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Published in:
Renewable and Sustainable Energy Reviews

DOI:
10.1016/j.rser.2021.111735

Publication date:
2022

The role of environmental technology for energy demand and energy efficiency: Evidence from OECD countries

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Abstract

The present study aims to fill an important research gap by investigating the role of environmental-related technologies on energy demand and energy efficiency in a sample of 28 OECD economies. The current study utilizes annual data for the period of 1990-2014 and employs panel estimation techniques, which addresses the issues of cross-sectional dependence, fixed effect, and endogeneity. The results, across various estimates, confirm that environmental technology has a substantial negative influence on energy consumption and also plays an important role in improving energy efficiency by reducing energy intensity. These evidences suggest that environmental technology helps the OECD economies to reduce their overall energy consumption and improves overall energy efficiency in their respective countries. The comprehensive empirical outcomes document that financial development and income are the key determinants of energy demand. Given these results, the study proposes several fruitful implications regarding sustainable development goals of OECD countries.

JEL classification: O33; Q41; Q47

Keywords: Environmental technology; energy demand; energy efficiency; OECD economies

1. Introduction

Economic growth and industrialization have led to a rise in the use of fossil fuels. The increased production and consumption of fossil fuels has had several adverse environmental impacts on countries including global warming, air pollution, and increased health risks. While fossil fuels are expected to continue to dominate energy supply in the imminent future due to greater energy density and length of time it takes for innovation, as argued by the Organisation for Economic Co-operation and Development (OECD, 2019); hence, the OECD nations have recognized the need to promote new sources of energy. To achieve this objective, the OECD countries have recognized the need to make significant investments in new low-carbon automation, renewable energy, and energy infrastructure. The environment-related technological progress can lead to meaningful decreases in energy consumption and increase energy efficiency. These technologies can help to decrease the negative effects of energy use and encourage nations to re-think how energy is consumed across activities. The efficient use of resources through recycling and eliminating waste can reduce the consumption of energy (European Environmental Agency, 2019).

The global energy efficiency, measured as energy consumption per unit of GDP, has been reduced by one-third from 1990 to 2015. More specifically, the energy intensity has been reduced in almost all regions of the world, with huge decreases of energy intensity in the OECD countries. The reports and facts on energy shows that OECD economies have less energy intensity as compared to energy intensity levels in non-OECD nations. Several OECD countries have moved from energy-intensive production to less energy-intensive service-based economic activities. While, the non-OECD countries rely on industrialization, which are usually energy-intensive. The OECD's overall energy intensity has fallen from 5.22 megajoule (MJ) to 4.13 MJ over 2000 to 2014. **Figure 1** illustrates the world energy intensity trends from 1990 to 2015, indicating that the energy intensity in OECD countries has been reducing in this period. The increase in efficiency can be attributed mainly to the relative efficiency of buildings, vehicles, and industrial processes heavily influenced by the local regulations, incentives, and market competition and energy-related technologies.

[Insert Figure 1 here]

According to the International Council on Clean Transportation, the fuel economy regulations are applied in approximately 80% of the world automobile market, while the remaining part lacks local efficiency standards. The energy efficiency policies can also differ significantly across countries, regions and the level of the economy[1]. There has been increasing emphasis by the OECD countries on energy policies that address environmental issues including the use of environmentally friendly technologies. Governments of the major economies' forum and the International Energy Agency (IEA) for example, have agreed to increase public sector investments in low carbon research and development and accelerate the use of low carbon technologies (EIA, 2017; OECD 2019).

The prime objective of present study is an attempt to propose fruitful solutions for two major problems (energy demand and energy efficiency) of OECD countries. According to the energy consumption reports, OECD countries have higher energy consumption, which is more than other regions of the world. The OECD nations' energy sources mainly constitute of fossil fuels, coal, gas, and natural resources etc. (Bashir et al., 2020). Hence, the current study attempts to examine whether the environmental related technologies are useful in controlling energy demand and promoting energy efficiency by enhancing the productivity with lower energy

[1] The developed nations have imposed strict and stringent policies for energy use (domestic and industrial) and energy efficiency.

consumption. Such a narrative is in line with the studies of Lin and Du, (2013); Li and Just (2018), who focused on China and California, respectively. In the energy-economics literature, the environmental technologies are portrayed as useful tool for cleaner and greener growth (Danish and Ulucak, 2020; Paramati et al., 2021).

The present study mainly offers three innovations to energy-economics literature. Firstly, this article highlights the significance of environmental related technologies for energy demand by studying the two proxies of energy use (energy use and total final energy consumption) in the context of OECD countries. On one side, the peak of energy demand benefits the economy of host countries, while the economic progress might be at the cost of the environment and human health (UCSUSA, 2016). As the use of fossil fuels (oil, gas, coal, etc.) contribute to the air pollution and more carbon in the atmosphere which further affects human health. The investigation into the role of environmental technologies for energy consumption of developed nations might provide us new conclusions and can be regarded as contribution in theoretical literature.

Secondly, this paper explores the impacts of environmental technologies on energy intensity of OECD countries. The innovative technologies and environmental related products are known as the key factors in energy generation, energy transformation and efficient energy usage. The environmental related technologies can affect energy demand, which leads toward the greener and cleaner growth (Danish and Ulucak, 2020). Such a fact is based on the motivation that environmental regulations (taxes, patents etc.) directed for technological change for the ultimate objective to reduce non-renewable energy demand and enhance renewables for emissions mitigation. The carbon mitigation and achieving greener growth is the focal point of recent research (Rafique et al., 2021; Shahzad et al. 2021a; Paramati et al., 2021). The rising greener growth awareness and knowledge about technological change has encouraged the governments and policymakers to establish for greener growth of resources and environmental protection especially in terms of energy efficiency[2] and energy transformation (Danish and Ulucak, 2020).

The technological progress and inventions have contributed to achieving major productivity gains, energy efficiency and improved environmental quality (Lin and Du, 2013; Danish and Ulucak, 2020. The environmental sustainability, energy efficiency and cleaner growth are also in line to achieve the Sustainable Development Goals (SDG's). This is explained from the reason that technological shifts, structural change and technology improvement are considered as pillars for energy supply, energy security and industrial purposes (Mccue, 2014; Saudi, et al., 2019). Lastly, this study reports new findings and innovative implications, which can be fruitful in achieving the Sustainable Development Goals (SDG's) such as; clean energy for everyone (SDG-7), sustainability of economic growth (SDG-8), sustainability in the consumption pattern (SDG-12) and improving the environmental quality (SDG-13) (Sinha et al., 2020; Bashir et al.,2020). In a general sense, the less consumption of energy helps to save costs, achieve energy efficiency goals and helps to reduce global greenhouse emissions. Such new implications are related with the greener growth, renewable energy and sustainable growth of developed economies. The study further accounts for important control factors in the model such as economic openness, financial development and per capita income. Surprisingly there is a dearth of empirical literature regarding the role of environmental regulations and policies for energy demand.

The estimated results from these alternative techniques may ensure the reliability of the findings. In a summary, the empirical results highlight that environmental related technologies

[2] Here the energy efficiency term refers to achieving higher output with less energy use, while energy transformation means conversion from non-renewable sources towards greener and renewable sources.

might be key tool to reduce energy consumption and improve energy efficiency by reducing the use of energy to produce one unit of economic output over the years. Hence, the policy makers should further initiate policies to promote the innovations in environmental and energy related technologies by ensuring sufficient research and development (R&D) funds. Therefore, further innovations in environmental and energy technologies will assist the OECD economies not only for reducing their overall energy consumption but also helps them to achieve their climate change targets by reducing greenhouse gas emissions.

The rest of this paper is structured as follows: Section 2 provides relevant energy literature on OECD and non-OECD economies. Section 3 reports details on data measurement, model setting, and empirical methodology. Section 4 presents detailed empirical results and their relevant discussions. Finally, Section 5 concludes the paper by summarising the overall findings and its related implications for the policy and practice.

2. Review of Literature

As per the existing literature, energy is a fundamental source in the production of goods and services, industrialization and economic purposes that lead towards human satisfaction. In line with this narrative, the paper has incorporated environmental technologies as a key determinant variable for energy consumption and efficiency policies. Studies on determinants of energy consumption are abundant but very limited in the context of energy efficiency and environmental technology; the present study is the pioneer to discuss the role of environmental technologies in the context of OECD countries. Our study joins the strand of recent studies on energy-environment (Lin and Du, 2013; Li and Just 2018; Vujanović et al., 2019; Murad et al., 2019; Bashir et al.,2020; Alola and Kadiri 2021;Shahzad et al. 2021a; Shahzad et al.2021b; Rafique et al. 2021), as these also considered technology and innovation as key determinant factor. The authors classify the literature review in two groups: (i) literature on energy demand and, (ii) literature on energy efficiency.

2.1 Literature on Energy Demand

During the past decade, the energy and climate issues has been interest of policymakers, industries, world leaders and environmental scientists. Notably, few of the studies investigated the determinants of energy consumption and energy intensity.

For instance, Apergis and Payne (2010) utilized panel cointegration and an error correction model, to study the relationship between economic progress and renewable energy consumption for OECD countries. The empirical findings of the study concluded that there exists long-run relationship between real GDP and renewable energy consumption. In the same line, Faisal et al. (2017) examine the relationship between energy consumption and GDP for Belgium from 1960 to 2012. Using an ARDL methodology, they find that GDP positively affects energy consumption in the long run and the short run.

Farhani and Solarin (2017) using data for the U.S over 1973 to 2004, and cointegration techniques examine if a long-run relationship exists between energy demand, financial development, foreign direct investment (FDI), economic growth, trade, and capital. They find that financial development, economic growth, and FDI lead to a fall in energy demand while trade and capital increase the demand for energy. Koengkan (2018) studied the role of income and trade for energy demand in four Andean community countries over 1917-2014. The panel empirics of system GMM reported that income and trade positively induce the energy consumption in studied countries. For the case of 16 Coastline Mediterranean Countries, Alola and Alola, (2018) examined the role of agriculture land usage and tourism for the renewable energy consumption. The results concluded that agriculture land and tourism have positive effects on the renewable energy consumption for Coastline Mediterranean Countries. For the case of 13 African countries, Asongu et al., (2020) examined the role of economic progress, urbanization, electricity use, fossil fuels and natural resources on the pollutant emissions. The empirical results of cointegration analysis and panel ARDL argued that fossil fuels, urbanization, and electricity use significantly enhance the pollution level. Some of the recent studies have reached at similar conclusions for income, technology, and globalization in context of energy demand and pollution level (Baloch et al., 2021; Bekun et al., 2020; Adedoyin et al., 2020).

The only studies to our knowledge, which investigates the effects of technology on energy and environment are Li and Just (2018); Danish and Ulucak, (2020); Köse et al, (2020); Alola and Alola (2018). Li and Just (2018) develop a theoretical model to study household energy use behaviour in California under multiple discrete technology choices. The empirical study documented the household demand for electricity, natural gas and long-run technology choices concerning washing, water heating and domestic purposes. The estimation results suggested the generalized conclusions in most of the areas across California. This study is restricted to households in California. In the same line, Danish and Ulucak, (2020) mentioned that enviornmenal related technologies promote cleener and greener growth in BRICS countries. More recently, Alam and Murad, (2020) argued that technological progress and trade openness improve renewable energy use in OECD countries.

2.2 Literature on Energy Efficiency

A study Geller et al., (2006) examines energy efficiency improvements in the major OECD nations since 1973. Their study shows that well-designed policies can lead to increased energy efficiency.

In the U.S., specifically designed programs led to a fall in energy use by 11%. Similar results are documented for Europe and Japan.

Meanwhile, conducting an empirical study on Chinese provinces, Lin and Du (2013) researched the energy efficiency and technology gap. By using the parametric meta frontier approach and cluster analysis the results mentioned that eastern region of China has higher energy efficiency and higher technology gap as compared to other regions. In the same line, the empirical study of Apergis et al., (2015) argued that that sustainable development in OECD economies can be achieved with enough energy supply, conditional of the balance between income level and energy efficiency.

In a sample of OECD countries, Parker and Liddle (2016) examined the impacts of prices on energy efficiency in the manufacturing sector over the period of 1980–2009.The authors opined that energy efficiency is the major driver for the observed reduction in energy intensity in OECD countries. For the developed and developing economies, the recent studies have reached at different conclusions. For instance, Chang et al., (2018) argued that higher GDP per capita and capital improves the energy efficiency in 31 OECD countries. The paper employed panel data for the period 1990 to 2014 and utilized the group-mean dynamic common correlated estimation (DCCE) technique as a benchmark methodology. The results revealed that more industrial production, strict energy market regulations and higher oil prices lead toward an increase in energy intensity.

Employing the comparative analysis method, Verma et al., (2018) investigated the significance of energy efficiency policy measures for three developed countries; Iceland, Norway, and New Zeeland. The study opined that energy efficiency is very important in the overall energy mix, while its level of interest varies across different renewable rich countries. The study further argued that synchronized policies regarding energy efficiency can be developed with technological advancements and innovations. More recently, Mavi and Mavi (2019) empirically examined the environmental efficiency and energy and for the case of OECD countries. The study opined that Ireland, Switzerland, and the United States have significantly improved the energy and environment efficiency during the past decade.

In a sample of 224 cities of China, Lv et al., (2019) studied the effects of income and urbanization on energy intensity. The study employed spatial panel data techniques for empirical analysis by using the annual data from 2005 to 2016. The empirical findings reported that income has a positive impact on energy intensity, while urbanization adversely affects the energy intensity in China. In the same line, Vujanović et al., (2019) documented that use of advanced renewable technologies and a combined installation of existing technologies can be conducive to promote energy saving and improve energy efficiency in buildings and construction. For the case of 16 European economies, Kose et al., (2020) examined the role of renewable energy, non-renewable energy and research & development for the sustainable growth. The empirical results of PMG argued that all forms of energy and research & development positively induce the economic growth in European economies.

Using data on Indonesia, Saudi et al., (2019) researched the role of technological innovation for energy intensity. By using auto-regressive distributed lags (ARDL) bound testing approach, the article highlighted that technological innovation helps to improve energy efficiency in Indonesia. Using the Chinese annual data from 1970 to 2014, Akadiri et al., (2020) concluded that electricity consumption, globalization and real GDP significantly influence the carbon emissions. In the same line, for the case of United States, Alola and Akadiri, (2021) examined the impacts of economic policy uncertainty, national security and trade policy on the renewable energy. The empirical estimations of ARDL, FMOLS and DOLS reached at conclusion that policy uncertainty, trade policy and national security have significant negative and positive impacts on renewable energy respectively.

As per the above-documented literature, there is sufficient gap regarding the role of environmental policies, regulations and technologies for energy demand and energy intensity. The current study is an attempt to extend the literature of energy efficiency by examining the crucial and important role of environmental-related technologies for a group of 28 OECD economies. Hence, this article reports a significant contribution to the body of knowledge on the issue of the role of environmental technologies on energy consumption and efficiency. The study also applies several panel econometric techniques, which help to ensure that the estimated results are reliable and robust.

3. Data and methodology

3.1 Data Specification

The prime aim of this study is to unveil the impacts of environmental-related technologies on energy uses and energy efficiency. In doing so, the authors gather the annual data from three main sources; International Moneytary Fund (IMF); World Bank (WB) and OECD statistics. Table 1 illustrate the selected indicators, measurement and data sources. We only selected 28 OECD economies out of the 36 countries due to the availability of data. Further, the selection of the sample period is also determined by the availability of data. In this paper, we utilize three indicators for energy demand and energy efficiency; (i) per capita energy consumption (ECPC), in kg of oil equivalent (ii), total final energy consumption (TFEC), in terajoule, and (iii) energy intensity level of primary energy in megajoule/$2011 PPP GDP. In our empirical modelling, we use the economic openness, financial development and GDP as controlling factors for energy intensity and energy consumption. More recently, Belloumi and Alshehry, (2016); Bashir et al., (2020) and Adedoyin et al., (2020b) also used the same indicators in energy economics literature to analyse the energy demand and energy efficiency for different countries. It is important to mention here that energy intensity is considered as proxy for energy efficiency; which is justified from the fact that higher units of energy intensity refers to more energy usage to produce an unit of output and vice versa. In the recent literature, such a fact is widely supported by the recent studies (Lv et al., 2019; Samargandi, 2019).

[Insert Table 1 here]

3.2 Model Construction

The recent studies of energy demand and efficiency (Lin and Du, 2013; Li and Just, 2018; Koengkan, 2018; Lv et al, 2019) argued that some specific factors of economic structure (trade openness, economic growth, financial development, urbanization, natural resources, technological advancement etc.) are the main determinants of overall energy demand and energy efficiency. Following these studies, we mainly attempt to build three econometric models to estimate the role of environmental technology for energy consumption, final energy consumption and energy efficiency. The environmental technology is considered as a key regressor. This is justified from the fact that environmental technologies affect overall consumption pattern, energy use behaviour, climate change and productivity issues in particular economic system (Li and Just, 2018; Danish and Ulucak, 2020; OECD, 2020). The reason for including the economic openness, economic growth and financial openness as controlling explanatory variables is owing to the fact that economic regulations, performance of financial institutions, trading relations and income level of population affect the overall energy usage and energy efficiency (Farhani and Solarin, 2017; Koengkan, 2018; Samargandi, 2019; Lv et al 2019; Alam and Murad, 2020).

The choice of selecting the variables is explained by following reasons; due to endogenous perspective in economy, the authors intend to explore the effects of environmental related technologies for energy demand and efficiency. Now, the energy demand and efficiency might be affected by number of factors, e.g., rise in income level, awareness about innovations and technologies. However, in this study the independent factors are selected in view of environmental technology, which might be endogenously catalysed (Faisal et al. 2017). As mentioned above, the prime source of energy consumption in OECD is the use of crude oil, gas and fossil fuels. As a matter of fact, the consumption of non-renewables is mainly from the industrial sector, transport and households. With the industrial growth, the income level improves, along with the improvement in financial market stability, trade regulations and increasing prospects in the urban areas. Consequently, all these activities gradually start to enhance the energy demand and environmental degradation by increasing ambient air pollution, faster depletion of natural resources and soil contamination (Koengkan, 2018; Lv et al 2019; Alam and Murad, 2020). In such a scenario, the policymakers and environmental scientists strive to enhance the technological innovation and use of technologies to improve energy efficiency. From this discussion, we added the environmental technologies, economic growth, economic openness and financial openness in our econometric modelling. In all the empirical models, we have the similar explanatory factors. Equation 1, 2 and 3 present our three base line empirical models to measure the energy consumption, final energy consumption and energy intensity.

$$ECPC_{i,t} = f\left(EO_{i,t}^{\beta_1}, FD_{i,t}^{\beta_2}, PI_{i,t}^{\beta_3}, ERT_{i,t}^{\beta_4}\right) + \mu_{i,t}$$

$$ECPC_{i,t} = \beta_0 + \beta_1 EO_{i,t} + \beta_2 FD_{i,t} + \beta_3 PI_{i,t} + \beta_4 ERT_{i,t} + \mu_{i,t} \quad (1)$$

$$TFEC_{i,t} = f\left(EO_{i,t}^{\beta_1}, FD_{i,t}^{\beta_2}, PI_{i,t}^{\beta_3}, ERT_{i,t}^{\beta_4}\right) + \mu_{i,t}$$

$$TFEC_{i,t} = \beta_0 + \beta_1 EO_{i,t} + \beta_2 FD_{i,t} + \beta_3 PI_{i,t} + \beta_4 ERT_{i,t} + \mu_{i,t} \quad (2)$$

$$EI_{i,t} = f\left(EO_{i,t}^{\beta_1}, FD_{i,t}^{\beta_2}, PI_{i,t}^{\beta_3}, ERT_{i,t}^{\beta_4}\right) + \mu_{i,t}$$

$$EI_{i,t} = \beta_0 + \beta_1 EO_{i,t} + \beta_2 FD_{i,t} + \beta_3 PI_{i,t} + \beta_4 ERT_{i,t} + \mu_{i,t} \quad (3)$$

Whereas, *i* refers to the country, *t* for the time period, $ECPC_{i,t}$ is per capita energy use; $TFEC_{i,t}$ is total final energy consumption; $EI_{i,t}$ is energy intensity; $EO_{i,t}$ refers to trade openness; $FD_{i,t}$ implies financial development; $PI_{i,t}$ represents per capita income; $ERT_{i,t}$ indicates environment-related technologies. The error term is represented by $\mu_{i,t}$.

3.3 Estimation strategy

The authors begin the investigation by applying a cross-sectional dependence (CD) test developed by Pesaran (2004). Given the estimates of CD test, it is important to avoid the conventional panel unit root tests, particularly when given a series is a cross-sectional dependence. İt is because the conventional unit root tests assume that the given series is cross-sectional independence and in such case, if still applied to a series which is having a cross-sectional dependence then the estimates are unreliable as these tests suffer due to low power. Given that backdrop, the study uses the Cross-Sectionally Augmented IPS (CIPS) unit root test of Pesaran (2007). To eliminate cross-sectional dependence asymptotically, Pesaran (2007) test augments with ADF regressions, with the cross-sectional averages of lagged levels and first differences for each unit. This unit root test takes into account of cross-sectional dependence and serial correlation in the error terms. Determining the order of integration of the variables is an essential step as it helps to choose the right methodology for the empirical investigation of the relationship among the variables.

After the unit root testing, the authors further utilize the Augmented Mean Group (AMG) estimator of Eberhardt and Teal (2010) and Eberhardt and Bond (2009) to explore the role of environmental technology on energy consumption and energy intensity. The AMG estimator is an effective estimator when it comes to the problem of internality caused by the error term. In addition to taking into account of cross-sectional dependence, this estimator also accounts for heterogeneous slope coefficients among panel members (Paramati and Roca, 2019). It is additionally superior to other estimators as predictions are made by weighting the arithmetic mean of individual co-integration coefficients (Sadorsky 2013).

For the robustness check, we use several different estimation methods to examine the effects of environment-related technologies on energy use and energy efficiency. These methods include the Fixed Effects estimation method, Dynamic Ordinary Least Square (DOLS) (Pedroni 2001), Fully Modified Least Squares (FMOLS) (Pedroni 2000, 2001), and Autoregressive Distributed Lag (ARDL) (Pesaran et al. 1999) methods. The ARDL methodology has the important advantage of being able to deliver super-consistent estimates of long-run parameters and asymptotically valid *t*-ratios in presence of endogenous explanatory variables (Pesaran and Shin, 1999). The panel ARDL method analyses the long-run relationship between studied variables with cross-equation restriction to long-run parameters by applying the maximum likelihood technique for given estimation in panel data (Shahzad, et al., 2018).

3.4 Preliminary investigation

The Preliminary investigation is conducted by checking the compounded annual growth rates of all selected variables for OECD economies (Table 2). The growth rates empirics show that half of the sample countries (14) have negative growth in per capita energy consumption while remaining countries have positive growth rates. Among these countries, South Korea, Chile, and Turkey have more than 1% growth in per capita energy during the study period. Likewise, the total final energy consumption has a negative growth in the United Kingdom, Hungary, the Netherlands, Denmark, Germany and Sweden; whereas all other countries have shown considerable positive growth. Interestingly, all the sample countries have substantial negative growth in energy intensity. This implies that the selected OECD economies have significantly improved their energy efficiency over a period of time. The economic openness is only negative in two countries (Norway and Israel) out of the 28 countries. The growth rates also show that OECD countries have positive growth income and financial development. Finally, the positive growth rate in environmental-related technologies is also observed in most of the sample countries (21). In summary, the growth rates suggest that the OECD economies have significantly improved their energy efficiency and had considerable technological growth.

[Insert Table 2 here]

4. Empirical Findings and Discussion

The findings on cross-sectional dependence and unit root tests are displayed in Table 3 and 4, respectively. The results confirm the presence of cross-sectional dependence in the data series. In such case, the literature recommends applying of second-generation unit root test to examine the unit root properties of the variable. Hence, we use the CIPS unit root test introduced by Pesaran

(2007). The unit root test indicates that all the variables are non-stationary in levels. However, the variables are stationary in their first differences and are statistically significant at the 1% level. Given these evidences, we explore the determinants of energy consumption (in terms of per capita and total) and energy intensity in the following sections.

[Insert Table 3 here]

[Insert Table 4 here]

In order to investigate the role of financial development, trade openness, economic growth and environmental technologies on per capita energy consumption, total final energy consumption and energy intensity in a sample of 28 OECD countries, we employ an augmented mean group (AMG) technique. The significance of this technique is that it estimates long-run parameters by accounting for the issue of cross-sectional dependence in the analysis. As argued by a number of recent empirical studies (e.g., Sadorsky, 2013), this method not only accounts for cross-sectional dependence in the analysis, but it also allows for heterogeneous slope coefficients across the cross-sections. In addition to that, the unobserved common factors in the AMG technique are treated as a common dynamic process. Therefore, the AMG estimator outperforms the Common Correlated Effects Mean Group (CCEMG) method. Hence, the findings obtained from the AMG estimator are more reliable and robust. Table 5 reports empirical findings of the AMG method for all three models such as per capita energy consumption, total final energy consumption and energy intensity. The empirical results show that per capita income positively drives per capita energy consumption and total final energy consumption. In other words, the results suggest that economic progress in the OECD countries leads to an increase in energy consumption, both in terms of per capita and total. This outcome supports both theoretical and empirical expectations. For instance, as income grows, individuals are tempted to buy luxury goods such as air conditioners, fans, televisions, refrigerators, washing machines, laptops, mobiles, etc. Hence, all of these goods raise the demand for energy. Therefore, a raise in income leads to higher demand for energy. Our estimates are inconsistent with the findings of Wang et al., (2019) for a sample of 186 countries. While, the empirical findings are in line with the conclusions of Adedoyin et al., (2021) for the case of 29 EU economies. Their study suggested the free-trade policy and use of high-tech products for achieving the sustainable development goals.

Interestingly, the empirical results indicate a significant and negative impact of GDP per capita towards energy intensity in OECD countries. The empirical finding is very interesting and encouraging one, indicating that as the income grows individuals may be adapting electric equipment which are energy efficient. On one side, income growth has a positive impact on energy consumption, on the other side, income growth play an important role for energy efficiency by encouraging individuals to adopt energy-efficient electric equipments. The empirical findings are in contrast with the evidence of Lv et al. (2019), who examined on Chinese cities. The difference in results with the previous literature could perhaps be due to regional heterogeneity and difference in the economic structure of countries. The AMG analysis further shows that financial development positively affects total final energy consumption, while environmental related technologies respond negatively towards final energy consumption. This might be due to the introduction of environmental friendly technology which consumes less fuel, oil and gas sources to reduce greenhouse gas emissions e.g. ultra-efficient heat pumps, carbon-fighting dryers, magnetic refrigerators, etc. The inverse nexus between financial development and total energy use in the OECD countries could perhaps be explained by the fact that financial development can pontentially assist the firms to acquire energy saving technologies by providing required capital assistance. It is important to note that energy efficiency or energy saving projects need long term financing facility which is relatively easily accessible in the developed countries (Farhani and Solarin, 2017), these long-term financing facilities might help to reduce financing costs and channel financial resources into new equipment, technology, and projects which are energy efficient consequently, controlling energy consumption.

[Insert Table 5 here]

4.1 Robustness checks

We carry out several robustness checks using fixed effects, DOLS, FMOLS and ARDL methods to see if our results are consistent across the different estimation methods. **Table 6** reports the long run estimations concerning our primary and control variables for the OECD countries. The results in Table 6 highlight that trade openness and environmental technologies negatively influence the energy use, total energy use and energy intensity in the OECD countries. It is possible that trade openness and liberalization help to control energy consumption and energy intensity. More open economies can encourage investments and energy-efficient products and technologies, and research and development which might explain this. The empirical findings are in contrast with the conclusions of Koengkan (2018) for the Andean community countries.

The coefficients of environment-related technologies are negative and significant at the 1% level. As stated above, the negative impacts of environment-related technologies might be due to the developments and innovations of energy-efficient technologies in OECD countries, which can lower energy use and consumption. For example, the OECD countries have increased the usage of renewable energy sources with significant magnitude, e.g. electricity generation of OECD countries from hydro-renewable sources was 54.2 percent in 2016 and electricity generation from non-hydro renewable sources was recorded at 10.9 percent in the similar period (IEA, 2017). The coefficients of GDP per capita and financial development are positive and significant at the 1% level, which are stable with our earlier findings. The results suggest that the provision of credit, long-term financing facilities, and economic progress might help to control energy consumption. This is supported by the fact that long-term financing opportunities assist in establishing energy-efficient technologies, which can help to reduce energy demand and provide more output.

The results imply that the economic growth in the OECD countries leads to a further rise in energy demand. It is because the OECD countries are dependent on manufacturing and industry, which use high energy-consuming technologies. Although, several OECD member countries are now shifting towards the service sector and high manufacturing sectors, which use technologies that tend to be less energy-intensive. While, economic growth is still reliant on energy consumption and energy demand (EIA, 2017). The empirical results are consistent with those of Faisal et al. (2017) for Belgium. However, energy intensity shows a positive association with financial development and negative effect with GDP per capita, indicating that economic growth in OECD countries is decreasing energy intensity. The negative impact of GDP per capita on energy intensity is in line with our main findings and is in contrast with the narrative of Lv et al., (2019). Accordingly, it can be argued that the energy consumption of OECD countries relies on economic progress, while economic development decreases energy intensity.

[Insert Table 6 here]

Overall, the paper provides very innovative and encouraging findings regarding energy consumption and energy intensity of OECD countries, which allow us to draw new conclusions and policies. The paper suggests that governments should adopt comprehensive strategies to promote the use of environment-related technologies e.g. regulations on industries, use of energy-efficient home appliances, taxes on traditional technologies etc. The governments and policymakers can introduce institutional measures such as; sponsoring the research on environment and energy efficiency policies, awareness campaigns on the use of energy-efficient products and legislative measures e.g. enforcing replacement of traditional products by innovative technologies. To protect the environment and save energy costs, the rich OECD countries can provide subsidies and economic incentives to enterprises and households to encourage the use of technological products and renewables. Further, the OECD countries should make significant efforts for synchronized policies regarding investments on environmental technologies and renewable sources to achieve energy efficiency and economic goals.

5. Conclusion with policy implications

In recent times, there is an increasing interest among policymakers, energy economists, and government officials to understand the factors that help to increase energy efficiency. However, there is a little empirical evidence on the factors which contribute for energy efficiency. This issue has attracted the attention of various stakeholders due to the increasing demand for energy from various economic activities. Given this backdrop, this study was designed to investigate the role of environmental-related technologies on energy demand, in terms of per capita and total, and energy intensity by accounting other key factors in the model such as economic openness, per capita income and financial development in a panel of 28 OECD economies. To achieve those objectives, our study utilized yearly data, 1990-2014, and employed various robust panel econometric techniques, which helped to address the issues of cross-sectional dependence, heterogeneity, endogeneity and serial correlation in the estimation process. Hence, we believe that the estimated results are more reliable and robust.

Our findings from various approaches confirmed that environmental-related technologies have substantial positive and negative influences on energy demand and energy intensity, respectively. These results indicated that environmental technology played an important role in condensing the demand for energy by assisting to improve energy efficiency. Further, evidence showed that economic openness also increased energy efficiency and reduced energy demand. However, the increase in per capita income raised energy demand and energy efficiency. Finally, the results also displayed that the increase in financial development put more pressure on energy demand and its impact on energy intensity is not stable across the estimates. Given these outcomes, we argue that environmental technologies have played an indispensable role in reducing energy use and improving (energy) efficiency in the selected OECD economies. Hence, we suggest the policymakers and various other think tank officials to realize the significant role that environmental technologies had played in terms of saving energy and improving energy efficiency. We advise that while initiating policies regarding improving energy efficiency, the officials must consider the role of environmental technologies and should support and encourage the innovations in environmental technologies as they occupy a dispensable role in that aspect.

Finally, the current study report academic contribution to the literature regarding the issue of energy demand, energy efficiency, and environmental related technologies. Given all of that, our study offers new findings and may add considerable value to the energy economics field. The future research can extend this model for developing and emerging economies on a broader scale. Similarly, the role of environmental technologies for international trade, product diversification and manufacturing processing’s can be further explored in the context of environmental sustainability.

Acknowledgement

The authors are grateful to editor and anonymous reviewers for providing useful comments and suggestions. The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. No funding was received for this research work.

References

Adedoyin, F.F., Alola, A.A., Bekun, F.V., 2021. The alternative energy utilization and common regional trade outlook in EU-27: Evidence from common correlated effects. Renew. Sustain. Energy Rev. 145, 111092. https://doi.org/10.1016/j.rser.2021.111092

Adedoyin, F.F., Alola, A.A., Bekun, F.V., 2020a. The nexus of environmental sustainability and agro-economic performance of Sub-Saharan African countries. Heliyon 6, e04878. https://doi.org/10.1016/j.heliyon.2020.e04878

Adedoyin, F.F., Bekun, F.V., Alola, A.A., 2020b. Growth impact of transition from non-renewable to renewable energy in the EU: The role of research and development expenditure. Renew. Energy 159, 1139–1145. https://doi.org/10.1016/j.ygyno.2016.04.081

Akadiri, S. Saint, Alola, A.A., Bekun, F.V., Etokakpan, M.U., 2020. Does electricity consumption and globalization increase pollutant emissions? Implications for environmental sustainability target for China. Environ. Sci. Pollut. Res. 27, 25450–25460. https://doi.org/10.1007/s11356-020-08784-3

Alam, M.M., Murad, M.W., (2020). The impacts of economic growth, trade openness and technological progress on renewable energy use in organization for economic co-operation and development countries. Renew. Energy 145, 382–390. https://doi.org/10.1016/j.renene.2019.06.054

Alola, A.A., Akadiri, S. Saint, 2021. Clean energy development in the United States amidst augmented socioeconomic aspects and country-specific policies. Renew. Energy 169, 221–230. https://doi.org/10.1016/j.renene.2021.01.022

Alola, A.A., Alola, U.V., 2018. Agricultural land usage and tourism impact on renewable energy consumption among Coastline Mediterranean Countries. Energy Environ. 29, 1438–1454. https://doi.org/10.1177/0958305X18779577

Asongu, S.A., Agboola, M.O., Alola, A.A., Bekun, F.V., 2020. The criticality of growth, urbanization, electricity and fossil fuel consumption to environment sustainability in Africa. Sci. Total Environ. 712, 136376. https://doi.org/10.1016/j.scitotenv.2019.136376

Baloch, M.A., Ozturk, I., Bekun, F.V., Khan, D., 2021. Modeling the dynamic linkage between financial development, energy innovation, and environmental quality: Does globalization matter? Bus. Strateg. Environ. 30, 176–184. https://doi.org/10.1002/bse.2615

Apergis N and Payne J (2010). Renewable energy consumption and economic growth: Evidence from a panel of OECD countries, Energy Policy 38, 656–660

Apergis, N. et al., (2015). Energy efficiency of selected OECD countries: A slacks based model with undesirable outputs. Energy Economics, Volume 51, pp. 45-53.

Apergis , N., Aye, G., Barros, C., Gupta , R., & Wanked, P. (2015). Energy efficiency of selected OECD countries: A slacks based model with undesirable outputs. Energy Economics, 51, 45-53.

Bashir, M.A., Sheng, B., Dogan, B., Sarwar, S., Shahzad, U., (2020). Export product diversification and energy efficiency : Empirical evidence from OECD countries. Struct. Chang. Econ. Dyn. 55, 232–243. https://doi.org/10.1016/j.strueco.2020.09.002

Belloumi, M., Alshehry, A.S., (2016). The Impact of Urbanization on Energy Intensity in Saudi Arabia 1–17. https://doi.org/10.3390/su8040375

Bekun, F.V., Yalçiner, K., Etokakpan, M.U., Alola, A.A., 2020. Renewed evidence of environmental sustainability from globalization and energy consumption over economic growth in China. Environ. Sci. Pollut. Res. 27, 29644–29658. https://doi.org/10.1007/s11356-020-08866-2

Bhattacharya, M., Churchill, S. A., & Paramati, S. R. (2017). The dynamic impact of renewable energy and institutions on economic output and CO2 emissions across regions. Renewable Energy, 111, 157-167.

Chang, C.-P.et al., (2018). Is higher government efficiency conducive to improving energy use efficiency? Evidence from OECD countries. Economic Modelling, Volume 72, pp. 65-77.

Danish, Ulucak, R., (2020). How do environmental technologies affect green growth? Evidence from BRICS economies. Sci. Total Environ. 712, 136504. https://doi.org/10.1016/j.scitotenv.2020.136504

Eberhardt, M. and Bond, S., (2009). Cross-section dependence in nonstationary panel models: A novel estimator. MPRA Paper, No. 17870, https://mpra.ub.uni-muenchen.de/17870/2/MPRA_paper_17870.pdf

Eberhardt, M., & Teal, F. (2010). Productivity Analysis in Global Manufacturing Production.

EIA, (2017). Link between growth in economic activity and electricity use is changing around the world. [Online] Available at: https://www.eia.gov/todayinenergy/detail.php?id=33812 [Accessed 07 July 2019].

European Environment Agency. (2019). Preventing plastic waste in Europe. Luxembour: European Environment Agency. Retrieved from https://www.eea.europa.eu

Faisal F, Tursoys T, and Ercantan O (2017). The relationship between energy consumption and

economic growth: Evidence from non-Granger causality test, Procedia Computer Science 120, 671–675

Farhani, S. & Solarin, S. A., (2017). Financial development and energy demand in the United States: New evidence from combined cointegration and asymmetric causality tests. Energy, Volume 134, pp. 1029-1037.

Geller H, Harrington P, Rosenfeld A , Tanishimad S, Unanderd F (2006). Polices for increasing energy efficiency: Thirty years of experience in OECD countries, Energy Policy, 34, 556–573.

IEA, (2017). Renewables Information 2017. [Online]

Available at: https://www.iea.org/newsroom/energysnapshots/shares-in-oecd-renewable-electricity-production-2016.html [Accessed 15 July 2019].

International Energy Agency. (2020, July 1). World Energy Balances: Overview. Retrieved from IEA Database: https://www.iea.org/reports/world-energy-balances-overview

International Moneytary Fund. (2019, July 15). IMF database. Retrieved July 25, 2019, from http://data.imf.org/MyProfile?tb=Downloads

Koengkan, M., (2018). The positive impact of trade openness on consumption of energy: Fresh evidence from Andean community countries. Energy, Volume 158, pp. 936-943.

Kose, N., Bekun, F.V., Alola, A.A., 2020. Criticality of sustainable research and development-led growth in EU: the role of renewable and non-renewable energy. Environ. Sci. Pollut. Res. 27, 12683–12691. https://doi.org/10.1007/s11356-020-07860-y

Li J and Just R (2018) Modeling household energy consumption and adoption of energy efficient technology, Energy Economics 72, 404–415.

Lin, B., Du, K., (2013).. Technology gap and China's regional energy efficiency: A parametric metafrontier approach. Energy Econ. 40, 529–536. https://doi.org/10.1016/j.eneco.2013.08.013

Lv, Y., Chen, W. & Cheng, J., (2019). Direct and Indirect Effects of Urbanization on Energy Intensity in Chinese Cities: A Regional Heterogeneity Analysis. Sustainability, 11(11), pp. 1-20.

Mavi, N. K. & Mavi, R. K., (2019).. Energy and environmental efficiency of OECD countries in the context of the circular economy: Common weight analysis for malmquist productivity index. Journal of Environmental Management, Volume 247, pp. 651-61.

Mccue, J., (2014). The-Impact of Technology On The Energy Industry. [Online]

Available at: https://powerlinesinc.com/the-impact-of-technology-on-the-energy-industry/ [Accessed 22 July 2019].

Murad, M.W., Alam, M.M., Noman, A.H.M., Ozturk, I., (2019). Dynamics of technological innovation, energy consumption, energy price and economic growth in Denmark. Environ. Prog. Sustain. Energy 38, 22–29. https://doi.org/10.1002/ep.12905

OECD (2020) Green Growth and Energy 2019. [Online] Available at: https://www.oecd.org/greengrowth/greening-energy/greengrowthandenergy.htm [Accessed 15 July 2019]

OECD statistics. (2020, Janaury 01). OECD data. Retrieved december 15, 2019, from https://stats.oecd.org/#

Paramati, S. R., Mo, D., & Huang, R. (2021). The role of financial deepening and green technology on carbon emissions: evidence from major OECD economies. *Finance Research Letters*, *41*, 101794.

Paramati S.R. and E.Roca. (2019). Does tourism drive house prices in the OECD economies? Evidence from augmented mean group estimator. Tourism Management, 74, 392-395.

Parker, S. & Liddle, B., (2016). Energy efficiency in the manufacturing sector of the OECD: Analysis of price elasticities. Energy Economics, Volume 58, pp. 38-45.

Pesaran, M. H., Shin, Y., & Smith, R. P. (1999). Pooled mean group estimation of dynamic heterogeneous panels. Journal of the American Statistical Association, 94(446), 621-634.

Pesaran, M. & Shin, Y., (1999). An autoregressive distributed lag modelling approach to cointegration analysis. Department of Applied Economics, University of Cambridge, England, pp. 1-33.

Pedroni, Peter (2001). "Purchasing Power Parity Tests in Cointegrated Panels," The Review of Economics and Statistics, 83, 727–731.

Pedroni, Peter (2000). "Fully Modified OLS for Heterogeneous Cointegrated Panels," in Baltagi, B. H. ed., Nonstationary Panels, Panel Cointegration and Dynamic Panels, 15, Amsterdam: Elsevier, 93–130.

Pesaran, M. (2004). General diagnostic tests for cross section dependence in panels. Cambridge Working Papers in Economics No. 0435. Cambridge University, Cambridge.

Pesaran, M. Hashem. (2007). A simple panel unit root test in the presence of cross-section dependence, Journal of Applied Econometrics 22 (2), 265–312.
Pedroni, Peter (2001). "Purchasing Power Parity Tests in Cointegrated Panels," The Review of Economics and Statistics, 83, 727–731.
Rafique M.Z., Doğan, B. Husain, S. Huang S., Shahzad U. (2021) Role of economic complexity to induce renewable energy: contextual evidence from G7 and E7 countries, International Journal of Green Energy, 18:7, 745-754, DOI: 10.1080/15435075.2021.1880912

Sadorsky, Perry. (2013). "Do Urbanization and Industrialization affect Energy Intensity in Developing Countries?", Energy Economics, 37, 52-59.

Saudi, M., Sinaga, O., Roespinoedji, D., & Ghani, E. (2019). The Impact of Technological Innovation on Energy Intensity: Evidence from Indonesia. International Journal of Energy Economics and Policy, 9(3), 11-17.

Shahzad, U., Sarwar, S., Amin, W., & Zaman, Q.-u. (2018). The Relationship among Economic Growth, Renewable Eenergy Consumption, CO2 Emissions and Agriculture Pproduction: Empirical Evidence for China and India. GLobal and Local Economic Review, 22(1), 41-68.

Shahzad, Umer, Buhari Doğan, Avik Sinha, and Zeeshan Fareed. (2021). Does Export product diversification help to reduce energy demand: Exploring the contextual evidences from the newly industrialized countries. *Energy* 214: 118881.

Shahzad U, Lv Y, Dogan B, Xia W (2021) Unveiling the heterogeneous impacts of export product diversi fi cation on renewable energy consumption: New evidence from G-7 and E-7 countries. Renewable Energy Journal 164:1457–1470. https://doi.org/10.1016/j.renene.2020.10.143

Sinha, A., Sengupta, T., Alvarado, R., 2020. Interplay between technological innovation and environmental quality: Formulating the SDG policies for next 11 economies. J. Clean. Prod. 242, 118549. https://doi.org/10.1016/j.jclepro.2019.118549

UCSUSA. (2016). The Hidden Costs of Fossil Fuels. Retrieved August 30, 2019, from https://www.ucsusa.org/clean-energy/coal-and-other-fossil-fuels/hidden-cost-of-fossils

Verma, P., Patel, N., Naira, N.-K., & Brentb, A. (2018). Improving the energy efficiency of the New Zealand economy: A policy comparison with other renewable-rich countries. Energy Policy, 122, 506-517.

Vujanović, M., Wang, Q., Mohsen, M., Duić, N., Yan, J., 2019. Special issue of applied energy dedicated to SDEWES conferences 2018: Sustainable energy technologies and environmental impacts of energy systems. Appl. Energy 256. https://doi.org/10.1016/j.apenergy.2019.113919

Wang, Q., Su, M., Li, R., & Ponce, P. (2019). The effects of energy prices, urbanization and economic growth on energy consumption per capita in 186 countries. Journal of Cleaner Production, 1-55.

World Development Bank. (2020). World Development Indicators. Retrieved July 15, 2019, from http://databank.worldbank.org/data/reports.aspx?source=world-development-indicators#

Figures and Tables:

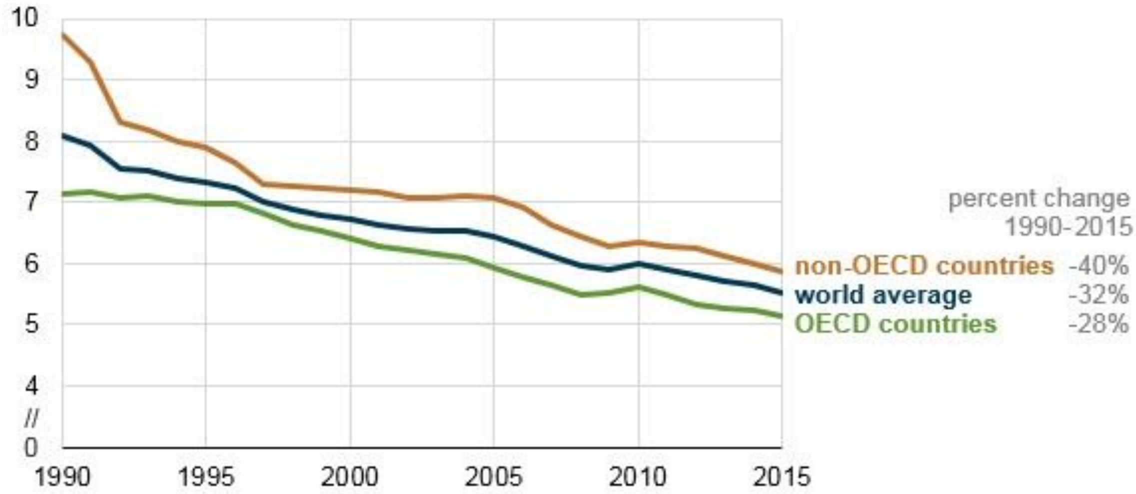

Figure 1: Trends in World Energy intensity (quadrillion British Thermal units per trillion Dollars GDP). Source: (EIA, 2017)

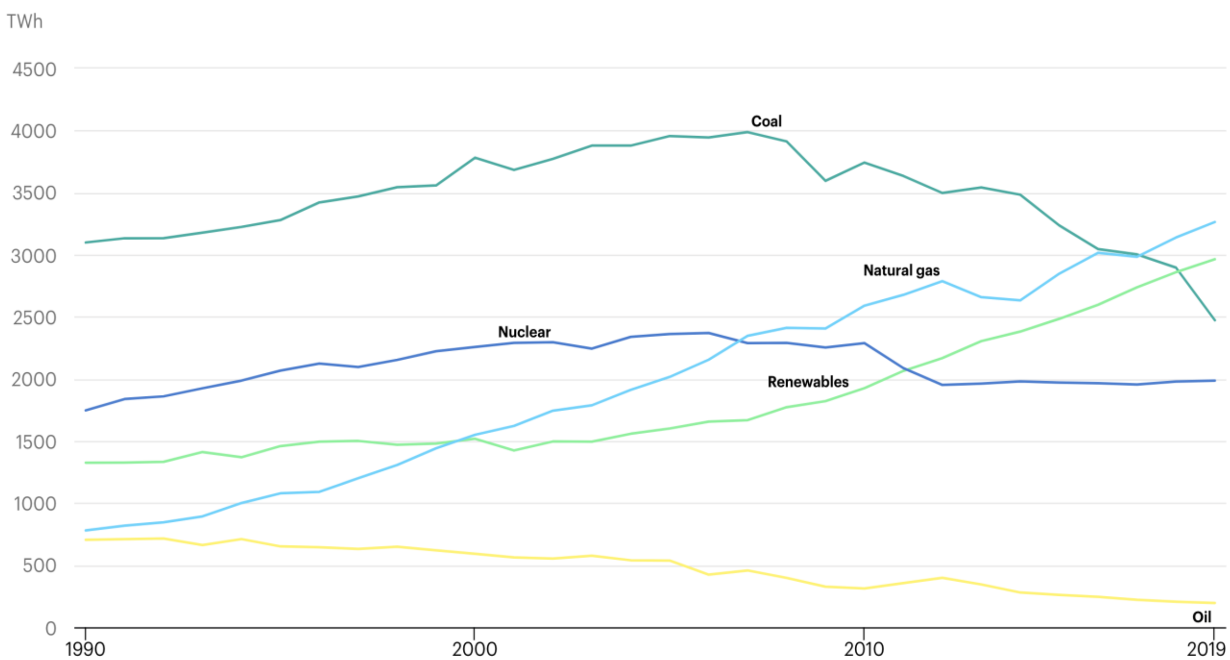

Figure 2: Electricity Generation by Source in OECD Source: (International Energy Agency, 2020)

Table 1: Data measurement and sources

Variables	Measurement	Data Source
ECPC	Per capita energy consumption (kg of oil equivalent)	WDI-World Bank
TFEC	Total final energy consumption (measured in terajoule)	Sustainable Energy-World Bank
EI	Energy intensity level of primary energy (megajoule/$2011 PPP GDP)	WDI-World Bank
EO	Sum of total exports and imports as share of GDP	WDI-World Bank
FD	Financial development index (the information on access, depth, efficiency of the financial institutions and markets)	IMF
PI	GDP per capita in constant 2010 US$	WDI-World Bank
ERT	Environment-related technologies as percentage of all technologies	OECD statistics

Table 2: Compounded annual growth rates, 1990-2014 (percent)

Country	ECPC	TFEC	EI	EO	FD	PI	ERT
Australia	0.210	1.470	-1.448	1.057	2.050	1.677	0.275
Austria	0.601	1.191	-0.813	1.494	0.266	1.387	-0.381
Belgium	-0.085	0.372	-1.293	1.253	1.163	1.209	1.224
Canada	0.141	0.717	-1.134	0.999	2.371	1.274	0.357
Chile	2.681	3.540	-0.986	0.214	2.493	3.686	3.831
Denmark	-0.645	-0.080	-1.871	1.688	0.810	1.158	3.057
Finland	0.351	0.470	-0.868	2.011	2.660	1.207	1.844
France	-0.181	0.060	-1.148	1.382	2.009	0.964	2.914
Germany	-0.626	-0.458	-1.901	1.841	0.417	1.333	1.369
Greece	0.040	0.268	-0.478	2.081	2.132	0.610	-2.417
Hungary	-0.722	-0.704	-1.921	3.700	1.364	1.890	0.180
Ireland	-0.113	1.453	-3.352	2.779	0.545	3.386	2.784
Israel	0.464	2.566	-1.645	-0.084	1.549	1.755	-1.134
Italy	-0.271	0.182	-0.667	1.717	2.596	0.399	1.744
Japan	-0.092	0.069	-1.043	2.595	1.114	0.928	1.732
Mexico	0.174	1.673	-0.892	2.639	0.898	1.080	0.777
Netherlands	-0.063	-0.099	-1.437	1.568	1.156	1.421	0.980
New Zealand	0.675	1.302	-0.747	0.035	1.455	1.431	-0.567
Norway	0.478	0.529	-1.169	-0.228	1.786	1.584	-1.000
Poland	-0.358	0.186	-3.788	2.962	2.612	3.510	-0.124
Portugal	0.766	1.077	-0.232	0.829	3.448	1.025	-3.437
South Korea	3.633	3.079	-0.499	2.511	2.180	4.312	3.604
Spain	0.247	1.240	-0.782	2.304	3.161	1.095	3.249
Sweden	-0.418	-0.034	-1.826	1.657	2.340	1.435	2.777
Switzerland	-0.678	0.095	-1.453	1.899	0.502	0.690	1.244
Turkey	1.933	3.097	-1.043	2.444	4.485	2.739	1.330
United Kingdom	-1.030	-0.376	-2.417	0.877	1.481	1.429	1.959
United States	-0.388	0.739	-1.717	1.706	1.726	1.358	1.778
Sample average	0.240	0.844	-1.377	1.640	1.813	1.642	1.070

Note: Non-log data is used.

Table 3: Findings from cross-sectional dependence (CD) test

Variable	CD-test	p-value	corr	abs(corr)
ECPC	29.250	0.000	0.301	0.487
TFEC	44.900	0.000	0.462	0.563
EI	74.740	0.000	0.769	0.769
EO	65.380	0.000	0.673	0.678
FD	78.400	0.000	0.806	0.806
PI	90.230	0.000	0.928	0.928
ERT	46.490	0.000	0.478	0.518

Note: *** indicates rejection of the null hypothesis at the 1% significance level.

Table 4: Findings from panel CIPS unit root test

	Level		First difference	
Variable	Zt-bar	p-value	Zt-bar	p-value
ECPC	1.116	0.868	-10.927***	0.000
TFEC	0.822	0.795	-9.145***	0.000
EI	1.309	0.905	-8.820***	0.000
EO	0.255	0.601	-6.369***	0.000
FD	0.061	0.524	-9.032***	0.000
PI	-0.247	0.402	-6.839***	0.000
ERT	1.880	0.970	-14.003***	0.000

Note: *** indicates 1% significance level.

Table 5: Long-run estimates using augmented mean group (AMG) estimator

	Coefficient	p-value	Coefficient	p-value	Coefficient	p-value
	ECPC = f (EO, FD, PI, ERT)		TFEC = f (EO, FD, PI, ERT)		EI = f (EO, FD, PI, ERT)	
Constant	1.124	0.153	6.848***	0.000	4.674***	0.000
EO	-0.033	0.396	-0.018	0.510	-0.018	0.649
FD	0.049	0.143	0.060*	0.068	0.045	0.187
PI	0.691***	0.000	0.737***	0.000	-0.298***	0.000
ERT	-0.010	0.322	-0.015*	0.089	-0.011	0.288

Note: *** & * imply 1% and 10% significance levels, respectively.

Table 6: Long-run estimates using fixed effect, DOLS, FMOLS and ARDL

	Coefficient	p-value	Coefficient	p-value	Coefficient	p-value
	ECPC = f (EO, FD, PI, ERT)		TFEC = f (EO, FD, PI, ERT)		EI = f (EO, FD, PI, ERT)	
Fixed effect						
Constant	4.202***	0.000	8.490***	0.000	7.875***	0.000
EO	-0.188***	0.000	-0.189***	0.000	-0.178***	0.000
FD	0.141***	0.000	0.181***	0.000	0.142***	0.000
PI	0.417***	0.000	0.592***	0.000	-0.584***	0.000
ERT	-0.062***	0.000	-0.036***	0.000	-0.063***	0.000
DOLS (Grouped-Mean approach)						
EO	-0.090*	0.052	-0.042	0.307	-0.084*	0.088
FD	0.055	0.207	0.079**	0.044	0.049	0.300
PI	0.546***	0.000	0.724***	0.000	-0.439***	0.000
ERT	-0.042***	0.000	-0.083***	0.000	-0.039***	0.002
FMOLS (Grouped-Mean approach)						
EO	-0.152***	0.000	-0.105***	0.000	-0.143***	0.000
FD	0.133***	0.000	0.123***	0.000	0.133***	0.000
PI	0.438***	0.000	0.662***	0.000	-0.562***	0.000
ERT	-0.073***	0.000	-0.049***	0.000	-0.074***	0.000
ARDL						
EO	-0.059***	0.000	-0.369***	0.000	-0.058***	0.000
FD	0.016	0.207	0.471***	0.000	0.005	0.726
PI	0.702***	0.000	0.896***	0.000	-0.336***	0.000
ERT	-0.052***	0.000	-0.057***	0.000	-0.064***	0.000

Note: ***, ** & * indicates 1%, 5% and 10% significance levels, respectively.