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Energy consumption and GDP in Tunisia: Cointegration and causality analysis

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ABSTRACT

In this paper, the Johansen cointegration technique is used to examine the causal relationship between per capita energy consumption (PCEC) and per capita gross domestic product (PCGDP) for Tunisia during the 1971–2004 period. In order to test for Granger causality in the presence of cointegration among the variables, a vector error correction model (VECM) is used instead of a vector autoregressive (VAR) model. Our estimation results indicate that the PCGDP and PCEC for Tunisia are related by one cointegrating vector and that there is a long-run bi-directional causal relationship between the two series and a short-run unidirectional causality from energy to gross domestic product (GDP). The source of causation in the long-run is found to be the error-correction terms in both directions. Hence, an important policy implication resulting from this analysis is that energy can be considered as a limiting factor to GDP growth in Tunisia. Conclusions for Tunisia may also be relevant for a number of countries that have to go through a similar development path of increasing pressure on already scarce energy resources.

1. Introduction

The topic of the causal relationship between energy consumption and income has been the subject of intense research over the past three decades using the concept of Granger causality. As the time series analysis has recently developed, various studies have focused on several countries and time periods and have used different proxy variables for energy consumption (EC) and income. The empirical findings of these studies are mixed and have not reached a consensus (Soytas and Sari, 2003). The results differ even on the direction of causality and the long-term versus short-term impact on energy policy. Depending upon what kind of causal relationship exists, the policy implications of these relationships can be significant.

The results from earlier studies can be summarized into mainly three main categories: (1) no causality, (2) unidirectional causality and (3) bi-directional causality between energy consumption and income. Unidirectional causality results can be further divided into two categories: (a) energy consumption causes income and (b) income causes energy consumption.

The ongoing debate among energy economists about the relationship between energy consumption and income has led to the emergence of two opposing views. One point of view suggests that energy is the prime source of value because other factors of production such as labor and capital cannot do without energy. Accordingly, energy consumption is expected to be a limiting factor to economic growth or its proxies such as employment. The other point of view suggests that energy is neutral to growth. This is known in the literature as the "neutrality hypothesis". The main reason for the neutral impact of energy on income or growth is that the cost of energy is very small as a proportion of gross domestic product (GDP), and, thus, it is not likely to have a significant impact on GDP growth. It has also been argued that the possible impact of energy consumption on growth will depend on the structure of the economy and the level of economic growth of the country concerned. As the economy grows, its production structure is likely to shift towards services, which are not energy intensive activities (Solow (1978), Denison (1985) and Cheng (1995)).

The findings from the studies vary not only across countries, but depend also on methodologies within the same country (see for example Soytas and Sari, 2003). While a country-specific causality study between energy consumption and economic growth can provide insight for the design of future energy policies, it is also important to reach unambiguous results for policy implementation. Multiple causality studies have been done for many countries in the world; however, none have focused on the causal relationship between energy consumption and GDP for Tunisia. This study attempts to examine this causal relationship. The mismatch between energy supply and GDP in Tunisia raises some important questions: does long-term equilibrium exist between energy consumption and GDP in Tunisia? How do they influence each other in the short term? Answers to these questions are necessary to define and implement the appropriate energy development policies in Tunisia.

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The remainder of this paper is organized as follows: Section 2 reviews the literature on the subject. Section 3 gives an overview of the energy sector in Tunisia. A discussion on the methodology of the study is presented in Section 4. Section 5 describes the data used and reports on our empirical results. We shall provide the policy implications of the empirical results and give conclusions in Section 6.

2. Review of literature

A brief review of the literature to date indicates that the paper by Kraft and Kraft (1978) is pioneering in the study of the causal relationship between energy consumption and income. This paper provided evidence to support unidirectional causality running from income to energy consumption for the USA over the 1947–74 period. This implied that energy conservation policies may be initiated without deteriorating economic side effects. This finding was contested by Akarca and Long (1980), who showed that Kraft and Kraft's study suffered from temporal sample instability. Since that study several authors have joined the debate, some who have opposed and empirically challenged Kraft and Kraft's initial findings and others who have supported their views.

The empirical literature on the USA shows that a testing procedure developed by Sims (1972) was adopted by Yu and Hwang (1984), who used annual data to confirm the absence of any causality between energy consumption and income over the sample period of 1947–79. However, using quarterly data with the same procedure revealed a unidirectional causation running from GNP to energy consumption over the 1973–81 period. The absence of any causality for the USA was also suggested by Yu and Choi (1985) and Erol and Yu (1987), both as part of broader studies covering several industrial countries. In an extension of this stream of literature, Abosedra and Baghestani (1989) found themselves in favor of unidirectional causation from GNP to energy and, thus, gave support to Kraft and Kraft (1978), but opposed Akarca and Long (1980), Yu and Hwang (1984), Yu and Choi (1985) and Erol and Yu (1987).

One of the major reasons for these apparently conflicting statistical findings, apart from many institutional, structural and policy differences, lies in methodological differences—the variables used as proxies for energy consumption and income, the type of causality techniques, tests and lag structures employed. Most studies thus far used bivariate causality testing approaches from Granger and Sims,[1] whose methodological limitations have already been cited (Masih and Masih, 1996).

Since these works were published, empirical studies have been extended to cover other industrial countries such as the United Kingdom, Germany, Italy, Canada, France and Japan. Yu and Choi (1985) studied the causal linkages between GNP and various types of energy consumption for a number of countries. They did not find any causal linkages for the USA, UK and Poland, but they found a causal relationship from income to total energy consumption for South Korea and from total energy consumption to income for the Philippines. Erol and Yu (1987) found some indications of a causal relationship between energy and output in a number of industrialized countries, the most significant being for Japan between 1950 and 1982. However, when the sample was restricted to the 1950–1973 period, the relationship was no longer significant.

Yu and Jin (1992) were the first to test whether energy and output cointegrated for monthly USA data. They concluded that energy consumption had no long-term relationship with income and employment. Stern (1993) initiated the debate among economists and energy analysts regarding the role of energy in the USA macroeconomy. In examining the causal relationship between energy use and GDP in the USA, he employed a multivariate vector autoregressive (VAR) analysis and used a weighting index of energy quality, where the energy content use is shifted from low-quality energy such as coal to high-quality energy such as electricity, rather than using a measure of total energy use. Using a different causality test, he found that total energy use was not Granger-caused GDP. However, using a weighting measure of energy, a Granger-caused GDP was found.

Cheng (1995) used a bivariate analysis and found no causality between energy use and GNP in the USA in either direction. Using a multivariate analysis, he also found no causal relationship between energy use and GNP. Masih and Masih (1996) found cointegration between energy and GDP in India, Pakistan and Indonesia, but no cointegration in Malaysia, Singapore or the Philippines. By using a vector error correction model (VECM), they showed that energy consumption is causal to income in India, income is causal to energy consumption in Indonesia, and bi-directional causality exists in Pakistan. This study applied an ordinary VAR model for the rest of the three non-cointegrated countries (Malaysia, Singapore and the Philippines) but did not find any causality.

Glasure and Lee (1997) examined the causality between energy consumption and GDP for South Korea and Singapore. They reported different results from the use of different methodologies. VAR-based Granger causality tests revealed no causal relationship for South Korea and a unidirectional causal relationship from energy consumption to GDP for Singapore. However, cointegration and error-correction models (ECMs) indicated bi-directional causality for both countries. By using the Granger causality, cointegration and error-correction approach, Cheng (1995) found a unidirectional causality running from economic growth to energy consumption in India. Yang (2000) studied the causal relationship between energy use and GDP in Taiwan. Using different measures of energy consumption, he found a bi-directional causality between energy and GDP. This result contradicts Cheng and Lai (1997), who found that there was a unidirectional causal relationship from GDP to energy use in Taiwan.

Asafu-Adjaye (2000) tested the causal relationship between energy use and income in four Asian countries using the cointegration and error-correction analysis. He found that causality ran from energy to income in India and Indonesia, and also showed a bi-directional causality in Thailand and the Philippines.

The study by Stern (2000) included capital and labor variables and used a quality-weighted index of energy input. He extended his analysis on the US economy by introducing cointegration analysis of the relationship between energy and GDP. He again found that total energy use does not seem to be Granger-causing GDP. However, if a quality-weighting index of energy is used, then it was determined to be Granger-causing GDP. His cointegration results showed that energy cannot be excluded from the cointegration space. In three of the five estimated models, he found unidirectional causality running from energy use to GDP. In the other two models, he found a bi-directional causal relationship between energy use and GDP. Stern's results suggest that energy is a significant explanatory factor that impacts GDP in the USA.

Chang and Wong (2001) studied the relationship between poverty, energy and economic growth in Singapore. They reported unidirectional causality from GDP to energy consumption with no

[1] Several analysts (Kraft and Kraft, 1978; Akarca and Long, 1980; Yu and Hwang, 1984; Abosedra and Baghestani, 1989) have used Granger (1969) or Sims (1972) tests to determine whether energy use causes economic growth or whether energy use is determined by the level of output. The results are generally inconclusive. Where significant results were obtained, they indicate that causality runs from output to energy use.

feedback. Aqeel and Butt (2001) investigated the causal relationship between energy consumption and economic growth as well as between energy consumption and employment for Pakistan. Cointegration and Granger causality tests inferred that economic growth causes total energy consumption. Further independent investigation revealed unidirectional causality from economic growth to petroleum consumption and showed no causality between economic growth and gas consumption, but it did indicate unidirectional causality from electricity consumption to economic growth. Fatai et al. (2002) analyzed the causal relationship between employment, energy consumption and economic growth in New Zealand. They found unidirectional causality from electricity consumption to employment and from oil to employment.

Soytas and Sari (2003) studied causality between energy consumption and GDP for the G-7 countries and for the top 10 emerging economies excluding China. They found bi-directional causality for Argentina, unidirectional causality from GDP to energy consumption in Italy and Korea, and unidirectional causality from energy consumption to GDP in Turkey, France, Germany and Japan.

There has been recent effort given to determining the causal relationship between electricity consumption and economic growth in China. However, the results have been contradicting. Lin (2003) covered the 1978–2001 period and concluded that economic growth is Granger-caused for electricity consumption but not vice versa. Shiu and Lam (2004) covered the 1971–2000 period and correctly obtained the opposite conclusion that there exists unidirectional Granger causality running from electricity consumption to economic growth.

Ghali and El-Sakka (2004) analyzed the causal relationship between energy use and output growth in Canada. They found that energy enters significantly into the cointegration space by testing for multivariate cointegration between output, capital, labor and energy use. Moreover, the short-run dynamics of the variables showed that the flow of causality ran in both directions between output growth and energy use.

Jumbe (2004) applied the Granger causality and error-correction techniques on 1970–1999 data for Malawi to examine cointegration and causality between electricity consumption and overall GDP, agricultural-GDP and nonagricultural-GDP. Cointegration was established between electricity consumption and GDP and nonagricultural-GDP, but not with agricultural-GDP. The Granger causality results detected bi-directional causality between electricity consumption and GDP, suggesting that electricity consumption and GDP are jointly determined, but that one-way causalities run from nonagricultural-GDP to electricity consumption. The error-correction model results detected causality running one-way from GDP (also from nonagricultural-GDP) to electricity consumption, which indicates that a permanent rise in GDP may cause a permanent growth in electricity consumption.

Lee (2005) re-investigated the co-movement and the causality relationship between energy consumption and GDP in 18 developing countries, using data for the 1975–2001 period and employing panel unit root tests, heterogeneous panel cointegration and panel-based error-correction models. The empirical results provided clear support for a long-run cointegration relationship after allowing for the heterogeneous country effect. The long-run relationship was estimated using a full-modified OLS. The evidence showed that there were long-run and short-run causalities running from energy consumption to GDP, but not vice versa. This result indicated that energy conservation might harm economic growth in developing countries regardless of being transitory or permanent.

Altinay and Karagol (2005) investigated the causal relationship between electricity consumption and real GDP in Turkey during the 1950–2000 period. They found that both of the series were stationary processes around a structural break. Thus, two different methodologies have been employed to test the Granger non-causality: the Dolado–Lütkepohl test using the VARs in levels, and the standard Granger causality test using the detrended data. Both tests have yielded a strong evidence for unidirectional causality running from the electricity consumption to income. This implies that the supply of electricity is vitally important to meet the growing electricity consumption, and hence to sustain economic growth in Turkey.

Wolde-Rufael (2005) applied a cointegration test and a modified version of the Granger causality test to investigate the long run and causal relationship between per capita GDP and per capita energy use for 19 African countries for the 1971–2001 period. Their results did not provide a definite stance on the existence or non-existence of a long-run or a causal relationship between energy consumption and economic growth; however, they showed that there was evidence of a long-term relationship for only eight of the nineteen countries and causality for twelve countries.

Mozumder and Marathe (2007) examined the causal relationship between the per capita electricity consumption and the per capita GDP for Bangladesh using a cointegration and vector error-correction model. Their results showed that there was unidirectional causality running from per capita GDP to per capita electricity consumption. Mehrara (2007) examined the causal relationship between the per capita energy consumption (PCEC) and the per capita GDP in a panel of 11 oil-exporting countries (Iran, Kuwait, Saudi Arabia, United Arab Emirates, Bahrain, Oman, Algeria, Nigeria, Mexico, Venezuela and Ecuador) by using panel unit root tests and panel cointegration analysis. The results showed a unidirectional strong causality from economic growth to energy consumption for the oil-exporting countries. In most major oil-exporting countries, governmental policies keep domestic prices below the free market level, resulting in high levels of domestic energy consumption. The results imply that energy conservation done through reforming energy price policies has no damaging repercussions on economic growth for this group of countries.

Yuan et al. (2007) applied the cointegration theory to examine the causal relationship between electricity consumption and real GDP for China during the 1978–2004 period. Their estimates indicated that real GDP and electricity consumption for China were cointegrated and that there was only unidirectional Granger causality running from electricity consumption to real GDP, but not vice versa. The Hodrick–Prescott (HP) filter was then applied to detrend the data and fluctuation component of the GDP and electricity consumption series. The estimation results indicated that there was cointegration between not only the trend components, but also the cyclical components of the two series, which implied that the Granger causality was probably related to the business cycle. In fact, the Granger causality analysis was sensitive to minor changes in model structure, such as adding a linear trend term in the cointegrated equation or changing the lag period from 2 to 3.

From this literature review, we can conclude that when applying the Granger causality analysis, we should be cautious with the empirical results and explain them carefully.

3. Overview of the energy sector in Tunisia

In response to the wide-ranging reforms it has undertaken since 1987, Tunisia has managed to make significant gains in the political, economic and social areas in spite of the country's modest natural resources. In the past two decades, Tunisia has achieved rapid economic growth. Its GDP has recorded an average annual growth rate of 5%. In 2007, Tunisia's GDP was distributed as follows: agriculture (11.4%), non-manufacturing industries (11.2%), manufacturing industries (17.6%) and services (59.8%) (National Statistics Institute, 2007).

Tunisia's oil and gas sector is supported by the efforts of a number of smaller companies. The Tunisian government created the country's state-owned oil company, Entreprise Tunisienne d'Activités Petrolières (ETAP), in 1972. ETAP's mission is to manage oil and natural gas exploration and production activities, and it has been active in attracting foreign firms to fund oil exploration.

Tunisia has geological structures that are similar to those of its larger neighbors, Algeria and Libya, which are OPEC members, although the scale of its resources has been more limited to date. Tunisia is currently focusing on the development of its downstream sector, again with the support of foreign investors. The energy structure of Tunisia is dominated by oil and natural gas. Since the end of the 1960s and during the 1970s and 1980s, the Tunisian energy sector had played a determining role in its economic development. Indeed, with an annual production, except for biomass, exceeding five million tons of oil equivalents (Mtoe), hydrocarbons widely contributed to the economic growth of the country during this period. Tunisian's total primary energy supply was 8.451 Mtoe in 2005, which is distributed as follows: oil (50.0%), gas (36.6%), combustible renewables and waste (13.3%) and hydropower (0.1%) (Energy Information Administration (EIA), 2006).

The acceleration of Tunisia's economic development has entailed a strong growth in energy demand. Since the early 1990s, Tunisia has dealt with the problem of energy dependence and recorded its first energy balance deficit in 1994. The Transmed (Enrico Mattei) pipeline runs through Tunisia on its way from Algeria to Italy, from which Tunisia supplements its own gas production with payment in kind from that link. A surplus was restored following the extension of the gas pipeline between Algeria and Italy and the start-up of operations in the Miskar gas field in 1996, but, as of 2001, deficits appeared again as a result of increasing demand and stagnating supply. Fig. 1 depicts historical trends of energy consumption and energy production (EP) for Tunisia. Tunisian energy consumption grew by 326% between 1971 and 2004. For the same period, the Tunisian energy production grew by only 38%.

Tunisian consumption of primary energy, which was 8.5 Mtoe in 2004, is dominated by oil with 48.7%, but natural gas is also significant at 37.6%. The biomass-energy, essentially used for the preparation of bread and cooking food in rural areas, contributes rather significantly, amounting to 13.1% of the primary consumption of energy. Finally, renewable energies (hydropower, wind energy and solar heating of water) represent 0.6% of the consumption of primary energy for the year 2004 (Amous, 2007).

Tunisia has modest proven oil reserves of 308 million barrels. The majority of Tunisia's oil reserves are located in the Gulf of Gabes and the Ghadames Basin in the southern part of the country. The majority of Tunisia's oil production (73%) comes from six concessions, which include Adam, Ashtart, Didon, El Borma, Miskar and Oued Zar. The remaining production comes from 26 smaller concessions. In 2005, the Adam field, located in the Borj el Khadra prospect in the Ghadames Basin, became Tunisia's largest producing oil field with 18,000 barrels per day (bbl/d). The onshore El Borma oil field, which was discovered in 1964 near the Algerian border, produces 12,000 bbl/d. This production level is down from the 1985 peak of 70,000 bbl/d. The Ashtart field, which is operated by ETAP, produces 11,500 bbl/d. In 2003, Tunisia produced around 66,000 bbl/d of oil. This represents a 45% decline from the country's peak oil output of 120,000 bbl/d during the 1982–1984 period (EIA, 2006).

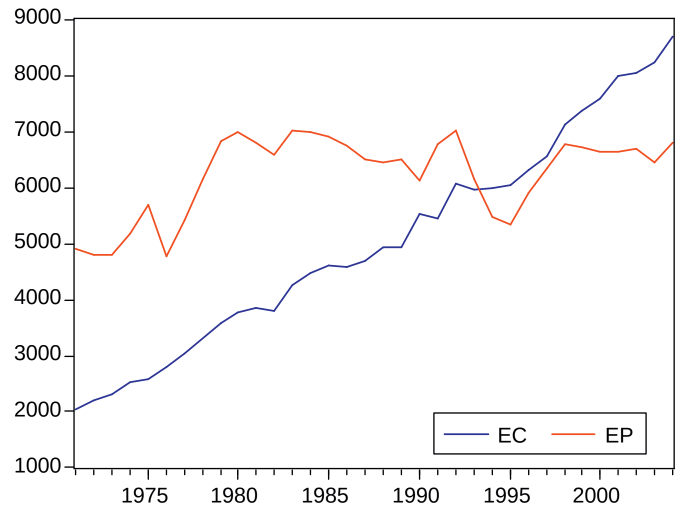

Fig. 1. Tunisia's energy consumption and energy production (in kt oil equivalent) from 1971 to 2004.

As domestic petroleum demand increases, the country's modest domestic production capacity is proving unable to meet it. Tunisia is increasingly turning to natural gas as a way of coping with steadily increasing domestic demand for energy. Tunisia has 2750 billion cubic feet (Bcf) of proven natural gas reserves, with about two-thirds of it offshore. In 2000, Tunisia produced 66 Bcf of natural gas. Output rose significantly to 79 Bcf in 2001. The majority of Tunisia's natural gas output comes from the Miskar field, located about 80 mile offshore in the Gulf of Gabes. The field was discovered in 1975 by Elf, but is now fully owned and operated by British Gas (BG), the largest investor in Tunisia's energy sector. According to BG, the field contains 1500 Bcf of natural gas reserves. In 2005, the Miskar field achieved record production levels of 200 million cubic feet per day (MMcf/d) of natural gas, which supplied more than 50% of Tunisia's total natural gas demand. BG also holds the Amilcar and Ulysse exploration permits in the Gulf of Gabes. Tunisia has four other producing natural gas fields (El Franning, El Borma, Baguel and Zinnia). Together, these fields account for most of the remaining domestic natural gas production.

Demand growth for natural gas has been even faster than for petroleum; between 2000 and 2001, Tunisia's consumption of natural gas grew from 109 to 135 Bcf (24%). Since 1990, demand for natural gas has grown almost 9% per year. Much of the demand growth comes from the electricity sector, but industrial and domestic use of natural gas has also increased. The state-owned natural gas and electricity company, Société Tunisienne de l'Electricité et du Gaz (STEG) has promoted the use of natural gas through an incentive program. According to STEG, natural gas represented 44% of the total initial energy consumption in Tunisia in 2005, compared to just 14% in 2003. The role of natural gas is growing, as it is currently the second largest fuel source, as well as being a main source for the industrial and electricity sectors (EIA, 2006).

As Tunisia became a net energy importer and following the increase of oil prices, the National Agency for Energy Conservation (NAEC) has conducted an assessment study of the impact of energy prices on demand in 2000. This study is aimed at establishing an energy pricing mechanism that is likely to reduce consumption, protect the environment and reduce the deficit of the balance of payments due to imports of oil products. The conclusions of this study have highlighted the need to revise the current energy prices structure and set up a pricing mechanism on the national level.[2] In 2007, the fiscal impact of higher oil prices included 0.7% of GDP in additional fuel subsidies as compared to the 2006 budget. The oil price now takes into consideration the evolution of prices on the international market to ensure better distribution of energy sources, as well as economic, social and environmental advantages (NAEC, 2000). In Tunisia, the price of lead-free petrol had risen to 1.320 Tunisian dinars (TND) (US$1.136) per liter. In the last five years, oil prices in Tunisia have doubled.

During the 2005–2008 period, Tunisia launched an energy conservation program. This program helped to reduce demand (8% lower in 2007, nearly 700,000 Toe savings), improve investments in renewable energy and developments in the widespread use of natural gas. In light of these results, the government has decided to launch a new four-year program covering the 2008–2011 period. This program intends to reduce energy consumption by 20% (or 2 Mtoe) between 2008 and 2011, involves energy conservation in all sectors of the economy, and focuses on the development of renewable energies in Tunisia. Energy conservation may be achieved through the promotion of energy-efficient appliances (lamps, refrigerators and others), energy efficiency standards, subsidies/incentives on energy efficiency improvement and energy technology standards. A strategic study on energy efficiency in Tunisia has shown that Tunisia can save 3 Mtoe by 2010, 30 Mtoe by 2020 and 80 Mtoe by 2030 (NAEC, 2005).

Tunisia also has great potential in the field of renewable energy (e.g., solar and wind). It is working hard to develop renewable energy resources. There are plans to build at least two wind farms in the northern part of the country, with the goal of producing about 400,000 MWh of renewable electricity annually. A strategic study on the development of renewable energy in Tunisia in 2004 showed that Tunisia has high potential for valorization of modern renewable energies, estimated at an aggregate 1.3 Mtoe by 2010, 7 Mtoe by 2020 and 19 Mtoe by 2030. The mobilization of this potential will allow for significant improvement of the contribution of renewable energies in the consumption of primary energy. It is in power production that the penetration of renewable energies would be the most significant, with 5.8% by 2010, 11.7% by 2020 and 12.2% by 2030. The wind energy branch for power production represents the most significant portion of this potential according to the time frames (between 70% and 80%). Solar water heating is ranked second (10% of the potential), followed by biogas (NAEC, 2004).[3]

4. Methodology

According to Engle and Granger (1987), a linear combination of two or more nonstationary series (with the same order of integration) may be stationary. If such a stationary linear combination exists, the series are considered to be cointegrated and long-run equilibrium relationships exist. The linear combination can be written as follows: $z_t = x_t - a - by_t$, where a and b are constant terms such that z_t is stationary. This relation is the long-run equilibrium relationship and z_t measures the deviation with respect to the equilibrium value.

Incorporating these cointegrated properties, a Vector error correction model could be constructed to test for Granger causation of the series in at least one direction (Engle, 1999). In this paper, the VECM is specifically adopted to examine the Granger causality between per capita GDP and per capita energy consumption in Tunisia.[4]

Since the use of the VECM requires the series to be cointegrated with the same order, it is essential to first test the series for stationarity. A series is said to be nonstationary, if it has a non-constant mean, variance and autocovariance over time. If a nonstationary series has to be differenced d times to become stationary, then it is said to be integrated of order d: i.e., $I(d)$. This first step is essential because the causality tests are very sensitive to the stationarity of the series (Stock and Watson, 1989), and the majority of macroeconomic series are nonstationary (Nelson and Plosser, 1982). When both series are integrated of the same order, we proceed to the next step by examining for the presence of cointegration.[5] There are many possible tests for cointegration. The bivariate approach of Engle and Granger is very restrictive. It can be applied only if there is one cointegrating relation. However, the most commonly used method is the Johansen cointegration test based on the autoregressive representation discussed by Johansen (1988) and Johansen and Juselius (1990). This test determines the number of cointegrating equations for any normalization used. It provides two different likelihood ratio (LR) tests; one is based on the trace statistic and the other on the maximum eigenvalue. We use the two statistics (trace and maximum eigenvalue) to test for cointegration.

Cointegration implies that causality exists between the two series, but it does not indicate the direction of the causal relationship. The presence of cointegration among the variables rules out the possibility of "spurious" correlation. Therefore, in the third step, we employ the vector error correction model to detect the direction of the causality.[6] We use a VECM instead of a VAR model, since the VAR model is unspecified in the presence of cointegration. VAR models may suggest a short-run relationship between the variables because the long-run information is removed in the first differencing, while a VECM can avoid such shortcomings. In addition, the VECM can distinguish between a long- and a short-term relationship among the variables and can identify sources of causation that cannot be detected by the usual Granger causality test. The dynamic Granger causality can be captured from the vector error correction model derived from the long-run cointegrating relationship (Granger, 1988). Engle and Granger (1987) showed that if two series are cointegrated, the vector error correction model for the per capita gross domestic product (PCGDP) and PCEC series can be written as follows:

$$\Delta y_t = \alpha + \sum_{i=1}^{k} \beta_i \Delta y_{t-i} + \sum_{i=1}^{k} \lambda_i \Delta x_{t-i} + \eta ECT_{t-1} + \varepsilon_{1t} \tag{1}$$

$$\Delta x_t = \alpha + \sum_{i=1}^{k} \beta_i \Delta x_{t-i} + \sum_{i=1}^{k} \lambda_i \Delta y_{t-i} + \eta ECT_{t-1} + \varepsilon_{2t} \tag{2}$$

where y_t and x_t represent per capita GDP and per capita energy consumption, respectively, Δy_t and Δx_t are the differences in these

[2] The Tunisian subsidy for oil prices is as follows: $28 per barrel in 2003; $38 per barrel in 2004 and $54 per barrel in 2005.

[3] European Union Leaders reached an agreement in principle in March 2007 that 20% of the bloc's energy should be produced from renewable fuels by 2020, as part of its drive to cut emissions of carbon dioxide, blamed in part for global warming.

[4] The Granger causality is strictly related to exogeneity. Hence, a variable x_t is weakly exogenic if it is not Granger-caused by y_t.

[5] Ohanian (1988) and Toda and Phillips (1993) showed that the distribution of the test statistic for block exogeneity in a VAR with nonstationary variables is not the standard χ^2 distribution. This means that the significance levels reported in previous studies of the Granger-causality relationship between energy and GDP may be incorrect, as both variables are generally integrated series. If there is no cointegration between the variables, then the causality test should be carried out on a VAR in differenced data, while if there is cointegration, standard χ^2 distributions apply when the cointegrating restrictions are imposed. Thus, testing for cointegration is a necessary prerequisite to causality testing.

[6] The causality test based on the VECM has the advantage of giving a causal relationship even without any significant estimated coefficients.

variables that capture their short-run disturbances, ε_{1t} and ε_{2t} are the serially uncorrelated error terms and ECT_{t-1} is the error-correction term (ECT) that is derived from the long-run cointegration relationship and measures the magnitude of the past disequilibrium. The coefficients, η of the ECT_{t-1}, represents the deviation of the dependent variables from the long-run equilibrium.

In each equation, change in the endogenous variable is caused by the previous period's disequilibrium in level, i.e., ECT_{t-1}. The error-correction representation allows for causality to emerge via two avenues. The ECM opens up an additional causality channel, which is overlooked by the standard Granger (1969) and Sims (1972) testing procedures. In the Granger sense, a variable X causes another variable Y if the current value of Y can be predicted better by using past values of X than by not doing so. The Granger causality testing procedure involves testing the significance of the λ_i conditional on the optimum lags. A VECM is set up for investigating short- and long-run causality. First, by testing the joint significance of the coefficients λ_i of the independent variable, we can check for short-term causality. The joint significance of 'λ_i' indicates that the dependent variable is responding to the short-term shocks to the stochastic environment. This can be implemented using a standard χ^2 Wald test.[7] Consider Eq. (1); if the estimated coefficients on lagged values of energy consumption are statistically significant, then the implication is that the energy consumption is Granger-caused per capita GDP in the short-run. Secondly, the long-run causality can be tested by looking at the significance of the speed of adjustment η, which is the coefficient of the error-correction term. The significance of 'η' indicates that the long-run equilibrium relationship is directly driving the dependent variable. If, for example, η is zero in the second equation, then it can be implied that the change in per capita energy consumption does not respond to deviation in the long-run equilibrium for the $t-1$ period.

It is also desirable to check whether the two sources of causation are jointly significant to test the Granger causality. This can be done by testing the joint hypotheses H_0: $\eta = 0$ and $\lambda_i = 0$ for all i in Eq. (1) or in Eq. (2). This is referred to as a strong Granger causality test. The joint test indicates which variable(s) bear the burden of short-run adjustment to re-establish long-run equilibrium, following a shock to the system (Asafu-Adjaye, 2000). A test of these restrictions can be done using the joint F test, Wald test or likelihood ratio test. If there is no causality in either direction, the 'neutrality hypothesis' holds.

In addition to the extra method for causality to emerge, the VECM offers another advantage that the lost information due to differencing is brought back into the system through the error-correction term.

5. Data and empirical results

Our empirical study uses the time series data of per capita GDP and per capita energy consumption for the 1971–2004 period in Tunisia. Data are obtained from the World Development Indicators (2006) produced by the World Bank. In this paper, per capita energy consumption is expressed in terms of kg oil equivalent and per capita GDP is expressed in constant 2000 US$. The choice of the starting period was constrained by the availability of data on energy consumption. The historical trends of per capita GDP and per capita energy consumption for Tunisia are depicted in Fig. 2. The two series are strongly correlated. The coefficient of correlation is equal to 0.97. Table 1 provides the descriptive statistics of these two series.

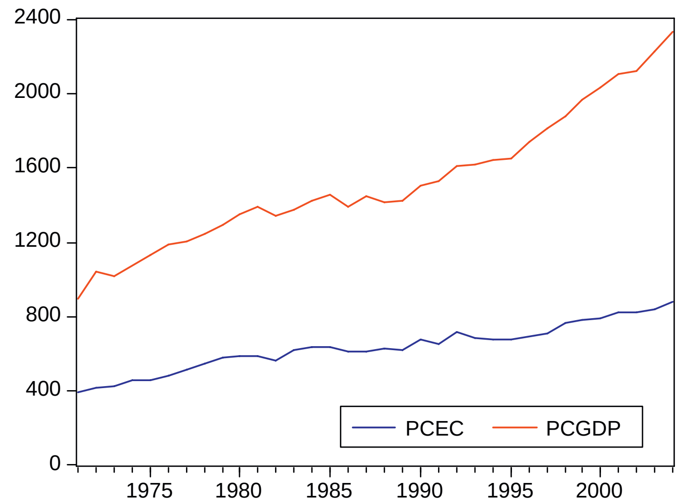

Fig. 2. Tunisia's per capita energy consumption and per capita GDP from 1971 to 2004.

A necessary but not sufficient condition for cointegration is that each of the variables should be integrated of the same order (more than zero) or that both series should contain a deterministic trend (Granger, 1988). In order to verify whether this preliminary condition was fulfilled, times series of per capita energy consumption and per capita GDP for Tunisia were tested for a unit root via various testing procedures due to augmented Dickey–Fuller (ADF) tests (Dickey and Fuller, 1979) and Phillips–Perron (PP) tests (Phillips and Perron, 1988). Table 2 reports the results of the ADF and PP tests on the integration properties of the per capita GDP and per capita energy consumption for Tunisia. Results of the two tests indicate that the two series are nonstationary according to their levels, but stationary in first differences. This indicates that the PCGDP and PCEC variables of Tunisia are individually $I(1)$.

Given that integration of the two series is of the same order, we continue to test whether the two series are cointegrated over the sample period. In this second stage, the Johansen maximum likelihood procedure is used to detect cointegration. This provides a unified framework for estimation and testing cointegrating relations in the context of a vector error-correction model. The asymptotic distribution of the LR test statistic for cointegration does not have the usual distribution and depends on the assumptions made with respect to deterministic trends. Therefore to carry out the test, we need to make an assumption regarding the trend underlying our data. We assume here that the level data have no deterministic trends and the cointegrating equations have intercepts. The choice of this specification is based on the investigation of the graphs of the two series and the unit root tests, which indicate that the two series do not have a common deterministic trend. We determine the optimum lag length for the Johansen cointegration test based on the minimum AIC through the unconstrained VAR estimation (two lag intervals in first differences for both series, see Table 3). The cointegration rank r of the time series is tested using two test statistics. Denoting the number of cointegrating vectors by r_0; the maximum eigenvalue (λ_{max}) test is calculated under the null hypothesis H_0: $r_0 = r$; against the alternative hypothesis H_1: $r_0 > r$. The trace test is calculated under H_0: $r_0 \leqslant r$; against H_1: $r_0 > r$.

Table 4 shows the results of the Johansen maximum likelihood cointegration tests using the Eviews package. Starting with the null hypothesis of no cointegration among the variables, i.e., H_0:

[7] Masih and Masih (1996) and Asafu-Adjaye (2000) interpreted the weak Granger causality as 'short-run' causality in the sense that the dependent variable responds only to short-term shocks to the stochastic environment.

Table 1
Summary statistics for both series.

Variables	Description	Mean	Standard deviation	Minimum	Maximum
y	Per capita GDP (in constant 2000 US$)	1526.13	363.05	899.05	2337.12
x	Per capita energy consumption (in kg oil equivalent)	634.62	126.59	392.26	876.22
Observations	34	34	34	34	34

Table 2
Unit root test results of PCGDP and PCEC series[a].

Variables	ADF test statistic		PP test statistic	
	Level	First difference	Level	First difference
PCEC	−0.41	−7.11	−0.42	−7.21
PEGDP	1.19	−6.07	1.34	−6.03
1% Critical value	−3.653	−3.653	−3.646	−3.653
5% Critical value	−2.957	−2.957	−2.954	−2.957
10% Critical value	−2.617	−2.617	−2.615	−2.617

Note: each test uses an intercept and no trend. Δ indicates a series in first difference. Each ADF statistic is reported for the shortest lag length which has been chosen based on the minimum AIC.

[a] The Phillips–Perron test uses the same models as the Dickey–Fuller tests, but uses a non-parametric correction, due to Newey and West (1987), to address the potential serial correlation. We chose the lag truncation for this non-parametric correction using an automated bandwidth estimator employing the Bartlett kernel (Andrews, 1991). The test statistics for both the Dickey–Fuller and Phillips–Perron tests have the same distributions. Critical levels are reproduced in Hamilton (1994) and Enders (1995).

Table 3
Selection of lag length.

Number of lags	Log likelihood function	AIC criterion	Schwartz criterion
4	−271.25	19.28	20.12
3	−280.47	18.99	19.64
2	−293.53	18.97	19.42
1	−311.40	19.23	19.50

$r_0 = 0$; the maximal eigenvalue statistic is 21.669, which is above the 5% critical value of 15.892. Hence, the null hypothesis of $r_0 = 0$ is rejected at the 5% level of significance. Turning to the trace test as shown in Table 4, the null hypothesis of no cointegration is also rejected at the 5% level of significance. Hence, results of both tests imply that we reject the hypothesis of no cointegrating equation at the 5% significance level. However, under H_0: $r_0 \leqslant 1$, the trace and maximum eigenvalue statistics are equal to 6.406, which are below the 5% critical value of 9.164. Hence, the null hypothesis is accepted at the 5% significance level. These results imply that the two PCEC and PCGDP series have one cointegrating equation; in other words, there is a long-run relationship between per capita GDP and per capita energy consumption for Tunisia.

Since the two series are cointegrated, a VECM is set up for investigating short- and long-run causality.[8] In the VECM, the first difference of each endogenous variable (per capita GDP or per capita energy consumption) is regressed on a one period lag of the cointegrating equation. 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. The VECM is estimated by the maximum likelihood method. The lag of the system is decided by the AIC criterion to be 2.

Table 5 shows the results of the causality test based on the VECM. We have performed several tests for Granger causality: (1) short-run causality—the joint significance of the coefficients of lagged terms of each explanatory variable by Wald χ^2 tests; (2) long-run causality—the significance of the error-correction terms by the t-test; (3) strong Granger causality—the joint significance of the two sources of causation (the sum of lagged terms of each explanatory variable and the ECT) by LR tests.

The robustness of the VECM is evaluated by using the normality residual test of Jarque–Bera, the Portmanteau autocorrelation test, the autocorrelation LM test, and the White homoscedasticity test. Using the Portmanteau autocorrelation test, the Box–Pierce and Ljung–Box Q-statistics are equal to 24.94 and 32.72, respectively. Thus, we accept the null hypothesis of no serial correlation up to lag 12. In addition, the autocorrelation LM test indicates that we accept the null hypothesis of no serial correlation up to lag 12. The normality residual test statistics of Jarque–Bera are equal to 3.01 and 2.51 in Eqs. (1) and (2), respectively, which indicate that we accept the null hypothesis of normality of the residuals. The joint test statistics of the White homoscedasticity test with the no cross terms is 33.50, with a p-value of 0.30, which indicates that we accept the null hypothesis of non-heteroscadasticity at a 5% confidence level. Hence, the model passes all the tests successfully and the residuals are Gaussian white noise.

Estimation of the VECM gives the cointegrating vector as (1, −14.53, −0.41). We have normalized the cointegrating equation with respect to the PCEC coefficient. Short-run causality is found only from per capita energy consumption to per capita GDP, but the converse is not true, i.e., there is unidirectional short-run Granger causality. From Table 5, the coefficient of the ECT is found to be statistically significant and negative in the two equations at the 1% level.[9] This result implies that the PCGDP and PCEC variables are not weakly exogenous, suggesting bi-directional long-run causality (feedback effect) between the PCGDP and PCEC.[10] The values of coefficient of the ECT in both equations of PCGDP and PCEC are equal, with values of -0.993 and −0.455, respectively. This implies that the adjustment coefficients (speed of convergence) are of 99% and 45% in the two equations, respectively. The corrections to the short-run disequilibrium are done rapidly. Additionally, by using a joint F-test, we confirm the bi-directional long-run causality between energy consumption and GDP because we reject, at the 5% level, the null hypotheses that the coefficients on the ECTs and the interaction terms are jointly zero in both the PCGDP equation and the PCEC equation.

The majority of studies in this field try to answer the question asked by Masih and Masih (1998): does economic growth take

[8] Cointegration implies the existence of Granger causality; however, it does not indicate the direction of the causality relationship.

[9] The VECM cannot be reduced here to only one equation, and the cointegrating vector appears in the two equations. The hypothesis that the PCGDP and PCEC are weakly exogenous is rejected.

[10] The standard Granger (1969) test concludes that there is a unidirectional causal relationship from the PCGDP to per capita energy consumption.

Table 4
Johansen cointegration estimation results between series of PCGDP and PCEC.

Rank test (trace)				Rank test (maximum eigenvalue)			
Number of cointegration	Eigenvalue	Trace statistic	5% Critical value	Number of cointegration	Eigenvalue	Max-Eigen statistic	5% Critical value
None	0.502	28.076	20.261	None	0.502	21.669	15.892
At most 1	0.186	6.406	9.164	At most 1	0.186	6.406	9.164

Table 5
Granger causality tests.

Dependent variable	Source of causation (short run)		Source of causation (long run)		
	ΔPCEC	ΔPCGDP	ECT	ECT/ΔPCEC	ECT/ΔPCGDP
ΔPCEC	–	3.543 (0.17)	−2.736*	–	3.832**
ΔPCGDP	8.142 (0.017)	–	−3.758*	7.253*	

* Is the 1% critical level.
** Is the 5% critical level. Values in parentheses are *p*-values.

precedence over energy use, or can energy use itself be a stimulus for economic growth via the indirect channels of effective aggregate demand and human capital, improved efficiency and technological progress? Our results are similar to those obtained by Oh and Lee (2004). Thus, in contrast with the neo-classical argument that energy use is neutral to growth, our results for Tunisia are consistent with the view that energy use does have a causal impact on GDP. Our results are also in line with findings by Stern (1993, 2000), Yang (2000) and Asafu-Adjaye (2000) who obtained similar results for other countries.

6. Policy implications and conclusions

This paper analyzes the causal relationship between energy use and GDP in Tunisia. Based on a VEC model after testing for multivariate cointegration between per capita energy use and per capita GDP, we find that energy enters significantly into the cointegration space. The short-run dynamics of the variables show that the flow of causality runs from energy use to GDP, and there is a long-run bi-directional causal relationship or feedback between the two series. Our results seem to significantly reject the neo-classical assumption that energy is neutral to growth. Consequently, we conclude that energy is a limiting factor to GDP growth in Tunisia, and, therefore, shocks to the energy supply will have a negative effect on GDP.

With the rise of oil prices, the empirical analysis of the relationship between energy consumption and GDP has important implications for Tunisia's economic policy. The long-run equilibrium implies that, in Tunisia, the policy of "energy must lead economic growth" should be reinforced for a long period. A high level of economic growth leads to a high level of energy demand and vice versa. In order not to adversely affect economic growth, energy conservation policies that aim at curtailing energy use must instead find ways of reducing consumer demand. In the long run, for Tunisia's development to be sustainable, Tunisia has to change its economic structure to a more efficiency-oriented and less resource-depleting one and rely more on renewable energy sources. Renewable energy technologies have an enormous potential to solve energy problems in Tunisia. The energy provided by the sun (solar energy) is many times greater than the current energy demand. The wind, waves and tides have a large potential as well. The question becomes how can we best utilize these resources? At the same time, efforts must be made to encourage industry to adopt technologies that minimize pollution.

The short-run Granger cause running from energy consumption to GDP indicates that energy shortage even in the short-term will constrain the regular pace of economic growth. Our finding indicates that Tunisia's economy is energy-dependent and is relatively vulnerable to energy shocks. More drastic energy conservation measures could be reinforced without severe impacts on economic growth.

As a Non-Annex 1 party, Tunisia has the right to insure favorable conditions to its development, which inevitably requires it to invest heavily in the promotion of renewable energies by developing scientific research in this particular field. Tunisia will have to understand that renewable energy is the main source of future energy and that traditional energy sources are coming to an end. Tunisian's environmental strategy is aiming for a 25% reduction in the consumption of fossil fuel by substituting oil with renewable energy. Tunisia's rationale for such a conversion is twofold: emissions into the atmosphere from conventional burning of fossil fuel must be reduced to prevent further environmental damage; and alternative energy sources must be used to enable sustainable development and economic growth that would otherwise be threatened by a lack of oil. Also, energy efficiency is a priority for Tunisia, which is conscious of the fact that the global environment must be preserved that all efforts must be made to avoid endangering the survival of future generations, and that development models to be adopted can be used to track environmental concerns.

Tunisia's economy will have to make a transition from a fossil fuel-based economy to a renewable energy-based economy. As such, Tunisia is willing to contribute to the world effort to fight climate change.

A better understanding of the link between energy consumption and GDP in Tunisia can help untangle the question as to what extent can economic growth be sustained under various energy availability scenarios. Conclusions for Tunisia may be relevant for a number of countries that have to go through a similar development path of increased pressure on already scarce energy resources.

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