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Original Article

The effect of nuclear energy on the environment in the context of globalization: Consumption vs production-based CO_2 emissions

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ABSTRACT

The earlier studies have analyzed theoretical links between nuclear energy and carbon dioxide (CO_2) emissions concerning territorial (or production-based) emissions. Here using the latest available dataset, this study explores the impacts of nuclear energy on production-based and consumption-based CO_2 emission in the era of globalization for the Organization for Economic Co-operation and Development (OECD) countries. The Driscoll-Kraay regression method reveals that nuclear energy is beneficial for the reduction of production-based CO_2 emissions. However, it is revealed that nuclear energy does not reduce consumption-based CO_2 emissions that are traded internationally and hence not comprised in conventional production-based emissions (territory) inventories. Globalization tends to reduce both production-based and demand-based carbon emissions. Finally, Environmental Kuznets Curve (EKC) is validated for both kinds of CO_2 emissions. The findings may deliver practical policy implications related to nuclear energy and CO_2 emissions for selected countries.

1. Introduction

The leading cause of global warming is the carbon emissions emitted from fossil fuel consumption mostly and a significant increase in energy demand leads to carbon emission [1]. Total carbon dioxide emissions (CO_2) by each country have got a great deal of attention so far, but less effort has been spent on the consideration of consumption-based CO_2 emissions related to the consumption of goods and services in each country. This is a key point because consumption-based CO_2 emissions are calculated by tracking different paths through traded goods and services and captures directly or indirectly emitted ones [2], thus accounts for carbon leakages which are one of the crucial problems for national emission inventories [3]. Achieving sustainable development without further environmental degradation is a critical challenge the world is facing today [4]. One of the effective strategies to combat global CO_2 emissions is to substitute fossil fuels with a clean energy source for electricity generation. The utilization ratio of renewable units is considerably beneath those of fossil fuel units. Accordingly, the capacity of installation of the renewable unit is greater than the power plants of fossil fuels to be replaced. In this space, nuclear energy may be a better alternative since nuclear power plants generate continuously and unveil capacity factors very close to 100% [5].

Recently, carbon emission mitigation emits by energy production and other industrial activities has received a great deal of attention. As the non-carbonized energy source generating electricity, thereof nuclear energy has been taking considerable importance in the global energy production systems. As clean energy sources, renewable energy and nuclear energy are expected to decrease carbon emission considerably and further contribute to the decarbonization of the planet in the future [6]. However, there is not plenty of time for waiting further energy-related technological development when considering the 1.5 °C rise in global temperature of the planet because of greenhouse gas emissions [7]. Therefore, a shift toward clean energy sources for the generation of electricity is urgently needed for mitigation [8].

Global warming and climate change are the most crucial threats the world face today and compel countries to generate electricity from clean sources instead of fossil ones. Among them, nuclear energy is receiving a massive consideration from policymakers [9]. Because it takes part not only in mitigating carbon emissions [10],

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plays an essential role in economic growth as well with lower cost of electricity generation [11,12]. Therefore, policies related to renewables are strongly backed for climate change, and consequently, present a politically reasonable path toward reducing carbon emissions and production costs [12,13].

Renewables, including nuclear, solar and wind, are considered as effectively carbon-free, have sparked interest worldwide. Increased renewable energy utilization in 2018 exerted an even more significant influence on CO_2 emissions, preventing 215 Million ton of emissions [14]. A large share of renewable energy in the energy portfolio will not only encourage economic growth and reduce CO_2 emissions but will also help to accomplish the Sustainable Energy goal as well as increase energy efficiency and decrease energy dependence [15]. Although renewable energy is a significant part of energy policy to increase/decrease efficiency/dependence, still in many countries no significant improvement has been observed in achieving the goals of environmental sustainability and the growth of renewable energy. Because there are certain problems with the deployment of renewable energy, such as lack of technology and infrastructure, high investment costs, inadequate political and public awareness and adaptation choices for climate change remain significant challenges [16–18].

There is no doubt that the shift toward clean energy is highly important to fight global warming and stabilize climatic conditions. Nuclear energy can deal with high energy prices and decrease dependence on energy imports [19] as well as decreasing CO_2 emissions [20]. Switching from fossil fuels to a larger share of renewables and nuclear energy reduce pollution and would decrease considerably the impacts of global climate change on the quality of life of the residents [21]. The current study focuses on quantifying emission mitigation from cleaner energy sources. The growing need for electricity generation and the necessity of clean energy transformation, nuclear energy seems as one of the best alternatives. Therefore, analyzing the causal relationship between CO_2 emissions, economic output, and nuclear energy in OECD countries is expected to provide new insights to policymakers.

Given the rapid development of nuclear energy consumption and its association with carbon mitigation effect in OECD countries is worthy to investigate as only several studies have examined the effects of nuclear energy in the environment for OECD countries [6,8]. To the best of our knowledge, none of the studies in the literature has investigated the nuclear energy impacts on two kinds of CO_2 emissions for OECD countries. Based on the backdrop above, the present study explores the nuclear energy impacts on production-based and consumption-based CO_2 emissions for the case of OECD countries. The investigation of production-based and consumption-based CO_2 emissions separately is important and interesting for several reasons. The separate analysis of production-based and consumption-based CO_2 emissions would give a detailed overview of whether or not nuclear energy consumption impacts both production-based and consumption-based CO_2 emissions. This inquiry will guide the decision-makers to design policy suggestions in detail. The production-based CO_2 emission takes the direct emissions in a particular country emits during the process of domestic production [22]. It measures the greenhouse gas emissions from fossil fuels consumed in a country by private households, industrial production of goods and services, and electricity production [3]. Meanwhile, consumption-based emissions include the direct and indirect GHG emissions caused due to domestic production and net imports [23]. The globalization effect may transfer consumption-based emissions to the final consumers and expedites following regional and global supply chains [24]. Hence, indicate to the level of pollution, countries are accountable for production-based CO_2 emissions; moreover, countries should take stringent measures to reduce the environmental consequences resulting from consumption [22]. The consumption-based and production-based CO_2 emissions have gotten immense attention in recent studies [25–27].

All OECD countries have agreed the Paris Climate agreement to decarbonize the power sector and compliance with the recommendations of the International Energy Agency to limit the rise in global mean temperatures to 2 Celsius degree, sometimes referred to as a two-degree scenario (2DS), keeping carbon concentrations not more than 450 ppm in the atmosphere [28]. These countries take ample advantage of energy-led growth and become the highest energy-consuming economies with a share of 41% in global energy use. A considerable share of this energy supply drives by coal, oil, and natural gas, which are the main culprits behind CO_2 emissions that lead to deteriorating environmental quality [6]. Like other renewable, nuclear energy discharges a negligible amount of CO_2 and influence carbon emissions mitigation. Due to the above mentioned reason, the study focuses on OECD economies. Nuclear energy has gained momentum in OECD countries since the 1970s and recently produced nearly 85% of the installed nuclear capacity worldwide [29].

The potential contribution of this study is threefold: first, previous literature focuses on the production-based emissions while assessing nuclear energy and pollution nexus. Therefore, for the first time, this study estimates the impact of nuclear energy on production-based and consumption-based CO_2 emissions separately. Second, the potential role of globalization is considered in the environmental impact of nuclear energy for OECD countries. The study adds significantly to the literature as it recommends a sustainable solution that can be applied to OECD countries for carbon emission reduction. Third, the study uses the DK-regression approach, which allows us to evaluate reliable and consistent results.

Globalization is one of the possible drivers of environmental pollution discussed in the literature [30,31] as it stimulates production and consumption levels and helps to diffuse environmental technologies [32]. More production and consumption activities can directly increase CO_2 emissions [33]. If production techniques remain intact during the process of globalization, environmental conditions will deteriorate. Conversely, if globalization brings about the deployment of eco-friendly technologies, environmental standards will improve with increasing trade volume and foreign direct investment [4]. Overall, pro-globalists argue that globalization has a positive effect on environmental standards, while anti-globalists suggest the opposite.

The remaining parts of the study are structured as follows: the literature on the nuclear energy-pollution nexus is presented in section 2; data description and methods are explained in section 3. Estimations and discussion of the results are presented in section 4, and section 5, respectively. Finally, section 6 concludes the study with policy and modelling lessons.

2. Literature review

Recently, studies have focused on how nuclear energy influence the environment in various aspects. Among them, some studies have covered the relationship between nuclear energy and environmental pollution [11,34–36]. However, due to the importance of clean energy, numerous researchers have investigated the extent to which economic development and environmental pollution level might be connected by taking nuclear energy into account [37,38]. In extreme clean energy scenarios, nuclear energy plays an important role in pollution mitigation compared to renewable energy [39–41]. But, Hassan et al. [42] recommend opposite views on the comparison. Recently, Danish et al. [10] bridge the IPAT hypothesis with the environmental Kuznets Curve (EKC) hypothesis,

and the empirical findings infer that nuclear energy consumption is beneficial for climate change mitigation.

Available studies on this setting have two different outputs. Some studies have agreed with the beneficial role of nuclear energy in the environment [8,43–45]. In the second strand of research, nuclear energy consumption worsening the environment [9,46,47]. Most of these studies employed the autoregressive distributive lag (ARDL) approach for empirical estimation. On the other hand, some studies built an argument that nuclear energy does not influence the environment; among those Mbarek et al. [48] for a panel of 18 developing and developed countries; Al-Mulali- [49] for 30 major nuclear energy-consuming countries; Saidi et al. [19] for developed countries and Jin & Kim [50] for 30 countries using renewable and nuclear energy. Summary of the literature on nuclear energy-emissions nexus is shown in Table 1.

Meanwhile globalization is widely used indicator of environmental pollution. Several authors argued globalization contribute to pollution. Among them, Pata & Caglar [51] for China; Aslam et al. and Etokakpan et al. [52,53] for Malaysia [54]; for European union countries; Wang et al. [55] for G-7 countries. Whereas few concluded globalization benefit the environment through pollution reduction, Akadiri et al. [56] for Italy; Baloch et al. [31] for BRICS countries. Some concluded insignificant globalization impact on pollution [57–59]. Some recent studies concluded renewable energy mitigates carbon emissions [60].

From related studies, it is observed evidence on nuclear energy and the environment. However, none of the studies in the literature considered the nuclear energy impacts on production-based and consumption-based CO_2 emissions. Besides, globalization as a potential variable has not been studied undertaking the environmental impact of nuclear energy consumption. This work fills the highlighted gap aiming nuclear energy impacts on production-based and consumption-based CO_2 emissions for OECD countries in the era of globalization. Further investigation on the nuclear energy-pollution nexus will probably be helpful to policy analysts in shaping adequate energy and environmental policy strategies.

3. Methodology

3.1. Data

This study uses annual data of 15 OECD countries for the period 2005–2016 based on the data availability of nuclear energy consumption for the largest number of years and countries. The study treated production-based and consumption-based CO_2 emissions as dependent variables, whereas economic output, nuclear energy, and globalization index are regressors. Data for production-based and consumption-based CO_2 emissions are sourced from OECD Statistics [62]. GDP per capita is an indicator that represents economic output and the data is retrieved from a database of the World Bank. Nuclear energy consumption data is gathered from the website of British Petroleum (BP) Statistics [63]. The globalization index data is collected from KOF Swiss Economic Institute. The data series, both kinds of CO_2 emissions and nuclear energy consumption are visually presented in Figs. 1–3.

3.2. Econometric strategy

This study carries out an investigation on nuclear energy impacts on production-based and consumption-based CO_2 emissions in the presence of control variables of economic output and globalization. In light of the recent work of [9,10,42], it estimates the following econometric equation:

$$CCO2_{it} = \alpha_0 + \alpha_1 Y_{it} + \alpha_2 Y_{it}^2 + \alpha_3 NEC_{it} + \alpha_4 RE_{it} + \alpha_5 NG_{it} + \alpha_6 OC_{it} + \mu_{it} \quad (1)$$

Table 1
Summary of literature nuclear energy and pollution nexus.

Authors	Country	Methods	Key results
Menyah & Wolde-Rufael [34]	The US	Toda and Yamamoto causality	Unidirectional causal relationship running from nuclear energy to CO_2 emissions
Iwata et al. [37]	France	ARDL method	Nuclear energy reduces emissions.
Apergis et al. [35]	Developing and developed countries	Panel causality test	The negative relationship between CO_2 emissions and nuclear energy is observed.
Jamil & Abu-hijleh [39]	United Arab Emirates	Scenario analysis	Nuclear energy is a more practical option for CO_2 emissions mitigation.
Baek & Pride [38]	Top six nuclear-generating countries	CVAR method	Nuclear energy helps in reducing emissions in sampled countries.
Baek [44]	Major nuclear-generating countries	Panel FMOLS and Panel DOLS	Nuclear energy helps in mitigating CO_2 emissions.
Jin & Kim [50]	30 Nuclear energy-consuming countries	FMOLS; DOLS	No relationship is found between nuclear energy and the environment.
Dong et al. [40]	China	ARDL	Nuclear energy reduces carbon emissions.
Sarkodie & Adams [46]	South Africa	ARDL	Nuclear energy tends to increase carbon emissions.
Lau eet al. [8]	OECD countries	GMM and FMOLS	Nuclear energy is beneficial for the environment.
Mahmood et al. [9]	Pakistan	ARDL	Nuclear energy contributes to carbon emissions.
Hassan et al. [42]	BRICS countries	CUP-FM and CUP-BC	Nuclear energy is helpful in pollution mitigation.
Saidi & Omri [6]	OECD countries	VECM procedure	Both nuclear energy and renewable energy help in environmental protection.
Vo et al. [61]	CPTPP countries	FMOLS; DOLS	Nuclear energy can control environmental pollution.
Danish et al. [10]	India	DARDL	Nuclear energy helps to mitigate environmental pollution.
Azam et al. [47]	Highest CO_2 emitting countries	FMOLS	Nuclear energy and renewable energy decrease emissions, while natural gas does not seem to do so.
Danish et al. [45]	China	DARDL	Nuclear energy and foreign direct investment contribute to reducing carbon emissions.

Note: ARDL = auto-regressive distributive lag; CVAR = cointegrated vector autoregression; FMOLS= Fully modified ordinary least square; DOLS = Dynamic ordinary least square; CUP-FM = Continuously-Updated and Fully-Modified; CUP-BC= Continuously Updated Bias Corrected; VECM = vector error correction model; DARL = Dynamic Auto-regressive distributive lag.

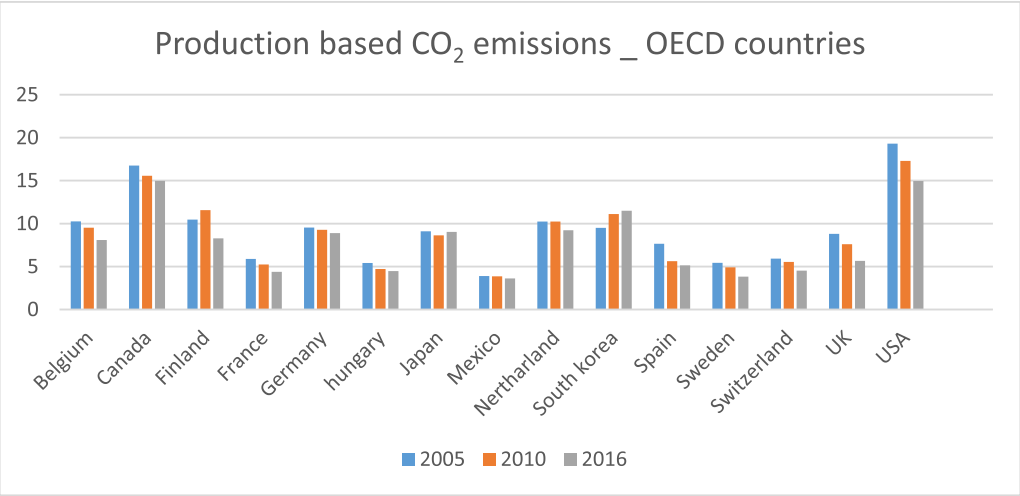

Fig. 1. Trend in the production based-CO_2 emission during 2005–2016.

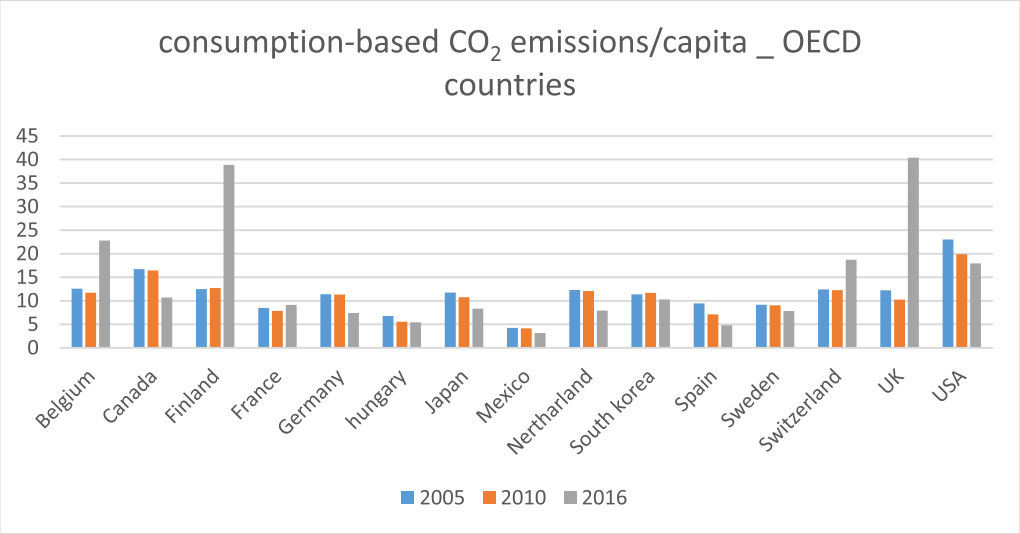

Fig. 2. Trend in the consumption based-CO_2 emission during 2005–2016.

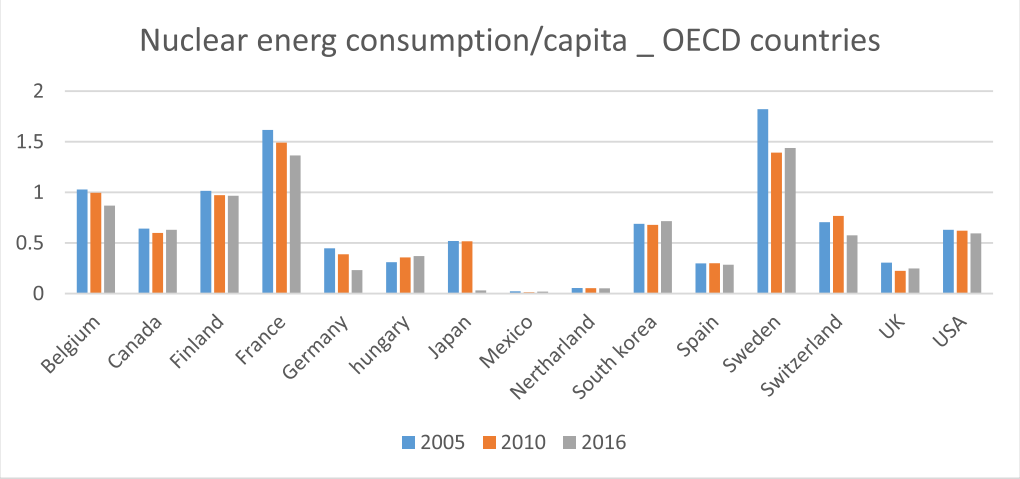

Fig. 3. Trend in nuclear energy consumption during 2005–2016.

$$PC02_{it} = \beta_0 + \beta_1 Y_{it} + \beta_2 Y_{it}^2 + \beta_3 NEC_{it} + \beta_4 RE_{it} + \beta_5 NG_{it} + \beta_6 OC_{it} + \varepsilon_{it} \quad (2)$$

Where CCO_2 and PCO_2 show consumption-based carbon emission and production-based carbon emission, respectively. *Y* is income (economic output-*GDP* per capita), *NEC* represents nuclear energy consumption and *GLOB* stands for globalization. Additional variables, renewable energy (RE), natural gas (NG), oil consumption (OC) are used in the model to validate the findings. $\alpha_{1,2...6}$ and $\beta_{1,2...6}$ are estimation parameters in'*t*' time and '*i*' cross-sections. μ and ε stand for stochastic error terms for model 1 and model 2, respectively. Nuclear energy can play an important not only in energy supply but in emission mitigation as well. In the scenario, it has been documented that nuclear energy is a significant part the environmental protection and sustainable development.

For the estimation of Eq (1) and Eq (2), this study employs the econometric methodology of Driscoll-Kraay (DK) standard errors for coefficients estimated by the fixed-effects estimator proposed by Driscoll & Kraay [64] since DK regression method produces robust standard errors and efficient estimates [65]. Also, the DK estimator undertakes that the error structure is heteroskedastic, auto-correlated, and correlated between the groups in the panel. So, this estimator provides reliable results in the presence of the above-mentioned error structure [4]. The DK estimator is useful for large *T* as is in the current study, and it uses a nonparametric technique for estimation. Also, the DK algorithm is effective in handling missing values and appropriate in employing for both balanced and un-balanced panel data series. The present study uses DK standard errors for pooled,": ordinary least squares (OLS) estimation by considering a linear model expressed as:

$$y_{i,t} = x\prime_{i,t}\beta + \varepsilon_{i,t}, \quad i = 1, ..., N, \; t = 1, ..., T \quad (3)$$

Where $y_{i,t}$ symbolizes the response variables (production-based and consumption-based carbon emissions) and $x_{i,t}$ indicates explanatory variables (economic output, nuclear energy, and globalization). The DK regression approach has got attention and has been widely used in energy economics literature recently [4,65–67].

4. Results

The descriptive statistics are calculated for the data series and presented in Table 2. In order to increase the explanatory power of regressors, we included each of the additional variables, including renewable energy (RE), natural gas (NG) and oil (OC) consumptions, in estimation models separately.

Considering the different structures of production and consumption-based emissions, which one of them decreases while the other may increase, the study constructed two alternative models with the EKC concept. So, the square of income variable was included in the estimated models. These models were differentiated by dependent variables in which production and consumption-based emissions were employed. Then, applying a robust panel data method, the panel Driscoll Kray (DK) estimator, model parameters were estimated to reveal how emissions in different forms respond to changes in GDP per capita, the square of GDP per capita, nuclear energy, and globalization. The square of GDP per capita included in estimations captures the composition and technique effects which explain why pollution may decrease as per capita income level increases [68,69]). In line with this expectation based on historical experiences of economies, our findings show that a one per cent increase in GDP per capita and the square of GDP per capita would lead to a 15.493% increase and 0.742% decrease in pollution, respectively, confirming a threshold level of income that pollution starts to fall after it reaches a threshold level, like a humped shape that is the story behind the EKC. Results validate the same relationship between GDP per capita, the square of GDP per capita and emissions for the second model employing consumption-based CO_2 emissions. In other words, initially, economic development hampers environmental quality [70], and later, after crossing a threshold level, economic development reduces pollution. Consequently, findings on per capita GDP and its square reveal an EKC relationship between pollution and per capita income in the sample countries.

Nuclear energy is a strategic variable and a focal point of this study, as explained in detail in previous sections. Moving on to estimation results for nuclear energy, it is pretty clear that estimations are statistically significant for production-based CO_2 emissions produces by the panel DK regression model. However, nuclear energy consumption has no significant impact on consumption-based CO_2 emissions. In other words, nuclear energy has no effect on consumption-based CO_2 emissions. Table 2 shows that a rise of 1% in nuclear energy consumption reduces production-based-CO_2 emissions by 0.07%.

Globalization has a negative and significant impact on production-based CO_2 emissions and consumption-based CO_2 emissions. A 1% rise in globalization contributes to 0.268%/0.438 reduction in production-based- and consumption-based CO_2 emissions, respectively.

Additional control variables, renewable energy, natural gas and oil consumption were added to validate the findings of the model. Of them, renewable energy consumption contributes both to the reduction of consumption-based and production-based CO_2 emissions. An increase of 1% in renewable energy causes a decline in consumption-based and production-based CO_2 emissions by 1.7537% and −0.97%, respectively. Natural gas and oil consumption as well were used as potential factors of CO_2 emissions. Table 3 shows that most of the results do not change significantly in cases where other control variables such as natural gas and oil consumption too.

Table 2
Results of descriptive statistics.

	Mean	Std. Dev.	Min.	Max.
Ln PCO_2	2.0368	0.4472	1.2830	2.9600
Ln CCO_2	2.3093	0.4269	1.1527	3.6988
Ln Y	10.5095	0.5299	9.0991	11.2507
Ln NEC	−0.9801	1.2545	−4.8218	0.5997
Ln RE	1.4742	0.0407	1.3292	1.5067
Ln NG	1.2271	0.0908	0.9138	1.4081
Ln OC	1.4692	0.3968	0.2356	1.8348
Ln GLOB	4.3713	0.1703	3.7783	4.5120

5. Discussions

The impact of GDP per capita on pollution may be twofold. On the one hand, the increase in GDP requires more resource usage, more production, more consumption, and thus more pollution. On the other hand, economies shift to service-intensive structures and may invest more in technological improvement, which results in less material usage and pollution, through the increasing income level. Similarly, globalization as well may bring about such twofold outcomes by triggering economic activities that increase pollution, and by accelerating technology transfers and environmental awareness [71–73]. This is an expected result according to the relationship between pollution and per capita GDP in the context of the EKC. This phase of economies is called the developing stage, and

Table 3
Result from DK- Regression estimation method.

	Dependent variable: Production-based CO_2 emissions				Dependent variable: consumption-based CO_2 emissions			
Regressors	Coef. [P>|t|]	Coef. [P>|t|]	Coef. [P>|t|]	Coef. [P>|t|]	Coef. [P>|t|]	Coef. [P>|t|]	Coef. [P>|t|]	Coef. [P>|t|]
Ln Y	15.493 [0.000]	15.207 [0.000]	9.617 [0.000]	15.420 [0.000]	8.2849 [0.000]	8.1624 [0.000]	2.1402 [0.009]	5.4411 [0.000]
Ln Y^2	−0.742 [0.000]	−0.728 [0.000]	−0.474 [0.000]	−0.738 [0.000]	−0.3805 [0.000]	−0.3745 [0.000]	−0.0926 [0.022]	−0.2405 [0.000]
Ln NEC	−0.071 [0.000]	−0.071 [0.000]	−0.116 [0.000]	−0.108 [0.000]	0.0040 [0.790]	0.0038 [0.782]	−0.0228 [0.186]	−0.0049 [0.770]
Ln RE	–	−0.970 [0.002]	–	–	–	−1.7537 [0.000]	–	–
Ln NG	–	–	−3.638 [0.000]	–	–	–	0.4929 [0.000]	–
Ln OC	–	–	–	−0.395 [0.000]	–	–	–	−0.1478 [0.000]
Ln GLOB	−0.268 [0.000]	–	–	–	−0.4383 [0.000]	–	–	–
Constant	−77.817 [0.000]	−77.513 [0.000]	−75.805 [0.000]	−51.132 [0.000]	−40.7061 [0.000]	−39.4080 [0.000]	−13.0043 [0.001]	−28.0257 [0.000]
F-test	1730.92 [0.000]	1167.08 [0.000]	11214.68 [0.000]	7066.51 [0.000]	1858.62 [0.000]	789.83 [0.000]		4527.04 [0.000]
R-squared	0.43	0.53	0.33	0.51	0.52	0.52	0.60	0.52
Root *MSE*	0.3393	0.3101	0.3703	0.3153	0.2970	0.2975	0.2705	0.2968

their structures mostly and heavily rely on the industrial sector that is less environmentally friendly than the service sector. Due to the increasing production and enlarging size of economies in this stage, the increase in pollution is attributed to the scale effect [16]. However, the square of GDP per capita shows the higher levels of per capita income that enable people to invest in new production techniques with material and energy-efficient properties. Further, the share of the service sector that produces less pollution than the industrial sector intensifies in an economy in parallel with the increasing income level.

The beneficial impact of nuclear energy on production-based CO_2 emissions reduction could also reveal and explain the absence of leakage phenomenon. In other words, nuclear energy reduce emission emits from production. The net effect of nuclear energy does not play a role in the exported emissions from other countries. From production-based emissions, our result claims that nuclear energy reduces CO_2 emissions in OECD countries. Therefore, diversifying energy supplies to nuclear energy is important for OECD countries to reduce pollution [47]. However, generation of electricity from nuclear sources requires a great deal of attention concerning safety matters. The radioactive waste management and installation of the nuclear plant need to be treated carefully to circumvent undesired accidents with environmental and health impacts [11]. Nuclear energy can serve as an alternative for conventional energy, however, it depends on the economic classification and socioeconomic factors that help to apply the energy storage for sustainable development [51]. Nuclear energy has phenomenal market potential, and it is also cost-effective. The development of nuclear energy ensures energy security and stimulates economic growth. The beneficial effect of nuclear energy in production-based emissions are in line with previous literature showing similar results (See Refs. [6,8,38,42,44,74]). However, the findings of Mahmood et al. [9] for Pakistan; Danish et al. [10] for India; Sarkodie & Adams [46] for South Africa, showed that nuclear energy contributes to pollution due to possible reasons such as improper nuclear waste or management practices. We also revealed by our findings that nuclear energy does not reduce consumption-based CO_2 emissions, which are traded internationally and hence not accounted in conventional production-based emissions (territory) inventories, in OECD countries.

From the results, it is evident that renewable energy helps reduce both kinds of carbon emissions. This supports the moderating role of renewable energy for struggling with global warming and climate change and suggests more investment in renewable energy generation. For instance, renewable energy integration cost is higher than non-renewable technologies. So, OECD countries should start the stage-wise transformation from conventional energy sources to green energy implying in household use, industrial and commercial sectors.

The impact of globalization on production-based and consumption-based CO_2 emissions is found negative and significant. In other words, globalization helps to reduce both production-based and consumption-based carbon emissions. The results are meaningful as international trade expansion may permit the utilization of environmentally friendly machinery for the production of goods and trade openness to promote energy-efficient technologies during globalization. There are similar results on the role of globalization in reducing the environmental pollution in the literature [32,71,75,76], which are in line with our findings. Also, traded goods in OECD countries utilize clean energy during the production of goods and services. This is especially the case for the high ratio of clean goods in trade of OECD countries.

The study provides empirical supports for the role of nuclear energy and renewable energy in mitigating carbon emission under some research limitations. Firstly, results are based on annual data, measured by national statistical offices of countries and provided to international databases. So, they may have measurements problems. Second, our results were obtained by assuming linear relationships between study variables and using the linear panel data estimation method, but they may change in nonlinear estimations. Third, the data range of the study covers the period 2005–2016 because of data unavailability for the nuclear energy variable, which requires the use of panel data techniques for the estimation. Therefore, we used the DK panel regression method with robust standard errors since there are 15 observations per cross-section. R-square values of our estimations are relatively lower than those that can be produced by time series econometric estimations. One of the possible causes of the low R-square value is the multicollinearity problem. However, we checked the multicollinearity and calculated a VIF (variance inflation factor) value less than 5 (4.71), meaning no

multicollinearity issue in the estimation. Although research shows that the R-square value of cross-section estimations may be much lower than time-series R-squares [77,78], this is another limitation for our results and interpretations so further research will shed light on the issue by using a wide data range, alternative methodologies and variables which may fit well in estimated models.

6. Conclusion and policy insights

Even though nuclear energy impacts on CO_2 emissions have been an area of interest recently, it has not been investigated for the potential role of globalization for two kinds' production-based and consumption-based CO_2 emissions. As most of the policy measures are based on production-based CO_2 emissions, in the context for equity consideration, consumption-based CO_2 emissions analyses are imperative [79]. This paper investigates the impacts of nuclear energy on two measures of CO_2 emissions for panel data of OECD countries. The econometric approach of DK regression with standard errors was employed, which infer that nuclear energy plays an important role in production-based carbon emissions. However, nuclear energy does not have any significant impact on consumption-based carbon emissions. Globalization has a statistically significant effect on both kinds of CO_2 emissions. Economic output significantly contributes to both kinds of CO_2 emissions. The inclusion of additional control variables confirms the robustness of the model.

The outcome may deliver worthwhile implications for policymakers in designing policies related to nuclear-and CO_2 emissions for OECD countries. The policy analyst should consider that the different impacts of nuclear energy on both kinds of carbon emissions. As nuclear energy is a cleaner energy source and can be helpful to meet growing energy demand, and it can reduce dependence on energy imports. Probably, the considerable amount of nuclear energy in OECD countries might be the reason for a connection between an aggregate measure of energy prices and CO_2 emissions. Further, nuclear energy could manage in achieving sustainable development goals and design better environmental strategies. Furthermore, the OECD countries requires more investment and reforms for nuclear energy and its intensification. Certainly, nuclear energy-related technology will continue to maintain the status of the country while contributing not only to economic growth but contribute to social and sustainable environmental improvement as well. Nuclear power generation has lower costs, ensuring energy security and reduce pollution generated from energy production from conventional sources. Countries should encourage to increase local and foreign investments in nuclear energy supply, keeping in view security and safety measures. Additionally, electricity generation from nuclear power would be helpful to reduce dependence on energy imports. Policymakers should emphasize being globalized more since it strengthens the beneficial impacts of nuclear energy in carbon emissions reduction. They may increase the share of nuclear energy through globalization, contributing to international trade and foreign direct investment, technology transfers and environmental awareness.

Declaration of competing interest

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.

References

[1] F.F. Adedoyin, N. Nwulu, F.V. Bekun, Environmental degradation, energy consumption and sustainable development: accounting for the role of economic complexities with evidence from World Bank income clusters, Bus. Strat. Environ. 30 (2021) 2727–2740, https://doi.org/10.1002/bse.2774.

[2] S.J. Davis, K. Caldeira, Consumption-based accounting of CO2 emissions, Proc. Natl. Acad. Sci. U. S. A 107 (2010) 5687–5692, https://doi.org/10.1073/pnas.0906974107.

[3] A. Franzen, S. Mader, Consumption-based versus production-based accounting of CO2 emissions: is there evidence for carbon leakage? Environ. Sci. Pol. 84 (2018) 34–40, https://doi.org/10.1016/j.envsci.2018.02.009.

[4] P.H. Leal, A.C. Marques, The environmental impacts of globalisation and corruption : evidence from a set of African countries, Environ. Sci. Pol. 115 (2021) 116–124, https://doi.org/10.1016/j.envsci.2020.10.013.

[5] E.E. Michaelides, D.N. Michaelides, Impact of nuclear energy on fossil fuel substitution, Nucl. Eng. Des. 366 (2020), 110742, https://doi.org/10.1016/j.nucengdes.2020.110742.

[6] K. Saidi, A. Omri, Reducing CO2 emissions in OECD countries: do renewable and nuclear energy matter? Prog. Nucl. Energy 126 (2020), 103425 https://doi.org/10.1016/j.pnucene.2020.103425.

[7] IPCC, Global Warming of 1.5°C, An IPCC Special Report on the Impacts of Global Warming of 1.5°C above Pre-industrial Levels and Related Global Greenhouse Gas Emission Pathways, in: The Context of Strengthening the Global Response to the Threat of Climate Change, 2018. Geneva, Switzerland.

[8] L.S. Lau, C.K. Choong, C.F. Ng, F.M. Liew, S.L. Ching, Is nuclear energy clean? Revisit of Environmental Kuznets Curve hypothesis in OECD countries, Econ. Modell. 77 (2019) 12–20, https://doi.org/10.1016/j.econmod.2018.09.015.

[9] N. Mahmood, K. Danish, Z. Wang, B. Zhang, The role of nuclear energy in the correction of environmental pollution: evidence from Pakistan, Nucl. Eng. Technol. (2019), https://doi.org/10.1016/j.net.2019.11.027.

[10] R. Danish, B. Ozcan Ulucak, An empirical investigation of nuclear energy consumption and carbon dioxide (CO2) emission in India: bridging IPAT and EKC hypotheses, Nucl. Eng. Technol. (2020), 104743, https://doi.org/10.1016/j.net.2020.12.008.

[11] I. Ozturk, Measuring the impact of alternative and nuclear energy consumption, carbon dioxide emissions and oil rents on specific growth factors in the panel of Latin American countries, Prog. Nucl. Energy 100 (2017) 71–81, https://doi.org/10.1016/j.pnucene.2017.05.030.

[12] M. Ben Mbarek, R. Khairallah, R. Feki, Causality relationships between renewable energy, nuclear energy and economic growth in France, Environ. Syst. Decis. 35 (2015) 133–142, https://doi.org/10.1007/S10669-015-9537-6.

[13] D. Evensen, Renewable energy policy: enumerating costs reduces support, Nat. Energy. 2 (2017) 1–2, https://doi.org/10.1038/nenergy.2017.106.

[14] F.F. Adedoyin, I. Ozturk, F.V. Bekun, P.O. Agboola, M.O. Agboola, Renewable and non-renewable energy policy simulations for abating emissions in a complex economy: evidence from the novel dynamic ARDL, Renew. Energy 177 (2021) 1408–1420, https://doi.org/10.1016/j.renene.2021.06.018.

[15] A.O. Acheampong, J. Dzator, D.A. Savage, Renewable energy, CO2 emissions and economic growth in sub-Saharan Africa: does institutional quality matter? J. Pol. Model. (2021) https://doi.org/10.1016/j.jpolmod.2021.03.011.

[16] R. Ulucak Danish, The pathway toward pollution mitigation : does institutional quality make a difference, Business. Abstract I (2020) 1–13, https://doi.org/10.1002/bse.2597.

[17] Y.A. Solangi, C. Longsheng, S.A.A. Shah, Assessing and overcoming the renewable energy barriers for sustainable development in Pakistan: an integrated AHP and fuzzy TOPSIS approach, Renew. Energy 173 (2021) 209–222, https://doi.org/10.1016/J.RENENE.2021.03.141.

[18] J. Lu, L. Ren, S. Yao, D. Rong, M. Skare, J. Streimikis, Renewable energy barriers and coping strategies: evidence from the Baltic States, Sustain. Dev. 28 (2020) 352–367, https://doi.org/10.1002/SD.2030.

[19] K. Saidi, M. Ben Mbarek, Nuclear energy, renewable energy, CO2 emissions, and economic growth for nine developed countries: evidence from panel Granger causality tests, Prog. Nucl. Energy 88 (2016) 364–374, https://doi.org/10.1016/J.PNUCENE.2016.01.018.

[20] T. Goh, B.W. Ang, Quantifying CO2 emission reductions from renewables and nuclear energy – some paradoxes, Energy Pol. 113 (2018) 651–662, https://doi.org/10.1016/j.enpol.2017.11.019.

[21] E. Santoyo-Castelazo, L. Stamford, A. Azapagic, Environmental implications of decarbonising electricity supply in large economies: the case of Mexico, Energy Convers. Manag. 85 (2014) 272–291, https://doi.org/10.1016/j.enconman.2014.05.051.

[22] T. Baležentis, G. Liobikienė, D. Štreimikienė, K. Sun, The impact of income inequality on consumption-based greenhouse gas emissions at the global level: a partially linear approach, J. Environ. Manag. 267 (2020), https://doi.org/10.1016/j.jenvman.2020.110635.

[23] X. Tian, M. Chang, C. Lin, H. Tanikawa, China's carbon footprint: a regional perspective on the effect of transitions in consumption and production patterns, Appl. Energy 123 (2014) 19–28, https://doi.org/10.1016/j.apenergy.2014.02.016.

[24] A.K. Jorgenson, S. Fiske, K. Hubacek, J. Li, T. McGovern, T. Rick, J.B. Schor, W. Solecki, R. York, A. Zycherman, Social science perspectives on drivers of and responses to global climate change, Wiley Interdiscip. Rev. Clim. Chang. 10 (2019) 1–17, https://doi.org/10.1002/wcc.554.

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

[26] C. Li, J. Zuo, Z. Wang, X. Zhang, Production- and consumption-based convergence analyses of global CO2 emissions, J. Clean. Prod. 264 (2020), 121723,

https://doi.org/10.1016/j.jclepro.2020.121723.
[27] S. Wu, S. Li, Y. Lei, L. Li, Temporal changes in China's production and consumption-based CO2 emissions and the factors contributing to changes, Energy Econ. 89 (2020), https://doi.org/10.1016/j.eneco.2020.104770.
[28] Y. Cai, C. Yan, T. Chang, Nexus between clean energy consumption , economic growth and CO2 emissions, J. Clean. Prod. 182 (2018) 1001–1011, https://doi.org/10.1016/j.jclepro.2018.02.035.
[29] S. Nazlioglu, F. Lebe, S. Kayhan, Nuclear energy consumption and economic growth in OECD countries: cross-sectionally dependent heterogeneous panel causality analysis, Energy Pol. 39 (2011) 6615–6621, https://doi.org/10.1016/j.enpol.2011.08.007.
[30] A.O. Acheampong, S. Adams, E. Boateng, Do globalization and renewable energy contribute to carbon emissions mitigation in Sub-Saharan Africa? Sci. Total Environ. 677 (2019) 436–446, https://doi.org/10.1016/j.scitotenv.2019.04.353.
[31] M.A. Baloch, I. Ozturk, F.V. Bekun, D. Khan, Modeling the dynamic linkage between financial development, energy innovation, and environmental quality: does globalization matter? Bus. Strat. Environ. (2020) https://doi.org/10.1002/bse.2615 bse.2615.
[32] S.C. Ilkay, V. Yilanci, R. Ulucak, K. Jones, Technology spillovers and sustainable environment: evidence from time-series analyses with Fourier extension, J. Environ. Manag. 294 (2021), 113033, https://doi.org/10.1016/J.JENVMAN.2021.113033.
[33] U.K. Pata, Linking renewable energy, globalization, agriculture, CO2 emissions and ecological footprint in BRIC countries: a sustainability perspective, Renew. Energy 173 (2021) 197–208, https://doi.org/10.1016/j.renene.2021.03.125.
[34] K. Menyah, Y. Wolde-Rufael, CO2emissions, nuclear energy, renewable energy and economic growth in the US, Energy Pol. 38 (2010) 2911–2915, https://doi.org/10.1016/j.enpol.2010.01.024.
[35] N. Apergis, J.E. Payne, K. Menyah, Y. Wolde-Rufael, On the causal dynamics between emissions, nuclear energy, renewable energy, and economic growth, Ecol. Econ. 69 (2010) 2255–2260, https://doi.org/10.1016/j.ecolecon.2010.06.014.
[36] A. Alam, Nuclear energy, CO2 emissions and economic growth: the case of developing and developed countries, J. Econ. Stud. 40 (2013) 822–834, https://doi.org/10.1108/JES-04-2012-0044.
[37] H. Iwata, K. Okada, S. Samreth, Empirical study on the environmental Kuznets curve for CO 2 in France : the role of nuclear energy, Energy Pol. 38 (2010) 4057–4063, https://doi.org/10.1016/j.enpol.2010.03.031.
[38] J. Baek, D. Pride, On the income-nuclear energy-CO2 emissions nexus revisited, Energy Econ. 43 (2014) 6–10, https://doi.org/10.1016/j.eneco.2014.01.015.
[39] H. Jamil, B. Abu-hijleh, The potential role of nuclear energy in mitigating CO 2 emissions in the United Arab Emirates, Energy Pol. 42 (2012) 272–285, https://doi.org/10.1016/j.enpol.2011.11.084.
[40] K. Dong, R. Sun, H. Jiang, X. Zeng, CO2 emissions, economic growth, and the environmental Kuznets curve in China: what roles can nuclear energy and renewable energy play? J. Clean. Prod. 196 (2018) 51–63, https://doi.org/10.1016/j.jclepro.2018.05.271.
[41] M. Piłatowska, A. Geise, A. Włodarczyk, The effect of renewable and nuclear energy consumption on decoupling economic growth from CO2 emissions in Spain, Energies 13 (2020), https://doi.org/10.3390/en13092124.
[42] S.T. Hassan, Salah-Ud-Din khan Danish, M. Awais Baloch, Z.H. Tarar, Is nuclear energy a better alternative for mitigating CO2 emissions in BRICS countries? An empirical analysis, Nucl. Eng. Technol. 52 (2020) 2969–2974, https://doi.org/10.1016/j.net.2020.05.016.
[43] G. Akhmat, K. Zaman, T. Shukui, F. Sajjad, M.A. Khan, M.Z. Khan, The challenges of reducing greenhouse gas emissions and air pollution through energy sources: evidence from a panel of developed countries, Environ. Sci. Pollut. Res. 21 (2014) 7425–7435, https://doi.org/10.1007/s11356-014-2693-2.
[44] J. Baek, A panel cointegration analysis of CO2 emissions, nuclear energy and income in major nuclear generating countries, Appl. Energy 145 (2015) 133–138, https://doi.org/10.1016/j.apenergy.2015.01.074.
[45] S.U. Danish, A. Khan, Ahmad, Testing the pollution haven hypothesis on the pathway of sustainable development: accounting the role of nuclear energy consumption, Nucl. Eng. Technol. (2021), https://doi.org/10.1016/j.net.2021.02.008.
[46] S.A. Sarkodie, S. Adams, Renewable energy, nuclear energy, and environmental pollution: accounting for political institutional quality in South Africa, Sci. Total Environ. 643 (2018) 1590–1601, https://doi.org/10.1016/j.scitotenv.2018.06.320.
[47] A. Azam, M. Rafiq, M. Shafique, H. Zhang, J. Yuan, Analyzing the effect of natural gas, nuclear energy and renewable energy on GDP and carbon emissions: a multi-variate panel data analysis, Energy 219 (2021), 119592, https://doi.org/10.1016/j.energy.2020.119592.
[48] M. Mbarek, K. Saidi, M. Amamri, The relationship between pollutant emissions, renewable energy, nuclear energy and GDP: empirical evidence from 18 developed and developing countries, Int. J. Sustain. Energy 37 (2018) 597–615, https://doi.org/10.1080/14786451.2017.1332060.
[49] U. Al-Mulali, Investigating the impact of nuclear energy consumption on GDP growth and CO2 emission: a panel data analysis, Prog. Nucl. Energy 73 (2014) 172–178, https://doi.org/10.1016/j.pnucene.2014.02.002.
[50] T. Jin, J. Kim, What is better for mitigating carbon emissions – renewable energy or nuclear energy ? A panel data analysis, Renew. Sustain. Energy Rev. 91 (2018) 464–471, https://doi.org/10.1016/j.rser.2018.04.022.
[51] U.K. Pata, A.E. Caglar, Investigating the EKC hypothesis with renewable energy consumption, human capital, globalization and trade openness for China: evidence from augmented ARDL approach with a structural break, Energy (2020), 119220, https://doi.org/10.1016/j.energy.2020.119220.
[52] M.U. Etokakpan, S.A. Solarin, V. Yorucu, F.V. Bekun, S.A. Sarkodie, Modeling natural gas consumption, capital formation, globalization, CO2 emissions and economic growth nexus in Malaysia: fresh evidence from combined cointegration and causality analysis, Energy Strateg. Rev. 31 (2020), 100526, https://doi.org/10.1016/j.esr.2020.100526.
[53] B. Aslam, J. Hu, M. Hafeez, D. Ma, T.S. AlGarni, M. Saeed, M.A. Abdullah, S. Hussain, Applying environmental Kuznets curve framework to assess the nexus of industry, globalization, and CO2 emission, Environ. Technol. Innov. 21 (2021), 101377, https://doi.org/10.1016/j.eti.2021.101377.
[54] P. Hipólito Leal, A. Cardoso Marques, Are de jure and de facto globalization undermining the environment? Evidence from high and low globalized EU countries, J. Environ. Manag. 250 (2019), 109460, https://doi.org/10.1016/j.jenvman.2019.109460.
[55] L. Wang, X. Vinh, M. Shahbaz, A. Ak, Globalization and carbon emissions : is there any role of agriculture value-added , financial development , and natural resource rent in the aftermath of COP21, J. Environ. Manag. 268 (2020), 110712, https://doi.org/10.1016/j.jenvman.2020.110712.
[56] S. Saint Akadiri, M.M. Alkawfi, S. Uğural, A.C. Akadiri, Towards achieving environmental sustainability target in Italy. The role of energy, real income and globalization, Sci. Total Environ. 671 (2019) 1293–1301, https://doi.org/10.1016/J.SCITOTENV.2019.03.448.
[57] S. Saint Akadiri, A. Adewale Alola, G. Olasehinde-Williams, M. Udom Etokakpan, The role of electricity consumption, globalization and economic growth in carbon dioxide emissions and its implications for environmental sustainability targets, Sci. Total Environ. 708 (2020), 134653, https://doi.org/10.1016/j.scitotenv.2019.134653.
[58] M. Salahuddin, J. Gow, M.I. Ali, M.R. Hossain, K.S. Al-Azami, D. Akbar, A. Gedikli, Urbanization-globalization-CO2 emissions nexus revisited: empirical evidence from South Africa, Heliyon 5 (2019), https://doi.org/10.1016/j.heliyon.2019.e01974.
[59] S. Saint Akadiri, A.A. Alola, A.C. Akadiri, The role of globalization, real income, tourism in environmental sustainability target. Evidence from Turkey, Sci. Total Environ. 687 (2019) 423–432, https://doi.org/10.1016/j.scitotenv.2019.06.139.
[60] F.F. Adedoyin, A.A. Alola, F.V. Bekun, The alternative energy utilization and common regional trade outlook in EU-27: evidence from common correlated effects, Renew. Sustain. Energy Rev. 145 (2021), 111092, https://doi.org/10.1016/j.rser.2021.111092.
[61] D.H. Vo, A.T. Vo, C.M. Ho, H.M. Nguyen, The role of renewable energy, alternative and nuclear energy in mitigating carbon emissions in the CPTPP countries, Renew. Energy 161 (2020) 278–292, https://doi.org/10.1016/j.renene.2020.07.093.
[62] OECD, Energy Technol, RDD Stat., 2019.
[63] BP, BP Statistical Review of World Energy, 2018, pp. 1–56.
[64] J.C. Driscoll, A.C. Kraay, Consistent covariance matrix estimation with spatially dependent panel data, Rev. Econ. Stat. 80 (1998) 549–560, https://doi.org/10.1162/003465398557825.
[65] S.A. Sarkodie, V. Strezov, Effect of foreign direct investments, economic development and energy consumption on greenhouse gas emissions in developing countries, Sci. Total Environ. 646 (2019) 862–871, https://doi.org/10.1016/j.scitotenv.2018.07.365.
[66] M.A. Baloch, S.U.-D. Khan Danish, Z.Ş. Ulucak, A. Ahmad, Analyzing the relationship between poverty, income inequality, and CO2 emission in Sub-Saharan African countries, Sci. Total Environ. 740 (2020), 139867, https://doi.org/10.1016/j.scitotenv.2020.139867.
[67] M. Danish, B. Wang Awais, Analyzing the role of governance in CO 2 emissions mitigation : the BRICS experience, Struct. Change Econ. Dynam. 51 (2019) 119–125, https://doi.org/10.1016/j.strueco.2019.08.007.
[68] G.M. Grossman, A.B. Krueger, Environmental Impacts of a North American Free Trade Agreement, 1991, https://doi.org/10.3386/w3914.
[69] G.M. Grossman, A.B. Krueger, Economic growth and the environment, Q. J. Econ. 110 (1995) 353–377.
[70] F.F. Adedoyin, A.A. Alola, F.V. Bekun, The nexus of environmental sustainability and agro-economic performance of Sub-Saharan African countries, Heliyon 6 (2020), e04878, https://doi.org/10.1016/j.heliyon.2020.e04878.
[71] S. Erdoğan, N.D. Çakar, R. Ulucak, Danish, Y. Kassouri, The role of natural resources abundance and dependence in achieving environmental sustainability: evidence from resource-based economies, Sustain. Dev. (2020), https://doi.org/10.1002/sd.2137 sd.2137.
[72] R. Ulucak, Danish, N. Li, The nexus between economic globalization and human development in Asian countries: an empirical investigation, Environ. Sci. Pollut. Res. (2019), https://doi.org/10.1007/s11356-019-07224-1.
[73] R. Ulucak, Danish, Y. Kassouri, An assessment of the environmental sustainability corridor: investigating the non-linear effects of environmental taxation

on CO2 emissions, Sustain. Dev. 28 (2020) 1010–1018, https://doi.org/10.1002/sd.2057.
[74] J. Baek, Do nuclear and renewable energy improve the environment? Empirical evidence from the United States, Ecol. Indicat. 66 (2016) 352–356, https://doi.org/10.1016/j.ecolind.2016.01.059.
[75] M.W. Zafar, S. Saud, F. Hou, The impact of globalization and financial development on environmental quality: evidence from selected countries in the Organization for Economic Co-operation and Development (OECD), Environ. Sci. Pollut. Res. 26 (2019) 13246–13262, https://doi.org/10.1007/s11356-019-04761-7.
[76] Shujah-ur Rahman, S. Chen, S. Saud, S. Bano, A. Haseeb, The nexus between financial development, globalization, and environmental degradation: fresh evidence from Central and Eastern European Countries, Environ. Sci. Pollut. Res. 26 (2019) 24733–24747, https://doi.org/10.1007/s11356-019-05714-w.
[77] E.F. Fama, K.R. French, The cross-section of expected stock returns, J. Finance 47 (1992) 427, https://doi.org/10.2307/2329112.
[78] B. Sanchez, Low R Square in the Cross Section of Expected Returns, 2015.
[79] B. Liddle, Consumption-based accounting and the trade-carbon emissions nexus, Energy Econ. 69 (2018) 71–78, https://doi.org/10.1016/j.eneco.2017.11.004.