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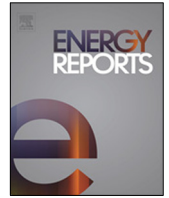
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Research paper

Does static and dynamic relationship between economic growth and energy consumption exist in OECD countries?



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HIGHLIGHTS

- Investigate the relationship between economic growth (EG) and energy consumption (EC) for the 34 OECD.
- Examine growth–energy nexus, energy–growth nexus and the two-way linkages between them.
- Empirical results confirm the positive and significant causality relationship between EG and EC (feedback effect).

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ABSTRACT

The main purpose of this paper is to investigate the relationship between economic growth (EG) and energy consumption (EC) for the 34 OECD (Organisation for Economic Co-operation and Development) countries over the period 1990–2015. Analyze the static and especially dynamic sense of relation among EG and EC in OECD always stay interesting. Using three models to examine growth–energy nexus, energy–growth nexus and the two-way linkages between them, this work consolidated the empirical insights in this research axis. Empirical results support an feedback effect between EG and EC. This results have provided key suggestions and recommendations which have important energy and economic policies implications for OECD policymakers. This ensures sustainable economic development and serve as a motivation to search alternative energy sources to meet the burgeoning energy demand in this countries.

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1. Introduction

EC is a key component of modern economies: it plays an essential role in production and occupies a large place in consumer spending. Otherwise, energy is an essential basis for social and economic development. The OECD countries need to ensure that their citizens have sufficient energy supply while ensuring sustainability, i.e. with minimum costs and reduced environmental effects. Furthermore, the share of EC in the OECD area in the world total is projected to be reduced from 35% in 1995 to 32% by 2020 (OECD, 2011). In view of the consumer trends that are driving the energy market, the strong underlying growth in energy demand is likely to continue in the foreseeable future. Although the effects of demand saturation will gradually exert their influence in OECD countries, the huge unmet demand of 3 billion people

aspiring to cover their basic needs will be overwhelming in relation to any localized saturation trends demand. The economic effects of EC have been thoroughly analyzed by academic research over the last few decades. The literature proves that energy is fundamental to strengthen economic productivity (Dedeoglu and Kaya, 2013; Nasreen and Anwar, 2014; Kasman and Duman, 2015). The rise in levels of EG is considered as one of the principal causes of EC increase. In this regard, one of the most important issues in energy economics literature is mainly focused on testing the relationship between growth and energy. If EC determines EG, it will indicate that the economy depends on energy in such a way that energy directly affects growth, implying that a deficiency in energy supply can have adverse consequences on growth. In addition, if the causality mechanism is reversed, this suggests a less energy-dependent economy. Thus, the energy conservation policies implemented may have little or no effects on EG. Finally, a lack of causality in either direction, i.e. the neutrality hypothesis, means that energy conservation policies do not affect EG.

Recently, the relation between energy and growth has been an active research area (see, e.g. Arouri et al., 2012; Apergis and

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Tang, 2013; Omri and Kahouli, 2014a; Saidi and Hammami, 2015; Heidari et al., 2015; Kasman and Duman, 2015; Lu et al., 2016; Antonakakis et al., 2017; Kahouli and Omri, 2017a; Kahouli, 2017b). In addition, there are several studies available in the existing literature investigating relationship between EG and EC in case of OECD countries (Coers and Sanders, 2013; Wong et al., 2013; Bella et al., 2014; Mercan and Karakaya, 2015). The empirical findings of mentioned studies are inconclusive and are not helpful to policy makers in articulating comprehensive economic and energy policy to sustain EG and realize energy efficiency in case of OECD countries. The present study is a try to fill the gap in energy literature regarding the case study of OECD countries. Knowing the direction and intensity of causal relationship between EG and EC represents an important foundation for design and implementation of the appropriate economic and energy policy. Although a strong causal relationship represents a stylized economic fact, the existence and direction of causality is still not clearly defined. This thematic area has been the subject of empirical research for the last several decades, although with no consensus on whether EG causes EC or whether EC acts as a stimulus of EG. The reasons for inconclusive results can be attributed to differences among countries, statistical techniques employed, time horizons and data sets. In order to avoid this gap and to make empirical results as robust and as representative as possible, and to determine as precisely as possible the causal relationship between EC and EG, new approaches in terms of newer data sets and sophisticated econometric methods will be used.

In this paper we investigated the relationship between EG and EC in the 34 OECD countries for the period 1990–2015 using an extensive panel data analysis. Conventionally, most empirical analysis of the relationship between these variables has been conducted from the time-series or the cross-sectional perspective. Consequently, this paper's empirical analysis has adopted the recently developed panel data econometric analysis.

The contribution of present study is the use of both static and dynamic techniques separately and simultaneously to capture the impact of EG and EC. As such, it prepares a strong theoretical ground for empirical analysis. It explores the channel variables through which EG may likely affect EC. To the best of my knowledge, no piece of research has yet emphasized and examined the importance of the EG and EC by using static and dynamic techniques. Hence, comes the endeavor of this study to examine the relations between EC and EG: nexus and causality with incorporating other explicative variables (trade, FDI, CO₂ emissions, Research and development expenditure, etc.) using static and dynamic panel data. The present study aims at investigating the static and dynamic linkages between EG and EC in OECD member countries based on economic theory and available empirical evidences. For this purpose, three questions are designed and have been evaluated as follows in this study: Does energy-led to EG? Does growth-led to EC? Is there a two way linking (feedback) between them?

The organizational structure of the paper is as follows: Section 2 provides a literature review on growth–energy nexus. Section 3 provides empirical methodology for this study. Section 4 discusses the empirical results. Section 5 concludes with a summary of the main findings and policy implications.

2. Literature review

The link between EG and EC has become a recurrent issue in the economic development debate in recent years. Following the seminal work of Kraft and Kraft (1978), growth–energy relation has been widely discussed both theoretically and empirically (Chontanawat et al., 2008; Sharma, 2010; Shahbaz and Lean, 2012; Shahbaz et al., 2013; Apergis and Tang, 2013; Omri and Kahouli, 2014b; Smiech and Papiez, 2014; Azam et al., 2015; Ozturk and

Al-Mulali, 2015; Kasman and Duman, 2015; Antonakakis et al., 2017; Kahouli and Omri, 2017a; Kahouli, 2017b), among others (see Table 1). These studies have confirmed the existence of a mixed (positive or negative) and sometimes conflicting on the direction of the causal link in short-term and long-term (Table 1). It is important to know that the type of causality between energy and growth (temporary or permanent) determine significantly the energy policy implications. The lack of consensus in the results of the studies in the same country or geographical area is therefore linked to the methodological and/or the data bases taken into account. A general observation from the literature is that the majority of these studies have used PVAR, VECM, ARDL, DOLS and FMOLS methods to explore the relationship between these two variables, although some studies have used the panel data approach. None of them, however, have used both the static and dynamic panel data techniques and simultaneous equations: OLS pooled, within, GLS, 3SLS and the GMM estimators and, more specifically, applied them to the OECD countries. In addition, this study incorporates several explanatory variables (trade, FDI, CO₂ emissions, research and development expenditures, etc.) to better understand the relationship between these two key variables.

Consistent with our research methodology of this paper, these empirical studies can be divided into two strands. Starting with the first strand, which focuses on the impact of EG on EC, and vice-versa (energy-led growth hypothesis and growth-led energy hypothesis). Both hypotheses suggest that there is a unidirectional relationship from energy to growth and from growth to energy, respectively. For instance, Yildirim and Aslan (2012) examines the relationship among EC and EG for 17 highly developed OECD countries within a multivariate production model from 1960 to 2009. The Toda–Yamamoto procedure and the bootstrap-corrected causality test have been used. Findings indicate that while there exists unidirectional causality running from EC to EG whereas for Japan. On the other hand, unidirectional causality from GDP to energy is found for Australia, Canada and Ireland whereas no causal nexus is found for all of other nine countries. Likewise, Coers and Sanders (2013) reassess the nexus between income and energy use in a panel of 30 OECD countries over the past 40 years. They use panel unit root and cointegration testing. Their results show a strong unidirectional causality running from GDP to energy. In another study, Saidi and Hammami (2015) investigate the impact of EG on EC for a global panel of 58 countries (among them the countries of the OECD) using dynamic panel data model estimated by means of the GMM for the period 1990–2012. EG has a positive and significant impact on EC. In the same context, Ozcana and Ari (2015) investigates the causal relationship between EC (nuclear) and EG for 15 OECD countries. To this aim, the bootstrap causality test is used within a multivariate production model from 1980–2012 that differs for each country. The results reveal that the neutrality hypothesis does hold for 10 out of 15 OECD countries. In other words, there is no causal relationship between nuclear EC and EG in any direction. In addition, Kasman and Duman (2015) examine the causal relationship between EC and EG for a panel of new EU member and candidate countries (includes several OECD countries) over the period 1992–2010. They use panel unit root tests, panel cointegration methods and panel causality. The main results indicate that there is a short-run unidirectional panel causality running from GDP to energy. Going further, Destek (2016) examines the relationship between EC (natural gas) and EG in 26 OECD countries within a multivariate production model from 1991 to 2013. According to FMOLS and DOLS, natural gas consumption in OECD countries positively affects GDP growth in the long-run. Furthermore, the VECM Granger causality test reveals unidirectional causality from natural gas consumption to GDP, which supports the growth hypothesis for the short-run.

The second strand of existing literature on this topic provides empirical evidence on the two way linking (feedback) between

EG and EC starting with [Lee et al. \(2008\)](#) who estimate the panel cointegration and panel VECM for a set of 22 OECD countries using annual data covering the period 1960–2001. They investigate the relationship between EC and income using an aggregate production function, as well as by exploring the dynamic directions of the causality among them. The panel causality test shows bidirectional causal linkages exist among EC and EG. At the same time, [Chontanawat et al. \(2008\)](#) found causality running from EC to GDP and stated that this result is more valid in the developed OECD countries compared with the developing non-OECD countries in a group of 100 countries. Similarly, [Belke et al. \(2011\)](#) examine the long-run relationship between EC and real GDP, for 25 OECD countries from 1981 to 2007. The results indicate that international developments dominate the long-run relationship between EC and real GDP. Furthermore, [Fuinhas and Marques \(2012\)](#) examine the nexus between primary EC and growth in Portugal, Italy, Greece, Spain and Turkey (PIGST), with annual time series data, from 1965 to 2009 by using ARDL bounds test approach. Empirical results suggest bidirectional causality between energy and growth in both the long-run and short-run, supporting the feedback hypothesis. By employ the panel cointegration technique and the Granger representation, [Dedeoglu and Kaya \(2013\)](#) investigate the relationship between energy–GDP for 25 OECD countries over the period 1980–2010. They found that the pair of energy–GDP is cointegrated and there is two-way Granger causality between them. Indeed, [Bozoklu and Yilanci \(2013\)](#) examine the causal relationship between EC and EG for 20 OECD countries over the period 1965–2011. They employ a Granger causality test in the frequency domain which allows us to distinguish short and long-run causality. The results provide evidence of both temporary and permanent causality relationships.

Another interesting approach is the one of [Omri and Kahouli \(2014b\)](#) which examines the interrelationship between EC and EG using dynamic panel data models in simultaneous-equations for a global panel consisting of 65 countries (contains some OECD countries) for the period 1990–2011. They find that there is bidirectional causal relationship between energy and growth only for the global panel and for the high- and middle-income countries. The main objective of [Smiech and Papiez \(2014\)](#) was to assess linkages between EC and EG in the EU member states (majority of them are OECD countries) in the period 1993–2011. The study uses the bootstrap Granger panel causality approach to verify the hypothesis of causality between EC and EG. The results obtained reveal that the level of compliance with energy policy targets influences linkages between EC and EG. Indeed, [Antonakakis et al. \(2017\)](#) examine the dynamic interrelationship in the output–energy nexus by applying PVAR and impulse response function analyses to data on EC, CO₂ emissions and real GDP in 106 countries (many of them are OECD countries) over the period 1971–2011. Causality between EG and EC is bidirectional. As revealed in a recent study, [Shahbaz et al. \(2018\)](#) examines the inter-linkages between EC and EG in top ten energy-consuming countries i.e. China, the USA, Russia, India, Japan, Canada, Germany, Brazil, France and South Korea. They use the quantile-on-quantile (QQ) approach. The results show a positive association between EG and EC, with considerable variations across economic states in each country. Given the fact that enormous studies use time series models to test the relationships among EG and EC, we will concentrate our analysis on panel model. In addition, the OECD case studies taking into account both static and dynamic aspects have not received significant attention. Many OECD countries (especially emergent countries) are growing rapidly, and as such, the relationship between economic growth and energy consumption could be highly dynamic. The key focus of this study is to examine growth–energy nexus, energy–growth nexus and the two-way linkages. In contrast with other studies, we aim not only to explain the econometric validity of a certain hypothesis regarding only the static relationship between economic growth and the energy consumption, but also to underline and substantiate the dynamic relationship.

3. Empirical methodology

3.1. Models

This research is concerned mainly with investigating the nexus between EC and EG in OECD countries a Cobb–Douglas production function will be applied. Succeeding the effort of [Shahbaz et al. \(2013\)](#), [Omri and Kahouli \(2014a\)](#), [Kahouli \(2017b\)](#) derived the empirical model based on the standard Cobb–Douglas production function having constant returns and the aggregate output function with time t . This function depends on capital stocks (K), labor force (L) and technical progress (A). Otherwise, we use the following extended Cobb–Douglas production function:

$$Y_t = A_t K_t^{\alpha_1} L_t^{\alpha_2} EC_t^{\alpha_3} e^u \quad (1)$$

Where, Y is the gross domestic product (GDP), EC denote energy consumption and e the error term. α_1 , α_2 and α_3 are the output elasticities respectively with respect to domestic capital, labor force, and EC . When Cobb–Douglas function is restricted to $(\alpha_1 + \alpha_2 + \alpha_3 = 1)$ we get constant returns to scale. In this paper we allow technology to be endogenously determined by trade (T), foreign direct investment (FDI) and research & development expenditure (RD) and within an augmented Cobb–Douglas production function ([Shahbaz and Lean, 2012](#); [Omri and Kahouli, 2014b](#)). FDI inflow encourages spillovers knowledge and technology transfer. Research & development expenditure (RD) facilitates and accelerates technological advancements and their diffusion. Trade (T) promotes EG via labor mobility and capital transfer. Therefore, we have:

$$A_t = \theta \cdot FDI_t^\alpha RD_t^\beta T_t^\gamma \quad (2)$$

Where, θ is time-invariant constant.

Substituting Eq. (2) into Eq. (1):

$$Y_t = \theta \cdot EC_t^{\lambda_1} FDI_t^{\lambda_2} RD_t^{\lambda_3} T_t^{\lambda_4} K_t^\alpha L_t^{1-\alpha} \quad (3)$$

Following [Shahbaz et al. \(2013\)](#), [Omri and Kahouli \(2014a\)](#), [Kahouli \(2017b\)](#), we divide both sides of Eq. (4) by population to get variables in per capita terms; but leave the impact of labor constant knowing that $\lambda_1 + \lambda_2 + \lambda_3 + \lambda_4 = 1$. It is important to leave the impact of work constant, since it is a crucial production factor and therefore a contributor to energy demand. By taking log, the linearized production function can be given as follows:

$$\ln Y_t = \alpha_0 + \alpha_1 \ln EC_t + \alpha_2 \ln FDI_t + \alpha_3 \ln RD_t + \alpha_4 \ln T_t + \alpha_5 \ln K_t + \varepsilon_t \quad (4)$$

Since our study is a panel data study, Eq. (4) can be written in panel data form as follows:

$$\ln Y_{it} = \alpha_0 + \alpha_1 \ln Y_{it-1} + \alpha_2 \ln EC_{it} + \alpha_3 \ln FDI_{it} + \alpha_4 \ln RD_{it} + \alpha_5 \ln T_{it} + \alpha_6 \ln K_{it} + \alpha_7 \ln HK_{it} + \alpha_8 \ln INF_{it} + \varepsilon_{it} \quad (5)$$

Where the subscript $i = 1, \dots, N$ denotes the country (in our study, we have 34 countries) and $t = 1, \dots, T$ denotes the time period (our time frame is 1990–2015), $\ln Y_{it}$ is real GDP per capita, $\ln Y_{it-1}$ is EG lagged variable, $\ln EC_{it}$ is the indicator of EC, $\ln FDI_{it}$ is foreign direct investment, $\ln RD_{it}$ is research & development expenditure, $\ln T_{it}$ is trade, $\ln K_{it}$ is real capital use, $\ln L_{it}$ is labor force. Other determinants of EG are human capital (enrollment at secondary school : $\ln HK_{it}$) and inflation rate ($\ln INF_{it}$). OECD should play an important role in regulating and supplying energy to avoid an uncontrolled increase in prices that could lead to higher production costs for companies, an acceleration of inflation and the reduction of household welfare as well as shortages and harmful to economic activity. As far as trade, capital stock and urbanization are concerned, we theoretically tend to believe that both capital and labor are used as potential inputs in the process of producing real economic output and in turn these inputs are also helping producers of an economy to demand for energy use ([Kahouli, 2017b](#)). ε_{it} is the error term.

Table 1
Summary of empirical studies on growth–energy nexus.

| Author | Country | Sample period | Methodology | Main findings |
|-----------------------------|------------------------------------|---------------|--|---|
| Kraft and Kraft (1978) | USA | 1947–1974 | Granger causality | Growth Granger causes energy. |
| Glasure (2002) | Korea | 1961–1990 | Cointegration, error correction, variance decomposition | Bidirectional between energy and growth |
| Sharma (2010) | 66 countries | 1986–2005 | GMM estimators | The results on the impact of energy are mixed. |
| Belke et al. (2011) | 25 OECD countries | 1981–2007 | Dynamic panel causality | The presence of a bi-directional causal relationship between EC and EG. |
| Fuinhas and Marques (2012) | PIGST Countries | 1965–2009 | ARDL Test | Bidirectional causality between energy and growth in both the long-run and short-run, supporting the feedback hypothesis. |
| Kahsai et al. (2012) | 40 SSA countries | 1980–20007 | Pedroni cointegration test, Granger causality test | Direct relationship between EG and energy demand. |
| Yildirim and Aslan (2012) | 17 OECD countries | 1960–2009 | Toda–Yamamoto procedure and the bootstrap-corrected causality test | Unidirectional causality running from EC to EG for Japan. On the other hand, unidirectional causality from GDP to energy is found for Australia, Canada and Ireland whereas no causal nexus is found for all of other nine countries. |
| Coers and Sanders (2013) | 30 OECD Countries | 1960–2000 | VECM | Strong unidirectional causality running from GDP to energy usage. |
| Bozoklu and Yilanci (2013) | 20 OECD countries | 1965–2011 | Granger causality test | The results provide evidence of both temporary and permanent causality relationships for countries examined. |
| Salahuddin and Gow (2014) | Gulf Cooperation Council countries | 1980–2012 | PMG (pooled mean group) ; SUR (seemingly unrelated regression) testing | EC and CO2 emissions Granger cause each other while unidirectional causal link running from EG to EC is also found to exist. |
| Yildirim et al. (2014) | 11 countries | 1980–2011 | Bootstrapped autoregressive metric causality approach | The neutrality hypothesis is valid for all of the countries except for Turkey. |
| Bella et al. (2014) | OECD countries | 1965–2006 | vector error correction model (VECM) | The long-run relationship between income and electric power consumption shows a U-shaped pattern, instead. |
| Omri and Kahouli (2014b) | 65 countries | 1990–2011 | GMM estimators | EC and GDP have positive and statistically significant. |
| Smiech and Papiez (2014) | EU countries | 1993–2011 | Bootstrap panel Granger causality | The level of compliance with energy policy targets influences linkages between EC and EG. |
| Saidi and Hammami (2015) | 58 countries | 1990–2012 | GMM estimator | EG has a positive impact on EC and statistically significant only for the four panel. |
| Salahuddin et al. (2015) | Gulf Cooperation Council (GCC) | 1980–2012 | DOLS, FMOLS and DFE techniques | Electricity consumption and EG have a positive long run relationship. |
| Ozturk and Al-Mulali (2015) | GCC countries | 1980–2012 | DOLS and FMOLS | The natural gas EC affects the GCC's countries GDP growth positively in the long run. |
| Mercan and Karakaya (2015) | OECD Countries | 1970–2011 | CDLM and CADF tests | The effect of EC on growth is positive and statistically significant. |
| Azam et al. (2015) | ASEAN-5 countries | 1980–2012 | Johansen co-integration test | EC has significant and long run relationship to EG for almost all ASEAN-5 countries. |
| Ozcana and Ari (2015) | 15 OECD countries | 1980–2012 | Bootstrap causality test | There is no causal relationship between nuclear EC and EG in any direction. |
| Elliott et al. (2015) | 224 cities in China | 2002–2007 | OLS, NLS and FE estimators | The exponent in the power law connecting capital with electricity to be 2/3. |
| Kasman and Duman (2015) | EU countries | 1992–2010 | the FMOLS estimations | Short-run unidirectional panel causality from GDP to EC. |
| Destek (2016) | 26 OECD countries | 1991–2013 | FMOLS and DOLS; Granger causality | Unidirectional causality from natural gas consumption to GDP, which supports the growth hypothesis for the short-run. |
| Antonakakis et al. (2017) | 106 countries | 1971–2011 | Panel Vector Autoregression (PVAR) | Causality between total EG and EC is bidirectional, thus making a case for the feedback hypothesis. |

Some researchers on energy economics, such as [Shahbaz et al. \(2013\)](#), [Salahuddin and Gow \(2014\)](#), [Omri and Kahouli \(2014b\)](#), [Saidi and Hammami \(2015\)](#), [Kahouli \(2017b,c\)](#), among others, included EG, CO2 emissions, capital stock, labor force, and total population variables in their empirical models to study the impact of these variables on EC. They generally found that these variables are important and have a statistically significant influence on EG. Empirically, to examine the relationship between economic growth and energy consumption we also specify a model where energy consumption is explained by the variables mentioned above. Thus, our proposed model, which seems to be consistent with the broader literature on the determinants of EC cited above, takes the following from:

$$\ln EC_{it} = \alpha_0 + \alpha_1 \ln EC_{it-1} + \alpha_2 \ln Y_{it} + \alpha_3 \ln FDI_{it} + \alpha_4 \ln T_{it} + \alpha_5 \ln RD_{it} + \alpha_6 \ln CO2_{it} + \alpha_7 \ln UR_{it} + \alpha_8 \ln CPI_{it}$$

$$+ \alpha_9 \ln POP_{it} + \varepsilon_{it} \quad (6)$$

Eq. (6) examines the determinants of EC per capita to explain the link between EC and EG. In addition to the variables mentioned above, we also mention $\ln EC_{it-1}$ is EC lagged variable. $\ln CO2_{it}$ is CO2 emissions. $\ln UR_{it}$ is urbanization. $\ln CPI_{it}$ is consumer price index. $\ln POP_{it}$ is population.

In the beginning, each model will be estimated statically and dynamically. Then, to examine the two-way linkages between growth and energy, the previous models (models 5 and 6) will be considered simultaneously. These simultaneous-equation models are also constructed on the basis of the theoretical and empirical insights from the existing literature ([Omri and Kahouli, 2014a](#); [Saidi and Hammami, 2015](#)). Furthermore, the model 7 allows to investigate at the same time the interrelationship between EC and EG estimated by 3SLS and GMM. In general, a simultaneous

equation model (SEM) can be used to capture the complex cause–effect relationships and interactions between EC and EG. SEM is a modeling technique that can handle a large number of (observed) endogenous and exogenous variables.

The two-way linkages between EC and growth are empirically examined by making use of the following two equations:

$$\begin{cases} \ln Y_{it} = \alpha_0 + \alpha_1 \ln Y_{it-1} + \alpha_2 \ln EC_{it} + \alpha_3 \ln FDI_{it} + \alpha_4 \ln RD_{it} \\ \quad + \alpha_5 \ln T_{it} + \alpha_6 \ln K_{it} + \alpha_7 \ln L_{it} + \alpha_8 \ln HK_{it} + \alpha_9 \ln INF_{it} + \varepsilon_{it} \\ \ln EC_{it} = \alpha_0 + \alpha_1 \ln EC_{it-1} + \alpha_2 \ln Y_{it} + \alpha_3 \ln FDI_{it} + \alpha_4 \ln RD_{it} \\ \quad + \alpha_5 \ln T_{it} + \alpha_6 \ln CO2_{it} + \alpha_7 \ln UR_{it} + \alpha_8 \ln CPI_{it} \\ \quad + \alpha_9 \ln POP_{it} + \varepsilon_{it} \end{cases} \quad (7)$$

In the above equations, the subscript $i = 1, \dots, N$ denotes the country and $t = 1, \dots, T$ denotes the time period. The first part of the Eq. (7) states that energy consumption (EC), foreign direct investment (FDI), research and development expenditure (RD), trade openness (T), capital stocks (K), labor force (L), human capital (HK), inflation rate (INF) are the driving forces of growth (Y). The second part of the Eq. (7) postulates that EC can be influenced by growth (Y), foreign direct investment (FDI), research and development expenditure (RD), trade openness (T), CO2 emissions (C), urbanization (UR), consumer price index (CPI), population (POP). The lagged dependent variables embody all the information that was important for determining the endogenous variable at that time, including time-varying unobservable. Indeed, the lagged dependent variable can serve as a partial control for them as well. Another important advantage of including lagged dependent GDP is that we can investigate one of the most important characteristics of a growth process: the dynamic path over time that it seems to be following. In this study, the presence of the lagged dependent variable in the model indicates the dynamic nature of EC which explains the interdependent EC across periods. One would expect a production process would require stable and continuous level of EC. In other words, the level of energy consumption would normally follow the similar pattern of the previous period consumption. Similarly, the overall EC by the end-user is assumed to invariably follow the similar pattern without sudden shocks.

There are two conditions to identify the equations as follow: rank condition and order condition. By analyzing endogenous and exogenous variables in the equations system, it can be said the two equations were overly identified. Rank condition is just one of the conditions for the identification of simultaneous equations. But one of the other conditions in relation to the identification of simultaneous equations is the order condition which is rated as a necessary and sufficient condition. If this condition is met, the rank condition is also met. A simultaneous equation has rank condition if at least one nonzero determinant of the endogenous variables and external factors outside of the equation but included in other equations can be found in it. With regard to the issues related to identification of simultaneous equations, it is clear that the above equations are overly identification and exactly identification.

3.2. Estimation strategies

To study the growth–energy nexus, energy–growth nexus and the causality relationship between them we use both static and dynamic techniques. Before everything else, models 5 and 6 are estimated statistically by using OLS pooled, within and the GLS estimators (static techniques). Therefore, we use the Hausman test which allows choosing between within and GLS estimators. However, they can be validly questioned due to concerns over the potential endogeneity and simultaneity of the energy and growth variables in the extant theoretical and empirical discussions. Likewise, the OLS estimator is inconsistent with the presence of endogeneity. This means that using single equation in cross-country regression model may produce inconsistent results. In

response to these concerns, the simultaneous system of equations (model 7) approach was adopted taking into account instrumental variables (dynamic techniques). The specification of the econometric model is that the two sets of equations (EC and EG models) are estimated jointly through the system of equations technique. Then, instrumental variable estimation technique has been used to estimate Eqs. (5)–(7) separately (GMM) and simultaneously (3SLS and GMM regressions). The use of the panel estimation techniques allows taking into consideration both of the specific temporal and transversal of data (Kahouli and Kadhraoui, 2012). These techniques produce more variability, more degrees of freedom, and more efficiency and minimize the risk of multicollinearity between the explanatory variables.

The GMM is the estimation method most commonly used in panel data. There are two variances of GMM estimators: The first difference GMM and GMM system estimator. The GMM estimator in first differences involves taking in each period the first difference from equation to estimate for eliminating country-specific effects instrumented and afterward the explanatory variables in the equation in first differences delayed by their level values of a period or more. The system GMM estimator that combines first difference equations with the level equations in which the variables are instrumented by their first differences, which appears more powerful than the one that was advanced by Arellano and Bond (1991) and Blundell and Bond (1998). The GMM method uses a set of instrumental variables to solve the endogeneity problem. It provides consistent and efficient estimates in the presence of arbitrary heteroskedasticity. The instruments' validity is tested using Hansen test which cannot reject the null hypothesis of over identifying restrictions. If appropriate instrumental variables can be found for the endogenous variables that appear as regressors in the simultaneous equation, the instrumental variable technique provides consistent estimates (Iamsiraroj, 2015). Consistency of the GMM estimator depends on the validity of the instruments. Two specification tests are used: Firstly, Sargan/Hansen test of over-identifying restrictions which tests for overall validity of the instruments and the null hypothesis is that all instruments as a group are exogenous. The second test examines the null hypothesis that error term of the differenced equation is not serially correlated particularly at the second order (AR2). One should not reject the null hypothesis of both tests.

In the simultaneous system of equations approach, EC, EG, FDI, R&D expenditure and openness to trade are considered as endogenous variables. The set of instrumental variables that is validated by the over-identifying restrictions test included a one-period lag of the endogenous variables and some explanatory variables: inflation, capital, labor and human capital. All other explanatory variables were used as instruments, but they were not lagged, assuming that they are exogenous.

3.3. Data and descriptive statistics

Global economic expansions are gaining momentum thanks to a robust increase in investment, a rebound in trade and restart the job, according to latest Interim Economic Outlook OECD. The economic and energy challenges of OECD countries present an analysis of the major economic trends that will mark the coming years. Demographic and economic growth translates into a rapid increase in energy demand in the OECD. Although associated with greater prosperity, this growing demand poses new challenges. Energy security problems are likely to arise, as the increase in the number of consumers requires ever more energy resources. However, these challenges can provide a road map for this study to examine the relationship between EC and EG, on one hand and learn about the effective economic and energy policy implications for the OECD, on another hand. To examine the relationship between EG and EC, a

balanced panel data consists of annual data regarding EG and EC of 34 OECD countries over the period 1990–2015 (see [Appendix A](#)). The timeframe was constrained by the availability of data.

This study employs data of per capita energy consumption (EC), real GDP per capita (Y). Trade openness (T) is the sum of exports and imports of goods and services measured as a percentage of GDP. Foreign direct investment (FDI), RD is defined as the total expenditure on R&D carried out by all resident companies, research institutes, university and government laboratories, etc. Carbon dioxide emissions (CO₂) (measured in metric ton per capita), urbanization (UR: % urban population of total), secondary gross enrollment ratio (HK). Capital stock is proxied by the gross fixed capital formation (constant 2005 US\$). The consumer price index (CPI), inflation rate (INF), population (in thousands) and total labor force (% of total population). All the data were gathered from the World Bank's Development Indicators database provided by the World Bank, OECD database, IMF database (DOTS). Data is transformed into log form for analysis that makes the interpretation of results comparatively easier. One of the reasons for transforming the economic models to logarithmic models is changing economic models into linear models. Variables used for estimation purpose with their measurement, definition, source, and expected sign are mentioned in [Appendix D](#).

The descriptive statistics ([Appendix B](#)) and the correlation matrix (for Eqs. (5) and (6)) are presented in the following (see [Appendix C.3](#) and [C.4](#)). The descriptive statistics shows that the data are fairly dispersed. The standard deviations show that the data are considerably homogeneous. The results show that EG, EC FDI, trade, R&D expenditure, capital stock, and human capital are normally distributed confirmed by Jarque–Bera test statistics. The correlation matrix for the two equations is reported to check for multicollinearity among variables. By looking at the results, the major observations that should be highlighted are as follows: there is a significant correlation between all variables for two equations at 5% level. Positive and significant correlations exist between EG and EC. There is also a strong correlation among EG and all explicative variables, except labor. EG is positively and significantly correlated with, FDI, trade, R&D expenditure, capital stock, and human capital. However, it is negatively correlated with the inflation rate. Concerning the variables in Eq. (6), EC is positively and significantly correlated with all variables except population. It can be argued that the expected results will be in the same direction that meaning a positive and significant relation between EG and EC and consequently the existence of a feedback relation.

4. Results and discussion

Parameter estimates of the EG and EC from Eqs. (5)–(7) are given in [Tables 2–4](#). The results are consistent with existing findings in the literature ([Sharma, 2010](#); [Belke et al., 2011](#); [Shahbaz et al., 2013](#); [Omri and Kahouli, 2014b](#); [Komal and Abbas, 2015](#); [Kahouli and Omri, 2017a](#); [Kahouli, 2017b](#)). [Table 2](#) shows the estimation results of the impact of EG on EC with static and dynamic panels. The empirical results about Eq. (6) i.e. the energy–growth nexus with static and dynamic panels are presented in [Table 3](#). Likewise, [Table 4](#) determines the causality relationship between EG and EC estimated by making use of 3SLS and GMM estimators. The unit root test rejects the null hypothesis for each variable. The result shows that the variables are stationary ([Levin et al., 2002](#); [Im et al., 2003](#)). For the three estimated Eqs. (5)–(7), most obtained coefficients have the expected signs at both the static and dynamic level. Furthermore, the explanatory power of R^2 is very important for EG model and less important for EC model, and F-statistics are statistically significant at 1% level for all models. This implies that the share of the intra-individual variability of the dependent variable explained by those of the explanatory variables

is higher in the growth model than in the case of energy. Likewise, [Tables 2–4](#) report the results for which diagnostic tests (the Hansen statistic test for over identification, and Arellano–Bond test for the existence of the second order autocorrelation in first differences (AR2 test) show a good statistical performance. For each of the estimates reported, the AR(2) tests show no evidence of autocorrelation at conventional levels of significance. Hansen tests show no evidence of miss specification at conventional significance levels. These results indicate that the dynamic panel EG and EC models are a good specification.

The specification tests reported at the bottom of [Tables 2](#) and [3](#) confirm relevance and validity of the instruments. The Kleibergen–Paap test for weak identification shows F-statistics that exceeds a widely used rule of thumb of 10 ([Staiger and Stock, 1997](#)). On this basis the joint significance of excluded restrictions in the first-stage regressions is not rejected. Indeed, F-statistics are above the reported [Stock and Yogo \(2005\)](#) weak ID test critical value (for 10–15% relative IV bias toleration) across different specifications of EG and EC, eliminating the concern that the excluded instruments are weakly correlated with the endogenous regressors ([Stock and Yogo, 2005](#)). Another weak-instrument diagnostic that we report is Shea partial R². It takes into account the inter-correlations among the instruments; the high value indicates that the endogenous regressor is not weakly identified. Then we can conclude that the instruments are sufficiently relevant and that the model can therefore be identified.

The validity of the instruments is tested with Hansen's J-test. As the reported p-values are greater than 0.05 in all the models, we do not reject the joint null hypothesis that the instruments are valid, i.e. they are uncorrelated with the error term, and conclude that the over-identifying restriction is valid.

Starting with [Table 2](#) and model 5, the results show that the majority of coefficients are statistically significant and their signs are according to economic theory. The Hausman test proves that Within estimator is more preferred than GLS estimator. As well as using of GMM techniques is verified following problem endogeneity. The Hansen statistics reported are equivalent to the Sargan test which can test restrictions on the identification and heteroscedasticity. Usually, the results confirm the acceptance of the null hypothesis that the restriction on the identification is valid. The results of the AR(2) tests reported indicate that the second order correlation is present in most models (same thing for Eq. (6)). The empirical results show that lagged EG is positively associated with GDP per capita and its coefficient is highly significant. The results highlight that GDP per capita of the previous year is a major contributor to GDP per capita of the current year. In addition, we find that EC has a positive and significant impact on GDP per capita. This suggests that an increase in EC per capita tends to rise EG in OECD countries. The difference between the two approaches (static and dynamic techniques) is not very marked in terms of sign, magnitude and statistical significance. The results imply that a 1% increase in EC increases EG by approximately 0.11%. This result is very consistent with the findings of [Dedeoglu and Kaya \(2013\)](#); [Raza et al. \(2015\)](#); [Kasman and Duman \(2015\)](#). This means that EC has a direct link with EG. [Sharma \(2010\)](#) mentioned that energy is an input in the production process, as it is used in commercial and non-commercial activities.

Regarding the FDI variable, we find that foreign investment has an insignificant positive impact on GDP per capita for dynamic regression. This result is consistent with the findings of [Ren et al. \(2014\)](#); [Sbia et al. \(2015\)](#) that FDI inflow leads to the creation of employment and consequently promotes EG. In the same context, we find that while R&D expenditure, trade and capital stock (GFCF) have a statistically significant positive effect and inflation has a statistically significant negative effect on EG, human capital and labor has a statistically insignificant effect on EG. These results

Table 2

Estimations the impact of Economic Growth on Energy Consumption with static and dynamic panel.

| Variables | Economic growth | | | Dynamic | | |
|-------------------------------|-----------------|------------------|-----------------|----------------------|-----------------|----------------|
| | Static | | | Dynamic | | |
| | OLS Pooled | Within estimator | GLS estimator | GMM DIFF | GMM one step | GMM two step |
| Lagged economic growth | – | – | – | .517 (8.54)*** | .877 (36.10)*** | .875 (9.79)*** |
| Energy consumption | .105 (3.64)*** | .066 (0.83) ** | .108 (1.63)** | .127 tabbr (3.07)*** | .010 (0.99)** | .026 (1.14)** |
| FDI | .022 (2.55)** | .002 (0.81) | .001 (0.44) | .000 (0.44) | .000(0.22) | –.000 (–0.13) |
| R&D expenditure | .149 (10.25)*** | .121 (3.69)*** | .180 (6.24)*** | .023 (1.68)* | .000 (0.09) | –.016(–0.52) |
| Trade | .068 (2.73)*** | .267(3.98)*** | .178(3.53)*** | .105 (4.89)*** | –.005 (–0.73) | –.013 (–0.93) |
| Capital | .777 (26.12)*** | .326 (7.89)*** | .367 (8.75)*** | .235 (8.35)*** | .110 (5.93)*** | .141 (2.88)*** |
| Labor | .006 (0.77) | .162 (1.51) | .025 (0.84) | –.028 (–0.41) | .000 (0.08) | .000 (0.10) |
| Human capital (School) | –.082 (–1.29) | –.077 (–1.00) | –.062 (–0.84) | .026 (1.80)* | –.004 (–0.27) | –.017 (–0.46) |
| Inflation | –.002 (–0.30) | –.010 (–2.06)** | –.010 (–1.92)** | –.004 (–2.73)*** | .001 (0.67) | .001 (0.71) |
| Constant | 3.139 (7.16)*** | 2.080 (1.06)*** | 3.269 (3.94)*** | – | .244 (1.68)* | .146 (0.35) |
| R | 0.956 | 0.875 | 0.921 | – | – | – |
| N | 454 | 454 | 454 | 362 | 454 | – |
| F-Statistique | (1491.83)*** | (104.69)*** | (834.30)*** | (3585.87)*** | (112987.90)*** | – |
| Hausman Test | – | (1873.99)*** | (1873.99)*** | – | – | – |
| Hansen test | – | – | – | 28.23 | 26.59 | 24.70 |
| AR(2) | – | – | – | 2.25 | 1.56 | 1.53 |
| Stock–Yogo weak ID test | – | – | – | 17.49 | 15.61 | 14.96 |
| Shea's partial R ² | – | – | – | 0.38 | 0.27 | 0.23 |
| Kleibergen–Paap F | – | – | – | 29.89 | 25.56 | 23.25 |

The values in parentheses are robust t student.

*Indicate significance level at 10%.

**Indicate significance levels at 5%.

***Indicate significance levels at 1%.

Table 3

Estimations the Impact of Energy Consumption on Economic Growth with Static and Dynamic Panel.

| Variables | Energy consumption | | | Dynamic | | |
|-------------------------------|--------------------|------------------|-----------------|-----------------|------------------|------------------|
| | Static | | | Dynamic | | |
| | OLS Pooled | Within estimator | GLS estimator | GMM DIFF | GMM one step | GMM two step |
| Lagged energy consumption | – | – | – | .120 (1.72)* | .586 (4.81)*** | .500 (3.41)*** |
| Economic growth | .049 (0.84) | .058 (1.36) | .092 (2.01)** | .131 (3.81)*** | .257 (3.89)*** | .140 (1.82)* |
| FDI | .014 (1.05) | .002 (1.11) | .001 (0.80) | .002 (0.98) | .006 (1.50) | .007 (1.75)* |
| R&D expenditure | .142 (4.76)*** | .048 (2.55) ** | .055 (2.90)*** | .003(0.38) | .195 (6.55) *** | .146 (3.35)*** |
| Trade | –.087 (–2.05)** | .065 (1.86)* | .040 (1.50) | .025 (0.80) | –.100 (–2.22)** | –.098 (–2.23)** |
| CO2 emissions | .532(14.98)*** | .585(10.52)*** | .572 (8.19) | .606 (20.56)*** | .234 (2.43)** | .264 (2.24)** |
| Urbanization | .269 (3.11)*** | –.166 (–0.67) | –.000 (–0.00) | –.073(–0.29) | .047 (0.30) | .063 (0.42) |
| Consumer price index | –.048 (–1.29) | .011 (0.84) | .011(0.75) | –.004 (–0.53) | .001 (0.06) | .003 (0.13) |
| Population | –.077(–4.71)*** | .116(0.63) | –.041 (–1.63) | .232 (0.86) | –.053 (–3.29)*** | –.050 (–3.29)*** |
| Constant | 5.729 (10.64)*** | 4.324 (1.72)* | 5.948 (6.90)*** | – | 4.523 (6.56)*** | 4.334 (4.92) *** |
| R | 0.775 | 0.629 | 0.728 | – | – | – |
| N | 454 | 454 | 454 | 381 | 454 | 454 |
| F-Statistique | (330.47)*** | (68.99)*** | (723.91)*** | (1397.01)*** | (1147.86)*** | (885.31)*** |
| Hausman Test | – | (25.51)*** | (25.51)*** | – | – | – |
| Hansen test | – | – | – | 24.32 | 24.69 | 24.69 |
| AR(2) | – | – | – | 1.23 | 1.97 | 1.87 |
| Stock–Yogo weak ID test | – | – | – | 15.35 | 13.42 | 11.98 |
| Shea's partial R ² | – | – | – | 0.29 | 0.21 | 0.18 |
| Kleibergen–Paap F | – | – | – | 21.54 | 19.58 | 18.98 |

The values in parentheses are robust t student.

*Indicate significance level at 10%.

**Indicate significance levels at 5%.

***Indicate significance levels at 1%.

are consistent with the findings of Sharma (2010); Omri (2013); Omri and Kahouli (2014b). Trade liberalization politics tend to promote EG (Kahouli and Kadhraoui, 2012); (Kahouli and et Maktouf, 2014a,b). Foreign trade needs a well-functioning transportation network and transportation consumes energy in moving goods by air, rail, road, water and pipeline. Likewise, capital plays an important role in EG and production. The effect of inflation on EG is detrimental and unfavorable. EG decreases by about 0.01 percent with an increase in inflation rate by one percent. This result is in line with economic theory that inflation reduces the purchasing power of the economic welfare (Kahouli and Kadhraoui, 2012; Omri and Kahouli, 2014b; Kahouli and et Maktouf, 2015).

Table 3 contains results for the estimations of Eq. (6) with static and dynamic panel. The results with EC as dependent variable

show that the coefficients of delayed EC have a positive and significant effect on current EC for all GMM regressions (Difference and system). The magnitude of 0.5 (GMM system) implies that 1% increase in lagged EC increases current EC by 0.5%. The results of dynamic techniques show that EG coefficients have a bigger and significant effect on EC compared to other variables such as FDI and trade. Specifically, 1% increase in EG associates with 0.25% increase in EC (GMM one step estimator). This result is very consistent with the findings of Coers and Sanders (2013); Fuinhas and Marques (2012) that EC will increase when the GDP for the OECD has increased. Trade openness has negative and statically significant effect on EC, which shows that EC decreases by about 0.1 percent

with increase in trade by one percent. This result is in line with economic theory that the reduction of trade barriers leads to the decline of the transport costs (Ghani, 2012; Kahouli and et Maktouf, 2014b, 2015). Concerning the dynamic regressions, the coefficient of R&D expenditure is positive and statistically significant. It shows that 1% increase in R&D has led to about 0.19% increase EC. This result is consistent with Garrone and Grilli (2010); Kahouli (2017b) which confirms that government R&D spending is not sufficient by itself to boost the energy innovation process. Public energy R&D has been successful in improving energy efficiency at country level. Indeed, Inglesi-Lotz (2017) mentioned that primarily R&D investment in Energy Efficiency technologies yields to high social benefits. In the same context, we find that while CO₂ emissions have a statistically significant positive effect and population has a statistically significant negative effect on EC, urbanization has a statistically insignificant effect on EC. This indicates that an increase in EC tends to promote environment degradation. However, some research found a linear relationship between CO₂ emissions and EC like the contribution of Shahbaz et al. (2013); Bella et al. (2014); Ajmi et al. (2015); Heidari et al. (2015). Our empirical results indicate that EC is a major contributor to CO₂ emissions in case of OECD countries. The transportation network requires EC which generates CO₂ emissions and consequently leads to the degradation of the environment. OECD policy makers should consolidate the existence of alternative energy sources such as nuclear and renewable energy. It suggests that a 1% increase in population decrease EC by 0.05% (dynamic regression). This observation seems to be abnormal and contradictory Omri and Kahouli (2014b); Saidi and Hammami (2015) that highlighted that the increase in the size of the market (consumers) raises energy use.

In terms of FDI and consumer price index (CPI), the results show that they are not having implications on EC. Table 3 shows no significant relationship between FDI and EC for OECD countries. This result might be due to the existing high level of technological adoption in OECD (equivalent to saying that there is a relatively small technological gap between domestic and foreign firms), the export-orientation of local production and the structure of production in OECD. This result is consistent with the finding of Hübner and Keller (2009); Eliott et al. (2012) who indicate that multinational companies (MNCs) use less energy per unit of output. Indeed, the fluctuation of price has no effect on EC in OECD countries. These results imply that the demand for energy does not depend on the income level of the populace. Extra income does not induce citizens to spend more on energy. However, the results are not consistent with the findings of Shafiei and Salim (2014); Saidi and Hammami (2015); Kasman and Duman (2015) who confirm the significant and positive relation between the demographic indicators (population and urbanization) and the EC. Likewise, the phenomenon of urbanization in the OECD countries has no effect on EC.

Table 4 reports the results for Eq. (7) which examines the causality relationship between EG and EC. Simultaneous equations are estimated by making use of three stage least squares (3SLS) and the generalized method of moments (GMM). The majority of estimated coefficient is significant. While the parameter estimates remained similar in magnitude and sign, the GMM estimation results are generally found to be statistically more robust. We see that the lagged variables (EG and EC) are positive and statically significant for model 3 and 4 respectively, by using GMM simultaneous technique. Information about the growth and EC from the previous year supports both variables for the following year. The empirical results imply the existence of a bidirectional causal relationship (feedback) between the two variables in static and dynamic level. Static and dynamic simultaneous regressions show that EC has a positive and significant impact on EG. The magnitude of 0.12 (3SLS) and 0.016 (GMM) implies that a 1% increase in EC

increases the EG by 0.12% and 0.017% respectively. This suggests that an increase in EC per capita tends to rise EG. This result is very consistent with the findings of Omri (2013); Sabbori et al. (2014); Salahuddin and Gow (2014); Kasman and Duman (2015) indicate a positive and significant association between EC and EG. The coefficients of GDP per capita have positive and significant effects on EC for OECD countries (Models 2 and 4). It shows that 1% increase in EG has led to about 0.027% increase in EC. This indicates that an increase in EG tends to promote EC. Our results are also in line with findings by Belloumi (2009); Omri (2013); Dedeoglu and Kaya (2013); Begum et al. (2015); Ajmi et al. (2015) that EC will increase when the GDP per capita has increased and that EG does have a causal relationship on EC. In this context, it can be confirmed the validity of the feedback hypothesis implies that growth and energy are jointly determined and affected from each other simultaneously.

In models 1 and 3, the results prove that FDI has positive and statistically significant impact on GDP per capita and EC. Specifically, 1% increase in FDI associates with 0.035% increase in EG (model 1). This result is consistent with the findings of Ting et al. (2011); Pao and Tsai (2011) that FDI inflows promote production and consequently increase EC. In the same context, we find that while R&D expenditure, CO₂ emissions and capital stock (GFCF) have a statistically significant positive effect, trade and population have a statistically significant negative effect on OECD EG and EC. The low birth rates observed (mostly negative) in most OECD countries in recent decades have led to a slowdown in population growth and are expected to profoundly transform the age pyramid (−0.69, −0.40 and −0.23 respectively for Germany, Italy and Japan for 2010–2020). Demographic trends are expected to have important economic effects, due to the double play of population size (slower growth) and their age structure (aging). In fact, this aging will deeply affect the structure of the economy in industrialized countries and in many ways by its repercussions on the labor market, the composition of demand, the rate of saving and accumulation of capital, etc. It is therefore expected that the phenomenon of the aging of the population implies a decline in the EC.

This result is in line with economic theory that the reduction of trade barriers leads to the decline of the transport costs (Ghani, 2012; Kahouli and et Maktouf, 2014b, 2015). Likewise, capital plays an important role in EG and production (Omri, 2013; Omri and Kahouli, 2014b). EC is a major contributor to CO₂ emissions (Kahouli and Omri, 2017a). The magnitude of 0.49 (Model 2) implies that 1% increase in EC increases CO₂ emissions by 0.5%. This result is also in line with economic theory that the increasing of EC leads to the rise in CO₂ emissions (Bella et al., 2014; Boutabba, 2014; Kasman and Duman, 2015). In addition, our empirical exercise indicates that although inflation has an insignificant positive impact on EG; nevertheless, consumer price index and labor has an insignificant and negative impact, respectively on EC and GDP per capita. These results are consistent with the findings of Sharma (2010); Omri (2013); Omri and Kahouli (2014b).

This research provides methodological implications by employing static and dynamic panel approach. The panel model allows for dynamic in the underlying process may be crucial for recovering consistent estimates of other parameters. The results based on dynamic panel models are very impressive and indicate a good fit of the model to the data. Critically, though, the results of this study pave the way for a more mixed method approach to economic and energy political decision in OECD. A supporting quantitative study may utilize some of the concerns made here and explore the meanings attached to constructs chosen. Like most studies, this study is subject to some limitations. First, the study uses the total expenditure on R&D carried out by all resident companies, research institutes, university and government laboratories, etc. However,

Table 4

Estimations the Causality Relationship between Economic Growth and Energy Consumption.

| Variables | Static Simultaneous Equations (3SLS) | | GMM Simultaneous Equations | |
|---------------------------|--------------------------------------|------------------------------|----------------------------|------------------------------|
| | Model 1 : GDP | Model 2 : Energy consumption | Model 3 : GDP | Model 4 : Energy consumption |
| Lagged economic growth | – | – | .916 (87.73)*** | – |
| Lagged energy consumption | – | – | – | .989 (89.21)*** |
| Economic growth | – | .027 (0.47)** | – | .022 (1.77)* |
| Energy consumption | .214 (6.29)*** | – | .016 (1.72)* | – |
| FDI | .035 (4.63)*** | .018 (1.44) | .002 (2.23)** | .005 (2.03)** |
| R&D expenditure | .177 (10.36)*** | .160 (5.14)*** | .005 (1.40) | –.010 (–1.42) |
| Trade | –.107 (–4.31)*** | –.115 (–2.98)*** | –.004 (–1.20) | –.004 (–0.55) |
| Capital | .767 (26.43)*** | – | .074 (6.52)*** | – |
| Labor | –.008 (–1.14) | – | –.002 (–1.61) | – |
| Human capital (School) | –.111 (–1.67)* | – | –.006 (–0.67) | – |
| Inflation | .000 (0.02) | – | .002 (1.08) | – |
| CO2 emissions | – | .499 (15.87)*** | – | .015 (1.76)* |
| Urbanization | – | .240 (2.77)*** | – | .018 (1.24) |
| Consumer price index | – | –.057 (–1.21) | – | –.012 (–1.43) |
| Population | – | –.083 (–7.90)*** | – | –.006 (–2.76)*** |
| Constant | 4.277 (9.23)*** | 6.195 (9.84)*** | .368 (3.94)*** | .078 (0.54) |
| R | 0.954 | 0.783 | – | – |
| N | 408 | 408 | 452 | 408 |
| Hansen J-test(p-value) | – | – | 13.337 (0.13) | 1.063 (0.785) |
| DWH test | – | – | (10.996)*** | (4.181)** |

The values in parentheses are robust t student. DWH test : Durbin–Wu–Hausman endogeneity test.

*Indicate significance level at 10%.

**Indicate significance levels at 5%.

***Indicate significance levels at 1%.

some OECD expenditure on R&D is not significant. Instead, it will be more efficient to use government expenditures since public investments in public utilities such as energy have an influence on EC and EG). Second, expand the time-series dimension by using quarterly data for electricity consumption and national income growth. Most public source economic databases provide mainly annual data for these variables, which significantly limits the observations for the OECD.

5. Conclusion

This paper has examined the growth–energy nexus, energy–growth nexus and the two-way linkages between them for 34 OECD countries from 1980 to 2015, explicitly taking into account the role of several other explanatory variables such as FDI, trade, R&D expenditure, macro-economic and demographic indicators, etc. For this purpose, several techniques at static and dynamic level have been used. Furthermore, the relationship between EG and EC is fundamental in achieving sustainable development. For this purpose, three questions are designed and examined by the models introduced in this study. Our main empirical finding proves the existence of a strong and robust link between them (Fig. 1.). The results obtained show that the dynamic model is true, it means that the static model suffers from the issue of omitted variables and endogeneity (GLS estimator is preferable then within estimator). The results suggest that there is a unidirectional relationship from energy to EG. According to static and dynamic estimators, the EC growth is one of the engines of EG. Therefore, the decrease of EC may hurt the process of EG. Likewise, there is a unidirectional causality from EG to accelerate the EC (especially in dynamic estimator). It implies that the restriction on EC have no or little adverse effects on the EG of the OECD countries. Furthermore, the result indicates that there is bidirectional causality between energy and growth. It implies that the EC and EG jointly determine each other.

This tendency is similar to the results of Dedeoglu and Kaya (2013); Sabbori et al. (2014); Omri and Kahouli (2014b); Salahuddin and Gow (2014); Kasman and Duman (2015); Raza et al. (2015). Indeed, we conclude that the relation between growth and energy is important and vital. In addition, the results have shown that

support of trade openness and FDI inflows in OECD countries is not enough. Policy makers need therefore to explicitly foster foreign investments that provide the decline of EC and improving the political environment as well as the quality of infrastructures. The presence of bidirectional causality stipulates that the two variables influence each other. This implies that energy and economic policies will have to be implemented jointly. Likewise, the result suggests that OECD countries must consolidate and restructure the energy sector so that it can have a strong influence on EG. To do this, governments must: First, invest in production infrastructure using renewable energy (hydro, solar, wind). Second, integrate energy into national and sectoral development strategies. Third, promote the establishment of new production units in the industrial sector. Nevertheless, the energy is the main source of CO2 emissions and results in adverse environmental effects in the OECD countries. These countries should promote the use of renewable sources such as wind in which they have clear advantage over many other countries.

The major policy implications that can be derived from our paper can be stated as follows. In the beginning, OECD governments are required to provide accurate information about energy demand in order to be able to predict the future requirements and to take into account the necessary capacity to satisfy future EC. The unidirectional causality running (static and dynamic estimators) from EG to EC suggests that the economy is relatively less dependent on energy and that maintaining the same level of EC will have a marginal impact on EG. In such a situation, policy makers can reduce the tax burden in order to attract the potential investors, or they can increase budget spending. However, the 3SLS and GMM estimators suggests that EC is important for EG. The presence of causality provides an avenue to continue the use of government policies that enhance the development of the energy sector. Afterwards, considering the adverse impact of EC on the environment (CO2 emissions), policy makers should provide additional and diversify sources of energy of domestic production (renewable energy, for example) and implementation policies that aim to reduce carbon emissions to protect the environment. Support for energy renewable in OECD countries is the most promising option to ensure the adoption of readily available solutions preserving the ability to reach the climate targets while

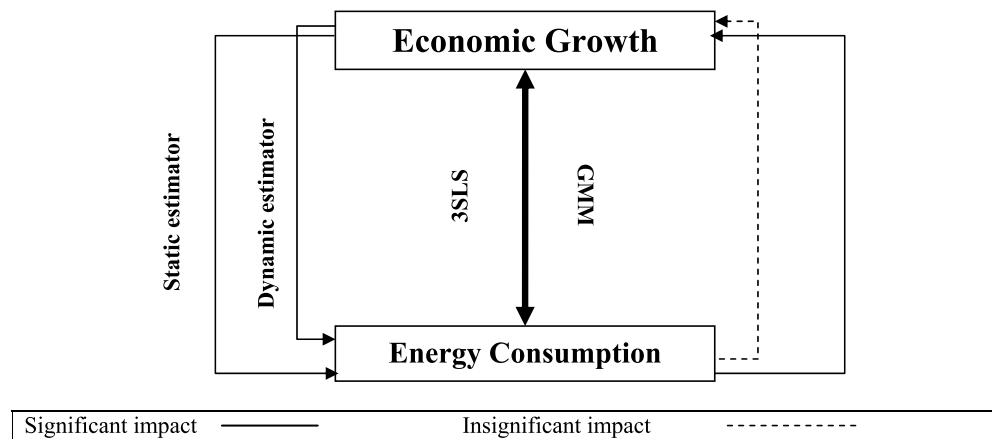


Fig. 1. Static and dynamic relationship between EG and EC.

stimulating the development. Likewise, OECD countries need to promote and increase expenditures on R&D in the field of energy. These countries should provide funding to R&D for companies to innovate and promote energy saving technologies. Finally, the complementarities between economic policy and energy policy are crucial and vital to consolidate the robust relationship between EG and EC. For OECD European countries, the establishment of the Energy Union will contribute to boosting the EU economy and strengthening its security as well as its determination to fight against climate change. The EU must also modernize aging energy infrastructure, fully integrate its energy markets and coordinate national energy prices. The establishment of a fully functional Energy Union will enable EU consumers and businesses to benefit from greater choice and lower prices. Indeed, the withdrawal of the United States from the Paris Agreement has a dual purpose. Economically at the internal level: it is about protecting jobs in some sectors of the US economy. Politics at the external level: by asserting the freedom and the independence of the United States vis-à-vis international constraints. This America First policy turns out to be counterproductive in the long term. The US federal government loses leadership on the international scene and internal leadership, for the benefit of federated states or local actors such as cities, without guarantees of economic return. This issue is also important for the United States as it is not an accounting requirement for international climate change negotiations. Despite their share in GHG emissions (16%), the threshold of 55% of emissions, chosen for the entry into force of the Kyoto Protocol and then the Paris Agreement, can be achieved with various coalitions.

As already mentioned in literature review, many empirical studies have given different and sometimes contradictory results. In order to avoid this gap and to make future empirical results as robust and as representative as possible, and to determine as precisely as possible the causal relationship between EC and EG, further research is needed. We recommend to expand the time-series dimension by using quarterly data for EC and EG. Most public source economic databases provide mainly annual data for these variables, which significantly limits the observations for the OECD economies. Exploration of national accounts for quarterly data could provide a probable solution for the short time-series dimension. Moreover, we would advise to investigate multivariate causality between EC and EG and, depending on the data availability and reliability, to use other control variables such as government expenditures, financial development, research and development stock, a dummy variable capture the impact of the recent economic crisis. Likewise, Future research on this subject can potentially become more important if a combination of the

Table A.1

OECD countries.

| | | | |
|----------------|---------|-------------|----------------|
| Australia | France | South Korea | Slovenia |
| Austria | Germany | Luxembourg | Spain |
| Belgium | Greece | Mexico | Sweden |
| Canada | Hungary | Netherlands | Switzerland |
| Chile | Iceland | New Zealand | Turkey |
| Czech Republic | Ireland | Norway | United Kingdom |
| Denmark | Israel | Israel | United States |
| Estonia | Italy | Portugal | |
| Finland | Japan | Slovakia | |

following sophisticated econometric methods is used: nonlinear threshold regression model; unit root and cointegration methodologies, the leveraged bootstrap technique, Factor Analysis and cross-sectional dependence modeling. Finally, it is also important to remember that policy implications of the direction of causality spread beyond the statistical analysis of causality between few selected variables, and are not as straightforward as they might seem. Therefore, the formulation of solid energy policies requires consideration of such factors as energy efficiency, institutional constraints, existing supply infrastructures that also should be evaluated together with the causality links.

Appendix A

See [Table A.1](#)

Appendix B

See [Table B.2](#)

Appendix C

See [Tables C.3](#) and [C.4](#)

Appendix D

See [Table D.5](#)

Table B.2

Descriptive statistics.

| | Variable | Obs | Mean | Median | Std. Dev. | Min | Max | Skewness | Kurtosis | Jarque–Bera |
|---------|----------------------|-----|----------|----------|-----------|-----------|----------|----------|----------|-------------|
| Eq. (5) | Capital | 837 | 6410.866 | 6342.849 | 3685.123 | 611.145 | 20008.36 | 0.723 | 3.588 | 85.142 |
| | Labor | 850 | 1.65e+07 | 5032197 | 2.73e+07 | 143061 | 1.61e+08 | 3.475 | 16.576 | 8239.248 |
| | Inflation | 828 | 4.994 | 2.512 | 10.490 | −5.204 | 137.964 | 6.528 | 59.190 | 114808.9 |
| | Human capital | 771 | 103.016 | 101.004 | 16.461 | 50.285 | 165.581 | 0.477 | 5.143 | 176.891 |
| | FDI | 814 | 1617.027 | 391.923 | 7700.968 | −61833.04 | 150005.9 | 10.989 | 198.451 | 1312046 |
| | R&D expenditure | 542 | 60053.07 | 62733.02 | 45224.05 | 1778.039 | 173563.4 | 0.388 | 2.028 | 34.925 |
| | Trade | 834 | 82.644 | 68.400 | 49.830 | 15.923 | 374.147 | 2.273 | 10.774 | 2818.622 |
| | EG | 836 | 29289.34 | 29629.23 | 16692.13 | 4144.147 | 87772.69 | 0.605 | 3.235 | 53.073 |
| | EC | 816 | 4226.712 | 3734.879 | 2275.21 | 946.565 | 17964.44 | 2.126 | 10.920 | 2747.865 |
| | | | | | | | | | | Eq. (6) |
| | CO2 emissions | 739 | 739 | 8.408 | 4.264 | 2.345 | 27.431 | 1.397 | 5.412 | 419.862 |
| | Urbanization | 850 | 75.790 | 76.835 | 11.204 | 47.915 | 97.818 | −0.380 | 2.641 | 25.088 |
| | Consumer price index | 820 | 81.458 | 84.796 | 22.007 | .067 | 135.661 | −1.238 | 4.949 | 339.363 |
| | Population | 850 | 3.45e+07 | 10420384 | 5.41e+07 | 254826 | 3.19e+08 | 3.198 | 14.826 | 6402.876 |

Table C.3

Correlation between variables from Eq. (5).

| Variable | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|-------------------|----------|----------|----------|----------|----------|----------|----------|--------|---|
| 1 EG | 1 | | | | | | | | |
| 2 EC | 0.631** | 1 | | | | | | | |
| 3 FDI | 0.300** | 0.152** | 1 | | | | | | |
| 4 R&D expenditure | 0.825** | 0.633** | 0.139** | 1 | | | | | |
| 5 Trade | 0.344** | 0.213** | 0.439** | 0.051 | 1 | | | | |
| 6 Human capital | 0.376** | 0.310** | 0.064 | 0.365** | 0.065 | 1 | | | |
| 7 Capital | 0.951** | 0.569** | 0.302** | 0.793** | 0.346** | 0.387** | 1 | | |
| 8 Labor | 0.026 | 0.096** | −0.077** | 0.161** | −0.411** | −0.201** | 0.001 | 1 | |
| 9 Inflation | −0.341** | −0.247** | −0.041 | −0.252** | −0.138** | −0.446** | −0.341** | −0.025 | 1 |

**Indicate significance levels at 5%.

Table C.4

Correlation between variables from Eq. (6).

| Variable | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|------------------------|---------|---------|----------|---------|----------|---------|---------|-------|---|
| 1 EC | 1 | | | | | | | | |
| 2 EG | 0.631** | 1 | | | | | | | |
| 3 FDI | 0.152** | 0.300** | 1 | | | | | | |
| 4 R&D expenditure | 0.633** | 0.825** | 0.139** | 1 | | | | | |
| 5 Trade | 0.213** | 0.344** | 0.439** | 0.051 | 1 | | | | |
| 6 CO2 emissions | 0.601** | 0.447** | 0.189** | 0.373** | 0.326** | 1 | | | |
| 7 Urbanization | 0.457** | 0.391** | 0.118** | 0.568** | −0.043 | 0.278** | 1 | | |
| 8 Consumer price index | 0.178** | 0.380** | 0.128** | 0.344** | 0.231** | 0.170** | 0.232** | 1 | |
| 9 Population | 0.051 | −0.015 | −0.083** | 0.113** | −0.428** | 0.219** | 0.052 | 0.050 | 1 |

**Indicate significance levels at 5%.

Table D.5

Names, definitions, sources and expected signs of variables.

| Variable | Description | Source | Expected sign | | | | | |
|----------|---|---------------------------|---------------|---------|---------|---------|---------|---------|
| | | | Eq. (5) | | Eq. (6) | | Eq. (7) | |
| | | | Static | Dynamic | Static | Dynamic | Static | Dynamic |
| i | 25 countries | | | | | | | |
| t | Years 1990–2015 | | | | | | | |
| Y | Real gross domestic product per capita (constant 2005 US\$) | WDI (2015) | | | + | +/- | | |
| Y(t-1) | Lagged EG | Calculation of author | | + | | | | ? |
| EC | EC (kg of oil equivalent per capita) | WDI (2015) | + | + | | | | ? |
| EC(t-1) | Lagged EC | Calculation of author | | | | +/- | | ? |
| FDI | Foreign direct investment net inflows | OECD database | + | + | +/- | +/- | +/- | +/- |
| CO2 | Carbon dioxide emissions (metric tons per capita) | WDI (2015) | | | − | − | − | − |
| RD | Research and development expenditure (%GDP) | WDI (2015)/ OECD database | + | + | +/- | +/- | +/- | +/- |
| Trade | Trade openness (The ratio of exports plus imports to GDP) | IMF DOTS (2015) | + | + | +/- | +/- | +/- | +/- |
| UR | Urbanization (% urban population of total population) | WDI (2015) | | | +/- | ? | ? | ? |
| K | Capital stock: Gross fixed capital formation constant (constant 2005 US\$). | WDI (2015) | + | + | | | +/- | +/- |
| HK | Human capital : Gross enrollment ratio, secondary, both sexes (%) | WDI (2015) | + | +/- | | | +/- | ? |
| INF | Inflation rate : GDP deflator (%) | IMF (2015) | − | − | +/- | ? | − | ? |
| CPI | Consumer price index (constant 2005 US\$) | WDI (2015) | | | +/- | +/- | +/- | − |
| L | Total labor force | WDI (2015) | +/- | +/- | | | ? | ? |
| POP | Population (Residents) | WDI (2015) | | | +/- | ? | ? | ? |

Note: the signs (+) and (−) correspond respectively to the expected positive and negative effects; the sign (+/−) mean that the impact depends on the scale; and finally the sign (?) is put for the indefinite effect or difficult to arrest.

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