Renewable, non-renewable energy consumption, economic growth, trade openness and ecological footprint: Evidence from organisation for economic Co-operation and development countries

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Renewable, non-renewable energy consumption, economic growth, trade openness and ecological footprint: Evidence from OECD countries

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ABSTRACT

The purpose of this study is to examine the validity of EKC hypothesis for ecological footprint with the role of renewable energy use, non-renewable energy use and trade openness in 24 OECD countries. For this purpose, we investigate the period from 1980 to 2013 using with second generation panel data methodologies which allow to cross-sectional dependence among countries. The group-mean results show that the inverted U-shaped EKC hypothesis does not hold in OECD countries because we found the U-shaped relationship between economic growth and ecological footprint. In addition, it is concluded that increasing renewable energy consumption reduces ecological footprint and increasing non-renewable energy consumption increases environmental degradation.

Keywords: Ecological footprint, Environmental Kuznets Curve, OECD countries

1. Introduction

Along the growth path of any nation, then at the nascent phase of growth, ecological quality depreciates swiftly due to deterioration of ambient air quality, decrease in forest cover, soil erosion, continuous variation in the pH value of water, and quite a few other such reasons. With rise in income, the speed of depreciation decelerates, and beyond certain level of income, environmental quality starts improving. This theorized income-pollution association resembles an inverted U-shaped form, and this particular incident is denoted as Environmental Kuznets Curve (EKC) hypothesis, named after Simon Kuznets (1955), who hypothesized inverted U-shaped association between income inequality and economic development. This association was found to be resembling with the finding of Grossman and Krueger (1991), while analyzing the ecological impact of the North American Free Trade Agreement (NAFTA).

Now, when we consider the impact of economic growth on environment, mostly the pollutants are chosen as the ecological indicator. However, in this study, we have chosen Ecological Footprint (EF) as the indicator of environmental quality. As characterized by Rees (1992), Wackernagel and Rees (1996, 1997) and Wackernagel et al. (1999), EF defines the carrying capacity of the earth, and as this measure has an inherent futuristic element, it is an indicator of sustainability, as well. According to them, it is the capacity of a collective ecological area to produce the resources consumed by the parties involved in an economic process, and at the same time, it is also the capability to absorb the waste being produced by those parties. Later, this definition was challenged by Wackernagel and Monfreda (2004). According to them, EF is the measure of the biocapacity necessary for an economic system to operate, i.e. the biocapacity should have essential pool of natural resources and it should also be able to absorb the waste generated by the economic system. As the revival rate of natural capital is lower than the rate of consumption, technological advancements can neither add to the ecological carrying capacity nor reduce the amount of waste (Wackernagel and Silverstein, 2000). Though there is a long-standing debate regarding the choice of EF as an indicator of ecological sustainability (Kissinger and Haim, 2008; Templet, 2000; Wiedmann and Barrett, 2010, and many others), EF reflects the human dependence on the ecological system, and therefore, it can act as a viable indicator for determining environmental quality (Deutsch et al., 2000; Moore et al., 2013; Galli, 2015). In the present study, we have considered EF as an indicator for environmental quality for several reasons. First, EF indicates the carrying capacity of earth, and therefore, it is a larger indicator for ecological sustainability. In view of the Sustainable Development Goals (SDGs), it is the only indicator, which captures the biological capacity of a planet for sustaining the economic activity (Rashid et al., 2018). Second, during the course of economic activity, natural resources are consumed, and this consumption can be in the form of minerals, water, forest, and land resources. Therefore, choosing the emissions as environmental indicator might restrict the focus of ecological sustainability within the major industrial activities, and thereby, disregarding the other human activities causing damage to ecological sustainability (Li et al., 2019). Third, the ecological sustainability of a nation also depends on its capacity to absorb the ambient pollution, which is significant from the perspective of addressing the SDGs (Pan et al., 2019).

Before moving on to the discussion on sustainable development, we need to discuss about the concern regarding EF across the globe. While moving along the growth path, nations thrive on energy consumption to achieve the economic growth, and in this pursuit, the carrying capacity of the earth is hindered owing to the consequential pollution. After a threshold level of economic growth, rising environmental awareness compels the policymakers to take corrective measures, and that is when the nations start experiencing technological advancement. This technological advancement is hypothesized to be carried out though the technology transfer route, as different nations might have specialization in various technological fronts. When nations start exploiting technological advancement, EF starts coming down. This is also the time, when nations start preferring renewable energy solutions over nonrenewable energy solutions, owing to the rising environmental concerns. Gradual shift from nonrenewable to renewable energy solutions leads to continuing improvement in ecological quality.

Now, from the perspective of the developed nations, it is necessary to understand the need to segregate the energy sources in order to assess their impacts on the EF, as these nations are considered to be the pioneers in the field of sustainable development. The energy consumed in these nations is characterized by nonrenewable and renewable energy sources, and both of these sources have different impacts on the overall growth and development of these nations. Therefore, we use the term "segregation" for identifying the two distinct sources of energy used in these nations. While talking about sustainable development, it is needed to remember the role of energy policy in not only reducing the level of environmental degradation, but also create sustainable jobs, which are enabled by green growth. Thereby, by virtue of segregated energy solutions and implementation of cleaner production policies, these nations can frame strategies to achieve the objectives of Sustainable Development Goals (SDGs). In this regard, the member countries of Organization for Economic Co-operation and Development (OECD) needs a special mention, as these nations are focusing at policy coherence to bring forth synergy between economic, social, and environmental policies. Now, researchers have identified the role of renewable energy consumption in addressing all the three aforementioned policy areas (Akella et al., 2009; Carbajo and Cabeza, 2018; Lozano et al., 2018). However, having a sole focus on renewable energy consumption and disregarding the contribution of nonrenewable energy consumption might hinder the economic growth, as the energy mix in the OECD nations is still dominated by nonrenewable energy consumption. Irrespective of the level of development, sole dependence on renewable energy consumption is yet to be experienced, and till the shift of energy source is in the process, the developmental actions will be largely dependent on the nonrenewable energy consumption, perhaps in the form of improved energy efficiency and implementation of cleaner production technologies. Given this background, it is imperative to assess the impact of segregated energy use on EF for OECD member countries, so that the foundation for synergetic sustainable policy formulation becomes possible (McDermott et al., 2018; Ribeiro et al., 2018). In terms of segregation, we intend to signify the two different sources of energy being used in the production processes, i.e. the renewable and non-renewable energy sources. This concept of energy use segregation has been adopted from the studies by Zrelli (2017), Appiah et al. (2019), and several other researchers. By far, the literature has focused on the impact of energy consumption on ambient air pollution for OECD countries, and in doing so, the studies have largely ignored the bigger picture of sustainable development, which has been reinstated by means of the SDGs. There lies the focus of the present article.

In the present study, we have evaluated the impact of energy consumption on ecological footprint for 24 OECD countries over the period of 1980 to 2014. The analysis in this study is carried out by segregating the energy consumption into renewable and non-renewable energy consumption, so that we can visualize the impacts of two different forms of energy consumption on EF, and thereby, can recommend the policy decisions more effectively. In order to achieve more insights on the present developmental scenario and achieve the objectives of SDGs, it is required to understand the differential impact of these two types of energy consumption on the quality of environment. The EKC estimation studies carried out for OECD countries have majorly focused on various pollutants differentially, without considering the environment as a whole. Hence, estimating the EKC for EF might give the policymakers with a wholesome perspective regarding the environmental degradation scenario, and consequent policy designs targeting the SDGs. Moreover, the existing EKC estimation studies for EF has majorly looked into the energy consumption, without considering differential impacts of the two forms of energy source. This another area, which is largely unaddressed in the literature. Therefore, from both model designing and policy devising perspectives, this study contributes to the literature of energy and environmental economics.

Saying this, we need to mention that segregation of energy usage also entails the technological advancement in these nations, which might be captured by means of technology transfer via trade route (Sinha et al., 2017; Yang et al., 2018; Ma et al., 2019). Therefore, for developed nations, trade openness can be considered as a proxy for economic growth, and trade openness is an enabler of economic growth. Now, going by the definition of EKC hypothesis, growth in income is considered as the definitive factor for environmental degradation, and this growth has been computed through diverse proxies in the literature. As the research context in this study is the developed nations and we are intended to segregate the energy sources, it is necessary to consider trade openness as a model variable. As implementation of renewable energy solutions might not be possible without technological advancement, hence trade openness needs to be included in the empirical model, for indicating both the economic growth and technological advancement. While the scale effect will be exerted by economic growth and the composition effect will be exerted by the segregated energy use, trade openness exerts the technical effect on the environmental quality (Sinha et al., 2017). In spite of the significant effects of the mentioned variables that should not be ignored, many studies such as Narayan and Narayan (2010); Jaunky (2011); Esteve and Tamarit (2012); Apergis (2016); Ahmad et al. (2017) ignore the above-mentioned stylized facts based on the assumption that the only factor determining environmental pollution is economic growth. However, the EKC studies based on reduced form empirical model created by non-structural variables are likely to encounter the risk of omitted variable bias (Stern, 2004). Therefore, alongside per capita income, this study has also taken trade openness as another explanatory variable for economic growth. This parameterization has been driven by the context setting.

The existing literature of energy and environmental economics majorly focused at analyzing the impact of segregated energy use on the ambient air pollutants (Sinha et al., 2017, 2019). However, ambient air pollutants cannot represent the environmental degradation in a wholesome manner, as the impact of energy-led industrialization can be visualized through the overall ecological imbalance. Moreover, in order to achieve a sustainable economic growth, the impact of energy mix on the overall environmental quality should also be analyzed from the perspective of SDGs. There lies the role of the present study. The present study contributes to the existing literature in several ways. First, from the perspective of sustainable development, it is needed to assess the impact of the energy consumption on the biological capacity of the nations, which is indicated by the EF. This study contributes to the literature of energy and environmental economics by analyzing the impact of energy consumption on EF from the perspective of addressing the SDG objectives. Second, by far in the literature, impact of the segregated energy sources has been observed majorly on the ambient air pollutants (e.g., see Apergis and Payne, 2012; Zrelli, 2017; Appiah et al., 2019). However, in keeping with the objectives of the SDGs, it is important to assess the impact of renewable and non-renewable energy consumption on the biological capacity of these nations. While addressing the objective of climate action, focusing only on ambient air pollutants might not provide a holistic picture, and therefore, this study has focused on the impact of the segregated energy consumption on EF. Third, the OECD countries are the pioneers in the implementation process of SDG objectives, and in this pursuit, it is important to understand how these nations are utilizing their energy mix for sustaining the environmental quality. The present study addresses this objective. While addressing these objectives, results obtained in our study give the policy level directions to implement the energy and associated economic policies to achieve sustainable development.

The rest of the paper is structured in the following manner: section 2 details the review of relevant literature, section 3 chalks out the empirical schema, section 4 describes the national policies regarding environmental degradation in OECD countries, section 5 discusses the results obtained in the study, section 6 outlines the implications for sustainable development, and section 7 concludes the study.

2. Literature review

Since last four decades, there has been a mounting mass of literature on the association between income growth, energy consumption, and environmental degradation, following the well-known EKC framework. Researchers have mostly considered several environmental quality indicators, and most of them are negative indicators, like pollutants. There is dearth of EKC studies in terms of the positive indicators of environmental quality, like ecological footprint. Our study hypothesizes an association between economic growth, energy consumption, trade openness and ecological footprint in case of OECD countries. In this section, we will discuss the studies, which are carried out on assessing the impact of trade openness and energy consumption on ecological footprint across various contexts, and thereby, substantiating the parameterization of our study.

2.1. Impact of energy consumption on ecological footprint

The association between energy consumption and ecological footprint can be explained by the economic growth pattern of the nations. At the nascent level of economic growth, energy demand is by and large accomplished by consumption of fossil fuel. This particular process then emits air pollutants in the ambient atmosphere, and this increases with the rise in consumption of fossil fuels. As a result, to a certain extent, pattern of economic growth puts forth damaging consequences on environmental quality. As soon as growth attains a certain extent, rise in environmental awareness insists policymakers and industries to mull over less polluting technologies and renewable energy resources, and thereby, economic growth pattern results in drop in environmental degradation. This hypothesizes that the relationship between ecological footprint and economic growth is U-shaped.

The earliest study on the impact of energy consumption of ecological footprint was conducted by Chen et al. (2007) for China over the period 1981-2001. They found that the fossil fuel consumption is having negative consequences on the ecological footprint. This study used the methodology formulated by Zhao et al. (2005), and this particular methodology focused on both renewable and non-renewable energy solutions, while computation of ecological footprint. This study was further extended by Chen and Chen (2007) and Chen and Lin (2008). The results obtained from these studies were in the similar lines with the results obtained by Chen et al. (2007). Gradually the studies on other and diverse contexts started following these studies.

Kissinger et al. (2007) analyzed the ecological footprint of Canadian forest, which is largely associated with the pulp production industry, and they found that continuous consumption of fossil fuel brings about the fall in ecological footprint of the Canadian forest. Li et al. (2007) analyzed the ecological footprint, value of energy footprint, the energy footprint intensity and the ecological pressure intensity of energy ecological footprint for China over the period 1996-2005. They found that ecological footprint of coal consumption is having a downward trend, whereas the ecological footprint of energy consumption is having an upward trend. Caviglia-Harris et al. (2009) analyzed the ecological footprint of 146 countries over the period 1961-2000, and they found that energy consumption needs to be reduced by half for achieving sustainable ecological footprint across the countries, irrespective of their income levels. Al-Mulali et al. (2015) analyzed the impact of GDP, energy consumption, trade openness and financial development on ecological footprint for 93 countries over the period 1980-2008, and the analysis was carried out using fixed effect regression and generalized method of moments models. For both the models and all the countries, energy consumption was found to have positive impact on ecological footprint. Al-Mulali et al. (2016) analyzed the impact of renewable energy, GDP, urbanization, and trade openness on ecological footprint for 58 developed and developing countries over the period 1980-2009. Following EKC framework and by taking fixed effect regression, difference and system GMM approaches, they found that renewable energy consumption has a positive impact on ecological footprint. Aşıcı and Acar (2016) analyzed the impact of per capita GDP, trade openness, biological capacity, population density, industry share, per capita energy use, and environmental regulation on ecological footprint for 116 countries over the period 2004-2008. Following the EKC framework, they found that per capita energy use has negative impact on per capita production footprint, and positive impact on per capita import footprint. Ozturk et al. (2016) analyzed the impact of income from tourism, urbanization, primary energy consumption, and trade openness on ecological footprint for 144 countries over the period 1988-2008. Following the EKC framework, they found energy consumption brings about rise in ecological footprint.

By and large, energy consumption is seen to augment the level of ecological footprint. Nevertheless, the form of energy used in these studies is mostly fossil fuel energies, and the impact of renewable energy on ecological footprint is yet to be discovered. By far, Al-Mulali et al. (2016) have considered renewable energy consumption within their empirical model. While analyzing the context of developed nations, this particular aspect might prove to be a crucial one, and therefore, adding both renewable and non-renewable energy consumption within our empirical framework is justified.

2.2. Impact of trade openness on ecological footprint

Trade openness can have a possible impact on ecological footprint by means of a number of channels and this impact can be either positive or negative. The level of development and industrialization in a nation determines this direction of the impact. For the case of an industrialized and developed nation, importing of improved technologies and cleaner production processes are feasible, and thereby, trade openness exerts the technique effect on the environment. Owing to this effect, the environmental quality gets improved during the production process. On the contrary, at the earlier stage of development, primary concern of the policymakers of any nation is to attain growth, even at the cost of environment. Therefore, cheap and polluting technologies are imported in those nations to boost the production, and in this course, the technique effect exerted by trade openness deteriorates the environmental quality.

Al-Mulali and Ozturk (2015) analyzed the influence of political stability, rural-urban migration, industrial output, energy consumption, and trade openness on ecological footprint for MENA countries over the period 1996-2012, and they have found that trade openness causally impacts the ecological footprint. Under the EKC framework, Al-Mulali et al. (2015) analyzed the impact of GDP, energy consumption, trade openness and financial development on ecological footprint for 93 countries over the period 1980-2008, and the analysis was carried out using fixed effect regression and generalized method of moments models. For lower middle-income and upper middle-income countries, the trade openness found to have positive impact on ecological footprint using both the models. However, for low income and high-income countries, the models produced contradicting results regarding the effect of trade openness on ecological footprint. For low income countries, negative impact of trade openness was found for fixed effect regression model, and positive impact of trade openness was found for generalized method of moments model. On the other hand, for high income countries, positive impact of trade openness was found for fixed effect regression model, and negative impact of trade openness was found for generalized method of moments model. Al-Mulali et al. (2016) analyzed the impact of renewable energy, GDP, urbanization, and trade openness on ecological footprint for 58 countries for 1980-2009. Following EKC framework and by taking fixed effect regression, difference and system GMM approaches, they found that trade openness has a positive impact on ecological footprint. Aşıcı and Acar (2016) analyzed the impact of per capita GDP, trade openness, biological capacity, population density, industry share, per capita energy use, and environmental regulation on ecological footprint for 116 countries over the period 2004-2008. Following the EKC framework, they found that trade openness has negative impact on per capita production footprint, and positive impact on per capita import footprint. Ozturk et al. (2016) analyzed the impact of income from tourism, urbanization, primary energy consumption, and trade openness on ecological footprint for 144 countries over the period 1988-2008. Following the EKC framework, they found trade openness to have positive impact on ecological footprint.

By far, we have analyzed the literature on the impact of trade openness on ecological footprint, and the results attained from these studies have been indecisive. These studies designate the influence to be bidirectional based on the research setting, choice of model parameters, and procedural applications.

3. Empirical schema

In the empirical pursuit, we have employed the Environmental Kuznets Curve (EKC) framework suggested by Grossman and Krueger (1991). With graduation of time, EKC hypothesis has made its place in the literature of energy and environmental economics. According to the description of this hypothesis, environmental degradation rises with the progression of economy, and after the economic activity reaches an extent, the environmental degradation starts coming down with further progression of economy (Shahbaz and Sinha, 2019). Our study hypothesizes that renewable and nonrenewable energy consumption should have respective positive and negative impact on the environmental quality (Dong et al., 2018; He and Lin, 2019; Yao et al., 2019). The progression of economy can be indicated by per capita income, and it will have an impact on the environmental quality through scale effect. The composition effect will be exerted by the energy mix, whereas the technique effect will be exerted by the trade openness, as the technology transfer can be proxied through this parametrization (Olale et al., 2018; Junxian et al., 2019). The detailed empirical framework is described in Figure 1.

<Insert Figure 1 here>

The yearly data for 1980-2014 is examined to investigate the relationship between ecological footprint, economic growth, renewable energy consumption, non-renewable energy consumption and trade openness in 24 OECD countries. The testable empirical version of our theoretical model as follows:

$$lnEF_{it} = \gamma_0 + \gamma_1 lnY_{it} + \gamma_2 lnY_{it}^2 + \gamma_3 lnRC_{it} + \gamma_4 lnNC_{it} + \gamma_5 lnTR_{it} + e_{it} \quad (1)$$

Where, t denotes year 1980-2014, i denotes the OECD countries under observation, and e_{it} denotes the stochastic error, respectively. In addition, $lnEF_{it}$ is the log-transformed per capita ecological footprint, lnY_{it} (lnY_{it}^2) is the log-transformed per capita real GDP (square of log-transformed per capita real GDP), $lnRC_{it}$ is log-transformed per capita renewable energy consumption, $lnNC_{it}$ is log-transformed per capita real non-renewable energy consumption, and $lnTR_{it}$ is log-transformed trade openness. The data on real GDP (2010 constant USD) and the trade openness (percentage of trade in GDP) are acquired from the World Development Indicators, data on renewable and non-renewable energy consumption (in kWh) from US Energy Information Administration, and data on ecological footprint from Global Footprint Network.

Disregarding the cross-sectional dependence in a panel data might bring about erratic outcomes. Consequently, we first check whether the cross-sections are interdependent in the data countries using with Pesaran (2004) cross-sectional dependence (CD hereafter) test. It can be designated as per the following:

$$CD = \sqrt{\left(\frac{2T}{N(N-1)}\right)} \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} (\hat{\rho}_{ij}) \square N(0,1) \quad (2)$$

Where, *N* and *T* denote the countries and the years of observation, respectively. Furthermore, $\hat{\rho}_{ij}$ is the model approximation of the combined correlation of the residuals.

In order to ponder upon the cross-sectional dependence, we used Pesaran (2007) cross-sectional ADF (CADF) unit root test. The empirical form of the test is described below:

$$\Delta y_{it} = a_i + \rho_i y_{it-1} + \beta_i \bar{y}_{t-1} + \sum_{j=0}^{k} \gamma_{ij} \Delta \bar{y}_{it-1} + \sum_{j=0}^{k} \delta_{ij} y_{it-1} + \varepsilon_{it} \quad (3)$$

where a_i is constant, *k* is the lag specification, $\bar{y}_t$ is the temporally defined cross-sectional average. In keeping with Eq. (3), *t*-statistics are acquired from distinct *ADF* statistics. Besides, cross-sectional IPS (*CIPS*) is attained from the mean of *CADF* values for individual cross-sections:

$$CIPS = \left(\frac{1}{N}\right) \sum_{i=1}^{N} t_i \,(N,T) \quad (4)$$

To analyze the long-run association among the model parameters, we utilized ECM-based cointegration technique developed by Westerlund (2007). In the estimation process, G_t, G_α, P_t, and P_α are computed to test the cointegrating association among the model parameters. Statistical significance of the error correction term in the restricted VECM is used to calculate the statistics. The estimation model can be formed as per the following:

$$\Delta Y_{it} = \delta_i' d_t + a_i Y_{i,t-1} + \lambda_i' X_{i,t-1} + \sum_{j=1}^{p_i} a_{ij} \Delta Y_{i,t-j} + \sum_{j=-q_i}^{p_i} \gamma_{ij} X_{i,t-1} + \mu_{it} \quad (5)$$

where d_t indicates the constant term, such that:

$$d_t = \begin{cases} 1, & constant\ trend \\ 0, & no\ constant\ trend \\ (1,t)', & \text{constant and trend} \end{cases}$$

Furthermore, a_i determines the speed of adjustment.

Pesaran (2006) devised a novel method that considers the cross-sectional dependence. Based on Eq. (1), the stochastic error term (e_{it}) can be written as:

$$e_{it} = \lambda_i' UF_t + u_{it} \tag{6}$$

where, UF_t is the $m\,x\,1$ matrix of unseen factors. Additionally, Pesaran (2006) uses cross-sectional means to handle cross-sectional dependence among residuals as reliable proxies for UF_t : $\overline{lnEF_t} = \frac{1}{N}\sum_{i=1}^{N} lnEF_{it}$, $\overline{lnY_t} = \frac{1}{N}\sum_{i=1}^{N} lnY_{it}$, $\overline{ln\Psi_t} = \frac{1}{N}\sum_{i=1}^{N} lnY^2{}_{it}$, $\overline{lnRC_t} = \frac{1}{N}\sum_{i=1}^{N} lnRC_{it}$, $\overline{lnNC_t} = \frac{1}{N}\sum_{i=1}^{N} lnNC_{it}$, $\overline{lnTR_t} = \frac{1}{N}\sum_{i=1}^{N} lnTR_{it}$

Finally, obtained regression model is as follows:

$$lnEF_{it} = \gamma_0 + \gamma_1 lnY_{it} + \gamma_2 lnY_{it}^2 + \gamma_3 lnRC_{it} + \gamma_4 lnNC_{it} + \gamma_5 lnTR_{it} + \gamma_0 \overline{lnEF_t} + \gamma_1 \overline{lnY_{it}} + \gamma_2 \overline{ln\Psi_t} + \gamma_3 \overline{lnRC_{it}} + \gamma_4 \overline{lnNC_{it}} + \gamma_5 \overline{lnTR_{it}} + e_{it} \tag{7}$$

Pesaran (2006) indicates that OLS estimators of the individual slope coefficients of CCE = (γ_1, γ_5) are called as "Common Correlated Effect" estimators.

4. Background of national policies

The rationale behind this section is to provide the institutional background of OECD countries by emphasizing their importance within the global economy. In this direction, the global shares of OECD countries in terms of the observed indicators over 1980-2014 are shown in Table 1. The statistics reveal that OECD countries account for 74.09% and 60.53% of global output in 1980 and 2014, respectively. Despite the decreasing share, the average share of our sample countries in global output is 71.50% for the observed period. In addition, they are also responsible for average of 41.88% of global ecological footprint. In case of energy consumption, OECD countries represent 57.19% of global total energy consumption, 49.22% of global renewable energy consumption and 59.22% of global non-renewable energy usage for the period from 1980 to

2014. Finally, it is seen that 63.80% of global trade is carried out by these countries for observed period.

<Insert Table 1 here>

Overall, despite the decline in global shares of OECD countries, the fact that they constitute 71% of the global output and cause 41% of the global ecological footprint indicate the significance of these countries on a global scale. Therefore, the determination of factors that increase and reduce the environmental degradation of these countries, and the environmental measures to be taken, may contribute to the improvement of global environmental quality in the following years.

<Insert Table 2 here>

Table 2 depicts the descriptive statistics of the variables of OECD countries for the period from 1980 to 2014. At a first glance, it can be seen that there is significant disparity in per capita income with the maximum USD 64,945.58 in Switzerland and the minimum USD 7,638.78 in Turkey. In Turkey, Mexico and Chile that the countries have the lowest per capita income, the ecological footprint per capita also appears to be significantly lower than the other OECD countries. Moreover, the countries such as Austria, New Zealand, Sweden and Switzerland, which have low levels of environmental degradation despite their high-income levels, have higher renewable energy consumption than their non-renewable energy consumption. However, Canada, which consumes the most renewable energy, has a high level of environmental degradation. This indicates that reducing the ecological footprint is not only possible by reducing carbon emissions. In case of trade, the most trade openness countries are Ireland, Belgium and Netherlands while the United States is the least trade openness country.

5. Empirical results

We first scrutinize whether the cross sections are interdependent, or not. This is essential to select the suitable unit root and cointegration tests. The results in Table 3 show that the cross-sections of the data are interdependent. It signifies transmission a shock occurred in one nation to the others. In order to validate the results of cross-sectional dependence test, we have conducted heterogeneity tests suggested by Breusch and Pagan (1979), White (1980), and Koenker (1981). The results reported in Appendix 1 show the presence of heterogeneity across the cross-sections, and thereby, validating the results of cross-sectional dependence tests.

<*Insert Table 3 here*>

Next, we employ CIPS and CADF unit root tests, which permit cross-sectional dependence in the data, while gauging the order of integration level of the model parameters. The results from Panel A of Table 4 indicate that all variables are non-stationary at level. However, they become stationary at first differenced form.

<*Insert Table 4 here*>

In the next step, we investigate the presence of the long-run relationship between variables using with Pedroni (1999) and Kao (1999) cointegration tests. In addition, we utilized with panel cointegration method of Westerlund (2007) to take account of the cross-sectional dependence in the data (see Panel B, Table 4). According to the results, the Pedroni cointegration tests reject the null hypothesis of there is no cointegration between variables. Similarly, Kao cointegration test results reject the null hypothesis. When the results of Westerlund's cointegration test are evaluated, Ga and Pa statistics confirms the null hypothesis, whereas, Gt and Pt statistics strongly reject it. Therefore, it can be inferred that the model parameters are cointegrated.

<*Insert Table 5 here*>

The results of panel mean-group estimator are reported in Table 5. Based on the findings from MG, FMOLS-MG and DOLS-MG tests, it is visible that the coefficients of real income and the square of real income are negative and positive, respectively, and are statistically significant.

This signify the shape of the income-EF association to be U-shaped. This segment of the findings resonates with the results obtained by Bagliani et al. (2008) for non-energy EF and Charfeddine and Mrabet (2017) for non-oil exporting MENA countries. However, this finding contradicts the findings of Wang et al. (2013), Aşıcı and Acar (2018), Ulucak and Bilgili (2018), Sarkodie and Strezov (2018), and many others. Moreover, increase in renewable energy use reduces ecological footprint, whereas energy consumption from non-renewable sources helps ecological footprint to surge. The results of CCE estimation also show that increased renewable energy use helps in diminishing ecological footprint and increased non-renewable energy use leads to rise in ecological footprint. Following the discourse of SDGs, it can be argued that the nations with a prominence in renewable energy consumption can demonstrate improvement in the environmental quality, and hence, providing a sustainable solution for encountering the climatic shift. In this pursuit, nation must gradually lessen the portion of nonrenewable energy solution in the energy mix and increase the share of renewable energy solutions. A policy directive in this direction can lead to sustainable environmental quality in these nations. This segment of the findings resonates with the results obtained by Stöglehner (2003) in case of footprint assessment, Deakin and Reid (2018) in case of smart-cities, and Isman et al. (2018) for Canadian cities. Along with these results, trade openness also found to have negative impact on ecological footprint. International trade opens the way for cross-border technology transfer, and thereby, the nations can have access to cleaner technologies, which can in turn reduce the level of ecological footprint and improve the environmental quality. This segment of the findings resonates with the results obtained by Destek et al. (2018) for EU countries and contradicts the finding of Charfeddine (2017) for Qatar. To sum up, we can conclude that there is a U-shaped relationship between per capita income and ecological footprint. This has a significant implication regarding the sustainable development scenario in the OECD countries. As the per capita income and ecological footprint are associated by a U-shaped form, then it is visible that the degradation of environmental quality falls with rise in income, and after arriving at an edge value, added rise in income results in further degradation of environmental quality. This phenomenon can be attributed to the energy mix being used in these nations. From Table 5, we can see that the elasticity of fossil fuel consumption is higher compared to that of the renewable energy consumption, and owing to this reason, perhaps the impact of technological advancements in developing the cleaner production processes is being neutralized. However, the shape of the income-ecological footprint association gives an indication that the existing energy policies in the OECD countries should be redesigned in order to address the objectives of SDGs, as with a progress of this stature, the environmental degradation in these nations might go up with the further rise in the economic growth. Consequently, these nations must look into the existing energy policies, trade policies, and research and development initiatives. As the fossil fuel-based solutions play a predominant role in these nations, the policymakers should focus on replacing these solutions with renewable and clean energy solutions.

<*Insert Table 6 here*>

Finally, we examine the country-specific effects of the explanatory variables on ecological footprint using with CCE and FMOLS estimators (see Table 6). For the CCE estimator, the income-ecological footprint association has been found to be U-shaped for Austria, Belgium, Canada, Greece, Italy, Japan, South Korea, Spain, Switzerland and the US. However, the generally accepted form of EKC is found in Germany and Turkey. In addition, renewable energy use decreases environmental damage through its negative effect on ecological footprint in Canada, Finland, Germany, Japan, Netherlands, Spain, Switzerland, Turkey and the US. The positive coefficient of non-renewable energy use on ecological footprint is found in Austria, Canada, France, Germany, Greece, Japan, Netherlands, Spain, Switzerland and the UK. Trade openness decreases ecological footprint in Belgium, Canada, Germany, Greece, Japan, South Korea, Spain, Switzerland and Turkey. In case of the results of FMOLS estimator, the income-ecological footprint association is U-shaped for Austria, Canada, Denmark, Greece, Italy, Japan, South Korea, Netherlands, Spain and the US. On the other hand, the inverted U-shaped EKC hypothesis is supported in Chile, France, Germany, Mexico, New Zealand, Portugal, Turkey and the UK.

6. Implications for theory and practice

As the nexus between ecological footprint, GDP, renewable and non-renewable energy consumption, and trade openness for the OECD countries have been assessed, we can now proceed with drawing implications for theory and practice, as the empirical outcome has unveiled quite a few understandings apropos the cleaner production processes and sustainable development preparations in these countries. The empirical results of the study indicate that the renewable energy consumption reduces ecological footprint, whereas the non-renewable, i.e. fossil fuel consumption increases ecological footprint. Trade openness has also been found to have a negative impact on ecological footprint. However, the income-ecological footprint association has been found to be U-shaped, which signifies that the ecological footprint might increase after a certain level of threshold income. This might pose a question before the prevailing policy directives in the OECD countries. Saying this, it should be remembered that the OECD countries are the pioneers in designing the objectives of SDGs, and they are in the process of aligning their policies along the lines of the objectives of SDGs. In such a scenario, the results of this study might turn out to be important for the policymakers of these nations, as the results of this study can help them achieve some of the objectives of SDGs.

These nations are characterized by high economic growth, and in order to achieve that level of growth, energy consumption is required. Now, for fulfilling that escalated energy demand, these nations rely mostly on the fossil fuel-based energy solutions, as the existing renewable energy solutions are not yet mature enough to cater to the existing level of demand of energy (Sinha, 2017; Lozano and Lozano, 2018; Van Fan et al., 2018). Therefore, the continued usage of fossil fuel is turning out to be detrimental for the environmental quality by resulting in increase in the ecological footprint. So, for ensuring sustainable development in these nations, the fossil fuel solutions need to be replaced gradually with the renewable energy solutions, to facilitate the growth trend remain unharmed (Čuček et al., 2012). In this process, involvement of the people can make a significant difference, as successful implementation of fossil fuel replacement entails enhancement of environmental awareness among the citizens, and this is possible through encouraging people-public-private partnership. For Next-11 countries, this phenomenon has been analyzed by Sinha et al. (2017). Once phase-wise shift of fossil fuel-based solutions will be complemented by the increase in the environmental awareness, the cleaner production technologies will start gaining prominence in these nations, and thereafter, these nations will be able to create green jobs.

While creating jobs, it is also needed to remember the negative impact of trade openness on ecological footprint. The policymakers of these nations should use the avenue of international trade as a way to sustain the environmental quality. As it might not be possible for small scale players in the industry to develop endogenous clean production processes, the international trade can be used for importing cleaner technologies, which might be utilized by those players. In this way, the players in the different levels of the industry will get enough time to develop their own clean production processes, and during the period of development, they can utilize the benefits of the imported technology. In this way, green trade policy can not only enable trade openness to help in reducing the ecological footprint, but also can provide these nations the required time to develop the endogenous cleaner production and renewable energy solutions.

As the OECD countries are the pioneers in designing the sole purpose of sustainable development goals (SDGs), therefore, it becomes their sheer responsibility to demonstrate the SDG accomplishment processes in a laconic and all-encompassing way, so that the rest of the world can take lessons from them. Initiatives for deploying the renewable energy solutions within and across the nations will promote the cleaner production processes, and the increase in environmental awareness might enable the policymakers in these nations to foster endogenous discovery of alternate energy solutions. It will help the nations to encounter the problems of climatic shift, i.e. achievement of SDG 13 (UNDP, 2017). If the continuous effort towards the renewable energy exploration and discovery is fostered by the government, then it will be easier for these nations to reduce the non-renewable energy consumption, and they will also be able to substitute the import of fossil fuel-based solutions. It will help these nations in making clean and reasonably priced energy solutions for everyone, i.e. achievement of SDG 7 (UNDP, 2017). Now, when these activities are in place, the ongoing support of policymakers and the emerging people-public-private partnerships will be able to create several green jobs, which will again add towards the economic growth of these nations. In this way, the citizens will be able to experience a decent growth-oriented lifestyle, and the nations will be progressing towards achieving SDG 8 (UNDP, 2017). These policy-level interventions will help these nations to take progressive steps towards achievement of these objectives by 2030, and in this process, cleaner production will be recognized as the vehicle.

While saying this, it should also be remembered that any sustainable policy calls for a collaborative movement among nations towards ensuring the sustainable future for them. However, the OECD countries have been exporting various types of waste, including hazardous waste, to the lower income countries, and the amount was nearly 4 billion in 2007 (OECD, 2008). Though the Basel Convention on the control of trans-boundary movements of hazardous wastes and their disposal and Basel Ban treaties are already in place, ratification of these treaties have not been successful, so far. In such a scenario, symbiotic action among OECD countries and its trade partners can reduce the movement of hazardous waste, and to enforce this, an informal arrangement can be made, similar to the Country-led Initiative (CLI) taken up by Switzerland and Indonesia (Basel Convention, 2018). On the other hand, the OECD nations should try to help their trade partners in strengthening their administrative practices to stop any unwarranted trans-boundary movement of wastes. This course of action will not only help in strengthening their international trade relations, but also will help the nations in achieving the SDG objectives in a more inclusive manner.

7. Concluding remarks

This study explores the presence of EKC for 1980-2014 in 24 OECD countries. In order to examine the validity of EKC hypothesis with more reliable environment indicator, we utilized with ecological footprint as a dependent variable and used real income per capita, renewable energy consumption per capita, non-renewable energy consumption per capita and trade openness as independent variables. Besides, we used second generation panel data methods for the empirical pursuit. The empirical analysis gives not only panel basis results, but also for each OECD country.

The cross-sectional dependence test and heterogeneity test validate the applicability of second-generation panel models. Unit root tests indicate that the variables are first-order integrated and cointegration tests divulge the long-run association among the variables. The panel-based empirical findings illustrate that U-shaped association persists between real GDP and ecological footprint, and therefore, EKC hypothesis does not hold in OECD countries. Furthermore, we discovered that ecological footprint is diminished by rise in renewable energy consumption and trade openness, whereas non-renewable energy consumption leads to its upsurge. According to the time series-based empirical findings, we found the evidence for the presence of EKC only in eight countries, i.e., Chile, France, Germany, Mexico, New Zealand, Portugal, Turkey, and the UK. For the remaining 16 countries, there is U-shaped relationship between real income per capita and ecological footprint, and therefore, EKC hypothesis does not hold in these countries. These findings contribute to the literature of energy and environmental economics by uncovering the impacts of renewable and non-renewable energy consumption on ecological footprint for OECD countries. From the perspective of attaining the SDG objectives, results obtained in this study are important for the policymakers in the OECD nations.

The implications based on all findings indicate that only 8 OECD countries can provide environmental sustainability with economic growth. For the other 16 OECD countries, these countries should improve some environmental regulatory standards especially in renewable energy technologies. These regulatory actions might be focused at introducing environmental taxes, removal of harmful subsidies, and defining the public property rights. One of the major reasons behind these regulatory enforcements is to internalize the negative environmental externalities caused by human activities. While improving the regulatory standards, the policymakers should also ponder upon the enforcement of the regulation, which can be possible by increasing environmental awareness among the citizens. Now, in order to increase this awareness, governments in these nations should encourage the people-public-private partnerships. These partnerships might have multifaceted benefits, which might help these countries in getting the objectives of SDGs fulfilled. Some of those benefits are: (a) the transition from traditional non-renewable to renewable energy sources can be smooth, as the citizens will be psychologically initiated with the advantages of renewable energy solutions, (b) implementation of cleaner production processes in an endogenous manner might create new vocational opportunities, (c) increase in environmental awareness and creation of green jobs might push the policymakers to invest more in research and development, and (d) endogenous research and development might lead towards import substitution for fossil fuel products and enforcement of green trade policies. Therefore, it might be stated that for ensuring the sustainable development in these nations, the cleaner production can be considered as the major driver.

Now, in order to implement these policies, the policymakers should take care not to harm the economic growth pattern, while shifting the fossil fuel-based solutions with renewable energy solutions. Therefore, they need to consider phase-wise transition in this case, which will encompass both households and the industrial sectors. In order to smoothen the shift, the renewable energy solutions will be provided to both the households and the industries at a rate predetermined by the government, and for households, the solutions should be subsidized. The industries will be provided with the solutions against loan from the government, and the rate of interest on the loan can be decided based on the financial position of the firms. The income received from the industrial sectors can be used to make renewable energy solutions affordable for the households. The households can also avail subsidized loans from the government to procure renewable energy solutions, and they might receive tax rebate and an interest rate holiday. This might enable the households to shift towards renewable energy solutions for their daily purpose. The industries with higher level of ecological footprint might be charged with higher rate of interest, so that the cleaner industries can get an incentive at the cost of the comparatively dirtier industries.

These solutions show an indication of internalizing the negative externalities caused by the fossil fuel-based economic growth. While carrying out phase-wise energy source transformation, the policymakers should also continue discouraging the industrial sector to use ecologically deteriorating fossil fuel energy sources through imposition of Pigouvian taxes or withdrawal of harmful subsidies on fossil fuel solutions. Taxing the negative environmental externalities should be carried out following a progressive taxation manner, based on the level of negative externalities caused. While doing this, the policymakers should also consider that putting a high Pigouvian tax rate at the very beginning might discourage the operation of the industrial sector, and that might have a negative impact on the economic growth pattern of these nations. Therefore, the Pigouvian tax rate should be increased gradually, so that the industrial sector gets suitable time to shift their energy sources. At the same time, the policymakers should also focus on defining the regulatory actions to be taken for supporting the parties, who are affected by the negative externalities caused by the industries. Fear of the legal actions to be taken from the state might also discourage the industries to continue the use of non-renewable energy sources. This particular action should be complemented with the help of people-public-private partnerships.

While doing this, the policymakers should also focus at endogenous development of renewable energy solutions, so that dependence on fossil fuel-based solutions can be discontinued. In doing so, government will be actually encouraging towards the creation of new green jobs, which will make full utilization of the clean production processes. The trade policies might be redesigned in order to accommodate the changes in the energy policies, and the trade policies will be directed towards betterment of environmental quality, i.e. the nations will be moving towards green trade policies. The excess energy can be sold to the other nations with high energy demand, and in this way the national income might rise, and this excess income can be devoted towards the discovery of new alternate energy sources and development of the more sophisticated clean technological solutions. In this way, these nations might be able of enable themselves for achieving the objectives of SDGs by 2030.

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