.

The GIRF are unique and do not require the prior orthogonalization of the shocks (the reordering of the variables in the system). On the other hand, the GIRF and the orthogonalized IRF (Cholesky) coincide if the covariance matrix, Σ, is diagonal and j=1. Standard deviations of impulse responses are obtained following Pesaran and Shin (1998).

Following Gil et al. (2007), to analyze the short-run dynamics, we have considered the restrictions on the long-run parameters shown in Table 3 and we have restricted the loading coefficients (2 restrictions) and $\Gamma_i$ parameters (5 restrictions) which were non-significant to zero. Generalized impulse response functions are plotted out in Figure 2.

The results indicate that the initial impact of an output growth is positive and significant for PGDP and PENE, but insignificant for $PCO_2$.

In addition, the responses of PENE appear to be slightly larger than those of $PCO_2$ and the significant output growth appears to have some permanent pressure on energy use and $CO_2$ emissions providing some support that economic growth in Tunisia takes precedence over energy consumption in the short-run. These results are in line with the argument that economic growth exerts a positive causal influence on energy consumption growth[13].

Note also that the response of carbon emissions is only significant five horizons after the initial shock, indicating that higher growth in Tunisia may lead to pollution as a consequence of emissions occurring during the production process.

On the other hand, the initial impact of a positive shock in $PCO_2$ is positive and significant for PENE and $PCO_2$, but insignificant for PGDP. Moreover, the response of output is only positive and significant two years after the initial shock in $CO_2$ emission.

Finally, the results show that the initial impact of a positive shock in energy consumption (PENE) is positive but statistically insignificant for PGDP, PENE and $PCO_2$.

**Granger-Causality Study**

The main purpose of this section is to complete the investigation of the short-run linkage between economic growth, energy consumption and $CO_2$ emissions with the application of causality analysis. Since cointegration is a sufficient but not a necessary condition for Granger-causality, we next investigate the direction of causality by estimating a VECM derived from the long-run cointegrating relationship (Engle and Granger, 1987 and Granger,

[13] In part, this result is in line with Sari and Soytas (2007) who find that a shock to real income growth affects energy consumption growth in the case of Tunisian data. But these authors find that income responds negatively in Tunisia in the second year and the responses of income to the shocks die out approximately by the end of the fifth horizons.

1988). The VECM contains the cointegration relation built into the specification so that it restricts the long-run behavior of the endogenous variables to converge to their cointegrating relationships while allowing for short-run adjustment dynamics.

In this empirical work, the VECM can be written as follow:

$$\begin{aligned}\Delta PGDP_t &= \mu_1 + \alpha_{11} ECT_{1,t-1} + \alpha_{12} ECT_{2,t-1} \\ &+ \sum_{i=1}^{k} \delta_{1i} \Delta PGDP_{t-i} + \sum_{i=1}^{k} \gamma_{1i} \Delta PCO2_{t-i} + \sum_{i=1}^{k} \varphi_{1i} \Delta PENE_{t-i} + \varepsilon_{1t}\end{aligned} \tag{6.1}$$

$$\begin{aligned}\Delta PCO2_t &= \mu_2 + \alpha_{21} ECT_{1,t-1} + \alpha_{22} ECT_{2,t-1} \\ &+ \sum_{i=1}^{k} \delta_{2i} \Delta PGDP_{t-i} + \sum_{i=1}^{k} \gamma_{2i} \Delta PCO2_{t-i} + \sum_{i=1}^{k} \varphi_{2i} \Delta PENE_{t-i} + \varepsilon_{2t}\end{aligned} \tag{6.2}$$

$$\begin{aligned}\Delta PENE_t &= \mu_3 + \alpha_{31} ECT_{1,t-1} + \alpha_{32} ECT_{2,t-1} \\ &+ \sum_{i=1}^{k} \delta_{3i} \Delta PGDP_{t-i} + \sum_{i=1}^{k} \gamma_{3i} \Delta PCO2_{t-i} + \sum_{i=1}^{k} \varphi_{3i} \Delta PENE_{t-i} + \varepsilon_{3t}\end{aligned} \tag{6.3}$$

In addition to the variables defined above, $ECT_{1,t-1}$ and $ECT_{2,t-1}$ are the lagged error-correction terms derived from the long-run cointegrating vectors (see Table 4) and $\varepsilon_{1t}$, $\varepsilon_{2t}$ and $\varepsilon_{3t}$ are serially independent random errors with mean zero and finite covariance matrix.

There are two sources of causation, i.e., through the ECT, if $\alpha \neq 0$, or through the lagged dynamic terms.

The error-correction terms, $ECT_{1,t-1}$ and $ECT_{2,t-1}$ both measure the long-run equilibrium relationships while the coefficients on lagged difference terms indicate the short-run dynamics.

The statistical significance of the coefficients associated with ECT provides evidence of an error-correction mechanism that drives the variables back to their long-run relationship.

Given the two separate sources of causation, three different causality tests can be performed, as mentioned in the econometric literature, i.e., short-run Granger non-causality, long-run weak exogeneity and overall strong exogeneity tests.

For example, in equation (6.1) to test that $\Delta PCO2$ does not cause $\Delta PGDP$ in the short-run, we examine the statistical significance of the lagged dynamic terms by testing the null $H_0 : \text{all } \delta_{1i} = 0$ using the Wald test. Non rejection of the null implies that $\Delta PCO2$ does not Granger-cause $\Delta PGDP$ in the short-run. Rejection of the null implies that pollution growth Granger causes output growth in the short-run.

The long-run weak exogeneity test, which is a notion of long-run non-causality test, requires satisfying the null $H_0 : \alpha_{11} = \alpha_{12} = 0$ for non-causality from long-run equilibrium deviation to $\Delta PGDP$. It is based on a likelihood ratio test which follows a $\chi^2$ distribution.

Finally, overall strong exogeneity which imposes stronger restrictions by testing the joint significance of both the lagged dynamic terms and error-correction terms can be performed (Charemza and Deadman, 1992). The overall strong exogeneity test does not distinguish between the short and the long-run causality, but it is a more restrictive test which indicates the overall causality in the system. This requires satisfying both short-run Granger non-causality and long-run weak exogeneity. In equation (6.1), $\Delta PCO_2$ does not cause $\Delta PGDP$ to require satisfying the null $H_0 : \text{all } \delta_{1i} = \alpha_{11} = \alpha_{12} = 0$ .

Statistical results presented in Table 6 provide support for causality running from $CO_2$ emissions growth (degradation of the environment) to output growth, both in the short-run and the long-run. The results also provide some support of mutual causal and feedback relationship in the long-run[14]. This pattern of development is consistent with the experiences of many developing countries.

When examining the linkage between output and energy, the results show strong evidence of output growth causing energy use and do not support the view that energy and output are neutral with respect to each other in Tunisia[15]. This result is consistent with the argument that economic growth exerts a positive causal influence on energy consumption growth.

Support for reverse causality is also found in the long-run[16]. Indeed, the finding of a bi-directional causality between output growth and growth in energy consumption in the long-run implies that Tunisia is an energy dependent economy. The Tunisian economy may be vulnerable to energy shocks in which an energy shortage may adversely affect output growth.

**Summary and Some Policy Implications**

The aim of this country specific study is to understand long and short-run linkages between economic growth, energy consumption and carbon emission using Tunisian data over the period 1971-2004. These linkages were largely under-considered and unanswered for policy makers in Tunisia and this empirical research attempts to present some findings to better integrate the environment into economic development decisions.

Results of the cointegration study detect the presence of two cointegrating vectors. The first vector reveals a positive linkage between output and energy use and the second indicates that $CO_2$ emission and energy consumption are positively related in the long-run. In addition, results of the long-run relationships provide some evidence of "inefficient use" of energy in Tunisia, since environmental degradation tends to rise more rapidly than economic growth.

In the short-run, empirical results provide support for causality running from $CO_2$ emissions growth to output growth (both in the short-run and the long-run). The results also provide some support of mutual causal and feedback relationship in the long-run. This pattern of development is consistent with the experiences of many developing countries.

The results have important implications for policy makers in Tunisia who should be mindful that a persistent decline in environmental quality may exert negative externalities to the economy through depressing the tourism sector and also through affecting human health and thereby reduce productivity and growth in the future.

Since statistical results confirm that an increase in pollution level induces economic expansion and in order not to adversely affect economic growth, more efforts must be made to encourage the Tunisian industry to adopt technology that minimizes pollution, as a serious environmental policy, although Tunisia has no commitment to reduce Greenhouse Gas (GHG) emissions.

---

[14] This result differ from Ang (2008) who found long-run causality running from the $CO_2$ emissions growth to the economic growth, but was not able to identify a feedback relationship.

[15] This result is consistent with the findings of Oh and Lee (2004) for Korean data and Ang (2008) for Malaysian data.

[16] This finding is in line with Masih and Masih (1996), Glasure and Lee (1997), Yang (2000), Wolde-Rufael (2005) and Ang (2008).

In Tunisia, there is potential to develop renewable energies (since renewable energies represent less than 1% of the primary energy use in Tunisia) but further efforts would require additional financing by policy makers.

In addition, the combined results of causality analysis and impulse response functions do not support the view that energy and output are neutral with respect to each other in Tunisia and the finding of a bi-directional causality between output growth and growth in energy consumption in the long-run implies that Tunisia is an energy dependent economy. The Tunisian economy may be vulnerable to energy shocks in which an energy shortage may adversely affect output growth. For this reason, it seems possible that energy conservation policies could be achieved through the rationalization of consumer and household demand and the reduction of the transportation sector consumption.

To conclude, it has to be said that the results presented in this empirical paper depend on the variables and the sample period chosen. Further analysis, including other variables (investment, trade, etc…) and an extended sample period, could be conducted in the future.

## References

Akarca, A.T., Long, T.V. 1980. On the Relationship between Energy and GNP: A Reexamination. *Journal of Energy Development,* 5, 326–331.

Ang, J.B. 2007. $CO_2$ Emissions, Energy Consumption, and Output in France. *Energy Policy,* 35, 4772–4778.

Ang, J.B. 2008. Economic Development, Pollutant Emissions and Energy Consumption in Malaysia. *Journal of Policy Modeling,* 30, 271–278.

Antweiler, W., Copeland, B.R., Taylor, M.S. 2001. Is Free Trade Good for the Environment? *American Economic Review,* 91, 877-908.

Asafu-Adjaye, J. 2000. The Relationship between Energy Consumption, Energy Prices and Economic Growth: Time Series Evidence from Asian Developing Countries. *Energy Economics,* 22, 615–625.

Blough, S.R. 1992. The Relationship between Power and Level for Generic Unit Root Tests in Finite Samples. *Journal of Applied Econometrics,* 7, 295-308.

Brüggemann, R., Lütkepohl, H. 2001. Lag Selection in Subset VAR Models with an Application to a U.S. Monetary System, in: Friedmann, R., Knüppel, L., Lütkepohl, H. (Eds.), Econometric Studies: A Festschrift in Honour of Joachim Frohn, LIT Verlag, Münster, pp. 107-128.

Charemza, W.W., Deadman, D. F. 1992. New Directions in Econometric Practice: General to Specific Modelling, Cointegration and Vector Autoregression. Aldershot, UK: Edward Elgar.

Cheng, B.S., Lai, T.W. 1997. An Investigation of Cointegration and Causality between Energy Consumption and Economic Activity in Taiwan. *Energy Economics,* 19, 435–444.

Coxhead, I. 2003. Development and the Environment in Asia. *Asian–Pacific Economic Literature,* 17, 22–54.

Dickey, D.A., Fuller, W.A. 1979. Distribution of the Estimators for Autoregressive Time Series with a Unit Root. *Journal of the American Statistical Association,* 74, 427–431.

Dickey, D.A., Fuller, W.A. 1981. The Likelihood Ratio Statistics for Autoregressive Time Series with a Unit Root. *Econometrica,* 49, 1057-1072.

Dinda, S. 2004. Environmental Kuznets Curve Hypothesis: A Survey. *Ecological Economics,* 49, 431–455.

Doornik, J., Hansen, H. 1994. A Practical Test for Univariate and Multivariate Normality. Discussion paper, Nuffield College, Oxford.

Ebohon, O.J. 1996. Energy, Economic Growth and Causality in Developing Countries: A Case Study of Tanzania and Nigeria. *Energy Policy,* 24, 447-453.

EIA. Energy Information Administration. http://eiadoegov/

Engle, R.F., Granger, C.W.J. 1987. Co-integration and Error Correction: Representation, Estimation and Testing. *Econometrica,* 55, 251–276.

Erol, U., Yu, E.S.H., 1987. On the Causal Relationship between Energy and Income for Industrialized Countries. *Journal of Energy and Development,* 13, 113–122.

Ghali, K.H., El-Sakka, M.I.T. 2004. Energy Use and Output Growth in Canada: A Multivariate Cointegration Analysis. *Energy Economics,* 26, 225–238.

Gil, J.M., BenKaabia, M., Chebbi, H.E., Forthcoming. Macroeconomics and Agriculture in Tunisia. *Applied Economics,* doi: 10.1080/00036840701604420

Glasure, Y.U., Lee, A.R. 1997. Cointegration, Error-correction, and the Relationship between GDP and Energy: The Case of South Korea and Singapore. *Resource and Energy Economics,* 20, 17–25.

Godfrey, L. G. 1988. Misspecification Test in Econometrics. Cambridge University Press.

Granger, C.W.J. 1969. Investigating Causal Relation by Econometric and Cross-sectional Method. *Econometrica,* 37, 424–438.

Granger, C.W.J. 1988. Developments in a Concept of Causality. *Journal of Econometrics,* 39, 199-211.

Grossman, G.M., Krueger, A.B. 1991. Environmental Impact of a North American Free Trade Agreement. Working Paper 3914, National Bureau of Economic Research, Cambridge, MA.

Johansen, S. 1988. Statistical Analysis of Cointegrating Vectors. *Journal of Economic Dynamics and Control,* 12, 231–254.

Johansen, S., Juselius, K. 1990. Maximum Likelihood Estimation and Inference on Cointegration with Application to the Demand for Money. *Oxford Bulletin of Economics and Statistics,* 52, 169–210.

Kraft, J., Kraft, A. 1978. On the Relationship between Energy and GNP. *Journal of Energy Development*, 3, 401–403.

Kwiatkowski, D., Phillips, P., Schmidt, P., Shin, Y. 1992. Testing the Null Hypothesis of Stationarity against the Alternative of Unit Root. *Journal of Econometrics,* 54, 159-178.

Lütkepohl, H. 1993. Introduction to Multiple Time Series. Spring Verlag, Berlin.

Masih, A.M.M., Masih, R. 1996. Energy Consumption, Real Income and Temporal Causality: Results from a Multi-country Study Based on Cointegration and Error-correction Modelling Techniques. *Energy Economics,* 18, 165–183.

Oh, W., Lee, K. 2004. Energy Consumption and Economic Growth in Korea: Testing the Causality Relation. *Journal of Policy Modeling,* 26, 973–981.

Paul, S., Bhattacharya, R.N. 2004. Causality between Energy Consumption and Economic Growth in India: A Note on Conflicting Results. *Energy Economics,* 26, 977–983.

Pesaran, M.H., Shin, Y. 1998. Generalised Impulse Response Analysis in Linear Multivariate Models. *Economics Letters,* 58, 17-29.

Sari, R., Soytas, U. 2007. The Growth of Income and Energy Consumption in Six Developing Countries. *Energy Policy,* 35, 889–898.

Sims, C.A. 1972. Money, Income, and Causality. *American Economic Review,* 62, 540–552.

Soytas, U., Sari, R. 2003. Energy Consumption and GDP: Causality Relationship in G-7 Countries and Emerging Markets. *Energy Economics,* 25, 33–37.

Soytas, U, Sari, R., Ewing, B.T. 2007. Energy Consumption, Income, and Carbon Emissions in the United States. *Ecological Economics,* 62, 482-489.

Stagl, S. 1999. Delinking Economic Growth from Environmental Degradation? A Literature Survey on the Environmental Kuznets Curve Hypothesis. Wirtschafts Universitat Wien Working Paper, 6. http://ssrn.com/abstract=223869.

Stern, D.I., 2004. The Rise and Fall of the Environmental Kuznets Curve. *World Development,* 32, 1419–1439.

Stern, D.I., 2000. A Multivariate Cointegration Analysis of the Role of Energy in the US Macroeconomy. *Energy Economics,* 22, 267–283.

WDI. World Development Indicators World Bank. http://publicationsworldbankorg/WDI/

Wietze, L., Van Montfort, K. 2007. Energy Consumption and GDP in Turkey: Is There a Co-integration Relationship? *Energy Economics,* 29, 1166-1178.

Wolde-Rufael, Y. 2005. Energy Demand and Economic Growth: The African Experience. *Journal of Policy Modeling,* 27, 891–903.

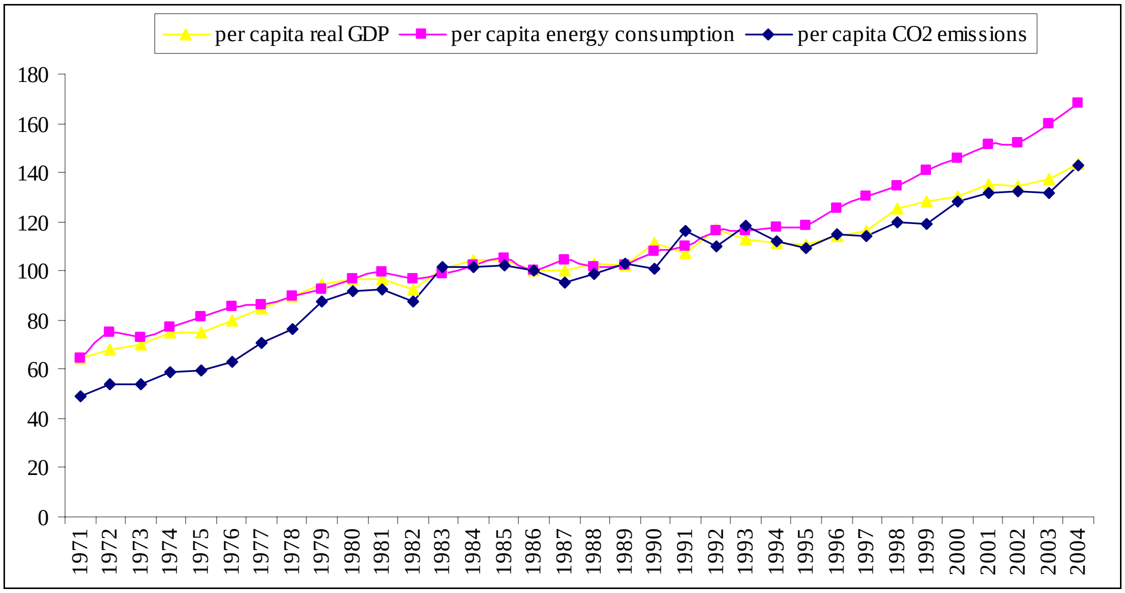
Yandle, B., Vijayaraghavan, M., Bhattarai, M. 2002. The Environmental Kuznets Curve: A Prime. PERC Research Study 02-1.

Yang, H.Y., 2000. A Note on the Causal Relationship between Energy and GDP in Taiwan. *Energy Economics,* 22, 309–317.

Yu, E.S.H, Choi, J.Y. 1985. The Causal Relationship between Energy and GNP: An International Comparison. *Journal of Energy and Development,* 10, 249–272.

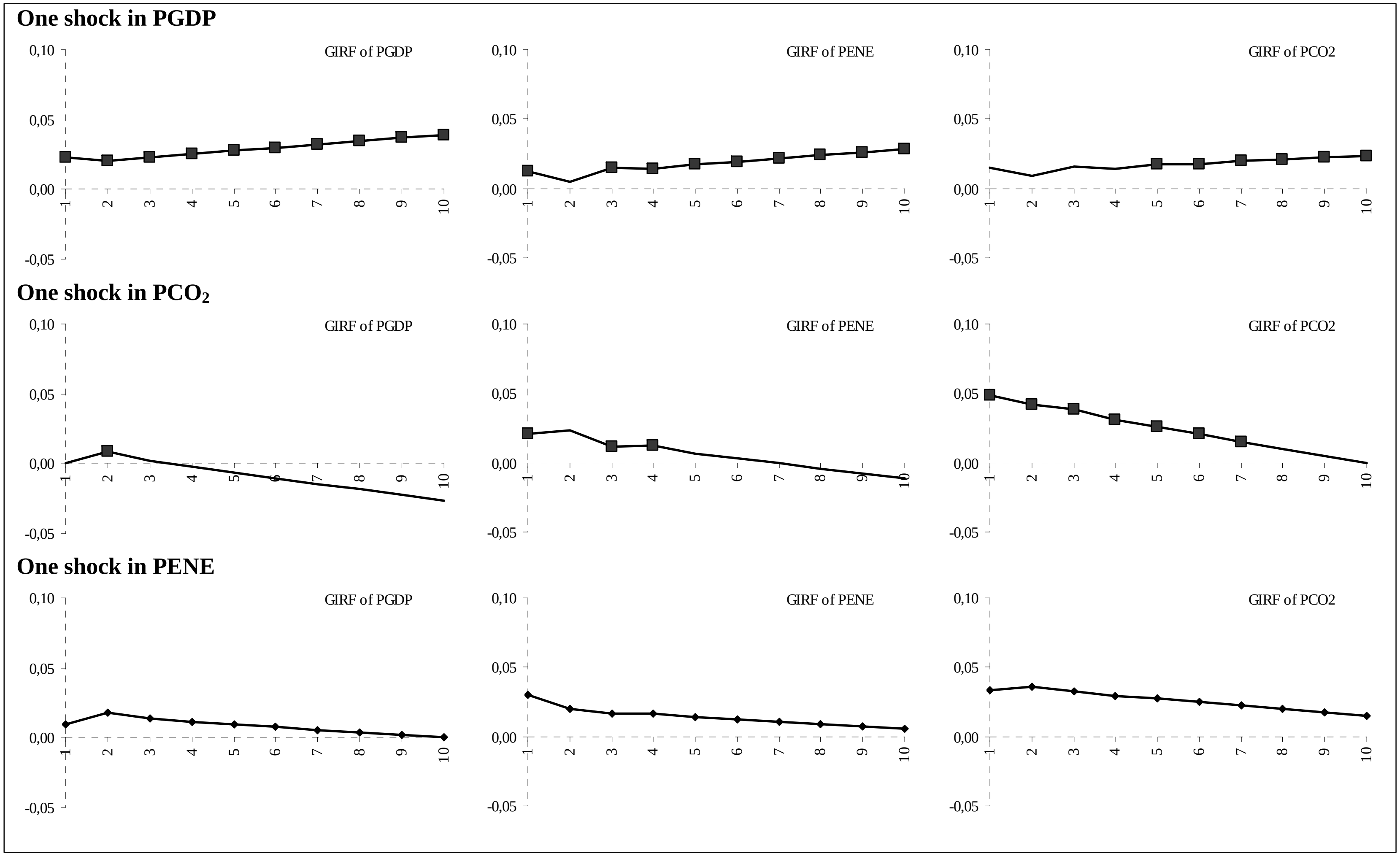
Yu, E.S.H, Hwang, B.K., 1984. The Relationship between Energy and GNP, further results. *Energy Economics,* 6, 186–190.

**Figure 1: Trends of the Indexed Series (basis 100=1986)**




Source: World Development Indicators (World Bank, 2008)

**Figure 2: Responses of Variables**




Note: Responses marked with a square indicate 5% level of significance

**Table 1: Energy Resources and Consumption in Tunisia**

| | 1990 | 1995 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 |
|---|---|---|---|---|---|---|---|---|
| | **Petroleum (Thousand Barrels per Day)** | | | | | | | |
| **Total Oil Production** | 97.7 | 90.1 | 80.5 | 72.6 | 78.5 | 77.4 | 81.7 | 76.9 |
| **Crude Oil Production** | 93.0 | 89.2 | 78.7 | 69.6 | 75.8 | 75.0 | 79.8 | 75.0 |
| **Consumption** | 63.2 | 70.0 | 84.5 | 87.2 | 87.9 | 87.7 | 89.4 | 90.0 |
| **Net Exports/Imports** | 34.5 | 20.0 | - 4.0 | - 14.6 | - 9.3 | - 10.3 | - 7.7 | - 13.1 |
| | **Natural Gas (Billion Cubic Feet)** | | | | | | | |
| **Production** | 12.0 | 11.7 | 66.4 | 79.5 | 75.9 | 80.9 | 84.8 | 88.3 |
| **Consumption** | 54.0 | 57.6 | 108.8 | 135.3 | 135.6 | 130.3 | 130.7 | 151.9 |
| **Net Exports/Imports** | - 42.0 | - 45.9 | - 42.4 | - 55.8 | - 59.7 | - 49.4 | - 45.9 | - 63.6 |
| | **Electricity (Billion Kilowatt-hours)** | | | | | | | |
| **Net Generation** | 5.2 | 6.9 | 10.0 | 10.7 | 11.1 | 11.7 | 12.3 | 12.8 |
| **Net Consumption** | 4.6 | 6.2 | 8.8 | 9.5 | 9.8 | 10.3 | 10.7 | 11.2 |
| | **Total Primary Energy (Quadrillion Btu)** | | | | | | | |
| **Production** | 0.2 | 0.2 | 0.2 | 0.2 | 0.3 | 0.3 | 0.3 | 0.3 |
| **Consumption** | 0.2 | 0.2 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.4 |

Source: Energy Information Administration (EIA, 2007)

**Table 2: Results of the ADF and KPSS Tests**

| | | | |
|---|---|---|---|
| | **Panel A: ADF Test (the null hypothesis is non-stationarity)** | | |
| **Variables** | **Level form** | | **First difference** |
| | **Intercept and time trend** | **Intercept, no time trend** | **Intercept, no time trend** |
| **PGDP** | -2.8166 | -0.9818 | -8.7645 |
| **$PCO_2$** | -2.3636 | -2.2248 | -7.2017 |
| **PENE** | -2.8067 | -1.7022 | -6.7333 |
| | **Critical Values** | | |
| | **Intercept and Time Trend** | | **Intercept, no time trend** |
| **1%** | -3.96 | | -3.43 |
| **5%** | -3.41 | | -2.86 |
| **10%** | -3.13 | | -2.57 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **Panel B: KPSS Test (the null hypothesis is stationarity)** | | | | | | | |
| | **Level form** | | | | **First difference** | | | |
| | l= 1 | | l = 3 | | l = 1 | | l = 3 | |
| | $\eta_\mu$ | $\eta_\tau$ | $\eta_\mu$ | $\eta_\tau$ | $\eta_\mu$ | $\eta_\tau$ | $\eta_\mu$ | $\eta_\tau$ |
| **PGDP** | 1.6399 | 0.2370 | 0.9337 | 0.1286 | 0.2145 | 0.2043 | 0.2091 | 0.1990 |
| **$PCO_2$** | 1.5039 | 0.2985 | 0.8627 | 0.1933 | 0.3604 | 0.1102 | 0.3160 | 0.1113 |
| **PENE** | 1.5927 | 0.2030 | 0.9087 | 0.1498 | 0.2341 | 0.1228 | 0.2316 | 0.1302 |
| | **Critical Values** | | | | | | | |
| | **Level Stationarity** | | | | **Trend Stationarity** | | | |
| **1%** | 0.739 | | | | 0.216 | | | |
| **5%** | 0.463 | | | | 0.146 | | | |
| **10%** | 0.347 | | | | 0.119 | | | |

Note: The lag length for the ADF tests — to ensure that the residuals are white noise — has been chosen based on the Akaike Info Criterion. The KPSS statistics test for lag-truncation parameters one and three (l=1 and l=3) since it is unknown how many lagged residuals has been used to construct a consistent estimator of the residual variance.

**Table 3: Results of Cointegration Tests**

| $H_0 : r$ | $H_1 : p - r$ | **LR-Trace** | **Critical Values** (90%) | **Critical Values** (95%) | **Critical Values** (99%) |
|---|---|---|---|---|---|
| 0 | 3 | 52.24*** | 32.25 | 35.07 | 40.78 |
| 1 | 2 | 25.02*** | 17.98 | 20.16 | 24.69 |
| 2 | 1 | 6.62 | 7.60 | 9.14 | 12.53 |

Note: (*), (**) and (***) indicate 10%, 5% and 1% level of significance, respectively.

**Table 4: Normalized Cointegration Relations β and Loading Coefficients (α)**

**Panel A**

$$\beta' = \begin{bmatrix} 1.000 & --- & \underset{(-16.413)^{***}}{-1.124} & 0.148 \\ --- & 1.000 & \underset{(-18.872)^{***}}{-1.352} & 8.154 \end{bmatrix} \times \begin{bmatrix} PGDP \\ PCO_2 \\ PENE \\ Constante \end{bmatrix} \qquad \alpha = \begin{bmatrix} \underset{(0.852)}{0.120} & \underset{(-1.337)}{-0.168} \\ \underset{(-0.603)}{-0.159} & \underset{(-2.017)^{***}}{-0.474} \\ \underset{(2.949)^{**}}{0.530} & \underset{(1.135)}{0.182} \end{bmatrix}$$

**Panel B**

LR-test (H1: unrestricted model): $\chi^2_7 = 10.8742$
p-value = 0.1442

$$\alpha = \begin{bmatrix} --- & \underset{(-5.295)^{***}}{-0.238} \\ --- & \underset{(-5.003)^{***}}{-0.331} \\ \underset{(7.790)^{***}}{0.532} & \underset{(3.018)^{***}}{0.203} \end{bmatrix}$$

Note: (*), (**) and (***) indicate 10%, 5% and 1% level of significance, respectively; and figures in the parentheses indicate t-ratio.

**Table 5: Results of Non-causality Tests**

| **Hypothesis of Non-causality** | **Short-run Granger Non-causality** | **Long-run Weak Exogeneity** | **Overall Strong Exogeneity** |
|---|---|---|---|
| $H_0 : PGDP \nrightarrow PENE$ | 4.8138** | 19.1665*** | 19.8034*** |
| $H_0 : PENE \nrightarrow PGDP$ | 0.0043 | 22.1858*** | 22.8668*** |
| $H_0 : PGDP \nrightarrow PCO_2$ | 1.1909 | 12.3698*** | 12.3707*** |
| $H_0 : PCO_2 \nrightarrow PGDP$ | 6.1183** | 22.1858*** | 26.9372*** |

Note: (*), (**) and (***) indicate the rejection of the null hypothesis at 10%, 5% and 1% level of significance, respectively.