RESEARCH ARTICLE

The intermittent effects of renewable energy on ecological footprint: evidence from developing countries

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Abstract
This paper examines the relationship between renewable, non-renewable energy, natural resources, human capital, and globalization on ecological footprint from 1990 to 2016 for developing countries. We apply Westerlund co-integration technique to check the long-run relationship among the variables. The long-run elasticity of the model is analyzed through MG, AMG, and DCCE. For the robustness check of the long-run relationship among the variables, we use FMOLS and DOLS approach. The direction of causal relationship is determined through Dumitrescu and Hurlin causality test. Our findings revealed that economic growth, non-renewable energy, natural resource, and urbanization are inducing the ecological footprint of developing countries and reducing the environment's quality. To cope up with this situation, developing countries are bound to use more fossil fuel energy. The use of non-renewable energy consumption leads to increase the extraction of natural resources like coal and oil. However, renewable energy reduces the ecological footprint or improves environmental quality. Similarly, human capital and globalization have negative effects on ecological footprint. The results of causality test reveal that there are feedback effects between ecological footprint with economic growth, globalization, and natural resources. This study suggests that these developing countries should focus more on the investment in the renewable energy sector, improve quality education, and make stringent environmental policy for protecting the nations from ecological issues.

Introduction

The country follows the path of development process relying on its resource base, including natural and human capital. In earlier phases of the economic development, it was easier to use and the pool of natural resources for a country. The rapid extraction of natural resources boosts the development process of developing countries, while the environmental quality of these countries impaired by pattern and use of natural resources (Bekun et al. 2019). Continuous use of natural resources steadily increases the degree of environmental

degradation. This leads to explore more renewable energy sources. Similarly, urbanization refers to the process of expansion in the proportion of the population residing in urban areas. Many cities are experiencing high growth of urbanization (United Nations 2017). The sudden rise of urbanization leads to environmental degradation, which is a global problem for the environment but is more detrimental to developing countries (Azam and Khan 2016). Similarly, globalization has also some positive effects like reducing poverty, closing the gap of income inequality in developing countries, but still the environmental consequences are debated (Salahuddin et al. 2019a, 2019b; Destek 2020; Khalid et al. 2020).

Along with the path of development, ecological quality is rapidly depreciating due to "deterioration of ambient air quality, reduction of forest cover, soil erosion, continuous variation in the pH value of water, and many other associated reasons." With income growth decelerating the rate of depreciation, environmental sustainability continues to increase above those income thresholds. The theoretical relation of income-pollution represents an inverse U-shaped, known as the theory of the environmental Kuznets curve (EKC) by

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Kuznets (1955) that assumed an inverted U-shaped linkage among environment and economic growth. In a seminal paper by Grossman and Krueger (1995), studying the impact of North American Free Trade Agreement (NAFTA) on the environment, it was found that an inverted U-shaped curve between growth and environmental quality. Today, when assessing the environmental effects of economic development, the ecological metric has chosen specifically as contaminants. In this analysis, however, we have selected the environmental sustainability indicator for the ecological footprint (EF). The ecological footprint describes the Earth's carrying capacity and the earth as an intrinsic futurist feature; it is also a measure of sustainability, as characterized by Rees (1992) and Wackernagel et al. (1999). They state that a common ecological region can provide the goods that the parties engaged in a plan to develop the use and at the same time of taking up the waste formed by those groups. Wackernagel and Monfreda (2004) later disregarded this concept. The ecological footprint, according to them a calculation of the biological potential required to manage an economic system which means that the natural capital of the bio-capacity should have an essential pool and also the waste produced by the economic system should be capable of absorbing.

However, in reaction to global climate change, environmentalists have pre-occupied themselves with studies on energy consumption (renewable and non-renewable), trade and urbanization, globalization, human capital, and their environmental impacts (Shahbaz et al. 2017a, 2017b; Usman and Hammar 2020; Sehrawat 2020; Yao et al. 2020; Khan 2020; Bakhsh et al. 2017; Xu and Lin 2017). Economic activity raises the energy demand and stimulates industrialization, encouraging trade in turn. Though some of the developing countries are rich in natural resources, yet weak technical and economic structures are catalyzing unsustainable energy usage and increasing greenhouse gas emissions. Since 2007, significant and unforeseen reductions in the cost of producing renewable energy have occurred. In conjunction with policy initiatives aimed at reducing greenhouse gas emissions, energy systems, particularly solar and wind, have produced a paradigm shift in energy systems (Arndt et al. 2019).

Developing countries are mainly concerned with high growth rate rather than the detrimental environmental implications of such growth. Energy Information Administration (EIA 2013) states that energy consumption of developing countries projected at 65% of world energy by 2040. It has regarded that developing countries are consuming high amount of non-renewable energy consumption than renewable energy, because of poor investment in renewable energy sector forcing them to use fossils fuels, which has high carbon contents (Hu et al. 2018). Changing the economic structure of the developing countries is one of the most important factors of high-energy consumption. Many developing countries depend on high-energy intensive sectors (Miketa and Mulder

2005). Hence, it leads to increase environmental pollution, adding harm to human health and sustainable environment. It is also projected that developing countries expected to experience the high population growth through by 2040 (Keho 2016). Due to population explosion in developing counties, resource scarcity can happen easily, triggering environmental problems like global climate change, erosion, and habitat destruction. It has also claimed that developing countries have resource endowments, unexplored renewable energy, and frangibleness climate. Among the developing countries, China and India are the 1st and 3rd position in terms of world's CO_2 emitters. Similarly, Indonesia, Mexico, and Brazil are 10th, 12th, and 14th carbon emitter in the world. These countries are highest emitter of CO_2 emissions because of high use of non-renewable energy consumption like coal and natural gas (Awodumi and Adewuyi 2020). As per the Global Footprint Network (Global Footprint Network, 2018), the world average ecological footprint per person was 2.75 global hectares, and bio-capacity of world average is 1.63 global hectares. Therefore, there is an ecological deficit of 1.1 in the world. A footprint smaller than the planet's bio-capacity is a critical requirement for humanity's long-term survival. If a country fails to absorb its own population footprint, the country is therefore called as an ecological debtor because it has an ecological deficit. Almost all developing countries are facing the ecological deficit like Bangladesh, Pakistan, India, Afghanistan, Haiti, Nigeria, Cameroon, and Sri Lanka. Hence, in this paper, we are considering that higher ecological footprint leads to reduced environmental quality. According to Global Footprint Network (GFN 2018), about 80% of the world's population lives in a country with a significant environmental crisis. The increased use of non-renewable energy, in tandem with negative trade and a rise in urbanization, would end environmental sustainability. Hence, this motivates us to attempt this study in the developing countries.

In this paper, we examine the relationship between renewable energy, non-renewable energy, globalization, and natural resources on the ecological footprint in 36 developing countries. The contributions of the paper to previous studies are as follows: (i) there are many researchers who have discussed the environment-growth-energy nexus in a panel as well as individual studies. This study is the first empirical analysis in the case of developing countries taking as ecological footprint (a positive indicator), human capital, natural resources, and globalization in a single lens. However, most of the previous studies have taken CO_2 emission as an indicator of environmental quality (Ito 2017; Akram et al. 2020; Ali et al. 2019; Salahuddin et al. 2019a, 2019b). EF includes six types of bio-productive land-use categories (grazing land, farm space, carbon footprint, cropland, land for building, and to the ocean). The EF is the only comparative metric against what the biosphere will renew the resource demand of government, corporations, and citizens. Due to the relatively stable

production growth in developing countries in recent years, through use of EF is optimal as it analyzes the ecological effects of producing goods, to encourage a lifestyle needed (Wachernagel and Rees 1996). (ii) This analysis is distinctive of analysis techniques developed in the embraced panel data that yield more accurate and robust forecasts. For the long-run analysis, we apply the augmented mean group (AMG), which permits to use of cross-sectional dependency presence in the series. Morever, the Mean Group (MG) technique, and Common Correlated Effects Mean Group (CCEMG) also apply to check the edogeneity problem in the model.

The rest of the paper are organized as follows: the "Review of related studies" section presents the review of related studies; in the "Theoretical underpinnings" section, we present the theoretical underpinnings; the Data and methodology" section discusses the data sources and methodology; results and discussion of the empirical analysis is presented in the "Results and discussion" section, and conclusion and policy implications are presented in the "Conclusion and policy implications" section.

Review of related studies

There are extensive studies done on examining the relationship between renewable, non-renewable energy consumption, trade, urbanization, economic growth, and environmental degradation. Researchers also used different indicators to measure environmental quality like CO_2 emissions (negative indicator) and ecological footprint and material footprint (positive indicators). The main objective of our study is to measure the relationship between renewable energy, non-renewable energy consumption, urbanization, and globalization on the ecological footprint (EF) in developing countries. Hence, in this section, we will discuss the previous studies on energy consumption, urbanization, and globalization on ecological footprint, and this substantiates our study's parameterization.

Energy consumption, economic growth, and ecological footprint

The relationship between energy consumption and ecological footprint depends on the economic growth or economic structure of a nation. On the very first level of economic development, the energy demand of the country is primarily focus on the use of non-renewable energy. This has the greatest effect on environmental degradation because of the gigantic consumption of fossil fuels. After a certain point, there will be a reverse relationship between energy consumption and environmental pollution; this is called environmental Kuznets curve (EKC). Studies which found similar results in the panel as well as a individual countries case such as Ahmed and Long (2013). Gokmenoglu and Taspinar (2018), Seppälä et al.

(2001), Işık et al. (2019), Rauf et al. (2018), Al-Mulali et al. (2015), Apergis and Payne (2014), Dogan and Turkekul (2016), Dogan and Seker (2016), Dogan and Aslan (2017), Dogan (2014), Udemba (2021), and Alharthi et al. (2021). In other set of literature estimated the existence of EKC hypothesis by using ecological footprint, a study by Uddin et al. (2016) investigated the relationship between income level and environmental quality in 22 countries during 1961–2011. They found that only 10 countries validate the existence of EKC hypothesis. They suggest that clean technology and efficient energy resources should be used in the production process to reduce the ecological footprint in the sample countries. Similarly, Dogan et al. (2019) examined the determinants of ecological footprint in case of MINT countries for the period of 1971–2013. They have applied ARDL bound testing approach for investigating the long-run and short-run relationship. They found that all four countries show the existence of EKC hypothesis in the sample period. A recent study by Haldar and Sethi (2020) investigated the relationship between renewable energy consumption, economic growth, and CO_2 emissions in developing countries. They also found the existence of EKC hypothesis in the sample countries.

A recent study on the linkage between energy consumption and the ecological footprint was led by Charfeddine (2017) using the Markov switching model in Qatar. He found that the ecological footprint and the ecological carbon footprint and CO2 emissions are positively related to energy use and financial growth. For a newly industrialized economy, Destek (2020) found that economic growth and ecological footprint are positively related to each other. Shahzad et al. (2020) examined the "relationship between energy consumption and ecological footprint in the USA." They reported that economic sophistication and the use of fossil fuel oil substantially increase the ecological footprint of the USA. In comparison, the quantitative causality empirics indicated the presence of causal connections with the ecological footprint between economic complexity and energy use. There also many studies which used other indicators for measuring the environmental quality like CO_2 emissions (Zhang and Lin 2012; Isenberg et al. 2002; Salahuddin and Gow 2014; Mert and Bölük 2016; Ali et al. 2016; Ehigiamusoe and Lean 2019; Apergis and Ozturk 2015; Apergis and Danuletiu 2014; Altinoz and Dogan 2021; Bhujabal et al. 2021; Omoke et al. 2020; Saint Akadiri et al. 2020; Yang et al. 2021).

Similarly, the study by Khan and Hou (2021) examined interlink between energy consumption and ecological footprint in 37 International Energy Agency (IEA) during 1995–2015. They used advanced panel technique for analyzing the results and found that energy consumption in these countries is reducing environmental quality in the long run. However, a study by Sharma et al. (2021) investigates the role of renewable energy consumption on environmental quality (proxy of ecological footprint) in eight developing countries of Asia.

They have applied cross-sectional autoregressive distributed lag model (CS-ARDL) for the long-run estimations and found that renewable energy enhances environmental quality in these countries. However, the effect of life expectancy is positive but insignificant. Majeed et al. (2021) studied in Pakistan on aggregate and disaggregate energy consumption and environmental quality. They apply non-linear autoregressive distributed lag (NARDL) model for the analysis, and the empirical results for marginal intake show that only harmful shocks have a substantial effect on ecological footprint. Similarly, different forms of energy consumption have asymmetric impacts on the environment.

Urbanization, globalization, and ecological footprint

A recent study by Rashid et al. (2018) investigated the relationship between urbanization and ecological footprint in two towns of Pakistan. They found that both the towns have used ecological footprint than bio-capacity. They suggest that utilization of green energy resources and energy-saving technology would be the best way to reduce ecological footprint. In contrast, Nathaniel et al. (2019) claimed that urbanization and energy consumption are enhancing environmental quality in the long run in south Asia during 1965–2014, while Nathaniel et al. (2020a, 2020b) investigated the relationship between renewable energy, financial development, and urbanization on ecological footprint in MENA countries and found that urbanization and financial development are deteriorating environmental quality. Urbanization has become a paradigm change from rural to urban environments with social and economic capacities. Developing countries have undergone rising urbanization speeds, while their industrialized counterparts appear to have high urbanization rates (Sadorsky 2014). Many other studies empirically analyzed the link between urbanization and environmental quality. A study by Liang et al. (2019) using advanced panel technique in the case of China found that due to urban agglomeration, it has a positive impact on environmental pollution in China. Similarly, a study by Shahbaz et al. (2019) examined the connection between urbanization and environmental quality in UAE for a period 1975–2011. They have found that urbanization worsens environmental quality. For a developing country, a study by Martínez-Zarzoso and Maruotti (2011) examined the nexus between urbanization and environmental degradation, and the outcome shows that urbanization and carbon pollution have an inverted U-shaped relationship. Combining the nations based on threshold analyses implies that pollution-urbanization has been negative at a given point, and emissions remain constant as urbanization goes beyond that point. Other groups' findings suggest that urbanization would not encourage greenhouse gas emissions, but rather income and population. Sharma (2011) studied for a panel of 69 nations and found that economic growth, financial development, and energy use enhance CO_2 emissions,

while urbanization reduces it. Natural systems in mountains have been severely impact by rapid urbanization. Ecological footprint is a vital basis for determining whether a country or region's growth is beyond its bio-capacity as a metric of fair utilization of natural resources (Ding and Peng 2018). Long et al. (2017) stated that ecosystems are subject to a variety of complex and heterogeneous effects because of urbanization. They have used ecological footprint to show the environmental sustainability in the sample period. A recent study by Godil et al. (2021) investigated the relationship between transport service, financial development, and urbanization on ecological footprint in Pakistan during 1980–2018. They have used quantile autoregressive distributed lag (QARDL) model for the long-run and short-run analysis. They found that transport service and financial development are enhancing environmental quality while urbanization deteriorating it. A recent study by Nathaniel et al. (2021) found that urbanization and natural resources are negatively related with ecological footprint.

According to Shahbaz et al. (2017a, 2017b), globalization means the transfer of technologies via industrialized to emerging markets by foreign direct investment (FDI) and imports, assistance in dividing labor, and increase in the value creation of the respective economies. Globalization has a strong influence on global prosperity with an increase in economic growth. Absolute productivity, FDI, and commerce thus implicitly rise energy use and depletion of the ecosystem. In comparison, Lv and Xu (2018) found that globalization reduces environmental quality. Similarly, for an 83 nations studied, You and Lv (2018) found an "undesirable association between globalization and CO_2 emissions." In contrast, Kwabena Twerefou et al. (2017) explored the correlation between globalization and environmental impacts for a panel of 36 African countries using GMM methodology. Similarly, with a panel of 25 developing countries, Shahbaz et al. (2018) investigated the impact of globalization on CO_2 emissions. It is important to note that the results show a favorable effect of globalization on pollution in developing economies. Using panel-estimating methods, Salahuddin et al. (2018) found that globalization improves environmental quality in SSA regions, while urbanization worsens it. Martens and Raza (2010) used the Maastricht globalization index (MGI) to analyze globalization's competitiveness against numerous sustainability parameters. They could not find any relation between them. A study by Ahmed et al. (2019) found that there was not any significant relation with globalization and ecological carbon footprint in Malaysia. However, it shows positive relation with ecological footprint. From the above literature, we found that there is a diverse finding between globalization and ecological footprint. There are fixed findings about the globalization and ecological footprint from the literatures (Dogan 2016; Sabir and Gorus 2019; Usman and Hammar 2021; Nathaniel et al. 2021).

Trade openness, population, and ecological footprint

Through the several channels, trade openness can have a potential effect on the ecological footprint, and this influence can be either beneficial or harmful. This trajectory of influence is determined by the degree of growth and industrialization in a country. In the case of an advanced and developing world, the importation of enhanced technological innovations and efficient manufacturing practices is possible, and trade openness has an impact on the climate through technology. Due to such consequences, mostly during the manufacturing process, environmental quality is enhanced. On the opposite, the main priority of lawmakers of any nation at the earlier stage of development is to achieve prosperity, even at the expense of the environment (Destek 2020). However, to improve efficiency, inexpensive and polluting technology is introduced into certain countries, and in this instance, the technique impact of trade openness negatively affects the ecological standard (Al-Mulali and Ozturk 2015). A recent study in the emerging country by Aydin and Turan (2020) examines the "relationship between financial openness and trade openness on the ecological footprint in BRICS countries." They found that in China and India, trade transparency has lowered environmental emissions, while in South Africa, it has increased. Similarly, a study by Kongbuamai et al. (2020) investigate the linkages between trade openness, population density, and economic growth on the ecological footprint in Thailand. They revealed that trade openness has reduced environmental quality, while population density increased during the study period. Similarly, Uddin et al. (2017) apply DOLS for the long-run estimations between economic growth, financial development, and trade openness on ecological footprint in 27 high-emitting countries and found that real income has positive effect on ecological footprint, while trade openness has negative effect but insignificant. However, a study by Ali et al. (2020) using dynamic common correlated effect in OIC countries during 1991-2016 found that trade openness has positively affected ecological footprint in these countries during the sample period. They found that trade openness has positively affected ecological footprint in these countries during the sample period. Mrabet and Alsamara (2017) have used two models for the empirical investigation between trade openness and financial development on CO_2 emissions and ecological footprint. They found that trade openness was positive link with CO_2 emissions whereas negatively related with ecological footprint. It means in ecological footprint case, trade openness enhances environmental quality in the long run.

Population size affects the size of a person's average ecological footprint. A density of population implies that in that country, there is a lot of land area per person. There could be more land and services available for an individual to use in his/her way of living. However, if the landscape is quite resource-limited, a low population density (Niccolucci et al. 2012) will not improve the ecological footprint size. There

could be more land and services available for an individual to use in his/her way of living. The relationship between population and ecosystem has been recognized since Malthus (1798). Toth and Szigeti (2016) claimed that environmental degradation is not due to increase in population; it is because of the consumption pattern of individuals. From the above literature, we found that there are dearth of studies that have been done on environmental quality in case of country-specific or panel studies. However, very few studies have carried out in developing countries case. Many studies have not taken care the endogeneity issue, while in this paper, we apply advance econometrics technique to solve the issue. Last but not the least, we have taken ecological footprint for the measurement of environmental quality in developing countries, by taking the variables like renewable and non-renewable energy, urbanization, and natural resources. In this way, this study adds contribution to the previous literatures.

Theoretical underpinnings

Ecological footprint monitors nature's demand and supply. The ecological footprint calculates on the demand side, the ecological assets needed by a civilized group to generate the natural resources it uses and to contain its waste, in particular carbon emissions. The ecological footprint monitors six types of viable surface areas: "cropland, livestock fields, fish stocks, built-up land, woodland areas, and demand for carbon on land." The bio-capacity of a country on the supply side reflects the productivity of its biological properties. It absorbs the waste particularly carbon emissions (Bilgili and Ulucak 2018). Initially, Rees (1992), later it was developed by Wachernagel and Rees (1996) and coined the term ecological footprint.

In pursuit of environmental analyses, ecological footprint measure is commonly use around the world (Van den Bergh and Verbruggen 1999). It encourages individuals in the economy to quantify and optimize the utilization of capital and investigate the viability of consumer lifestyles (GFN, 2019). Many studies also used the term carbon footprint, which is expressed as the weight of CO_2. Carbon footprint is a part of ecological footprint. Hence, in this paper, we used ecological footprint and its macro determinants in developing countries, i.e., renewable and non-renewable energy consumption, urbanization, globalization, population, and trade.

In the twentieth century, along with the exponential increase of the human population, there was extensive migration to major cities. The subsequent losses in biodiversity and shifts in habitats rival some of the mass extinctions suffered by the planet in the past (Magurran and Dornelas 2010). Most improvements in the landscape, including agricultural and industrial use, are the result of human land-use activities. In this land-use practice, urbanization is exceptional in both the speed as well as the degree of all its effect on natural

ecosystems (Wear and Bolstad 1998). Globalization is characterized as "a move to a more interconnected, interdependent global economy from self-constrained and independent national economies with trade and investment barriers, regulations, and cultural differences" (Ahmed et al. 2019). Through trade and foreign direct investment channels, globalization may influence the environment. For example, while starting or expanding their business ventures, foreign investors can use sophisticated technology to improve the quality of the environment by reducing energy demand.

It is very important to know effects of human capital on ecological footprint. Ecological learning is a way that encourages people to discuss global hazards, participate in solving problems, and take steps to change the ecosystem (Daniels and Walker 1996). As a result, people have a better understanding of environmental challenges and have the skills to build informed and rational choices. Human capital decreases the use of fossil fuels, which ultimately increases the efficiency of the atmosphere by controlling high carbon emissions without affecting economic development. Knowing the idea of ecological footprints shows that the populace is such a key element of development. Rees (1992) explicitly showed that mankind cannot afford to consume more than the Earth can create, by developing a quantitative instrument for understanding the availability and demand for natural resources. There will be a mismatch between the demand and supply of resources if population growth will be accelerating. According to GFN (2018), when the demand for natural resources is higher than supply, it is called an ecological deficit or when the population growth rate is higher than the area's bio-capacity. Valin et al. (2013) pointed out that one-third of environmental degradation is cause by global food production. Each human introduced to the Earth needs to feed, which increases the global production of food steadily and, as a result, increases the number of greenhouse gases that reach the atmosphere. By considering the above linkages of ecological footprint, we have chosen explanatory variables like urbanization, globalization, trade, renewable, population density, and non-renewable energy consumption in developing cases. Figure 1 describes the relationship between the dependent variable and independent variables graphically.

Data and methodology

Data

We use the annual data of 36 developing countries (see Table 10 Appendix) from 1990 to 2016. The period of this study is based on the data availability of the main variable "ecological footprint." For determining environmental quality, we use data of ecological footprint per capita measured as global hectares (gha/person). Many researchers also proposed

Fig. 1 Conceptual framework. Source: Author's construction

this indicator for calculating environmental quality (Isenberg et al. 2002; Nathaniel et al. 2019; Shahzad et al. 2020). The description of the variables is presented in Table 1 as follows:

Model specification

The main objective of this paper is to examine the relationship between urbanization, globalization, and natural resources on ecological footprint. To achieve this objective, we follow studies such as Stöglehner (2003), Zhao et al. (2005), Miller et al. (2013), Figge et al. (2017), and Sabir and Gorus (2019) by including an inclusive measurement of urbanization and globalization index on ecological footprint as follows:

$$EF = f\left(GDP, RE, NRE, TR, GI, URB, PO, NR, HC\right) \quad (1)$$

where EF represents ecological footprint, GDP is economic growth, RE and NRE denote renewable and non-renewable energy consumption, TR is trade openness, GI measures globalization index, and urbanization symbolized as URB. PO and NR denote population density and natural resources, respectively. HC represents human capital index based on the average year of schooling (Barro and Lee 2013). To smoothness the data, all variables are transformed into natural logarithmic, and this may produce appropriate long-run results (Sahoo and Sethi 2020a; Sahoo and Sethi 2020b). The above functional form can be written as:

$$
\begin{aligned}
lnEF_{it} = {} & \Upsilon_0 + \Upsilon_1 lnGDP_{it} + \Upsilon_2 lnRE_{it} + \Upsilon_3 lnNRE_{it} \\
& + \Upsilon_4 lnTR_{it} + \Upsilon_5 lnGI_{it} + \Upsilon_6 lnURB_{it} \\
& + \Upsilon_7 lnPO_{it} + \Upsilon_8 NR_{it} + \Upsilon_9 HC_{it} + \varepsilon_{it}
\end{aligned} \quad (2)
$$

Table 1 Description of the variables

Variables	Symbol	Measurement	Sources
Dependent variable			
Ecological Footprint	EF	Ecological footprint per capita as global hectares (gha/person)	GFN (2018)
Independent variables			
Gross domestic product	GDP	GDP (constant $2010)	World Bank (2018)
Renewable energy	RE	Total final renewable energy consumption (kilo tons)	IEA (2019)
Non-renewable energy	NRE	Non-renewable energy consumption to primary energy (kilo tons)	IEA (2019)
Trade	TR	Total export minus import (% GDP)	World Bank (2019)
Globalization index	GI	Economic, social, and political dimensions of globalization	KOF Swiss Economic Institute, Dreher (2006).
Urbanization	URB	Urban population (% of total population)	World Bank (2019)
Population density	PO	Population density (people per square land of area)	World Bank (2019)
Natural resources	NR	Total natural resources rent (% of GDP)	World Bank (2019)
Human capital	HC	Index of human capital per capita	Penn World Tables (PWT 9.0.)

Notes: IEA represents the International Energy Agency; GFN is Global Footprint Network

Source: Authors' compilations

where t denotes the time period from 1990 to 2016, i represents the countries observe in this paper, and ε is the error term. $\Upsilon_0 \dots \Upsilon_8$ discuss the log run coefficient of variables used in this paper.

Econometrics methods

Cross-sectional dependency and slope homogeneity test

In the first case of panel studies, it is essential to examine the CD test. Otherwise, it will give spurious results. Growing associations trigger cross-sectional dependency (CD) across socio-economic structures and typical unidentified shock, which makes traditional panel estimation methods inaccurate. Hence, ignoring cross-sectional dependence will also have severe implications (Ertur and Musolesi 2017). It is best to work with CD even though standard unit root testing implies cross-section independence. Therefore, depending on methods that presume cross-sectional independence, it can yield inaccurate findings. We use CSD to fulfill this function, which was introduced by Pesaran (2007). The CD equation is given as:

$$CD = \sqrt{\frac{2T}{N(N-1)}}\left(\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\widehat{\rho}_{ij}\right) \qquad (3)$$

Besides, we have applied a slope homogeneity test in our model. It was developed by Pesaran and Yamagata (2008). The test equation is calculated through "delta-tilde and adjusted delta-tilde."

Unit root test

The normal unit root tests in models presume that "independence of cross-sections and slope homogeneity and can therefore generate misleading consequences." In this paper, we use a second-generation unit root test, which checks the problem of CD in the equation. The second-generation tests used in this paper are CIPS and CADF introduced by Pesaran (2007). The equation for the CIPS can be written as:

$$\Delta z_{it} = \alpha_i + \beta_i z_{i,t-1}, + \rho_i T + \sum_{j=1}^{n}\delta_{ij}\Delta z_{i,t-1} + \varepsilon_{it} \qquad (4)$$

swhere z_{it} is respect variables, ρ is deterministic components, δ is level of significance, and ε is error term in the model. We can get the cross-sectional augmented Dickey Fuller (CADF) from the above equation:

$$CIPS = \frac{1}{N}\sum_{i=1}^{N}CADF_I \qquad (5)$$

where $CADF_i$ represents "cross-sectional augmented dickey fuller test" and N is the number of observations.

Co-integration test

To examine the long-run elasticity among the variables, it is a prerequisite to test the co-integration on the sated variables. In this paper, we apply the Westerlund (2007) panel co-integration technique to get the association among the variables. The main advantage of the technique is that it controls slope heterogeneity and cross-sectional dependency in the model. This test has four results: two results indicate group statistics, and the other two denote panel measurement. The

co-integration test of the error correction base is presented in Eq. (6).

$$\Delta y_t = \gamma_i d_t + \rho_i \left(y_{i,t-1} - \beta_i x_{i,t-1} \right) + \prod_{j=1}^{ni} \delta_{ij} \Delta y_{i,t-j}$$

$$+ \prod_{j=0}^{ni} \delta_{ij} \Delta x_{i,t-j} + \varepsilon_{it} \tag{6}$$

where cross-sections are indicated by N (i = 1,………,N) and T (t = 1, ……,T) denotes number of observations.

AMG, MG, and DCCE technique

Once the long-term co-integration of variables has been established, the next procedure is to examine the magnitude of the variables. Several studies have claimed that CD occurs between nations because of economic shocks and unobserved components like trade openness and globalization. In this modernization period, global developments in some countries because of trade openness, each nation has been greatly influenced (Dogan et al. 2020). To know the main results of this study, we have applied the "augmented mean group (AMG), mean group (MG) introduced by Pesaran et al. (1999), and dynamic common correlated effect (DCCE) technique." Chudik and Pesaran (2015) developed the DCCE technique. Compared to other conventional approaches, this estimation methodology is more appropriate even in the presence of CD and common shock. The strategy of the DCCE can comfortably deal with by considering heterogeneous slopes in which the parameters differ through cross-sections, heterogeneity, and CSD problem in results. For robustness, we have used "full modified ordinary least square (FMOLS) and dynamic OLS (DOLS)." The FMOLS and DOLS are also extremely effective in overseeing the effective processing of the problems of heterogeneity and serial correlations (Danish et al. 2018).

Panel D-H causality test

The non-causality test for Dumitrescu and Hurlin 2012) (D-H) coping the heterogeneous panels and CD. This test is applicable when T<N and T>N (Dogan and Seker 2016). The D-H technique can be written as:

$$Y_{it} = \theta_i + \sum_{j=1}^{J} \gamma_i^{J} X_{i(t-1)} + \sum_{j=1}^{J} \eta_I \left(Y_{i(t-j) + \varepsilon_{it}} \right) \tag{7}$$

where γ_i^j and η_i^j represent the coefficient of estimator, which fluctuate across all nation. Y and X measures the causality. The D-H causality test as follows:

$H_o : \alpha_i = 0$ for θ_i

$$H_1 : \begin{pmatrix} \alpha i = 0 & \text{for all } i = 1, 2, 3, \ldots\ldots\ldots Ni \\ \alpha i = 0 & \text{for all } i = N + 1, 2, 3, \ldots\ldots\ldots Ni \end{pmatrix} \tag{8}$$

Here H_0 and H_1 represent the null and alternative hypothesis, respectively.

Results and discussion

The descriptive and correlation matrices are presented in Table 2. In descriptive statistics, we discuss the mean, standard deviation, minimum, and maximum of series used in this study. It is observed that the average value of ecological footprint, GDP, renewable, and non-renewable energy is 1.25, 3.48, 6.62, 4.54, and 6.85, respectively. However, the average values of natural resources, globalization, and urbanization are 2.41, 5.90, and 2.75, respectively. Standard deviation measures the dispersion or spread of value from the mean. In our case, it has shown that the standard deviation of ecological footprint is 2.52, which means different countries have a different footprint as per their consumption, population, and area of bio-capacity. Similarly, std. deviation of urbanization, population, and natural resources varies across different developing countries. The minimum and maximum values in our observation are 0.10 and 96.24, respectively.

The correlation matrix is presented in Table 2. It measures the strength of the linear correlation between the variables. Some variables are positive, and some are negatively related to each other significantly. It is described that "economic growth and ecological footprint are positively related to each other." The ecological footprint tracks not just emissions as a direct result of economic activity, but also the loss of resources needed to facilitate economic activity. Hence, available bio-capacity may affect economic growth in developing countries. Similarly, natural resources, population density, urbanization, and non-renewable energy consumption have positively related to EF. However, renewable energy, human capital, globalization, and trade are negative and significantly affect ecological footprint.

In next step, we verify whether the cross-sections are interdependent. This is important for the selection of the required root unit and tests for co-integration. Table 3 discusses the CD tests. It implies a transmission of shock in one country against the other. The null is that "there are independent among the countries against the alternative hypothesis of a cross-sectional dependency across the regions." The results of the CD test delineate the cross-sectional dependency across the developing countries as it rejects the null hypothesis at a 1% level of significance. We also apply the Pesaran and Yamagata (2008) homogeneity test, which suggests a methodology to try to know the homogeneity of the slope in this study. The slope homogeneity test is presented in Table 4. As per the results of both CD and slope homogeneity tests, we use heterogeneous panel models as well as the panel techniques which control the cross-sectional dependency.

Table 2 Descriptive and correlation matrix

	EF	GDP	RE	NRE	TR	GI	URB	PO	NR	HC
Mean	1.25	3.48	6.62	4.54	6.85	5.90	2.75	0.78	2.41	0.58
Std. deviation	2.52	0.45	0.56	0.98	0.63	0.54	1.88	2.54	4.75	0.49
Min.	0.57	2.48	1.58	0.96	1.75	0.57	0.86	0.10	0.78	0.04
Max.	85.71	45.05	96.24	56.45	75.52	10.63	80.45	5.75	8.85	0.79
EF	1									
GDP	0.05*	1								
RE	−0.45*	0.10*	1							
NRE	0.36*	0.218	0.11*	1						
TR	−0.03	0.45*	−0.42	0.26*	1					
GI	−0.08*	0.13*	0.05*	0.12*	0.45*	1				
URB	0.31*	0.30*	0.03*	0.40*	0.43*	0.31*	1			
PO	0.24*	0.09	0.43	0.35*	0.12*	0.41*	0.24*	1		
NR	0.02*	0.20*	0.31*	0.25*	0.40*	0.36*	0.13*	0.06*	1	
HC	−0.30*	0.32*	0.01*	−0.13*	0.30*	0.05*	0.01*	0.42*	−0.02*	1

Notes: * represents 1% level of significance

Source: Authors' calculation

After knowing the CD and slope of homogeneity in the sample, we apply the cross-section augmented Dickey-Fuller (CADF) and cross-section Im-Pesaran (CIPS) unit root test as per the recommendation of Pesaran (2007). Table 5 presents the panel unit root tests. To know the order of integration, it shows that all variables in the series are stationary at level and it became stationary after first differentiation. Hence, order of integration of variables is I (1) at different levels of significance.

The conventional panel co-integration test like Pedroni, Kao, and Fisher techniques does not capture the cross-sectional dependency. Hence, in this paper, we apply Westerlund 2007 co-integration, which can be used in the presence CD. In Westerlund, co-integration has four coefficient parameters i.e., two are group coefficient and the other two are panel coefficient, which are presents in table 6. The results from co-integration reveal that we can reject the null hypothesis of no co-integration and accept the alternative hypothesis of co-integration among the variables in the sample period.

The result in Table 7 discusses the effect of the long-run elasticity of independent variables on the dependent variable or ecological footprint. We apply three long-run tests, i.e., mean group (MG), augmented mean group (AMG), and dynamic common correlated effects (DCCE) approach. The results of MG reveal that economic growth increases ecological footprint in developing countries, or it reduces environmental quality. There is always a range of contributors to the degree of economic growth and prosperity in each nation. To promote high growth, developing countries adopted different mechanism, and the available potential of natural resources. Development may have detrimental environmental consequences. There are many aspects, which include environmental (pollution), nature reserves overuse, wildlife destruction, and depletion, and climate change. These are the main problems that may be confronting developing countries; the deterioration in environmental sustainability is considered a major problem in the present and long-lasting living conditions of the population. This finding is stable with Hassan et al. (2019) for BRICS economies, Aşıcı and Acar (2016) for developing countries, and Ahmad et al. (2020) for emerging economies.

However, renewable energy consumption reduces the ecological footprint in developing countries. One percent increase in renewable energy consumption leads to a reduced ecological footprint by 0.04%. In line with this, in their respective studies, Sinha et al. (2017) have determined that an intensification of the use of renewable energy technologies could

Table 3 Cross-sectional dependence test

	EF	GDP	RE	NRE	TR	GI	URB	PO	NR	HC
Pesaran CD	*0.54**	*1.41**	*5.12**	*9.11***	*2.42**	*4.72**	*4.31***	*2.04**	*5.06***	*1.04**
P value	*0.002*	*0.000*	*0.000*	*0.012*	*0.004*	*0.000*	*0.030*	*0.000*	*0.024*	*0.003*

Notes: * and ** represent 1 and 5% level of significance

Source: Authors' calculation

Table 4 Results of Pesaran-Yamagata homogeneity test

	EF	GDP	RE	NRE	TR	GI	URB	PO	NR	HC
Delta	45.21*	63.48*	23.75*	12.51**	29.45*	13.45*	28.40*	51.12**	14.19**	23.12*
Adjusted delta	51.89*	86.52*	42.84**	14.72*	46.24*	49.12*	32.49*	54.71**	34.56*	47.01*

Notes: * and ** represent 1 and 5% level of significance

Source: Authors' calculation

regulate ecological footprint. Hastik et al. (2016) have indicated that renewable energy use alone could not solve environmental challenges without improving energy-saving manufacturing processes.

Further, the study revealed that non-renewable energy consumption endorses an ecological footprint. To cope up with the current momentum, developing countries are highly using fossil fuel energy. The use of non-renewable energy consumption leads to increase extraction of natural resources like coal and oil. Furthermore, the growth of the service industry, which is the product of economic development, will continue energy needs and, thus, contribute to emissions, thereby reducing environmental quality. The continuous use of carbon-based energy has a direct impact on our health and well-being, all of which are directly related to the environmental consequences of non-renewable energy. Evidently, the use of non-renewable energy sources has many adverse consequences on our environment, either because of how they are produced and stored or because they are used and ultimately disposed of. Accordingly, the continuing use of fossil energy turned out to be dangerous for the nature of the atmosphere, resulting in an improvement in the ecological footprint in these countries. Therefore, to

ensure sustainable progress in these countries, it is important to substitute fossil fuel solutions with clean energy solutions to promote the growth pattern (Dincer 2000).

Similarly, trade openness shows a positive relationship with the ecological footprint. As economic growth and trade are closely connected, this may lead to an increased ecological footprint in developing countries. Economic growth arising from trade expansion may have an apparent direct effect on the bio-capacity. The finding is similarly in line with Al-Mulali et al. (2015). They have also found that trade openness, urbanization, and energy use increase the ecological footprint in 58 countries. In the same way, urbanization is positively related to the ecological footprint. As the pace of growth of urbanization varies across regions, it is very important to remember that rapidly due to migration of people from rural areas to urban areas for better life, developing countries' population in urban areas are growing. As the population is overcrowded in the urban areas, they demanded more energy consumption, and it will create an imbalance in the regeneration of resources and absorption of waste. Martínez-Zarzoso and Maruotti (2011) found similar results in the case of developing countries while using CO_2-based indicator as environmental quality.

Unlike urbanization, globalization reduces the ecological footprint in sample countries. It means globalization enhance environmental quality in developing countries in the study period. Through globalization, advanced or efficient technology is a transfer from developed countries to developing countries. There are many advantages for globalizations to the environment like it lowers the cost of production, developing

Table 5 Results of CIPS and CADF panel unit root tests

	CADF		CIPS	
	Level	1st difference	Level	1st difference
EF	−2.42	−2.96**	−2.12	−4.52**
GDP	−1.21	−3.45**	−1.96	−3.45**
RE	−1.86	−2.76**	−1.36	−3.86**
NRE	−2.78	−5.42*	−2.42	−4.15*
TR	−1.65	−4.12**	−1.23	−3.72**
GI	−1.52	−3.45**	−1.85	−3.62**
URB	−1.32	−3.75*	−1.62	−5.23*
PO	−2.91	−4.72**	−2.63	−5.27*
NR	−1.06	−3.51*	−1.40	−3.81*
HC	−1.54	−3.46**	−2.66	−4.12**

Notes: * and ** represent 1 and 5% level of significance

Source: Authors' calculation

Table 6 Westerlund's panel co-integration test

Statistics	Coefficient	P value
G_t	−2.39**	0.04
G_a	−3.58*	0.00
P_t	−2.78**	0.05
P_a	−4.61*	0.00

Notes: * and ** represent 1 and 5% level of significance

Source: Authors' calculation

Table 7 Results of MG, AMG, and DCCE tests

Variables	MG		AMG		DCCE	
	Coefficient	t statistics	Coefficient	t statistics	Coefficient	t statistics
GDP	1.57*	6.08	2.16*	7.47	1.75*	6.40
RE	−0.04**	−3.64	−0.07**	−2.38	−0.06**	−3.89
NRE	0.68*	5.05	0.74*	6.29	0.14*	5.38
TR	0.09**	1.65	0.33**	3.05	0.03**	3.99
GI	−0.17**	−1.21	−0.58*	−6.80	−0.72**	−2.35
URB	0.27**	2.02	0.04**	2.76	0.02**	2.31
PO	0.05	0.03	0.66	0.02	0.45	0.08
NR	0.06**	4.09	0.26*	5.91	0.56**	3.95
HC	−0.36*	−5.98	−0.41*	−6.36	−0.19**	−2.21

Notes: *, **, and *** represent 1, 5, and 10% level of significance

Source: Authors' calculation

better environmental regulations and standards. Via forums for international practices such as fair trade and eco brands, it has been at the forefront of building public awareness of labor and environmental standards. This result is also hold up by literatures like Ansari et al. (2020) and Zafar et al. (2019). Similarly, the natural resource has a positive effect on the ecological footprint. It means that 1% increase in natural resources is leading to a growth of 0.75% in ecological footprint. The positive value of the natural resources' coefficient means that countries with no natural resource will import energy from fossil fuels (e.g., oil or gas) (Balsalobre-Lorente et al. 2018). These findings indicate that these developing countries are not adequately exploiting their natural resources and are using poor energy policies that are unable to reduce the country's dependency on traditional sources of energy. The ecological footprint in developing countries, especially in relation to their mining activities, can be attributed to the influence of the availability of natural resources. Natural resources play a beneficial role in environmental destruction as sustainable and maintenance options are balanced with demand and development. As a result, the rate of natural resource loss and environmental stress decreases, allowing natural resources to recover.

However, the result delineates that human capital reduces the ecological footprint in developing countries. This means that an increase of 1% in human resources improves environmental sustainability by 0.20%. Standard living, education, and life expectancy measure human capital. When education and living conditions are improved, wages increase, and clean energy options are used rather than risks that obstruct a healthier way of life. Education also increases awareness among the people about the use of energy-saving or green technology in their daily life. The studies which are similarly in line with our findings are Ahmed and Wang (2019), Hassan et al. (2019), Chen et al. (2019), and Nathaniel (2020). However, the

coefficient of population density is positive but not significant. We also found that the results of AMG and DCCE confirm the same sign and magnitude as the dependent variable.

Robustness check

We have applied FMOLS and DOLS for the robustness check. The FMOLS and DOLS are superior to OLS estimator because they permit to apply in case of small sample and control endogeneity problem. Table 8 discusses the results of FMOLS and DOLS.

The results of FMOLS and DOLS also support the previous long-run results of MG, AMG, and DCCE. The results reveal that economic growth, non-renewable energy, trade openness, urbanization, and natural resources abundance are increasing ecological footprint significantly. However renewable energy consumption, globalization index, and human capital reduce it, thereby enhancing the environmental quality in the sampled countries. Hence government of each nation should more focus on the investment in the renewable energy sector and make stringent environmental policies for protecting the domestic nation from environmental issues.

The causal interaction among the stated variables is describes in the D-H causality test in Table 9. This test is more suitable in the case of heterogeneous panels and the presence of cross-sectional dependency in the model. The D-H causality test reveals that there are feedback effects on economic growth to ecological footprint, ecological footprint to globalization, and ecological footprint to natural resources and trade to globalization in these countries. This supports the idea that urbanization in these economies is a significant concern. However, urbanization, trade openness, renewable energy, and population density drive ecological footprint.

Table 8 Results of FMOLS and DOLS tests

Variables	FMOLS		DOLS	
	Coefficient	t statistics	Coefficient	t statistics
GDP	2.18*	6.78	1.61*	5.09
RE	−0.10**	−3.24	−0.23**	−4.38
NRE	0.98*	5.62	0.51**	2.27
TR	0.01**	3.91	0.09**	4.22
GI	−0.46*	−6.01	−0.69**	−5.00
URB	0.07**	2.48	0.13**	3.49
PO	0.37	0.05	0.78	0.12
NR	0.75**	3.42	0.15**	4.21
HC	−0.20**	−2.26	−0.03***	−1.64

Notes: *, **, and *** represent 1, 5, and 10% level of significance

Source: Authors' calculation

These findings are similarly in line with Nathaniel et al. (2020a, 2020b), Chen and Fang (2018), and Nyasha et al. (2018).

Table 9 Results of D-H Granger non-causality test

Null hypothesis	W-bar	Probability value	Direction
EF≠GDP	8.35	0.008	EF↔GDP
GDP≠EF	10.54	0.000	
RE≠EF	9.41	0.000	RE→EF
EF≠NRE	6.74	0.005	EF→NRE
URB≠EF	4.72	0.034	URB→EF
TR≠EF	5.36	0.002	TR→EF
EF≠GI	7.39	0.000	EF↔GI
GI≠EF	8.41	0.000	
EF≠NR	5.02	0.026	EF↔NR
NR≠EF	6.64	0.013	
PO≠EF	5.86	0.038	PO→EF
GDP≠RE	4.30	0.064	GDP→RE
NRE≠GDP	6.45	0.004	NRE→GDP
TR≠GDP	4.96	0.060	TR→GDP
GI≠GDP	7.62	0.000	GI→GDP
NR≠GDP	9.45	0.000	NR→GDP
RE≠GI	8.53	0.000	RE→GI
NR≠RE	5.26	0.007	NR→RE
PO≠RE	4.25	0.047	PO→RE
PO≠NRE	6.79	0.003	PO→NRE
TR≠NRE	8.22	0.000	TR→NRE
GI≠NRE	7.54	0.001	GI→NRE
TR≠GI	5.12	0.009	TR↔GI
GI≠TR	8.55	0.000	

Source: Authors' calculation

Notes: ≠ represents "does not homogeneously cause"

Conclusion and policy implications

This paper examines the relationship between renewable energy, non-renewable energy, globalization, natural resources, and human capital on ecological footprint for a balanced data of 36 developing countries from 1990 to 2016. We consider other explanatory variables like urbanization, economic growth, trade openness, and population in this study. Cross-sectional dependency and second-generation unit root tests are employed to know the dependency among the cross-sections and order of integration among the variables to use in this paper. After getting the results of the order of integration, we apply Westerlund (2007) panel co-integration, as it can be used in the presence of cross-sectional dependency in the series. To know the main results of our analysis or long-run elasticity among the independent variables and dependent variables, MG, AMG, and DCCE panel techniques are employed. Results of MG reveal that economic growth increases ecological footprint in developing countries, or it reduces environmental quality. There is always a range of contributors to the degree of economic growth and prosperity in each nation. Development mechanisms were established in various economies depending on the unique features of each nation and the possible natural resources required encouraging high growth. Development may have detrimental environmental consequences. This finding is like "Hassan et al. (2019) for BRICS economies, Aşıcı and Acar (2016) for developing countries, and Ahmad et al. (2020) for emerging economies."

Consumption of renewable energy in developing countries lowers ecological footprint. Our results supported the findings of Sinha et al. (2017). They found that intensification of the use of renewable energy technologies could regulate ecological footprint in the long run. Hastik et al. (2016) indicated that renewable energy use alone could not solve environmental challenges without improving energy-saving manufacturing processes. However, non-renewable energy consumption endorses an ecological footprint. To cope up with this situation, developing countries are highly using fossil fuel energy. The use of non-renewable energy consumption leads to increase extraction of natural resources like coal and oil. Furthermore, the growth of the service industry, which is the product of economic development, will continue energy needs and, thus, contribute to emissions, thereby reducing environmental quality. Accordingly, the use of fossil energy turned out to be dangerous for the nature of the atmosphere, resulting in an improvement in the ecological footprint in these countries. Therefore, "to ensure sustainable progress in these countries, it is important to eventually substitute fossil fuel solutions with clean energy to promote the growth pattern" (Dincer 2000).

However, the result delineates that human capital reduces the ecological footprint in developing countries. It means a 1% increase in human capital reduces 0.20% of ecological footprint or increases environmental quality. Standard living,

education, and life expectancy measure human capital. When education and living conditions are improved, wages increase, and clean energy options are used rather than risks that obstruct a healthier way of life. Hence, government of each nation should more focus on the investment in the renewable energy sector and improvement of quality education and make stringent environmental policy for protecting the domestic nation from environmental issues.

From the empirical results, we suggest some important policy implications of this paper. As the results indicate that nonrenewable energy, consumption increases ecological footprint. This suggests that appropriate environmental policies are required in the developing countries to mitigate the ecological footprint. This necessitates serious intentions to increase energy efficiency and reduce the share of fossil fuels in the energy mix while still considering renewable energy's considerable potential in this regard. As the elasticity of renewable energy, consumption is negative and significant. More importantly, the importance of renewable energy use indicates that the developing economies are on track to become carbon-free and achieving long-term prosperity. Government and policy makers should focus on the more production of renewable energy, and respective government of each country should allocate more funds for the innovation of infrastructure development in the renewable energy sector. To create a sustainable future, it is recommended that developing country should increase the share of renewable energy in their energy mix, handle their natural resources effectively, and monitor their urbanization trend in a similar way to their current consequences. Government should provide subsidies for using the clean energy in these countries, so that people will prefer to use more renewable energy than the fossil energy consumptions. These renewable energy sources vary from fossil fuels in that they are pure and emit few pollutants. Increased investment in environmentally sustainable technology would reduce pollution while also boosting productivity. In the case of natural resources, illegal activities such as extraction and logging are widespread, so enhanced public consciousness and stringent legislation are needed to keep this nefarious behavior in check. Government should make it easy for the small-scale miners for getting the license simpler. Furthermore, when dealing with national energy protection challenges, lawmakers should pay attention to natural resource mining practices by requiring businesses that harvest mineral resources to use energy-efficient equipment in their operations. As urbanization, showing positive effect on ecological footprint, hence smart infrastructure and electricity hybrid cars can be introduced to transform urban traffic to green transportation. Eventually, environmental awareness and emerging educational reform practices can continue to reap the benefits of long-term sustainability.

The present study has some limitations as follows: (i) it is only focused on developing countries, (ii) the study is limited to the period up to 2016 due to unavailability of data of ecological footprints, and (iii) the study also ignored some of the important variables such ecological footprints, globalization, and natural resources due to unavailability data for some countries. It can be further carried out by including all the developing countries. Moreover, we have used ecological footprints as a proxy of environmental pollution in our study; however, other environmental indicators such as nitrogen and sulfur emissions and carbon and material footprint may also be added for further analysis. In addition, as per the development of new empirical methodology, advanced methodologies can be applied for the empirical analysis.

Author contribution All the authors contributed to the study conception and design. Malayaranjan Sahoo and Narayan Sethi performed material preparation and data collection, and Malayaranjan Sahoo performed analysis. Both the authors wrote the first draft of the manuscript; and Narayan Sethi commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Declarations

Ethics approval and consent to participate   Not applicable

Consent for publication   Not applicable

Competing interests   The authors declare no competing interests.

Appendix

Table 10   Sample countries considered for the study

Argentina	Congo Republic	Kenya	Peru
Bangladesh	Colombia	Sri Lanka	Philippines
Bolivia	Costa Rica	Mexico	Paraguay
Brazil	Dominican Republic	Mozambique	El Salvador
Botswana	Ghana	Malaysia	Togo
Chile	Haiti	Nigeria	Thailand
China	Indonesia	Nicaragua	Tunisia
Cote d'Ivoire	India	Pakistan	Turkey
Cameroon	Jordan	Panama	Tanzania

References

Ahmad M, Jiang P, Majeed A, Umar M, Khan Z, Muhammad S (2020) The dynamic impact of natural resources, technological innovations and economic growth on ecological footprint: an advanced panel data estimation. Res Policy 69:101817. https://doi.org/10.1016/j.resourpol.2020.101817

Ahmed K, Long W (2013) An empirical analysis of CO2 emission in Pakistan using EKC hypothesis. J Int Trade Law Policy 12:188–200. https://doi.org/10.1108/JITLP-10-2012-0015

Ahmed Z, Wang Z (2019) Investigating the impact of human capital on the ecological footprint in India: an empirical analysis. Environ Sci Pollut Res 26(26):26782–26796

Ahmed Z, Wang Z, Mahmood F, Hafeez M, Ali N (2019) Does globalization increase the ecological footprint? Empirical evidence from Malaysia. Environ Sci Pollut Res 26(18):18565–18582

Akram R, Chen F, Khalid F, Ye Z, Majeed MT (2020) Heterogeneous effects of energy efficiency and renewable energy on carbon emissions: evidence from developing countries. J Clean Prod 247:119122. https://doi.org/10.1016/j.jclepro.2019.119122

Alharthi M, Dogan E, Taskin D (2021) Analysis of CO 2 emissions and energy consumption by sources in MENA countries: evidence from quantile regressions. Environ Sci Pollut Res:1–8. https://doi.org/10.1007/s11356-021-13356-0

Ali HS, Law SH, Zannah TI (2016) Dynamic impact of urbanization, economic growth, energy consumption, and trade openness on CO 2 emissions in Nigeria. Environ Sci Pollut Res 23(12):12435–12443

Ali R, Bakhsh K, Yasin MA (2019) Impact of urbanization on CO2 emissions in emerging economy: evidence from Pakistan. Sustain Cities Soc 48:101553. https://doi.org/10.1016/j.scs.2019.101553

Ali S, Yusop Z, Kaliappan SR, Chin L (2020) Dynamic common correlated effects of trade openness, FDI, and institutional performance on environmental quality: evidence from OIC countries. Environ Sci Pollut Res 27:11671–11682. https://doi.org/10.1007/s11356-020-07768-7

Al-Mulali U, Ozturk I (2015) The effect of energy consumption, urbanization, trade openness, industrial output, and the political stability on the environmental degradation in the MENA (Middle East and North African) region. Energy 84:382–389. https://doi.org/10.1016/j.energy.2015.03.004

Al-Mulali U, Weng-Wai C, Sheau-Ting L, Mohammed AH (2015) Investigating the environmental Kuznets curve (EKC) hypothesis by utilizing the ecological footprint as an indicator of environmental degradation. Ecol Indic 48:315–323. https://doi.org/10.1016/j.ecolind.2014.08.029

Altinoz B, Dogan E (2021) How renewable energy consumption and natural resource abundance impact environmental degradation? New findings and policy implications from quantile approach. Energy Sources, Part B: Economics, Planning, and Policy:1–12. https://doi.org/10.1080/15567249.2021.1885527

Ansari MA, Haider S, Masood T (2020) Do renewable energy and globalization enhance ecological footprint: an analysis of top renewable energy countries? Environ Sci Pollut Res 28:1–14. https://doi.org/10.1007/s11356-020-10786-0

Apergis N, Danuletiu DC (2014) Renewable energy and economic growth: evidence from the sign of panel long-run causality. Int J Energy Econ Policy 4(4):578–588

Apergis N, Ozturk I (2015) Testing environmental Kuznets curve hypothesis in Asian countries. Ecol Indic 52(1):16–22

Apergis N, Payne JE (2014) Renewable energy, output, CO2 emissions, and fossil fuel prices in Central America: evidence from a nonlinear panel smooth transition vector error correction model. Energy Econ 42(5):226–232

Arndt C, Arent D, Hartley F, Merven B, Mondal AH (2019) Faster than you think: Renewable energy and developing countries. Annu Rev Resour Economics 11:149–168

Aşıcı AA, Acar S (2016) Does income growth relocate ecological footprint? Ecol Indic 61:707–714. https://doi.org/10.1016/j.ecolind.2015.10.022

Awodumi OB, Adewuyi AO (2020) The role of non-renewable energy consumption in economic growth and carbon emission: evidence from oil producing economies in Africa. Energy Strategy Rev 27:100434. https://doi.org/10.1016/j.esr.2019.100434

Aydin M, Turan YE (2020) The influence of financial openness, trade openness, and energy intensity on ecological footprint: revisiting the environmental Kuznets curve hypothesis for BRICS countries. Environ Sci Pollut Res 27(34):43233–43245

Azam M, Khan AQ (2016) Urbanization and environmental degradation: evidence from four SAARC countries—Bangladesh, India, Pakistan, and Sri Lanka. Environ Prog Sustain Energy 35(3):823–832

Bakhsh K, Rose S, Ali MF, Ahmad N, Shahbaz M (2017) Economic growth, CO2 emissions, renewable waste and FDI relation in Pakistan: new evidences from 3SLS. J Environ Manag 196:627–632. https://doi.org/10.1016/j.jenvman.2017.03.029

Balsalobre-Lorente D, Shahbaz M, Roubaud D, Farhani S (2018) How economic growth, renewable electricity and natural resources contribute to CO2 emissions? Energy Policy 113:356–367

Barro RJ, Lee JW (2013) A new data set of educational attainment in the world, 1950–2010. J Dev Econ 104:184–198. https://doi.org/10.1016/j.jdeveco.2012.10.001

Bekun FV, Alola AA, Sarkodie SA (2019) Toward a sustainable environment: nexus between CO2 emissions, resource rent, renewable and non-renewable energy in 16-EU countries. Sci Total Environ 657:1023–1029. https://doi.org/10.1016/j.scitotenv.2018.12.104

Bhujabal P, Sethi N, Padhan PC (2021) ICT, foreign direct investment and environmental pollution in major Asia Pacific countries. Environ Sci Pollut Res:1–21. https://doi.org/10.1007/s11356-021-13619-w

Bilgili F, Ulucak R (2018) Is there deterministic, stochastic, and/or club convergence in ecological footprint indicator among G20 countries? Environ Sci Pollut Res 25(35):35404–35419

Charfeddine L (2017) The impact of energy consumption and economic development on ecological footprint and CO2 emissions: evidence from a Markov switching equilibrium correction model. Energy Econ 65:355–374. https://doi.org/10.1016/j.eneco.2017.05.009

Chen Y, Fang Z (2018) Electricity consumption, education expenditure and economic growth in Chinese cities. Econ Model 69:205–219. https://doi.org/10.1016/j.econmod.2017.09.021

Chen S, Saud S, Saleem N, Bari MW (2019) Nexus between financial development, energy consumption, income level, and ecological footprint in CEE countries: do human capital and biocapacity matter? Environ Sci Pollut Res 26(31):31856–31872

Chudik A, Pesaran MH (2015) Common correlated effects estimation of heterogeneous dynamic panel data models with weakly exogenous regressors. J Econ 188(2):393–420

Daniels SE, Walker GB (1996) Collaborative learning: improving public deliberation in ecosystem-based management. Environ Impact Assess Rev 16(2):71–102

Danish, Wang B, Wang Z (2018) Imported technology and CO2 emission in China: collecting evidence through bound testing and VECM approach. Renew Sust Energ Rev 82:4204–4214. https://doi.org/10.1016/j.rser.2017.11.002

Destek MA (2020) Investigation on the role of economic, social, and political globalization on environment: evidence from CEECs. Environ Sci Pollut Res 27(27):33601–33614

Dincer I (2000) Renewable energy and sustainable development: a crucial review. Renew Sust Energ Rev 4(2):157–175

Ding Y, Peng J (2018) Impacts of urbanization of mountainous areas on resources and environment: based on ecological footprint model. Sustainability 10(3):765–778

Dogan E (2014) Energy consumption and economic growth: evidence from low-income countries in Sub-Saharan Africa. Int J Energy Econ Policy 4(2):154–164

Dogan E (2016) Analyzing the linkage between renewable and non-renewable energy consumption and economic growth by considering structural break in time-series data. Renew Energy 99:1126–1136. https://doi.org/10.1016/j.renene.2016.07.078

Dogan E, Seker F (2016) Determinants of CO2 emissions in the European Union: the role of renewable and non-renewable energy. Renew Energy 94:429–439. https://doi.org/10.1016/j.renene.2016.03.078

Dogan E, Turkekul B (2016) CO 2 emissions, real output, energy consumption, trade, urbanization and financial development: testing the EKC hypothesis for the USA. Environ Sci Pollut Res 23(2):1203–1213

Dogan E, Taspinar N, Gokmenoglu KK (2019) Determinants of ecological footprint in MINT countries. Energy Environ 30(6):1065–1086

Dogan E, Ulucak R, Kocak E, Isik C (2020) The use of ecological footprint in estimating the environmental Kuznets curve hypothesis for BRICST by considering cross-section dependence and heterogeneity. Sci Total Environ:138063. https://doi.org/10.1016/j.scitotenv.2020.138063

Dreher A (2006) Does globalization affect growth? Evidence from a new index of globalization. Appl Econ 38(10):1091–1110

Dumitrescu EI, Hurlin C (2012) Testing for Granger non-causality in heterogeneous panels. Econ Model 29(4):1450–1460

Ehigiamusoe KU, Lean HH (2019) Effects of energy consumption, economic growth, and financial development on carbon emissions: evidence from heterogeneous income groups. Environ Sci Pollut Res 26(22):22611–22624

Energy information Administration (2013) future world energy demand driven by trends in developing countries. Retrieved from https://www.eia.gov/todayinenergy/detail.php?id=14011

Ertur C, Musolesi A (2017) Weak and strong cross-sectional dependence: a panel data analysis of international technology diffusion. J Appl Econ 32(3):477–503

Figge L, Oebels K, Offermans A (2017) The effects of globalization on ecological footprints: an empirical analysis. Environ Dev Sustain 19(3):863–876

Gfn (2018) Global Footprint Network. WWW Document https://data.footprintnetwork.org/?_ga=2.134472181.508123949.1609248689-1393775646.1607921298#/

Global Footprint Network (2018) National footprint accounts. http://data.footprintnetwork.org/#/countryTrends?cn=351&type=BCpc,EFCpc. Accessed 18 Nov 2020

Godil DI, Ahmad P, Ashraf MS, Sarwat S, Sharif A, Shabib-ul-Hasan S, Jermsittiparsert K (2021) The step towards environmental mitigation in Pakistan: do transportation services, urbanization, and financial development matter? Environ Sci Pollut Res 28:1–13. https://doi.org/10.1007/s11356-020-11839-0

Gokmenoglu KK, Taspinar N (2018) Testing the agriculture-induced EKC hypothesis: the case of Pakistan. Environ Sci Pollut Res 25(23):22829–22841

Grossman GM, Krueger AB (1991) Environmental impacts of a North American free trade agreement (No. w3914). National Bureau of economic research. https://doi.org/10.3386/w3914

Haldar A, Sethi N (2020) Effect of institutional quality and renewable energy consumption on CO 2 emissions− an empirical investigation for developing countries. Environ Sci Pollut Res 28:1–19. https://doi.org/10.1007/s11356-020-11532-2

Hassan ST, Baloch MA, Mahmood N, Zhang J (2019) Linking economic growth and ecological footprint through human capital and biocapacity. Sustain Cities Soc 47:101516. https://doi.org/10.1016/j.scs.2019.101516

Hastik R, Walzer C, Haida C, Garegnani G, Pezzutto S, Abegg B, Geitner C (2016) Using the "footprint" approach to examine the potentials and impacts of renewable energy sources in the European Alps. Mt Res Dev 36(2):130–140

Hu H, Xie N, Fang D, Zhang X (2018) The role of renewable energy consumption and commercial services trade in carbon dioxide reduction: evidence from 25 developing countries. Appl Energy 211:1229–1244. https://doi.org/10.1016/j.apenergy.2017.12.019

IEA (2019) Energy and Climate Change. World Energy Outlook Special Report, Paris. https://www.iea.org/data-and-statistics

Isenberg G, Edinger R, Ebner J (2002) Renewable energies for climate benign fuel production. Environ Sci Pollut Res 9(2):99–104

Işık C, Ongan S, Özdemir D (2019) Testing the EKC hypothesis for ten US states: an application of heterogeneous panel estimation method. Environ Sci Pollut Res 26(11):10846–10853

Ito K (2017) CO2 emissions, renewable and non-renewable energy consumption, and economic growth: evidence from panel data for developing countries. Int Econ 151:1–6. https://doi.org/10.1016/j.inteco.2017.02.001

Keho Y (2016) What drives energy consumption in developing countries? The experience of selected African countries. Energy Policy 91:233–246. https://doi.org/10.1016/j.enpol.2016.01.010

Khalid K, Usman M, Mehdi MA (2020) The determinants of environmental quality in the SAARC region: a spatial heterogeneous panel data approach. Environ Sci Pollut Res 28:1–15. https://doi.org/10.1007/s11356-020-10896-9

Khan M (2020) CO2 emissions and sustainable economic development: new evidence on the role of human capital. Sustain Dev 28(5):1279–1288

Khan I, Hou F (2021) The dynamic links among energy consumption, tourism growth, and the ecological footprint: the role of environmental quality in 38 IEA countries. Environ Sci Pollut Res 28(5):5049–5062

Kongbuamai N, Zafar MW, Zaidi SAH, Liu Y (2020) Determinants of the ecological footprint in Thailand: the influences of tourism, trade openness, and population density. Environ Sci Pollut Res 27(32):40171–40186

Kuznets S (1955) Economic growth and income inequality. Am Econ Rev 45:1–28

Kwabena Twerefou D, Danso-Mensah K, Bokpin GA (2017) The environmental effects of economic growth and globalization in Sub-Saharan Africa: a panel general method of moments approach. Res Int Bus Financ 42(939):949–949. https://doi.org/10.1016/j.ribaf.2017.07.028

Liang L, Wang Z, Li J (2019) The effect of urbanization on environmental pollution in rapidly developing urban agglomerations. J Clean Prod 237:117649. https://doi.org/10.1016/j.jclepro.2019.117649

Long X, Ji X, Ulgiati S (2017) Is urbanization eco-friendly? An energy and land use cross-country analysis. Energy Policy 100:387–396. https://doi.org/10.1016/j.enpol.2016.06.024

Lv Z, Xu T (2018) Is economic globalization good or bad for the environmental quality? New evidence from dynamic heterogeneous panel models. Technological Forecasting and Social Change, 137, 340-343.c growth, and financial development on carbon emissions: evidence from heterogeneous income groups. Environ Sci Pollut Res 26(22):22611–22624

Magurran AE, Dornelas M (2010) Biological diversity in a changing world. https://doi.org/10.1098/rstb.2010.0296

Majeed MT, Tauqir A, Mazhar M, Samreen I (2021) Asymmetric effects of energy consumption and economic growth on ecological footprint: new evidence from Pakistan. Environ Sci Pollut Res:1–17. https://doi.org/10.1007/s11356-021-13130-2

Malthus TM (1798) An Essay on the Principle of Population. J. Johnson, London, Originally published anonymously. Republished Liberty Fund, Inc., 2000. Retrieved from https://oll.libertyfund.org/title/malthus-an-essay-on-the-principle-of-population-1798-1st-ed

Martens P, Raza M (2010) Is globalisation sustainable? Sustainability 2(1):280–293

Martínez-Zarzoso I, Maruotti A (2011) The impact of urbanization on CO2 emissions: evidence from developing countries. Ecol Econ 70(7):1344–1353

Mert M, Bölük G (2016) Do foreign direct investment and renewable energy consumption affect the CO 2 emissions? New evidence from a panel ARDL approach to Kyoto Annex countries. Environ Sci Pollut Res 23(21):21669–21681

Miketa A, Mulder P (2005) Energy productivity across developed and developing countries in 10 manufacturing sectors: patterns of growth and convergence. Energy Econ 27(3):429–453

Miller RG, Hutchison ZL, Macleod AK, Burrows MT, Cook EJ, Last KS, Wilson B (2013) Marine renewable energy development: assessing the Benthic Footprint at multiple scales. Front Ecol Environ 11(8): 433–440

Mrabet Z, Alsamara M (2017) Testing the Kuznets curve hypothesis for Qatar: a comparison between carbon dioxide and ecological footprint. Renew Sust Energ Rev 70:1366–1375. https://doi.org/10.1016/j.rser.2016.12.039

Nathaniel SP (2020) Biocapacity, human capital, and ecological footprint in G7 countries: the moderating role of urbanization and necessary lessons for emerging economies. Ene Ecol and Envt:1–16. https://doi.org/10.1007/s40974-020-00197-9

Nathaniel S, Nwodo O, Adediran A, Sharma G, Shah M, Adeleye N (2019) Ecological footprint, urbanization, and energy consumption in South Africa: including the excluded. Environ Sci Pollut Res 26(26):27168–27179

Nathaniel S, Anyanwu O, Shah M (2020a) Renewable energy, urbanization, and ecological footprint in the Middle East and North Africa region. Environ Sci Pollut Res 27:1–13. https://doi.org/10.1007/s11356-020-08017-7

Nathaniel S, Nwodo O, Sharma G, Shah M (2020b) Renewable energy, urbanization, and ecological footprint linkage in CIVETS. Environ Sci Pollut Res 27(16):19616–19629

Nathaniel SP, Barua S, Ahmed Z (2021) What drives ecological footprint in top ten tourist destinations? Evidence from advanced panel techniques. Environ Sci Pollut Res:1–10. https://doi.org/10.1007/s11356-021-13389-5

Niccolucci V, Tiezzi E, Pulselli FM, Capineri C (2012) Biocapacity vs ecological footprint of world regions: a geopolitical interpretation. Ecol Indic 16:23–30. https://doi.org/10.1016/j.ecolind.2011.09.002

Nyasha S, Gwenhure Y, Odhiambo NM (2018) Energy consumption and economic growth in Ethiopia: a dynamic causal linkage. Energy & Environment 29(8):1393–1412

Omoke PC, Nwani C, Effiong EL, Evbuomwan OO, Emenekwe CC (2020) The impact of financial development on carbon, non-carbon, and total ecological footprint in Nigeria: new evidence from asymmetric dynamic analysis. Environ Sci Pollut Res 27(17):21628–21646

Pesaran MH (2007) A simple panel unit root test in the presence of cross-section dependence. J Appl Econ 22(2):265–312

Pesaran MH, Yamagata T (2008) Testing slope homogeneity in large panels. J Econ 142(1):50–93

Pesaran MH, Shin Y, Smith RP (1999) Pooled mean group estimation of dynamic heterogeneous panels. J Am Stat Assoc 94(446):621–634

Rashid A, Irum A, Malik IA, Ashraf A, Rongqiong L, Liu G, Ullah H, Ali MU, Yousaf B (2018) Ecological footprint of Rawalpindi; Pakistan's first footprint analysis from urbanization perspective. J Clean Prod 170:362–368. https://doi.org/10.1016/j.jclepro.2017.09.186

Rauf A, Liu X, Amin W, Ozturk I, Rehman OU, Hafeez M (2018) Testing EKC hypothesis with energy and sustainable development challenges: a fresh evidence from belt and road initiative economies. Environ Sci Pollut Res 25(32):32066–32080

Rees WE (1992) Ecological footprints and appropriated carrying capacity: what urban economics leaves out. Environ Urban 4(2):121–130

Sabir S, Gorus MS (2019) The impact of globalization on ecological footprint: empirical evidence from the South Asian countries. Environ Sci Pollut Res 26(32):33387–33398

Sadorsky P (2014) The effect of urbanization on CO2 emissions in emerging economies. Energy Econ 41:147–153. https://doi.org/10.1016/j.eneco.2013.11.007

Sahoo M, Sethi N (2020a) Impact of industrialization, urbanization, and financial development on energy consumption: Empirical evidence from India. J Public Aff 20(3):e2089. https://doi.org/10.1002/pa.2089

Sahoo M, Sethi N (2020b) Does remittance inflow stimulate electricity consumption in India? An empirical insight. South Asian Jour of Busi Studies. https://doi.org/10.1108/SAJBS-05-2020-0158 ahead-of-print

Saint Akadiri S, Alola AA, Alola UV, Nwambe CS (2020) The role of ecological footprint and the changes in degree days on environmental sustainability in the USA. Environ Sci Pollut Res 27(20):24929–24938

Salahuddin M, Gow J (2014) Economic growth, energy consumption and CO2 emissions in Gulf Cooperation Council countries. Energy 73: 44–58. https://doi.org/10.1016/j.energy.2014.05.054

Salahuddin M, Alam K, Ozturk I, Sohag K (2018) The effects of electricity consumption, economic growth, financial development and foreign direct investment on CO2 emissions in Kuwait. Renew Sustain Energy Rev 81:2002–2010. https://doi.org/10.1016/j.rser.2017.06.009

Salahuddin M, Ali MI, Vink N, Gow J (2019a) The effects of urbanization and globalization on CO 2 emissions: evidence from the Sub-Saharan Africa (SSA) countries. Environ Sci Pollut Res 26(3): 2699–2709

Salahuddin M, Gow J, Ali MI, Hossain MR, Al-Azami KS, Akbar D, Gedikli A (2019b) Urbanization-globalization-CO2 emissions nexus revisited: empirical evidence from South Africa. Heliyon 5(6): e01974. https://doi.org/10.1016/j.heliyon.2019.e01974

Sehrawat M (2020) Modelling the nexus between human capital, income inequality, and energy demand in India: new evidences from asymmetric and non-linear analysis. Environ Sci Pollut Res 28:1–12. https://doi.org/10.1007/s11356-020-10733-z

Seppälä T, Haukioja T, KAIvo-ojA, J. A. R. I. (2001) The EKC hypothesis does not hold for direct material flows: environmental Kuznets curve hypothesis tests for direct material flows in five industrial countries. Popul Environ 23(2):217–238

Shahbaz M, Balsalobre-Lorente D, Sinha A (2019) Foreign direct Investment–CO2 emissions nexus in Middle East and North African countries: Importance of biomass energy consumption. J Clean Prod 217:603–614. https://doi.org/10.1016/j.jclepro.2019.01.282

Shahbaz M, Bhattacharya M, Ahmed K (2017a) CO2 emissions in Australia: economic and non-economic drivers in the long-run. Appl Econ 49(13):1273–1286

Shahbaz M, Khan S, Ali A, Bhattacharya M (2017b) The impact of globalization on CO2 emissions in China. Singap Econ Rev 62(04):929–957

Shahbaz M, Shahzad SJH, Mahalik MK (2018) Is globalization detrimental to CO 2 emissions in Japan? New threshold analysis. Environ Model Assess 23(5):557–568

Shahzad U, Fareed Z, Shahzad F, Shahzad K (2020) Investigating the nexus between economic complexity, energy consumption and ecological footprint for the United States: new insights from quantile methods. J Clean Prod 279:123806. https://doi.org/10.1016/j.jclepro.2020.123806

Sharma SS (2011) Determinants of carbon dioxide emissions: empirical evidence from 69 countries. Appl Energy 88(1):376–382

Sharma R, Sinha A, Kautish P (2021) Does renewable energy consumption reduce ecological footprint? Evidence from eight developing countries of Asia. J Clean Prod 285:124867 Retrieved from https://mpra.ub.uni-muenchen.de/id/eprint/104277

Stöglehner G (2003) Ecological footprint—a tool for assessing sustainable energy supplies. J Clean Prod 11(3):267–277

Toth G, Szigeti C (2016) The historical ecological footprint: from overpopulation to over-consumption. Ecol Indic 60:283–291. https://doi.org/10.1016/j.ecolind.2015.06.040

Uddin GA, Alam K, Gow J (2016) Does ecological footprint impede economic growth? An empirical analysis based on the environmental Kuznets curve hypothesis. Aust Econ Pap 55(3):301–316

Uddin GA, Salahuddin M, Alam K, Gow J (2017) Ecological footprint and real income: panel data evidence from the 27 highest emitting countries. Ecol Indic 77:166–175. https://doi.org/10.1016/j.ecolind.2017.01.003

Udemba EN (2021) Nexus of ecological footprint and foreign direct investment pattern in carbon neutrality: new insight for United Arab Emirates (UAE). Environ Sci Pollut Res:1–19. https://doi.org/10.1007/s11356-021-12678-3

United Nations (2017) World Urbanization Prospects. Retrieved from https://www.unfpa.org/urbanization

Usman M, Hammar N (2020) Dynamic relationship between technological innovations, financial development, renewable energy, and ecological footprint: fresh insights based on the STIRPAT model for Asia Pacific Economic Cooperation countries. Environ Sci Pollut Res 28:15519–15536. https://doi.org/10.1007/s11356-020-11640-z

Usman M, Hammar N (2021) Dynamic relationship between technological innovations, financial development, renewable energy, and ecological footprint: fresh insights based on the STIRPAT model for Asia Pacific Economic Cooperation countries. Environ Sci Pollut Res 28(12):15519–15536

Valin H, Havlík P, Mosnier A, Herrero M, Schmid E, Obersteiner M (2013) Agricultural productivity and greenhouse gas emissions: trade-offs or synergies between mitigation and food security? Environ Res Lett 8(3):12–21

Van den Bergh JC, Verbruggen H (1999) Spatial sustainability, trade and indicators: an evaluation of the 'ecological footprint'. Ecol Econ 29(1):61–72

Wackernagel M, Monfreda C (2004) Ecological footprints and energy. Encyclopedia of energy 2(1):1–11

Wackernagel M, Onisto L, Bello P, Linares AC, Falfán ISL, García, J. M., ... & Guerrero, M. G. S. (1999) National natural capital accounting with the ecological footprint concept. Ecol Econ 29(3):375–390

Wachernagel M, Rees W (1996) Our ecological footprint. Gabriola Island. New Society Publishers, British Columbia, Canada, p 166 Retrieved from https://escholarship.org/uc/item/7730w81q

Wear DN, Bolstad P (1998) Land-use changes in southern Appalachian landscapes: spatial analysis and forecast evaluation. Ecosystems 1(6):575–594

Westerlund J (2007) Testing for error correction in panel data. Oxf Bull Econ Stat 69(6):709–748

World Bank (2018) World Bank Development Indicators database (online) Available at https://data.worldbank.org/. Accessed 24 Oct 2018

World development indicators (2020) https://databank.worldbank.org/source/world-development-indicators. Accessed 18 Nov 2020

Xu R, Lin B (2017) Why are there large regional differences in CO2 emissions? Evidence from China's manufacturing industry. J Clean Prod 140:1330–1343. https://doi.org/10.1016/j.jclepro.2016.10.019

Yang B, Jahanger A, Ali M (2021) Remittance inflows affect the ecological footprint in BICS countries: do technological innovation and financial development matter? Environ Sci Pollut Res 28:1–19. https://doi.org/10.1007/s11356-021-12400-3

Yao Y, Ivanovski K, Inekwe J, Smyth R (2020) Human capital and CO2 emissions in the long run. Energy Econ 91:104907. https://doi.org/10.1016/j.eneco.2020.104907

You W, Lv Z (2018) Spillover effects of economic globalization on CO2 emissions: a spatial panel approach. Energy Econ 73:248–257. https://doi.org/10.1016/j.eneco.2018.05.016

Zafar MW, Saud S, Hou F (2019) 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(13):13246–13262

Zhang C, Lin Y (2012) Panel estimation for urbanization, energy consumption and CO2 emissions: a regional analysis in China. Energy Policy 49:488–498. https://doi.org/10.1016/j.enpol.2012.06.048

Zhao S, Li Z, Li W (2005) A modified method of ecological footprint calculation and its application. Ecol Model 185(1):65–75