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Energy consumption and economic growth: New evidence from the OECD countries

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ABSTRACT

This paper introduces a growth model that considers the indicator of economic complexity as a measure of capabilities for exporting the high value-added (sophisticated) products. Empirically, the paper analyzes the effects of the renewable and the non-renewable energy consumption on the economic growth in the panel data of 29 Organization for Economic Co-operation and Development (OECD) countries for the period from 1990 to 2013. For this purpose, the paper considers the panel autoregressive distributed lag (ARDL) and the panel quantile regression (PQR) estimations. The paper finds that not only the economic complexity, but also both the non-renewable and the renewable energy consumption are positively associated with a higher rate of economic growth.

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1. Introduction

Renewable energy gains significant attention during the last decade. Indeed, renewables have been the fastest growing energy source in the world since the late 2000s [5]. The main reason for the rise of renewable energy is related to the climate change, one of the leading problems in today's world. Scientists are on the consensus that production of fossil fuel has a significant effect on greenhouse emissions, and this has been the fundamental source of the global warming. In other words, fossil fuel can drive the climate change. Climate change becomes to threaten the sustainable growth [26]; and therefore, policymakers gear up the investments in renewable energy, especially in most developed countries and some developing countries (e.g. Brazil and China). Indeed, effective renewable energy policies can reduce the level of greenhouse emissions and this can decelerate the climate change; i.e. renewable energy can provide the sustainable economic growth. At this stage, some efficient government policies, such as credit and tax benefits, renewable energy portfolio standards, and renewable energy certificates has also promoted the renewables [6]. Another reason for the rise of renewable consumption is that the technological improvement, which reduces the total costs of renewable energy installation facilities [11]. According to [6] and [7]; the remarkable price volatility in oil markets during the last decade is also a significant factor that leads to the rise of the renewable energy sources.

In the light of these developments, our paper aims to reanalyze the energy-growth in the panel data of 29 OECD countries for the period from 1990 to 2013. For this purpose, it theoretically builds up a new growth model that considers the impact of the economic complexity indicator as a measure of “capabilities” for exporting the high value-added (sophisticated) products. At this point, previous papers have paid regard to the effects of the capital and the

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labor in the growth models for analyzing the relationship between energy consumption and economic growth. This type of empirical modeling can be called as a "traditional" approach and it is mainly considered for addressing the issue of omitted variable bias (e.g. Refs. [6,7,9,5]). However, the traditional approach is actually based on the neoclassical K-L (Solow-Swan) growth model, which considers the effects of merely the capital and the labor on the economic growth.

However, the empirical growth literature has recently addressed the role of human capital (skills) and institutional quality (the rule of law and property rights) on economic growth. Technological improvement is closely associated with research and development (R&D) expenditures. It is also important to emphasize that the R&D expenditures are also one of the leading determinants of economic growth [43].[1] Indeed, the technological process is the main source of the economic growth and is closely related to the "capabilities" of an economy [20,21,23]. Therefore, the production in advanced economies is mainly based on the production of goods and services, which require the skilled labor and a higher level of technology. In the seminal paper [22], criticizes the above mentioned "traditional approach" to understand the economic growth process. The traditional approach assumes that there are only two factors (capital and labor) to explain economic growth; however [22], indicates that a production process not only depends on capital and labor but also requires "capabilities". According to [20]; "capabilities" consists of physical infrastructure (airports, highways, etc.), human capital (knowledge and skilled labor force), and institutional quality (patent laws, property rights, and the rule of law).

At this point, the capabilities of a country can be measured by the Economic Complexity Indicator (henceforth ECI) [19]. The ECI is firstly introduced by Ref. [20]. The ECI is constructed from international trade data from the COMTRADE database of the United Nations (UN) and the indicator considers the exporting goods; i.e. not all goods produced in a country. A higher value of the ECI indicates a higher level (sophisticated) capabilities of a country in the production process, especially in the manufacturing. Therefore, the ECI reflects the production characteristicş i.e. capabilities of a country [19].[2] In short, the ECI is also a measure of sophisticated and skilled-based labor production of a country as well as it captures the knowledge on the production of a country to achieve the desired (efficient) level of gross domestic product (GDP) [20,21]. In short, the ECI is closely related to the sustainable growth.[3]

In this paper, we propose a new approach to explain the economic growth process. In our empirical model, GDP per employed person is determined by the ECI and the primary energy consumption. Following [5]; we also divide the total energy consumption as the renewable- and the non-renewable energy consumption. At this stage, we empirically test the validity of our "new approach" for the economic growth and focus on 29 OECD countries for the period from 1990 to 2013. According to the dataset of [19]; the OECD countries are the highest level of the economic complexity and this could be the main driver of the economic growth. In other words, a higher industrialization and capabilities of an economy can lead to a higher level of economic growth in the OECD countries. However, achieving higher levels of economic complexity can also require a higher level of energy consumption. To test this hypothesis, that is, whether energy consumption and economic complexity lead to a higher economic growth, we run the panel autoregressive distributed lag and the panel quantile regression estimations.

To the best of our knowledge, our paper is the first in the literature to analyze the impacts of economic complexity as well as the renewable- and the non-renewable energy consumption within the context of "new" growth fundamentals. The context of "new" growth fundamentals are measured by the economic complexity indicator. The results of our paper demonstrate that not only the economic complexity but also the non-renewable and the renewable energy consumption are positively associated with a higher rate of economic growth in 29 OECD countries for the period from 1990 to 2013.

The rest of the paper is organized as follows. Section 2 briefly reviews the previous literature on the relationship between the energy consumption and the economic growth. Section 3 introduces the empirical model and the data as well as it explains the econometric methodology. Section 4 reports the empirical findings. Section 5 concludes the paper by discussing the findings and the policy implications.

2. Literature review

There are four hypotheses about the causality for the energy-growth nexus. First is the "growth hypothesis" and it indicates that the energy consumption causes to the economic growth. Second is the "conservation hypothesis", which proposed that the growth causes to the energy consumption. Third, is the "feedback hypothesis", and it suggests a bidirectional causality between the energy consumption and the growth. Finally, the "neutrality hypothesis" implies that there is no statistically significant causality between the growth and the energy consumption. Indeed, many papers empirically analyze the relationship between the energy consumption and the economic growth in different countries and regions by different datasets. These papers also consider different econometric methods; and therefore, the empirical results are miscellaneous. For example, the recent literature survey of [2] reviews 136 papers, which are published in the last three decades and the paper concludes that 41% of them obtain validity of the feedback effect, 25% of them conclude validity of the growth hypothesis, 21% of them propose the validity of the conservation hypothesis, and 13% of them find the validity of the neutrality hypothesis in the energy-growth nexus.

The energy consumption-economic growth nexus has been widely investigated; however, the papers focus on the effects of both the non-renewable- and the renewable energy consumption on economic growth are still limited.[4] For instance, considering the panel ECM [5], demonstrate a bidirectional causality between the renewable energy and the economic growth as well as the non-renewable energy and the economic growth in 80 countries over the period 1990–2007. Using the ordinary least squares (OLS), the dynamic ordinary least squares (DOLS), and the fully-modified ordinary least squares (FMOLS) estimations [25], find the validity of growth hypothesis for both the relationship from the renewable and the non-renewable energy consumption to the economic growth in 69 countries over the period 1980–2010. Using the panel data estimation techniques that capture the cross-sectional dependence and the heterogeneity [10], examine the impacts of energy consumption on the economic growth in 38 countries for the period from 1991 to 2012. Recently [40] examine the dynamic relationship between the electricity consumption, the oil price, and

[1] Technological improvement can be defined a process that reduces production costs or causes the emergence of new products.

[2] Furthermore [17], observe the positive effect of economic complexity indicator on economic development [18]. also find the suppressing effect of economic complexity on the income inequality.

[3] For the details of the ECI, visit https://atlas.media.mit.edu/en/.

[4] See the literature reviews of [2,32]; and [44].

the GDP in 157 countries and they conclude that developing countries rely heavily on the electricity consumption in providing the economic growth [41]. also analyze the asymmetric relationship between the energy consumption and the economic growth and the paper shows that the negative shocks of energy consumption have only the significant impact on the economic growth. According those previous papers, the non-renewable energy consumption is positively related to the economic growth in most of the countries, but there is no significant relationship in the most of the cases for the renewable energy-growth nexus.

There are also panel data studies for analyzing the relationship between the renewable energy consumption and the economic growth. Using a panel cointegration test [37], finds the significant causality that runs from the renewable energy to the economic growth in the G7 countries for the period from 1980 to 2005. Similarly [36], runs the panel error correction model (ECM) and observes the causal relationship that runs from the growth to the renewable energy consumption in 18 emerging countries over the period 1994–2003 [38]. use the Granger causality test and find that there is a bidirectional causality between the renewable energy and the economic growth in six emerging economies from 1980 to 2006 in the short-run. However, a different finding is obtained for the long-run that is the significant causal relationship that runs from the economic growth to the renewable energy [6]. focus on the panel dataset of 20 OECD countries for the period from 1985 to 2005. The empirical results from the vector error correction model (VECM) and the Granger causality test show that there is the bidirectional causal relationship between the renewable energy and the economic growth. A similar finding of bidirectional causality between the related two variables is obtained by Ref. [7] and their empirical analysis is based on the panel dataset of 13 Eurasian countries over the period 1992–2007. Using the FMOLS estimations [9], also conclude that there is the bidirectional causality between the renewable energy consumption and the economic growth in six Central America countries for the period from 1980 to 2006. Considering the FMOLS estimations [4], examine the renewable energy-growth nexus in 108 countries for the period from 1980 to 2009 and they find that there is the bidirectional causality between the renewable energy and the economic growth in 85 of 108 countries. Using the FMOLS and the panel smooth transition VECM estimations [8], observe that the bidirectional causality between the renewable energy and the economic growth in seven Central American countries from 1980 to 2010. Using the ARDL model [39], find the bidirectional causal relationship between the renewable energy and the economic growth in BRICS countries from 1971 to 2010. Using the heterogeneous panel Granger causality test [14], also find the bidirectional causality between the renewable energy and the economic growth in the G7 countries from 1990 to 2011. Using the K-L model and the Toda–Yamamoto causality test procedure [46], investigate the validity of energy-growth nexus in 17 OECD countries. The paper only finds the causal relationship from the energy consumption to the economic growth only in Japan. A bidirectional causality is obtained in Italy, New Zealand, Norway, and Spain. Besides, there is the significant causality from the economic growth to the energy consumption in Australia, Canada, and Ireland. Furthermore, using the random-effect model [31], finds that there is no significant causal relationship between the renewable energy consumption and the economic growth in 27 European countries over the period 1997–2007. Using the OLS estimations [1], find no significant causality in the renewable energy-growth nexus in African countries. Using the ECM and the Granger causality test procedures [3], also observe that there is no significant causal relationship between the renewable energy and the economic growth in 11 African countries for the period from 1980 to 2008.

Some papers have considered the R&D expenditures or the human capital in the empirical growth model. For instance [16], consider the K-L model (augmented production function) in the energy-growth nexus and their paper is the first to include the human capital into the empirical model. Using the panel unit root and the panel cointegration tests that capture the effects of cross-sectional dependence, they find that the economic growth causes to the energy consumption in the panel dataset of 16 Asia Pacific countries over the period 1970–2011. For example, using the OLS estimations [15], observes that there is the significant causal relationship that runs from the renewable energy to the economic growth in China for the period from 1978 to 2008. The empirical model in Ref. [15] uses the R&D expenditures to capture the technological progress. Following [15,24] also includes the R&D expenditures into the K-L model. Using the Pedroni's panel cointegration test [24], examines the effects of the renewable energy consumption on the economic growth in the panel data of 34 OECD countries for the period from 1990 to 2010. The paper finds the significant causality that runs from the renewable energy consumption to the economic growth.

To conclude the literature review, the mixed results from the renewable energy-growth nexus are observed in the previous literature. Specifically, the mixed results are obtained by Ref. [45] in the G7 countries; by Ref. [33] in the MIST countries; by Ref. [29] in China; by Ref. [13] in the U.S; by Ref. [42] in the Latin American countries. The mixed findings are due to the different choices of empirical growth model and the country samples or the econometric methodology. Using the economic complexity indicator instead of the capital and the labor, our paper offers a different approach. At this stage, we do not claim that our empirical model is better. We attempt to justify that there would be a different approach to enhance our knowledge on the growth-energy nexus. We demonstrate that our new approach fits well with the panel data of 29 OECD countries.

3. Data, empirical model, and methodology

3.1. Data and empirical model

The previous literature on energy-growth nexus is based on a “traditional” growth model, known as the K-L model (e.g. Refs. [6,7,9]; and [5].) In the K-L model, income (GDP), which is represented by Y is a function of two factors: capital (K) and labor (L). This model can be represented by the following formulae:

$$Y = f(K, L) \tag{1}$$

If we divide the equation with L then we can obtain the following:

$$Y/L = f(K/L) \tag{2}$$

By adding the renewable energy (RE) and the non-renewable energy consumption (NRE) into the growth model in Eq. (2), we can obtain the following[5]

$$Y/L = f(K/L, RE, NRE) \tag{3}$$

What we basically do to replace the (K/L) with the economic complexity indicator (ECI), since it is also a measure of the productivity and the economic structure (K/L); and then, our growth

[5] Instead of the total (overall) primary energy consumption, we aim to see there could be potentially different effects of the non-renewable and the renewable energy consumption on the economic growth. Doing so, we also attempt to link with the broader literature by including the renewable energy consumption.

model will be written as follows:

$$Y/L = f(ECI, RE, NRE) \quad (4)$$

The empirical model in Eq. (4) considers the ECI and the renewable- and the non-renewable energy consumption and provides the baseline evidence on the role of the ECI in the energy-growth nexus for a panel of 29 countries: Australia, Austria, Belgium, Canada, Chile, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Israel, Italy, Japan, the Netherlands, New Zealand, Norway, Poland, Portugal, Slovakia, South Korea, Spain, Sweden, Switzerland, Turkey, the United Kingdom (UK), and the United States (U.S.). The data cover the time spanning from 1990 to 2013. The selection of the countries and the period is based on the availability of the data. Our baseline modeling framework is given as follows in general notation:

$$(Y/L)_{it} = f\left(ECI_{it}^{\alpha_1}, RE_{it}^{\alpha_2}, NRE_{it}^{\alpha_3}\right) \quad (5)$$

The empirical model in Eq. (5) is defined in logarithmic form as follows[6]

$$\log(Y/L)_{it} = \alpha_0 + \alpha_1 ECI_{it} + \alpha_2 logRE_{it} + \alpha_3 logNRE_{it} + \varepsilon_t \quad (6)$$

where, Y/L_{it} denotes the real GDP in billions of constant 2005 U S. Dollars per engaged labor (employment); RE_{it} is the total renewable energy consumption defined in million tonnes oil equivalent; NRE_{it} is the total non-renewable energy consumption defined in million tonnes oil equivalent; and ECI_{it} is the economic complexity indicator (ECI), which measures how a country can produce and export a complex product. In other words, if a country has a higher level of economic structure, it can be able to produce and to export complex (higher value-added) products.

The real GDP and the total labor force data are obtained from the World Development Indicators (WDI) of the World Bank. The total renewable and the non-renewable energy consumption come from the Statistical Review of World Energy of the British Petroleum (BP) (2016 version). The economic complexity indicators are obtained from the Atlas of the Economic Complexity of [19]. A summary of descriptive statistics is reported in Appendix Table 1 and the graphs of the variables are provided in Appendix Fig. 1. At this stage, we expect that the ECI, the renewable energy consumption, and the non-renewable energy consumption are positively related to the economic growth.

3.2. Econometric methodology

To test the validity of our new economic growth approach, which is introduced in the previous subsection, we use the panel ARDL and the PQR estimations.

3.2.1. Panel autoregressive distributed lag (ARDL) model

Due to the possibility of the mixed nature of stationary for variables of interest, we employ the panel ARDL model with the country fixed-effect and the period fixed-effect, as proposed by Ref. [34]. Another advantage of the panel ARDL test is that it allows the nonlinear relationship between the GDP per employed person, the total renewable energy consumption (RE), the total non-renewable energy consumption (NRE), and the economic complexity indicator (ECI). The model is specified as follows:

$$\Delta\frac{lnY}{L_{it}} = \lambda_{0+}\sum_{i=1}^{m}\lambda_{1i}\,\Delta\frac{lnY}{L_{it-1}} + \sum_{i=1}^{m}\lambda_{2i}\,\Delta lnRE_{it-1} + \sum_{i=1}^{m}\lambda_{3i}\,\Delta lnNRE_{it-1} + \sum_{i=1}^{m}\lambda_{4i}\,\Delta ECI_{it-1} + \lambda_5\frac{lnY}{L_{it-1}} + \lambda_6 RE_{it-1} + \lambda_7 lnNRE_{it-1} + \lambda_8 ECI_{it-1} + \upsilon_{it} \quad (7)$$

where m is the lag order and v_t is assumed to be an independent and identically distributed error term. Eq. (7) can be transformed into an error correction model (ECM) yielding:

$$\Delta\frac{lnY}{L_{it}} = \lambda_0 + \sum_{i=1}^{m}\lambda_{1i}\,\Delta\frac{lnY}{L_{it-1}} + \sum_{i=1}^{m}\lambda_{2i}\,\Delta lnRE_{it-1} + \sum_{i=1}^{m}\lambda_{3i}\,\Delta lnNRE_{it-1} + \sum_{i=1}^{m}\lambda_{4i}\,\Delta ECI_{it-1} + \xi\left(\frac{lnY}{L_{it-1}} + \beta_1 RE_{ti-1} + \beta_2 lnNRE_{it-1} + \beta_3 ECI_{it-1}\right) + \mu_{it} \quad (8)$$

where ξ is the speed of adjustment parameter. β_1 and β_2 , and β_3 are the long-run coefficients for the RE, the NRE, and the ECI respectively. The short-run parameters are represented by σ_{1i} σ_{2i} , σ_{3i} , and σ_{4i} . Therefore, the panel ARDL (p, q, k, g) model yields:

$$\Delta ln\frac{lnY}{L_{it}} = \sigma_{0+}\sum_{i=1}^{p}\Delta\sigma_{1i}\Delta ln\frac{lnY}{L_{it-p}} + \sum_{i=1}^{q}\Delta\sigma_{2i}\Delta lnRE_{it-q} + \sum_{i=1}^{k}\Delta\sigma_{3i}\Delta lnNRE_{it-k} + \sum_{i=1}^{g}\Delta\sigma_{4i}\Delta ECI_{it-g} + \xi\left(ln\frac{lnY}{L_{it-1}} + \beta_1 lnRE_{ti-1} + \beta_2 lnNRE_{it-1} + \beta_3 ECI_{it-1}\right) + \mu_{it} \quad (9)$$

The methodology used the ARDL model is to address these variables in the short run and the long run co-integrated variables, jointly. This method has advantages over other conventional multivariate methods of the cointegration.[7]

3.2.2. Panel quantile regression (PQR)

In this section, we conduct the PQR methodology as a robustness test and estimate the parameters at different points on the (conditional) output per labor (i.e. the economic growth). The main advantage of using the PQR is that it can minimize the biases raised from outliers, and the PQR estimator is more efficient than OLS estimators when error terms are not normally distributed. More importantly, the effects of the renewable energy consumption, the economic complexity indicator, and the non-renewable energy consumption may be different for a country at the different productivity levels. Given a set of independent variables $X_{it,}$ we can write τ th quantile ($0< \tau <1$) as the conditional distribution of the dependent variable (i.e. the log of real GDP per labor), such that:

$$Q_\tau\left(\frac{Ln\left(\frac{Y}{L}\right)_{it}}{X_{it}}\right) = \alpha_\tau + \beta_\tau X_{it} + \alpha_\tau \mu_{it} \quad (10)$$

In Eq. (10), $Ln(Y/L)_{it}$ is the log of real GDP per labor of county i at

[6] We did not use the natural logarithmic of the economic complexity indicator since there are the negative values in the dataset.

[7] At this stage, the panel ARDL estimations used in our paper take also the effects of the structural changes into account as the robustness check. The results are similar to the benchmark estimations; and therefore, we did not report the results to save space.

time t and X_{it} represents the vector of three independent variables; i.e. the non-renewable energy consumption ($LnNRE_{it}$), the renewable energy consumption ($LnRE_{it}$), and the economic complexity indicator (ECI). u_{it} denotes unobservable factors, such as the institutional quality. The parameters in Eq. (10) are estimated by minimizing the absolute value of the residuals, using the following objective function:

$$Q_\tau(\beta_\tau) = \min_{\beta} \sum_{i=1}^{n} \left[\left| Ln\left(\frac{Y}{L}\right)_{it} - \beta_\tau X_{it} \right| \right]$$
$$= \min_{\beta} \left[\sum_{i:Ln\left(\frac{Y}{L}\right)_{it} \geq \beta X_i}^{n} \tau \left| Ln\left(\frac{Y}{L}\right)_{it} - \beta_\tau X_{it} \right| + \sum_{i:Ln\left(\frac{Y}{L}\right)_{it} < \beta X_{it}}^{n} (1-\tau) \left| Ln\left(\frac{Y}{L}\right)_{it} - \beta_\tau X_{it} \right| \right], \quad (11)$$

At this stage [27], suggests using the shrinkage methodology to estimate a vector of the fixed-effects and [12] introduces a two-step methodology of estimating panel quantile regression models with the fixed-effects. We use the PQR estimations of [12] in the empirical estimations.

4. Empirical findings

Table 1 reports the degree of integration and the stationary properties of the respective variables. We first use the panel ADF (LLC) test proposed by Ref. [28] by assuming the homogeneity in the dynamics of the autoregressive coefficients for all panel units. In addition, we use the nonparametric tests of [30] including the Fisher-ADF and the Fisher-PP tests, take into account of the heterogeneity across units. Finally, we consider the cross-sectional dependence unit root (CIPS) test of [35]. The panel unit root tests indicate that ECI and lnNRE is stationary; while, lnRE and lnY/L are ambiguous and possibly integrated of order one.

Table 2 presents the results for Equations (7) and (8); the error-correction coefficient (−0.061) was found to be negative and statistically significant at the 1% level, indicating that the adjustment speed is about 6.1%. Table 2 also displays the long-run parameter estimates based on the panel ARDL. The coefficients are positive and statistically significant at the 1% level for the non-renewable energy consumption, the renewable energy consumption, and the economic complexity indicator, but the coefficient is only significant at the 10% level for the renewable energy consumption. Since energy consumption variables are expressed in natural logarithms, the parameter estimates of the model can be interpreted as elasticity estimates. The results indicate that a 1% increase in non-renewable energy consumption increases real GDP per labor by 1.08%; a 1% increase in renewable energy consumption increases real GDP per labor by 0.40%, and a 1% increase in economic complexity increases real GDP per labor by 1.27%. Table 2 also shows the results from the panel error correction model, and it indicates that the renewable energy consumption, the non-renewable energy consumption, and the economic complexity index have the positive impact on productivity (Y/L) in the short-run.

The empirical findings from the PQR approach of [12] are reported in Table 3; we can see all estimates are positive and significant at the 1% level, except the coefficient of the renewable energy consumption at the high quantile of productivity (i.e. $\tau = 0.9$). More interestingly, the marginal effects of the economic complexity indicator on the productivity are higher at the higher quantiles of productivity. However, we do not observe the system effects of the non-renewable and the renewable energy consumption on the GDP per employed person at the high quantile of GDP per employed person.

The main policy implication of the estimation results of the PQR model is that there is a significant heterogeneity across the OECD countries for the effects of the renewable energy on the economic growth process. The results are differentiated at the high quantile of the GDP per labor since the higher income countries can provide more sources for enhancing renewable energy. Since the renewable energy investments require a long-term funding and they are the expensive investment, income level can be the main reason (mechanism) that differentiation of the findings from the PQR. Therefore, policymakers should consider the role of the economic complexity and renewable energy sources to provide the sustainable economic growth.

The result of the positive effect both of the renewable- and the non-renewable energy consumption on economic growth suggest the validity of the growth hypothesis and this result is also parallel with the previous results of [25] for 69 countries. The results for the validity of the growth hypothesis for the non-renewable energy-growth nexus are in line with the findings of [10]. The findings of the validity of the growth hypothesis in renewable energy-growth nexus are in line with the findings of [24] and [37] in the panel data sets of 34 OECD and the G7 countries, respectively.

Table 1
Results of the panel unit root tests.

Variables	LLC	Fisher-ADF	Fisher-PP	CIPS
Y	−5.08***	55.44	83.91***	−2.28
ΔY	−14.39***	278.14***	294.37***	−3.97***
RE	−1.86***	95.94***	35.89	−2.26
ΔRE	−13.67***	267.09***	257.32***	−3.89***
NRE	−7.89***	117.69***	148.21***	−2.95***
ΔNRE	15.049***	316.56***	564.71***	−4.95***
ECI	−3.69***	99.95***	103.49***	−2.81**
ΔECI	−20.61***	360.63***	897.69***	−5.24***

Notes: ***p < 0.01 and **p < 0.05. The number of lag is based on the Akaike Information Criteria (AIC). Maximum number of lag is 3.

5. Conclusion

In this paper, we analyzed the effects of the renewable- and the non-renewable energy consumption on the economic growth in 29 OECD countries. To this end, we introduced the growth model that captures the effects of the economic complexity indicator as the measure of capabilities and productivity for exporting the high value-added (sophisticated) products. Empirically, we tested the validity of our growth model in the panel dataset of 29 OECD countries for the period from 1990 to 2013. For this purpose, we run the panel unit root tests of well as the panel ARDL and the PQR estimations. To the best of our knowledge, our paper is the first paper that controls the effects of the economic complexity on the energy-growth nexus. We found the positive impact of the economic complexity on the economic growth and there is the positive effects of both the renewable- and the non-renewable energy consumption on the economic growth. The findings from the PQR estimations also indicate the heterogeneity across countries in the role of the renewable energy in affecting the economic growth. In short, our results are robust for implementing different econometric techniques.

We observed that both the renewable- and the non-renewable energy consumption positively affect the economic growth and this means that both types of energy sources are crucial for the economic growth. At this point, it is important to note that the difference between the related energy sources is based on the

Table 2
Results of the panel ARDL estimations.

Variables	Coefficients	Standard Errors	t-Statistics	Probability
Long Run Equation				
LNNONRENE	1.0839***	0.1587	6.8298	0.0000
LNRENE	0.4021***	0.0699	5.7507	0.0000
ECI	1.2683***	0.2182	5.8136	0.0000
Short Run Equation				
COINTEQ01	−0.0609**	0.0252	−2.4211	0.0162
D(LNNONRENE)	0.2357***	0.0662	3.5610	0.0004
D(LNNONRENE(-1))	0.0533	0.0717	0.7431	0.4581
D(LNNONRENE(-2))	−0.0108	0.0785	−0.1377	0.8906
D(LNNONRENE(-3))	0.0033	0.0591	0.0550	0.9562
D(LNRENE)	0.0282	0.0213	1.3232	0.1869
D(LNRENE(-1))	0.0078	0.0167	0.4656	0.6419
D(LNRENE(-2))	0.0029	0.0173	0.1662	0.8681
D(LNRENE(-3))	0.0045	0.0108	0.4169	0.6771
D(ECI)	0.0074	0.0337	0.2193	0.8266
D(ECI(-1))	0.0279	0.0338	0.8255	0.4099
D(ECI(-2))	0.0288	0.0250	1.1526	0.2501
D(ECI(-3))	−0.0023	0.0210	−0.1110	0.9117
C	0.1910***	0.0645	2.9622	0.0033
@TREND	0.0075**	0.0030	2.4941	0.0133
Mean dependent VAR	0.015537	S.D. dependent VAR		0.027652
S.E. of regression	0.014014	Akaike info criterion		−4.53994
Sum squared residuals	0.050666	Schwarz criterion		−1.6795
Log likelihood	2017.898	Hannan-Quinn criteria.		−3.43392

Notes: The dependent variable: D (LN(Y/L)). The model lag selection method is the Akaike Information Criteria (AIC). Dummy variables for the period fixed-effect and the country fixed-effect are also used in the estimations.

Table 3
Results of the panel quantile regression (PQR) estimations.

	Estimate	Bootstrapped Standard Errors
$\tau = 10$th		
(Intercept)	9.6510***	0.0923
(ECI)	0.0919***	0.0157
ln(RE)	0.0190***	0.0065
ln(NRE)	0.1963***	0.0097
$\tau = 25$th		
(Intercept)	9.7539***	0.0669
(ECI)	0.0971***	0.0085
ln(RE)	0.0210***	0.0052
ln(NRE)	0.1844***	0.0063
$\tau = 50$th		
(Intercept)	9.8121***	0.0567
(ECI)	0.0974***	0.0082
ln(RE)	0.0195***	0.0043
ln(NRE)	0.1803***	0.0057
$\tau = 75$th		
(Intercept)	9.8631***	0.0635
(ECI)	0.0978***	0.0092
ln(RE)	0.0203***	0.0045
ln(NRE)	0.1757***	0.0059
$\tau = 90$th		
(Intercept)	9.8247***	0.1099
(ECI)	0.1218***	0.0163
ln(RE)	0.0162**	0.0079
ln(NRE)	0.1805***	0.0099

Notes: The bootstrapped standard errors with 2000 replications are reported. ***$p < 0.01$ and **$p < 0.05$. The OLS standard errors are robust. The number of observations is 685.

carbon emissions. The renewable energy consumption can decrease the level of carbon emissions. As indicated by Refs. [26] and [6,7,9] and [5], the rise of the renewable energy meets the sustainable growth since it can decelerate the climate change. Renewable energy is related to the technological change. Therefore, the rise of the renewable energy can also help to upgrade the complexity of exports basket and this can also positively affect the economic growth. In addition, according to [10]; investments in renewable energy projects can enhance renewable energy consumption and this can promote the economic growth as well as decrease environmental degradation. To put it differently, the benefit of renewable energy for decelerating climate change is also in line with the sustainable growth objectives. At this point, our findings imply that policymakers should not only focus on the rise of renewable energy but also on the non-renewable energy to support the economic growth.

The novelty of our paper is that to construct the theoretical model to link the economic complexity between the energy-growth nexus. We can suggest that our theoretical model will be suitable to analyze the energy-growth nexus when we consider the state-of-art- of the growth models. Economic complexity can capture the effects of human capital and institutions on the economic growth. Therefore, policymakers should consider the role of the economic complexity to provide the sustainable economic growth.

It is important to note that our empirical model assumes that energy causes (or not) economic growth; and not vice versa or both simultaneously. Despite nothing wrong with this assumption (all models make their own assumptions), we cannot examine the relationship in each country. Therefore, a future paper can analyze the dynamic effects of economic complexity on the energy-growth nexus in other countries. In here, a future paper can use the nonlinear models and the time-series analysis to analyze the case of each county.

Finally, our paper includes the non-renewable- and the renewable energy consumption at the aggregated level for investigating the impact of the economic complexity indicator on the economic growth. Therefore, a future paper can focus on the renewable energy consumption at the disaggregated level (e.g. the biomass, the geothermal, the solar, and the wind) and the non-renewable energy consumption (e.g. coal, oil, natural gas, and nuclear) in the energy-growth nexus by using the economic complexity indicator.

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Appendix

Table 1
Descriptive Summary Statistics in 29 OECD Countries, 1990–2013 (685 Observations)

Variable	Unit	Data Source	Mean	Standard Deviation	Skewness	Kurtosis
Real per Capita GDP per engaged labor employment	Logarithmic Form	World Bank, WDI	10.83	0.577	−0.896	2.805
Total Renewable Energy Consumption	Million Tonnes Oil Equivalent	British Petroleum (BP)	2.297	5.523	5.253	38.67
Total Non-renewable Energy Consumption	Million Tonnes Oil Equivalent	British Petroleum (BP)	175.3	398.7	4.508	23.11
Economic Complexity Indicator	Index	[19]	1.254	0.678	−0.401	2.475

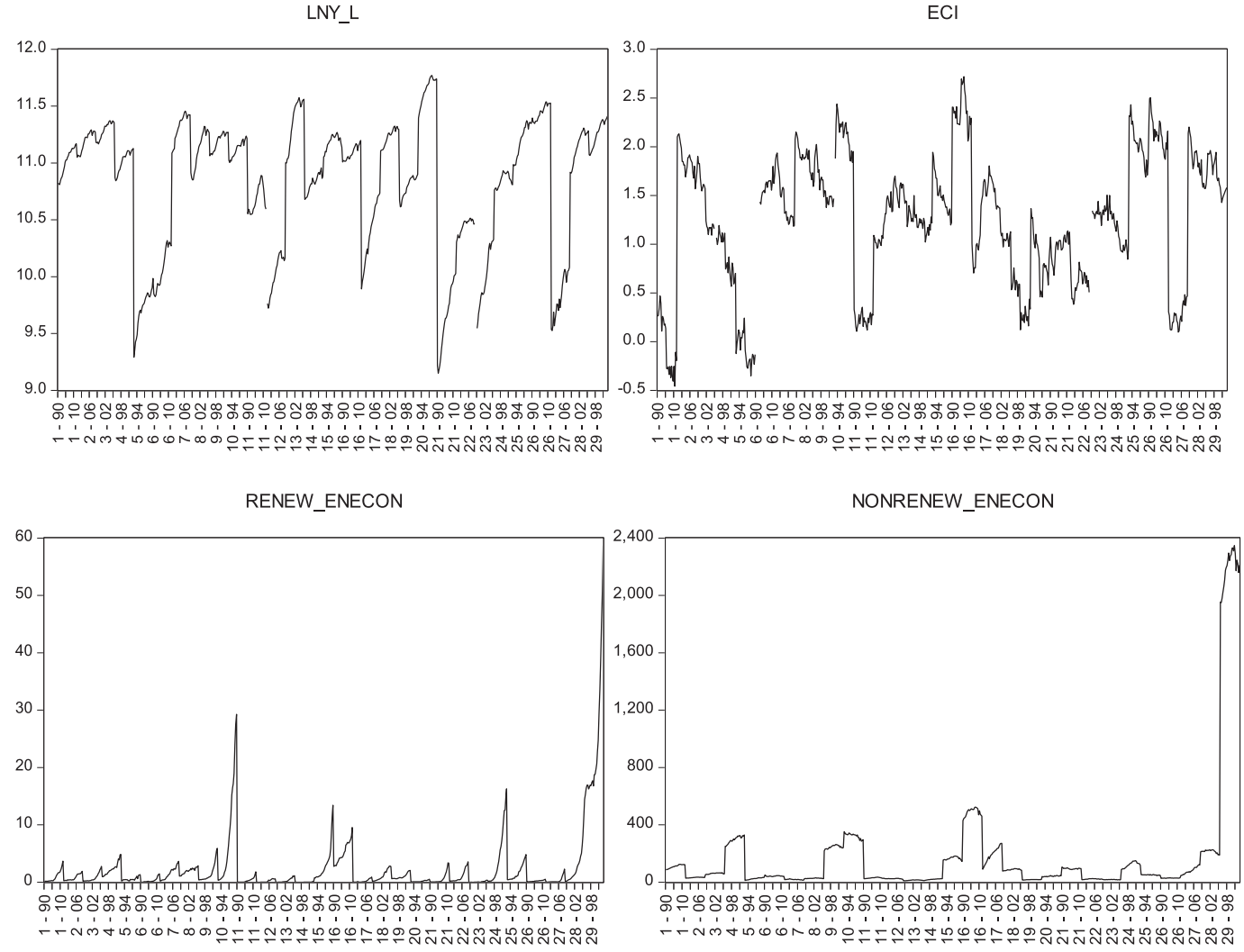


Fig. 1. Graphs for Output per Worker, Economic Complexity and Renewable and Non-renewable Energy Consumption.

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