GeoJournal (2022) 87:2345–2372
https://doi.org/10.1007/s10708-020-10370-6

The Environmental Kuznets Curve hypothesis for carbon and ecological footprints in South Asia: the role of renewable energy

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Accepted: 29 December 2020

Abstract Mitigation of environmental deterioration along the economic growth stream has become a critically important policy agenda among governments across the globe. Thus, the contemporary growth policies are ought to be aligned with the environmental sustainability targets as well. Against this backdrop, this paper aimed to evaluate the validity of the Environmental Kuznets Curve (EKC) hypothesis using carbon and total ecological footprints to quantify environmental quality in the context of five South Asian economies: Bangladesh, India, Pakistan, Sri Lanka and Nepal. Moreover, the EKC hypothesis analysis is precisely focused on the role of promoting renewable energy use for mitigating the environmental adversities in South Asia. Using annual data from 1995 to 2015 and controlling for cross-sectional dependency and slope heterogeneity issues, the results confirmed the validity of the EKC hypothesis for the panel of the selected South Asian nations. Besides, enhancing the levels of renewable energy consumption and renewable electricity outputs were found to be pertinent in diminishing the carbon and ecological footprints. Moreover, the country-specific analysis led to statistical validation of the EKC hypothesis for Bangladesh, India, Nepal and Sri Lanka but not for Pakistan. However, enhancing the overall use of renewable energy was unanimously associated with environmental betterment in all five South Asian nations. Hence, the results implicate that economic growth is both the short-run cause and the long-run solution to the environmental adversities within South Asia. Besides, augmenting renewable energy into the national energy-mixes is ideal for safeguarding environmental well-being in South Asia.

Keywords Ecological footprints · EKC hypothesis · Renewable energy · Renewable electricity · Cross-sectional dependency · Slope heterogeneity

Introduction

Environmental sustainability has become a critically important global issue that has attracted a significant amount of attention amongst environmental advocates

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and policymakers. Although the traditional economic development policies have largely turned a blind eye towards the environmental adversities that have accompanied the growth performances, such flawed strategies have been criticized in the contemporary era. Besides, it is believed that socioeconomic development, without paying heed to environmental issues, is unlikely to sustain over the long-run (Murshed and Dao 2020). According to a report by the World Bank (2016), environmental degradation was alleged to be a vital factor that inhibits socioeconomic growth globally, to which South Asia is no exception. South Asia comprises of quite a few of the briskly developing nations that have sustained robust growth of their respective economies in the last couple of decades. Between 2014 and 2019, the average annual per capita GDP growth rate of South Asia has been around 5.4% which is quite impressive compared to that of other similar developing countries (World Bank 2019). However, such noteworthy economic growth performances were traded-off with multifaceted environmental adversities. Over the period from 2010 to 2016, the per capita Carbon dioxide emissions (CO2E) in South Asia have shot up by more than 25% (World Bank 2019) while the Ecological Footprints (EFP) have almost surged by 20% (Global Footprint Network 2019). Besides, Bangladesh, India and Pakistan are among the five most-polluted global nations (IQ Air 2019). On the other hand, the South Asian economies are signatories of the Paris Agreement which obliges these nations to reduce environmental pollution in order to keep the global temperature rise to below 2 °C above the pre-industrial level (Kugelman 2015). Moreover, the South Asian economies are also committed to ensuring environmental sustainability by achieving the 2030 Sustainable Development Goals (SDG) agenda of the United Nations (Asadullah et al. 2020). Thus, it is pertinent to ascertain the factors undermining environmental quality in South Asia.

The nexus between economic growth and environmental quality has been extensively explored under the theoretical underpinnings of the Environmental Kuznets Curve (EKC) hypothesis (Zakaria and Bibi 2019; Mehmood and Tariq 2020). This hypothesis postulates that economic growth initially deteriorates environmental quality due to the growth policies not incorporating the environmental welfare policies. As a result, during this period, economic growth stimulates the deterioration of the environmental attributes (Murshed et al. 2020a). However, as the economy develops and attains a threshold income level, the economic growth-environmental degradation trade-off is phased out. Hence, economic growth is hypothesized to be the short-term cause and the long-term panacea to the environmental hardships within an economy (Murshed 2020b). Keeping into consideration the rising trends in South Asia's economic growth rates, CO2E and EFP, it can be assumed that the South Asian economies are yet to attain the respective national income thresholds beyond which economic and environmental welfares can be achieved in tandem. In this regard, identification of the macroeconomic factors that facilitate economic growth without marginalizing the environmental quality has become a critically important policy agenda in South Asia. Also, these factors can also be expected to portray major roles in initiating the phasing-out of the economic growth-environmental degradation trade-off.

Although the EKC hypothesis was theorized to hold for all economies in general, its validity is not always guaranteed (Sarkodie and Strezov 2019). It is assumed that the authenticity of the EKC hypothesis is affected by several other factors that influence the economic growth-environmental quality nexus. Besides, Brock and Taylor (2005) asserted that the validity of the EKC hypothesis is conditional on the scale of production, the composition of the inputs and, most importantly, the production technology used to perform the economic activities. Hence, linking production scales and input choices to energy consumption, several studies have controlled for aggregate energy consumption within the EKC analysis (Dogan and Turkekul 2016). Since energy use is inextricably linked to both economic growth and greenhouse gas emissions, it is relevant to control for energy consumption levels in examining the non-linear relationship between economic growth and environmental quality. Besides, the global energy consumption-induced CO2E are anticipated to be elevated by around 6% between 2015 and 2050; unless major structural and compositional reforms in the energy policies are undertaken (Gielen et al. 2019). Consequently, the implementation of appropriate energy policies is to be prioritized keeping both economic and environmental welfares into cognizance.

Although energy, in general, is acknowledged to contribute to higher economic growth (Rahman and Velayutham 2020), its impacts on environmental quality are conditional on the type of energy resource consumed (Fatima et al. 2020). For instance, it is said that the combustion of renewable energy resources, as opposed to the use of non-renewable fossil fuels, attributes to lower emissions (Saidi and Omri 2020). Thus, it is pertinent to control for Renewable Energy Consumption (REC) levels within the EKC analysis (Sadorsky 2009; Zoundi 2017). The role of undergoing a transition from non-renewable to renewable energy utilization in ensuring environmental sustainability has also been acknowledged in the 7th goal of the SDG declarations of the United Nations (EEA 2014; UNDP 2015; Murshed 2018). Moreover, replacing conventional fossil fuels with renewable alternatives, not only would diminish these emissions, but it would also be effective in ensuring energy insecurity to expedite the rate of economic expansion (Sebri and Ben-Salha 2014). In the context of South Asia, the majority of the South Asian economies have traditionally been overwhelmingly dependent on non-renewable fossil fuels to meet their aggravating energy demand (Sharma et al. 2014). Such monotonic fossil fuel dependency and the associated emissions from combustion of these fuels are regarded as the major factors inhibiting environmental sustainability in South Asia (IPCC 2014). As a consequence, it has become essential for the South Asian economies to diversify their respective energy consumption baskets through the augmentation of renewable resources in the national energy-mixes.

On the other hand, the preceding studies within the EKC hypothesis narrative have primarily used CO2E to measure environmental quality (Ali et al. 2020; Murshed 2020a; Shahbaz et al. 2020). However, quantifying environmental quality simply in terms of CO2E is not sufficient to capture the multi-dimensionality of the environmental hardships. Hence, to account for this limitation of the previous studies, Wackernagel and Rees (1998) proposed the EFP as a more comprehensive yardstick to indicate environmental quality. The EFP takes into consideration the human demand for different environmental resources and the corresponding environmental capacities (or biocapacities) to meet the demand and absorb the wastes generated in the process (Wackernagel et al. 2004). Besides, the EFP is claimed to be a more appropriate measure of environmental quality since it specifically accounts for both the direct and indirect environmental impacts of economic activities (Nathaniel 2020; Nathaniel et al. 2021). In contrast, CO2E are more of direct environmental consequences of human activity (McDonald and Patterson 2004). Consequently, the use of EFP in the EKC analysis has attracted the interests of researchers in recent times (Hassan et al. 2019; Nathaniel and Khan 2020; Khan et al. 2020).

Against this premise, this paper aims to evaluate the EKC hypothesis using Carbon Footprints (CFP) and total EFP to quantify environmental quality in the context of South Asian countries between 1995 and 2015. The selected South Asian countries include Bangladesh, India, Pakistan, Sri Lanka and Nepal.[1] The economic growth-environmental quality nexus is controlled for renewable energy use and other key macroeconomic attributes as per the underlying theoretical justifications. Although a plethora of the existing studies has evaluated the authenticity of the EKC hypothesis in the case of South Asia (Rehman et al. 2012; Al-Mulali et al. 2016), this current study contributes to the literature on several grounds. Firstly, as opposed to the conventional approach of using CO2E, this paper uses the CFP and EFP to measure environmental quality under the theoretical framework of the EKC hypothesis. The majority of the preceding studies have probed into the CO2E-induced EKC hypothesis in South Asia (Murshed et al. 2020b). However, simply using the levels of CO2E in this regard vaguely accounts for the overall environmental hardships faced by the South Asian economies. In contrast, both the CFP and total EFP are expected to provide a more comprehensive measure of environmental quality (Ulucak and Bilgili 2018). Apart from a few recent studies by Sabir and Gorus (2019) and Sabir et al. (2020), the use of EFP and CFP in assessing the authenticity of the EKC hypothesis in the context of the panel of South Asian countries is yet to be extensively documented in the literature. However, some country-specific findings have been documented in the literature (Aziz et al. 2020). Secondly, the empirical analysis conducted in this paper separately controls for both the per capita REC and Renewable Electricity Output (REO) levels within the EKC analysis. Most studies focusing on the EKC hypothesis for EFP have controlled for the REC levels while very few have considered controlling for the REO levels. However, it is pertinent to control for the REO levels

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[1] The selection of the countries was based on data availability which resulted in the exclusion of Afghanistan, Maldives and Bhutan from the analysis.

since electricity is the most commonly used form of secondary energy resource within any economy. Hence, generating electricity from renewable resources would also account for the utilization of renewable energy resources within the South Asian economies. Besides, enhancing the shares of REO in the aggregate electricity output levels is also assumed to improve environmental quality to a large extent (Silva et al. 2012). Finally, this paper addresses both the cross-sectional dependency and slope heterogeneity concerns within the elasticity estimations. The previous studies have predominantly accounted for the cross-sectional dependency issues and have largely overlooked the possible slope heterogeneity problems in the data. However, overlooking this important issue results in the estimation of biased elasticity estimates (Pesaran and Yamagata 2008). Thus, to account for both cross-sectional dependency and slope heterogeneity, the Common Correlated Effects Mean Group (CCEMG) and Augmented Mean Group (AMG) estimators proposed by Pesaran (2006) and Bond and Eberhardt (2013), respectively, are applied.

The remainder of the paper is structured as follows. "An overview of the CFP and EFP as measures of environmental quality" section presents some stylized facts in the context of CFP and EFP across South Asia and also discusses how these provide a relatively more comprehensive measure of the quality of the environment. The relevant literature is reviewed in "Literature review" section. "Empirical model and data" section provides the empirical models used in this paper and explains the attributes of the associated dataset. The econometric methodology is outlined in "Methodology" section while "Results and discussions" section reports and discusses the corresponding results. Finally, "Conclusions and policy recommendations" section concludes and highlights policy implications.

An overview of the CFP and EFP as measures of environmental quality

Quantifying environmental degradation simply in terms of greenhouse gas emissions does not account for a broad understanding of the environmental hardships stemming from the diverse economic activities. For instance, there has been a shift in the composition of the total greenhouse gas emissions, from traditionally being characterized as mostly nitrogen and sulfur to being more intensive in terms of carbon and smoke in the contemporary era (Ulucak and Bilgili 2018). Thus, measuring environmental quality simply via emissions of these pollutants is not ideal in understanding the true dynamics of environmental welfare. In contrast, the EFP, put forward by Rees (1992), and later on improvised by Wackernagel and Rees (1998), basically measures environmental quality from multiple aspects. The EFP consider both the human demand for environmental resources and the corresponding environmental capacities to meet them and absorb the wastes generated in the process (Wackernagel et al. 2004). This is particularly important from the perspective of ensuring environmental sustainability which requires the environmental capacities to be higher than the respective human demand. Thus, EFP are more of an environmental sustainability indicator that can be appropriately tapped to comprehensively assess environmental quality (Bagliani et al. 2008).[2] The most unique feature of EFP is that an array of different environmental indicators is compiled to compute a particular index. Thus, the EFP are comprehensive in the sense that it reflects a broad spectrum of the diverse environmental attributes that cumulatively account for the overall state of the environment (Costanza 2000). Moreover, environmental deterioration is said to be a multifaceted phenomenon comprising of different aspects that are both directly and indirectly responsible for the degradation of the environment. Hence, using EFP to measure environmental quality is effective since EFP also take into account the indirect environmental impacts of economic activities which are largely overlooked whenever environmental quality is measured simply in terms of emissions (McDonald and Patterson 2004).

The EFP are calculated by dividing the human ecological demands by the natural capacities of different land types to meet the resource demand (Nathaniel et al. 2019). These include croplands, pasture lands, fishing bodies, forests, built-up lands and carbon (Caviglia-Harris et al. 2009). Amongst these, this paper particularly focuses on the CFP which takes into account the number of natural forestlands required for absorbing the CO2E. The CFP, in contrast to using per capita CO2E within the EKC analysis, is

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[2] For more information on the features of EFP see Ulucak and Bilgili (2018).

anticipated to precisely estimate the real impacts of the CO2E which particularly stem from fossil fuel combustions, keeping the natural environmental capacities into cognizance (Nathaniel et al. 2020).

Table 1 provides an analysis of the trends in the CFP and EFP figures of the five South Asian economies considered in this paper. India leads amongst the South Asian countries with respect to its per capita CFP and EFP figures. A particular reason behind this phenomenon could be reasoned by the sheer enormity of the Indian economy which accounts for a lion's share in the total geographic territory of South Asia. However, between 1995 and 2015, the per capita CFP of Nepal and Bangladesh surged the most by almost 4.67 and 3.39-folds, respectively, followed by Sri Lanka, India and Pakistan registering corresponding growths of 3.24, 2.98 and 2.08-folds, respectively (Global Footprint Network 2019). On the other hand, as far as the total EFP per capita figures are concerned, Bangladesh heads the list registering a rise in its per capita EFP figures by almost 2.5-fold between 1995 and 2015; followed by India, Sri Lanka, Nepal and Pakistan accounting for corresponding growths in their respective EFP by 1.91, 1.66, 1.65 and 1.54-folds, respectively. Therefore, it is quite apparent from Table 1 that the quality of the environment across the selected South Asian economies has, on average, persistently deteriorated over the aforementioned period. Thus, these concerning trends tend to suggest that the economic growth policies pursued across South Asia are not aligned with the environmental sustainability goals.

Literature review

This particular section is divided into two subsections. The former discusses the theoretical framework engulfing the EKC hypothesis in the context of environmental quality being measured in terms of EFP. The latter reviews the corresponding empirical evidence documented in the literature.

Theoretical framework

The EKC hypothesis has emerged as a variant of the Kuznets curve hypothesis that was originally put forward in the seminal paper by Kuznets (1955). The Kuznets curve hypothesis postulated a non-linear association between economic growth and income inequality. Keeping the non-linearity aspect unaltered, the EKC hypothesis asserts that economic growth is both the short-run cause and the long-run solution to the environmental hazards that accompany the growth streams. According to the EKC hypothesis in the context of environmental quality being quantified in terms of the EFP figures, economic growth initially is hypothesized to deteriorate the environment by boosting the levels of EFP. This can be explained from the perspective that during the initial stages of growth there is a gradual structural transformation of an agrarian economy into a modern industrialized one. As a result, the economic activities are likely to increase which could lead to the extraction and employment of natural resources. Consequently, the EFP figures can be expected to grow. Thus, during this growth period, economic growth is expected to be positively correlated to the EFP figures. This trade-off between economic growth and environmental degradation can be credited to the scale effects of economic growth (Kaika and Zervas 2013). Then, as the economy operates in the industrial phase, further extraction and use of the natural resources are believed to boost the EFP further. This phenomenon can be classified as the scale and composition effects of economic growth (Tsurumi and Managi 2010). As a result, economic growth and EFP can once again be expected to depict a positive relationship. Moreover, it is to be mentioned that during the pre-industrialization and industrialization phase, developing economies tend to overlook the biocapacities of the respective economies to meet the human demand for natural resources and also to absorb the wastes that are produced in the process. As a consequence, the difference between the biocapacities and the EFPs tend to shrink; thus, the quality of the environment tends to deteriorate.

However, the EKC hypothesis also posits that beyond a certain level of economic growth, the trade-off between economic and environmental welfares can be assumed to phase-out. As a result, further growth of the economy would result in lower levels of EFP to improve the quality of the environment. Hence, during this phase, economic growth is believed to be negatively correlated to the volumes of EFP. The pashing out of the economic growth-environmental degradation tradeoff ideally takes place towards the end of the industrialization phase and throughout the post-industrialization era whereby a technique effect tends to

Table 1 Trends in CFP and EFP across the selected South Asian economies. *Source*: Global Footprint Network (2019)

Period	Bangladesh	Sri Lanka	India	Nepal	Pakistan
Panel A: carbon footprints (million global hectares per capita)					
1995–2000	12.49	5.37	310.88	2.04	37.19
2001–2005	18.91	7.18	385.95	2.80	47.45
2006–2010	29.95	8.44	560.86	3.51	63.14
2011–2015	42.85	11.38	757.50	5.31	65.47
Panel B: total ecological footprints (million global hectares per capita)					
1995–2000	65.65	21.17	859.35	18.77	108.45
2001–2005	80.49	23.01	952.91	21.97	121.75
2006–2010	100.53	25.02	1192.45	23.25	146.01
2011–2015	124.97	29.73	1445.69	27.80	147.13

The CFP and EFP figures are the consumption CFP and EFP figures

reduce the EFP without marginalizing the rate of economic growth. The technique effect is referred to the impacts of technological innovations which enable economies to ensure economic and environmental sustainability in tandem (Gill et al. 2018a). It is assumed that the technique effect bends the EKC at the threshold level of economic growth. Thus, it can be claimed that beyond the growth threshold, the difference between the EFP and the biocapacity of a nation can be anticipated to increase; thus, implicating environmental improvement.

Empirical evidence

Studies in the context of the EKC hypothesis were pioneered by Grossman and Krueger (1991) in which the authors investigated the trends in the emissions of sulfur dioxide and smoke in the context of Mexico. However, the results from the empirical exercises could not validate the inverted-U shaped association between the growth of the Mexican economy and these emissions, thus, invalidating the EKC hypothesis. Since then, a plethora of studies have probed into the economic growth-environmental quality nexus, in light of the EKC hypothesis, using diverse measures to quantify environmental well-being (Dinda 2004; Sarkodie and Strezov 2019).

Among these, Cho et al. (2014) found statistical evidence to authentication the EKC hypothesis using total greenhouse gas emissions to indicate environmental quality in a panel of 22 Organization for Economic Cooperation and Development (OECD) countries. However, the country-specific results in this regard validated the EKC hypothesis for only 8 out of the 22 OECD nations. Similar support to the existence of the EKC for total greenhouse gas emissions was put forward by Olale et al. (2018) in the context of Canada. On the other hand, Apergis and Ozturk (2015) disaggregated total greenhouse gas emissions and found the EKC hypothesis for CO2E to be valid for 14 Asian countries. Similar results were reported by Al-Mulali et al. (2016) for panels of countries from Central and Eastern Europe, Western Europe, East Asia and the Pacific, Middle East and North Africa, South Asia and North America; but, the EKC hypothesis did not hold for the panel of Sub-Saharan African economies. Among the other major types of greenhouse gas emissions, the EKC hypothesis was also examined in the context of methane (Benavides et al. 2017), nitrous oxide (Sinha and Sengupta 2019) and sulfur dioxide (Wang et al. 2016a, b).

Although different types of greenhouse gas emissions were popularly featured in the EKC literature in the past, the contemporary studies have considered the EFP data to assess the validity of the EKC hypothesis in the global context. Al-Mulali et al. (2015) examined the EKC hypothesis quoting EFP as an indicator of environmental deterioration across 93 low, middle and high-income countries. The results depicted the inverted U-shaped relationship between economic growth and EFP only in the context of the upper-middle and high-income countries while in the context of the low-income countries economic growth was found to monotonically increase the EFP. In another relevant study, Charfeddine and Mrabet (2017) found the EKC hypothesis to hold for 15 Middle Eastern and North African (MENA) nations. However, upon disaggregating the entire sample into sub-panels of oil-exporting and non-oil-exporting nations, the EKC hypothesis was validated only for the oil-exporting sub-panel. Recently, the EKC hypothesis for EFP received statistical authenticity in the studies by Alola et al. (2019) and Adedoyin et al. (2020) for 16 European Union (EU) countries, Ansari et al. (2020) for Central and East Asian countries and Aydin and Turan (2020) for India. In contrast, Caviglia-Harris et al. (2009) found the EKC hypothesis to be invalid for a panel of 146 global economies. This particular study took the possible endogeneity issues in the dataset into consideration to perform the two-stage least squares regression analysis. Moreover, the EKC analysis was replicated using the different components of the EFP variable. Amongst the authors found economic growth to initially reduce CFP while increasing it beyond a threshold level, thus invalidating the EKC hypothesis for CFP. Similar findings against the authenticity of the EKC hypothesis for EFP were highlighted in the studies by Dogan et al. (2020) for BRICS countries and Turkey, Aydin et al. (2019) for 26 European nations, Pata and Aydin (2020) for six hydropower consuming countries and Yilanci and Pata (2020) for China.

Table 2 provides a summary of the other relevant studies that have used the EFP within the EKC hypothesis analysis. It is apparent from the findings of the studies reported in Table 2 that the validity of the EKC hypothesis for EFP has revealed equivocal statistical support.

Studies on the EKC hypothesis have controlled for different macroeconomic aggregates that were hypothesized to affect, both directly and directly, the overall validity and the curvature of the EKC. Among the diverse macroeconomic aggregates controlled for, relevant existing studies have particularly controlled for urbanization rate (Li et al. 2020), financial development (Pata 2018), trade openness (Ertugrul et al. 2016) and foreign direct investment inflows (Seker et al. 2015). However, the majority of the studies within the EKC narrative have controlled for the level of energy consumption within the econometric models keeping the impacts of energy on both economic growth (Aqeel and Butt 2001) and environmental quality (Wang et al. 2016a, b) into cognizance. In a study on the BRICS nations, Pao and Tsai (2010) found aggregate energy consumption to stimulate CO2E while statistical validity for the EKC hypothesis was also reported. Similar conclusions were made by Arouri et al. (2012) for 12 MENA countries, Heidari et al. (2015) for 5 Southeast Asian countries and Acaravci and Ozturk (2010) for Denmark and Italy.

Moreover, categorizing aggregate energy use into non-renewable and renewable energy use, a wide array of the existing studies has augmented these figures into the empirical models to assess the validity of the EKC hypothesis. Bölük and Mert (2014) found fossil fuel consumption to account for twice as much as greenhouse emissions as that emitted from the consumption of renewable energy resources in the context of 16 EU nations. However, no statistical evidence of the EKC hypothesis was ascertained. Similarly, Shafiei and Salim (2014) found non-renewable energy use to stimulate CO2E while REC was found to curb CO2E within 29 OECD countries. Besides, the validity of the EKC hypothesis was confirmed only for the panel of the 29 OECD nations. In a more relevant study that used EFP to measure environmental quality, Destek et al. (2018) remarked that REC attributed to lower levels of EFP while non-renewable energy consumption increased the EFP levels in 15 EU economies. However, the corresponding findings could not validate the existence of the EKC hypothesis. Recently, Danish et al. (2020) also concluded that REC played a critically important role in reducing EFP and validating the EKC hypothesis in the BRICS countries. Similarly, Aziz et al. (2020) also highlighted the negative relationship between REC and EFP in the context of Mexico, Indonesia, Nigeria and Turkey. The validity of the EKC hypothesis was ascertained, as well. The results corroborate the findings documented by Sharif et al. (2020) for the case of Turkey. Furthermore, Sharma et al. (2020) also claimed that REC curbed EFP in South and Southeast Asian countries but the authors could not ensure the authenticity of the EKC hypothesis.

On the other hand, augmenting electricity use into the EKC analysis, Farhani and Shahbaz (2014) found per capita renewable electricity consumption to attribute to higher CO2E in the context of 10 MENA countries. The authors also reported the validity of the EKC hypothesis in this regard. Conversely, Balsalobre-Lorent et al. (2018) found renewable electricity generations to account for lower greenhouse emissions across five EU nations. However, the results from the econometric analyses affirmed an N-shaped association between economic growth and greenhouse emissions. Thus, the authenticity of the EKC hypothesis could not be established. In a recent study concerning

Table 2 Summary of the literature on the EKC hypothesis using EFP data

Study	Country (time period)	Environmental indicator	Findings on the EKC
Liu et al. (2018)	Korea, Japan and China (1990–2013)	EFP	EKC hypothesis is validated for only Korea and Japan
Ahmed and Wang (2019)	India (1971–2014)	EFP for consumption	EKC hypothesis is validated in the long-run only
Fakher (2019)	Iran, Algeria, Thailand, Indonesia, Saudi Arabia, United Arab Emirates, Qatar (1996–2016)	Ecological CFP	EKC hypothesis is validated
Ozturk et al. (2016)	144 countries (1988–2002)	EFP	EKC hypothesis is more persistent among the upper-middle-income and high-income nations
Bagliani et al. (2008)	141 countries (2001)	EFP and its components	EKC hypothesis does not hold
Mrabet and Alsamara (2017)	Qatar (1980–2011)	EFP; CO2E	EKC hypothesis holds for CO2E but not for EFP
Hassan et al. (2019)	Pakistan (1970–2014)	EFP	EKC hypothesis is valid both in the short- and long-runs
Bello et al. (2018)	Malaysia (1971–2016)	EFP; CFP; WFP; CO2E	EKC hypothesis is validated for all indicators of environmental quality
Ozcan et al. (2018)	Turkey (1961–2013)	EFP	EKC hypothesis is not validated
Hervieux and Darné (2016)	Argentina, Brazil, Chile, Colombia, Paraguay, Canada, France, Norway, Portugal, Spain, Sweden (1971–2007)	EFP from consumption; EFP from production	The EKC hypothesis is not valid in the short-run
Boutaud et al. (2006)	130 countries (2001)	EFP	No conclusive evidence to validate the EKC hypothesis
Destek and Sinha (2020)	24 OECD countries (1980–2014)	EFP	EKC hypothesis does not hold
Altintaş and Kassouri (2020)	14 European countries (1990–2014)	EFP; CO2E	EKC hypothesis is validated only in the context of EFP as an indicator of environmental quality

EFP, CFP, EFP and CO2E stand for total ecological footprint, carbon footprint, water footprint and carbon dioxide emissions, respectively

China, Chen et al. (2019) found renewable electric power generations to effectively reduce CO2E. Moreover, the interlinkage between renewable electricity and CO2E was confirmed by the evidence of the bidirectional causation between these variables. In addition, the statistical estimates also validated the existence of the EKC hypothesis in the context of China. Likewise, Belaid and Youssef (2017) found a positive impact of higher renewable electricity consumption on CO2E in Algeria, while non-renewable electricity consumption and economic growth were seen to stimulate higher CO2E. In another study, Bento and Moutinho (2016) also found higher REO to be associated with lower per capita CO2E in Italy.

Table 3 summarizes the existing studies on the EKC hypothesis which have controlled for the use of renewable energy. Once again, the ambiguous nature of the validity of the EKC hypothesis is evident from the findings reported in Table 3.

Literature on EKC hypothesis in the context of South Asia

In the context of South Asia, Ali et al. (2017) found statistical validity of the EKC hypothesis in the context of Bangladesh, India, Pakistan and Sri Lanka. Using annual data from 1980 to 2013, the authors remarked that economic growth within these nations although initially aggravating the CO2E eventually goes on to reduce the emissions to improve the environment. In addition, non-renewable energy use was found to stimulate CO2E while REC led to lower CO2E. The country-specific results in this regard validated the EKC hypothesis for all four South Asian nations. However, the heterogeneous impacts of energy consumption on CO2E were also ascertained. In a similar study, Al-Mulali et al. (2016) also found statistical support to the EKC hypothesis for Bangladesh, India, Pakistan, Sri Lanka and Nepal. Moreover, the authors also opined that REC led to lower carbon emissions across South Asia. Bibi and Jamil (2020) also concluded in favor of the EKC hypothesis for CO2E holding true in South Asia over the 2000–2018 period. Among the country-specific analyses, Sinha and Shahbaz (2018) found renewable electricity output to curb CO2E in India and also the EKC hypothesis to hold. In the context of Sri Lanka, Uddin et al. (2016) found a long-run association between economic growth and CO2E between 1971 and 2006. Similarly, Islam et al. (2013) remarked in favor of the EKC hypothesis holding true in Bangladesh. The authors used annual data from 1971 to 2010 and found energy consumption to contribute to higher CO2E.

Table 3 Summary of the literature on EKC controlling for renewable energy use

Study	Country (Time period)	Environmental indicator	Renewable energy indicator	EKC hypothesis	Other findings
Yao et al. (2019)	17 developed and developing countries	CO2E	Renewable energy consumption share	Valid	REC reduces CO2E
Destek and Sinha (2020)	24 OECD countries (1980–2014)	EFP	Renewable energy consumption per capita	Invalid	REC reduces EFP
Allard et al. (2018)	74 countries (1994–2012)	CO2E	Renewable energy consumption share	Mixed	REC reduces CO2E
Ike et al. (2020)	G7 countries (1960–2014)	CO2E	Renewable energy consumption per capita	Valid	REC reduces CO2E in Germany, Italy, United Kingdom and the United States
Danish et al. (2020)	BRICS countries (1992–2016)	EFP	REC share	Valid	REC reduces EFP
Zhang (2019)	5 Central Asian countries (1992–2013)	CO2E	Renewable energy consumption per capita	Invalid	REC reduces CO2E
Zafar et al. (2019)	18 emerging economies (1990–2015)	CO2E	Renewable energy consumption per capita	Valid	REC reduces CO2E
Akram et al. (2020)	66 developing countries	CO2E	Renewable energy consumption share	Valid	REC reduces CO2E
Gill et al. (2018b)	Malaysia (1970–2011)	CO2E	Renewable electricity output share	Invalid	Renewable electricity reduce CO2E
Sugiawan and Managi (2016)	Indonesia (1971–2010)	CO2E	Renewable electricity per capita	Valid	Renewable electricity reduces CO2E

REC, EFP and CO2E denote renewable energy consumption, ecological footprints and carbon dioxide emission, respectively

On the other hand, not many existing studies have used EFP to evaluate the authenticity of the EKC hypothesis in the South Asian context. Among the few studies in this regard, Sabir and Gorus (2019) found the EKC hypothesis to be valid in the context of Bangladesh, India, Pakistan, Sri Lanka and Nepal. Similar conclusions both in the short- and long-run were asserted by Sabir et al. (2020) for India, Bangladesh, Pakistan and Sri Lanka. Besides, the authors found that aggregate energy consumption was positively correlated to short- and long-run EFP levels. In another relevant study on South and Southeast Asian nations, Sharma et al. (2020) concluded that the economic growth-EFP nexus portrayed an N-shaped relationship. However, the authors did assert that REC led to a reduction in the EFP. Among the country-specific studies that have explored the EKC hypothesis for EFP in South Asia, Aziz et al. (2020) found evidence of the EKC hypothesis holding true for Pakistan. Similarly, Hassan et al. (2019) and Ahmed and Wang (2019) also found the EKC hypothesis to be valid in the long-run for Pakistan and India, respectively. Hence, it is apparent from the aforementioned EKC related studies on South Asia that the use of CFP and EFP as comprehensive measures of environmental quality is yet to be extensively documented in the literature. Thus, this paper aims to bridge the gap in this regard.

Table 4 provides a summary of the existing empirical studies that have investigated the validity of the EKC hypothesis in the context of South Asia.

Empirical model and data

The validity of the EKC hypothesis is evaluated using non-linear double-log econometric models in which the two indicators of environmental quality, namely per capita CFP and EFP, are expressed as separate functions of economic growth, renewable energy-use/renewable electricity output, financial development, urbanization and trade openness. These can be specified as:

$$\begin{aligned} ln\ CFPpc_{it} = {} & \partial_0 + \partial_1 ln\ RGDPpc_{it} + \partial_2 ln\ RGDPpc_{it}^2 \\ & + \partial_3 ln\ RECpc_{it} + \partial_4 ln\ FD_{it} \\ & + \partial_5 ln\ URB_{it} + \partial_6 ln\ OPEN_{it} + \varepsilon_{it} \end{aligned} \quad (1)$$

where i, t and ε denote the individual cross-sections (countries), the time period (years), and the error-term, respectively. The parameter ∂_k is the intercept and $\partial_k (k = 1, \ldots 6)$ are the elasticity parameters to be predicted. The variable CFPpc refers to the per capita carbon footprint in terms of global hectares of land. Higher values of CFPpc denote environmental deterioration while lower values denote environmental improvement. RGDPpc abbreviates for the real per capita gross domestic product which is used to proxy for the level of economic growth of the concerned economies and measured in terms of constant 2010 US dollar prices. The squared term of real gross domestic product RGDPpc^2 is included to test the validity of the EKC hypothesis in the context of the selected South Asian nations. The positive and negative signs, and their statistical significance, of the elasticity parameters ∂_1 and ∂_2 would validate the EKC hypothesis and vice versa. The variable RECpc stands for the per capita renewable energy consumption levels measured in terms of kilograms of oil equivalent. In line with the underlying theoretical framework concerning the positive impacts of renewable energy on the environment, the sign of the elasticity parameter ∂_3 can be anticipated to be negative, thus, implying higher REC to account for lower per capita CFP (Destek and Sinha 2020). Among the other key macroeconomic variables controlled for within the econometric analysis, FD refers to financial development which is proxied by the share of domestic credits extended to the private sector in the gross domestic product of the respective South Asian economies. The use of ratio has been popularly used across the literature as a measure of financial development (Ozatac et al. 2017). The sign of the elasticity parameter ∂_4 can be expected to be either positive or negative since the impacts of financial development on environmental quality have exhibited ambiguity in the literature (Haseeb et al. 2018). The econometric model is also controlled for the rate of urbanization (URB). Urbanization rate measured in terms of the share of the urban residents in the total population of the respective South Asian economies. It is often claimed that unplanned urbanization, especially across South Asia, has led to environmental deterioration within the developing countries in particular (Ramachandra and Aithal 2016). Hence, the sign of the elasticity parameter ∂_5 can be expected to depict a positive sign to implicate the negative impacts

Table 4 Summary of the literature on the EKC hypothesis in the context of South Asia

Study	Country (time period)	Environmental indicator	EKC hypothesis
Sabir and Gorus (2019)	Bangladesh, India, Pakistan, Sri Lanka, Nepal (1975–2017)	EFP	Valid
Sabir et al. (2020)	Bangladesh, India, Pakistan, Sri Lanka (1984–2019)	EFP	Valid
Zakaria and Bibi (2019)	Bangladesh, India, Pakistan, Sri Lanka, Nepal (1984–2015)	CO2E	Invalid
Khan et al. (2019)	Bangladesh, India, Pakistan, Sri Lanka, Nepal (1990–2015)	CO2E	Valid
Narayan and Narayan (2010)	Bangladesh, India, Pakistan, Sri Lanka (1980–2004)	CO2E	Valid
Rehman et al. (2012)	Bangladesh, India, Pakistan and Sri Lanka (1984–2008)	SO2E	Valid
Mallick and Tandi (2015)	Bangladesh, India, Pakistan and Sri Lanka (1972–2010)	CO2E	Invalid
Zhang et al. (2017)	Pakistan (1970–2012)	CO2E	Valid
Shahbaz et al. (2015)	India (1970–2012)	CO2E	Valid
Tiwari et al. (2013)	India (1966–2009)	CO2E	Valid
Rabbi et al. (2015)	Bangladesh (1972–2012)	CO2E	Invalid

SO_2 and CO2E denote sulfur dioxide and carbon dioxide emissions, respectively

of urbanization on the environment (Ozturk et al. 2016). Finally, the impacts of international trade on the economic growth-CFP nexus are accounted for by including the trade openness index (OPEN) variable into the EKC model. Openness to trade is measured as the sum of total exports and imports as a percentage share in the GDP for the respective South nations. Since the impacts of trade openness on the environment have been acknowledged to be ambiguous in the existing literature, the sign of the elasticity parameter ∂_6 could be expected to be either negative or positive (Managi et al. 2009).

To assess the effects of REO on the validity of the EKC hypothesis, the per capita REC variable in model (1) is replaced by the per capita REO figures across the concerned South Asian economies. This model can be specified as:

$$\begin{aligned} \ln CFPpc_{it} = {} & \partial_0 + \partial_1 \ln RGDPpc_{it} + \partial_2 \ln RGDPpc^2_{it} \\ & + \partial_3 \ln RELECpc_{it} + \partial_4 \ln FD_{it} \\ & + \partial_5 \ln URB_{it} + \partial_6 \ln OPEN_{it} + \varepsilon_{it} \end{aligned} \tag{2}$$

where RELECpc stands for the per capita electricity generated from renewable resources, measured in terms of billion kilowatt-hours per capita. The expected signs of the elasticity parameters in model (2) can be assumed to conform to the corresponding signs of the elasticity parameters in the context of model (1).

To examine the validity of the EKC hypothesis from a broader perspective, taking into account the different sources of environmental deterioration, models (1) and (2) are re-estimated using per capita EFP as the dependent variable. The corresponding econometric models can be specified as:

$$\begin{aligned} \ln EFPpc_{it} = {} & \partial_0 + \partial_1 \ln RGDPpc_{it} + \partial_2 \ln RGDPpc^2_{it} \\ & + \partial_3 \ln RECpc_{it} + \partial_4 \ln FD_{it} \\ & + \partial_5 \ln URB_{it} + \partial_6 \ln OPEN_{it} + \varepsilon_{it} \end{aligned} \tag{3}$$

$$\begin{aligned} \ln EFPpc_{it} = {} & \partial_0 + \partial_1 \ln RGDPpc_{it} + \partial_2 \ln RGDPpc^2_{it} \\ & + \partial_3 \ln RELECpc_{it} + \partial_4 \ln FD_{it} \\ & + \partial_5 \ln URB_{it} + \partial_6 \ln OPEN_{it} + \varepsilon_{it} \end{aligned} \tag{4}$$

where EFPpc is the per capita total ecological footprint in terms of global hectares of land.

Following, Murshed et al. (2020c, d), all the variables have been transformed into their natural logarithms which can be interpreted from the prefix ln. The natural log transformations reduce the sharpness of the data to generate consistent elasticity estimates (Murshed et al. 2020e; Banerjee and Murshed 2020). Table 5 provides the descriptive statistics and the corresponding sources of all these aforementioned variables.

Methodology

The econometric analysis begins with the panel cross-sectional dependency analysis. The problem of cross-sectional dependency is said to generate biased and inconsistent stationarity and cointegrating properties (Li et al. 2020). Thus, it is pertinent to investigate whether the panel series in the dataset are independent or not. Cross-sectional dependency usually stems from spatial effects whereby a particular economic data of two or more economies exert an impact on one another, thus, associating the countries globally or regionally (Chudik and Pesaran 2013). This paper primarily employs the Breusch and Pagan (1980) Lagrange Multiplier (LM) test to identify the possible cross-sectional dependency issues in the panel data series. The LM test statistic can be specified as:

$$LM = \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} T_{ij} \hat{\rho}_{ij}^2 \rightarrow \chi^2 \frac{N(N-1)}{2} \tag{5}$$

where N is the number of countries, T is the time period and $\hat{\rho}_{ij}^2$ is the predicted correlation coefficient sourced from the residuals of the econometric model. Besides, the Pesaran (2004) cross-sectional dependency test, ideally suited for handling datasets with small cross-sections and short time dimensions, is also employed. The Pesaran (2004) cross-sectional dependency test statistic can be specified as:

$$CD = \sqrt{\frac{2}{N(N-1)}} \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} T_{ij} \hat{\rho}_{ij}^2 \rightarrow N(0,1) \tag{6}$$

The test statistics for all the aforementioned cross-sectional dependency investigation techniques are estimated under the null hypothesis of cross-sectional independence against the alternative hypothesis of cross-sectional dependency. The results from the cross-sectional dependency analyses are displayed in Table 6. The statistical significances of the test statistics reject the null hypothesis, for the respective models, to validate the existence of the cross-sectional dependency among the panel series. Hence, the application of the conventionally used first-generation panel unit root and cointegration methods is no longer valid since these methods fail to account for the cross-sectional dependency issues in the dataset.

In addition to the cross-sectional dependency investigations, it is important to check for the slope homogeneity concerns as well. Ignoring the possible heterogeneity of the slope coefficients across the cross-sections could result in the estimations being biased. Thus, this paper uses the slope heterogeneity test proposed by Pesaran and Yamagata (2008) which estimates two test statistics, $\tilde{\Delta}$ and $\tilde{\Delta}_{adj}$, under the null hypothesis of slope homogeneity against the alternative hypothesis of slope heterogeneity. The corresponding results from the slope homogeneity test, for all four models, are reported in Table 6. The statistical

Table 5 Descriptive statistics

Variable	Min	Max	Mean	SD	Skewness	Kurtosis	Source
lnCFP_{PC}	14.307	20.538	17.116	1.764	0.447	2.162	Global Footprint Network (2019)
lnEFP_{PC}	16.657	21.1616	18.355	1.429	0.685	2.246	Global Footprint Network (2019)
$\text{lnRGDP}_{\text{PC}}$	5.870	8.234	6.575	0.567	0.629	2.811	World Bank (2019)
$\text{lnRGDP}^2_{\text{PC}}$	34.457	67.809	43.557	1.915	0.803	2.409	World Bank (2019)
lnREC_{PC}	4.433	5.849	5.295	0.437	− 1.165	2.891	World Bank (2019)
$\text{lnRELEC}_{\text{PC}}$	− 19.220	− 15.149	− 16.781	1.276	− 0.887	2.422	World Bank (2019) and British Petroleum (2019)
lnFD	2.177	4.392	3.332	0.419	− 0.174	2.654	World Bank (2019)
lnURB	2.181	3.590	3.132	0.350	− 0.647	2.659	World Bank (2019)
lnOPEN	2.741	4.485	3.700	0.389	− 0.098	2.531	World Bank (2019)

Table 6 Cross-sectional dependency and slope homogeneity test results

	Model (1)		Model (2)		Model (3)		Model (4)	
	Statistic	*p*value	Statistic	*p* value	Statistic	*p* value	Statistic	*p* value
CD tests								
Breusch and Pagan (1980) LM	68.924*	0.000	30.909*	0.001	24.444*	0.007	27.172*	0.002
Pesaran (2004) CD	3.970*	0.000	3.435*	0.000	3.756*	0.000	5.496*	0.000
Slope heterogeneity test								
$\tilde{\Delta}$	18.129*	0.000	18.002*	0.000	11.221*	0.000	11.309*	0.000
$\tilde{\Delta}_{adj}$	18.778*	0.000	18.239*	0.000	11.309*	0.000	11.982*	0.000

*Indicates statistical significance at 1% level

significances of the test statistics, at 1% level, reject the null hypothesis to affirm slope heterogeneity issues within the data set.

Second generation panel unit root analysis

The second generation panel unit root techniques are claimed to generate estimates via addressing the cross-sectional dependency issues. In contrast, the conventionally used first-generation panel unit root tests assume cross-sectional independence. Thus, upon confirmation of the cross-sectional dependency problem, the second generation panel unit root tests are employed. This paper uses the Cross-sectionally Augmented Dickey–Fuller (CADF) and the Cross-sectionally Augmented Im, Pesaran and Shin (CIPS) panel unit root estimation techniques proposed by Pesaran (2007). The CADF test statistic can be obtained from the generalized regression given below:

$$\Delta y_{it} = a_i + b_i y_{i,t-1} + c_i \bar{y}_{t-1} + \sum_{j=0}^{s} d_{ij} \Delta \bar{y}_{t-j} + \sum_{j=1}^{s} \delta_{ij} \Delta \bar{y}_{i,t-j} + e_{it} \quad (7)$$

where $\bar{y}$ and $\overline{\Delta y}$ are the cross-sectional averages of lagged levels and first differences, respectively, at time T for all cross-sections. The estimated t-statistic from Eq. (7) is then used to compute the CIPS statistic which can be specified as:

$$CIPS = N^{-1} \sum_{i=1}^{N} CADF_i \quad (8)$$

where CADF_i is the t-statistic estimated from the CADF regression model shown in Eq. (7). Both the CADF and CIPS tests are performed under the null hypothesis of non-stationarity of the respective variable against the alternative hypothesis of stationarity.

Second generation panel cointegration analysis

The popularly used panel cointegration methods namely the Pedroni (1999) residual-based cointegration technique does not take the cross-sectional dependency problem among the panels into account. Thus, the Westerlund (2007) panel cointegration analysis, which is robust to handling cross-sectionally dependent panel datasets, is employed to investigate the long-run associations between the concerned variables included in the econometric models. The cross-sectional dependency is accounted for under the Westerlund (2007) cointegration approach via estimation of the probability values of the test statistics using bootstrapping methods. A total of two group-mean tests and two panel tests are performed under the null hypothesis of no cointegration against the alternative hypothesis of cointegration among at least one cross-sectional unit or cointegration among the whole panel, respectively. The four tests under the Westerlund (2007) panel cointegration approach are structured in the context of an error-correction model which can be expressed as:

$$\Delta y_{it} = \delta_i' d_t + \alpha_i \left(y_{i,t-1} - \beta_i' x_{i,t-1} \right) + \sum_{j=1}^{p_i} \alpha_{ij} \Delta y_{i,t-j} + \sum_{-q_i}^{p_i} \gamma_{ij} \Delta x_{i,t-j} + e_{it} \tag{9}$$

where d_t stands for the deterministic components and p_i and q_i are the lag lengths and lead orders which are allowed to vary across individual cross-sections. The two group-mean test statistics G_t and G_a and the two panel test statistics P_t and P_a within the Westerlund (2007) cointegration analysis can be specified as:

$$G_t = \frac{1}{N} \sum_{i=1}^{N} \frac{\widehat{\alpha}_i}{SE(\hat{\alpha}_i)} \tag{10}$$

$$G_a = \frac{1}{N} \sum_{i=1}^{N} \frac{T\widehat{\alpha}_i}{\hat{\alpha}_i(1)} \tag{11}$$

$$P_t = \frac{\widehat{\alpha}_i}{SE(\hat{\alpha}_i)} \tag{12}$$

$$P_a = T\hat{\alpha} \tag{13}$$

The statistical significance of these test statistics rejects the null hypothesis to suggest long-run associations between the variables included in the model. The presence of cointegrating relationships is a prerequisite to estimating the long-run estimates using appropriate regression methods.

Panel regression analysis

The presence of cross-sectional dependency issues in the dataset is likely to be translated into misspecification problems resulting in biased regression outputs (Damette and Marques 2019). Similarly, the slope heterogeneity issues are also likely to generate similar problems as well (Pesaran and Yamagata 2008). Although the conventionally used panel data estimation techniques namely the Fully-Modified Ordinary Least Squares (FMOLS) and Dynamic Ordinary Least Squares (DOLS) are claimed to be able to handle the cross-sectional correlations among the panels, such methods overlook the slope heterogeneity issues by inappropriately assuming the existence of the homogeneous slope coefficients across all the cross-sections. To account for this problem, this paper uses three panel data regression estimators which, in addition to handling the cross-sectional dependency issues, allow for the slope coefficients to vary across the cross-sectional units (Damette and Marques 2019).

The Mean Group (MG) estimator developed by Pesaran and Smith (1995) is said to accommodate the slope heterogeneity issues in the data. The MG estimation primarily involves the estimation of the slope coefficients for each of the cross-sections, within the panel dataset, using the Ordinary Least Squares (OLS) method and then averaging them across the panel units. This allows for the possible heterogeneity of the slope coefficients across the different cross-sections to overcome the inefficiencies of the FMOLS and the DOLS techniques. The MG estimator can be specified as:

$$\hat{\beta}_{MG} = N^{-1} \sum_{i=1}^{N} \hat{\beta}_i \tag{14}$$

where $\hat{\beta}_{MG}$ is the simple mean of the individual slope estimators from each cross-sectional unit. However, a major limitation of this technique is that it fails to account for the cross-sectional dependency in the data. Thus, the CCEMG estimator, proposed by Pesaran (2006), is the first of the two panel data regression techniques used in this paper. The CCEMG estimation process is a cross-sectionally augmented version of the MG estimator to handle the cross-sectional dependency issues as well. The CCEMG corrects the limitations of the MG estimator by incorporating the time-variant unobserved common factors stemming from the cross-sectional dependency issues into the estimation process via augmenting these unobserved common factors into the regression model before estimating the individual slope coefficients for each of the cross-sections and then averaging them across the panel units. Likewise the MG estimator, the CCEMG estimator can also be specified as:

$$\hat{\beta}_{CCEMG} = N^{-1} \sum_{i=1}^{N} \hat{\beta}_i \tag{15}$$

where $\hat{\beta}_{CCEMG}$ is once again the mean of the individual slope estimates from each cross-sectional unit. The only difference between the MG and the CCEMG estimators, respectively expressed in Eqs. (14) and (15), is that the CCEMG estimator estimates and averages the individual slope coefficients via augmenting the common factors across the cross-sections into the empirical model which is not the case in the context the MG estimator.

The AMG estimator proposed by Bond and Eberhardt (2013) is the second panel data regression technique used in this paper. The AMG estimator, much like the CCEMG estimator, also allows for slope heterogeneity and cross-sectional dependency issues in the data. However, the AMG estimator augments the year dummies into the model and refers the time-variant unobserved common factors to exhibit a dynamic process whereas the CCEMG estimator includes the unobserved common factors in the error term (Mrabet et al. 2019). The robustness of the panel long-run elasticity estimates are checked by estimating the models using the Continuously Updated Fully Modified (CUP-FM) and Continuously Updated Bias Corrected (CUP-BC) cross-sectionally dependent panel data regression techniques proposed Bai et al. (2009).

Finally, for analyzing the possible heterogeneity of the long-run elasticity estimates, the long-run elasticity estimates for the individual South Asian nations are separately estimated using the Fully Modified Ordinary Least Squares (FMOLS) time-series regression estimator introduced by Phillips and Hansen (1990). Several studies in the literature have employed the FMOLS estimator to asecertain the long-run elasticities (Murshed et al. 2020f).

Results and discussions

Identification of the order of integration among the variables is pertinent to employ the appropriate methods for panel data analysis. The results from the second generation panel unit root tests are reported in Table 7. It is evident from the statistical insignificances of the calculated statistics, from both the CADF and the CIPS, tests that all the variables are non-stationary at their respective level forms. However, they become stationary at their first differences. The statistical significance at 1% level rejects the null hypothesis of non-stationarity to affirm a common order of integration, at I(1), among the variables. Hence, the possibility of predicting spurious regression estimates is nullified by the stationarity of the variables.

The unit root analysis is followed by the Westerlund (2007) second generation panel cointegration exercises. The corresponding results from the Westerlund (2007) test, as reported in Table 8, confirms the presence of cointegrating equations in all the four models considered in this paper. The statistical significance of the predicted test statistics, at 1% level, rejects the null hypothesis of no cointegration among the variables in the respective models. Thus, these findings implicate towards the existence of long-run associations between CFP/EFP, economic growth, levels of per capita REC/REO, financial development, urbanization rate and trade openness.

Table 9 reports the long-run elasticities predicted using the CCEMG and AMG techniques in the context of models (1) and (2). The overall results suggest that the elasticity estimates are robust across these two panel regression approaches. This is evident from the similarity of the signs and the corresponding statistical significance of the elasticity estimates reported in Table 9. The positive and negative signs of the statistically significant elasticity parameters attached to RGDPpc and its squared term, respectively, confirm the inverted-U shaped nexus between economic growth and CFP in the context of the South Asian economies. Thus, the EKC hypothesis is validated. The findings suggest that economic growth initially imposes environmental adversities by increasing the CFP. However, beyond a threshold level of economic growth, further growth of the South Asian economies lead to environmental betterment by reducing the CFP. Therefore, in line with these results, it can be asserted that economic growth could be the long-term solution to the environmental degradation woes of the selected South Asian economies. A 1% rise in the per capita real GDP level initially increases the CFP by 4.66–5.97% while in the later stages it reduces the CFP figures by 0.23–0.41%, on average, *ceteris paribus*. The validity of the EKC hypothesis in the South Asian context is also reported in the study by Sharma et al. (2020).

Moreover, both REC and REO levels are found to be associated with lower CFP levels across the South Asian economies. The statistically significant negative elasticities imply that a 1% rise in the per capita REC and REO figures attribute to reductions in the CFP levels by 0.85–0.89% and 0.10–0.26%, respectively, on average, *ceteris paribus*. These results impose key policy implications regarding the pertinence of

Table 7 Results from panel unit root test with cross-sectional dependency

Variable	Level		1st difference		Order of Integration
	Intercept	Intercept and trend	Intercept	Intercept and trend	
Pesaran CADF test					
lnCFP_{PC}	− 1.128	− 1.771	− 3.529*	− 3.983*	I(1)
lnEFP_{PC}	− 1.087	− 1.608	− 3.700*	− 3.988*	I(1)
lnRGDP_{PC}	− 1.490	− 1.252	− 3.216*	− 3.410*	I(1)
lnRGDP^2_{PC}	− 1.440	− 1.552	− 3.316*	− 3.393*	I(1)
lnREC_{PC}	− 2.025	− 2.472	− 4.799*	− 4.981*	I(1)
lnRELEC_{PC}	− 1.518	− 2.381	− 3.864*	− 3.781*	I(1)
lnFD	− 1.678	− 1.759	− 3.643*	− 3.507*	I(1)
lnURB	− 2.221	− 1.775	− 4.087*	− 4.881*	I(1)
lnOPEN	− 1.683	− 1.485	− 2.998*	− 3.009*	I(1)
Pesaran CIPS test					
lnCFP_{PC}	− 1.364	− 1.931	− 4.857*	− 5.138*	I(1)
lnEFP_{PC}	− 1.709	− 1.611	− 5.349*	− 5.583*	I(1)
lnRGDP_{PC}	− 2.111	− 2.153	− 4.430*	− 4.498*	I(1)
lnRGDP^2_{PC}	− 2.104	− 2.209	− 4.267*	− 4.599*	I(1)
lnREC_{PC}	− 1.298	− 1.807	− 5.922*	− 6.071*	I(1)
lnRELEC_{PC}	− 2.110	− 2.331	− 5.842*	− 5.981*	I(1)
lnFD	− 1.763	− 1.592	− 4.247*	− 4.417*	I(1)
lnURB	− 1.270	− 1.908	− 5.160*	− 5.367*	I(1)
lnOPEN	− 1.670	− 1.759	− 4.466*	− 4.693*	I(1)

The optimal lags are chosen based on the Akaike Information Criterion (AIC)

The test statistics are estimated under the null hypothesis of non-stationarity against the alternative hypothesis of otherwise

*Indicates statistical significance at 1% level

augmenting renewable energy into the national energy-mixes of the South Asian economies for ensuring environmental betterment in South Asia. The results are parallel to the conclusions made by Destek and Sinha (2020) in the context of the OECD economies, Ike et al. (2020) for the G7 nations and Bello et al. (2018) for Malaysia.

Besides, other results indicate that financial development, urbanization and international trade account for environmental hardships in South Asia. The positive signs and statistical significances of the corresponding elasticity estimates affirm these claims. It can be perceived from the estimated elasticity parameters attached to lnFD that a 1% rise in the share of domestic credits extended to the private sector in the GDP elevates CFP by 0.16–0.24%, on average, *ceteris paribus*. Hence, it is ideal for the governments of the concerned South Asian economies to incentivize the lenders to provide loans to the private firms that are relatively more intensive in employing renewable energy inputs to source their respective outputs. The negative impacts of financial development on the environment were also highlighted in the study by Destek and Sarkodie (2019) in the context of Singapore. Similarly, a 1% rise in the share of the urban residents in the aggregate population of the respective South Asian nations is found to elevate the CFP figures by 0.69–2.12%, on average, *ceteris paribus*. This particular finding once again addresses the need for the concerned governments to leave no stones unturned in overcoming the unplanned urbanization issues. The negative impacts of urbanization on the environmental quality was also remarked by Poumanyvong and Kaneko (2010) in which the authors opined that urbanization exerts adversities on the environment irrespective of the income-group to

Table 8 Westerlund (2007) panel cointegration test results

Test statistic	Model (1) Value	Model (2) Value	Model (3) Value	Model (4) Value
Gt	− 2.810*	− 3.825*	− 2.990*	− 2.890*
	(0.000)	(0.000)	(0.000)	(0.000)
Ga	− 13.123*	− 13.121*	− 13.988*	− 13.298*
	(0.000)	(0.000)	(0.000)	(0.000)
Pt	− 5.120	− 5.298	− 4.878	− 4.900
	(0.200)	(0.220)	(0.300)	(0.200)
Pa	− 14.189*	− 13.621*	− 13.778*	− 14.001*
	(0.000)	(0.000)	(0.000)	(0.000)

The bootstrapping regression, considering both intercept and trend, is conducted with 500 replications

The optimal lag selection is based on AIC

The test statistics are estimated under the null hypothesis of no cointegration against the alternative hypothesis of otherwise

p values are reported within the parentheses

*Denotes statistical significance at 1% level

Table 9 Panel Long-run elasticity estimates from the CCEMG and AMG panel regression analyses

Model Estimator	(1) CCEMG	(1) AMG	(2) CCEMG	(2) AMG
Dep. var: carbon footprint per capita (CFPPC)				
$\ln RGDP_{PC}$	5.966*	4.660*	5.269*	5.119*
	(1.012)	(1.021)	(2.190)	(2.128)
$\ln RGDP^2_{PC}$	− 0.407**	− 0.285**	− 0.235*	− 0.271**
	(0.204)	(0.141)	(0.092)	(0.235)
$\ln REC_{PC}$	− 0.853*	− 0.893*	–	–
	(0.326)	(0.370)		
$\ln RELEC_{PC}$	–	–	− 0.103**	− 0.261*
			(0.050)	(0.080)
lnFD	0.237**	0.208**	0.163*	0.181**
	(0.121)	(0.099)	(0.034)	(0.090)
lnURB	1.903*	2.122**	0.690**	0.190*
	(0.293)	(1.061)	(0.344)	(0.021)
lnOPEN	0.130**	0.117*	0.201**	0.282**
	(0.600)	(0.029)	(0.093)	(0.140)

The standard errors are reported within the parentheses

*, ** and ***denote statistical significance at 1%, 5% and 10% levels, respectively

which a particular economy belongs to. Finally, the statistically significant elasticity parameters attached to lnOPEN denotes that a 1% rise in the trade openness indices of the selected South Asian economies is accompanied by a corresponding rise in the CFP figures by 0.12–0.28%, on average, *ceteris paribus.* Thus, it can be asserted that the cross-border flows of tradable goods and services across South Asia embody carbon and other greenhouse emissions which could be reasoned by the relatively less stringent environmental policies within this region. As a result, these economies are likely to be targeted by foreign investors to outsource the relatively dirty-outputs by cashing-in the weak environmental laws across South Asia. Similar negative impacts of international trade on the environment were reported by Al-Mulali et al. (2015) in the context of 93 low, middle and high-income economies.

Table 10 reports the long-run elasticity estimates from the CCEMG and the AMG panel regression analyses in the context of models (3) and (4). Once again, the robustness of the findings across these two alternate regression approaches is confirmed by the similarity of the predicted signs and statistical significances of the elasticity estimates.

The elasticity estimates, reported in Table 10, reveal that economic growth initially accounts for higher levels of EFP while in the latter stages it reduces the EFP levels across the South Asian economies. Hence, these results, much like in the cases of models (1) and (2), validate the existence of the EKC hypothesis in South Asia. A 1% rise in the real per capita GDP level initially increases the EFP figures by 2.08–4.06%, on average, *ceteris paribus*. However, after attaining a certain level of growth, the marginal growth impacts tend to reduce the EFP levels by 0.19–0.26%, on average, *ceteris paribus*. Hence, it can be asserted that the overall sustainability of the environment depends on the long-term growth of the economy. Thus, the policies aimed at persistently enhancing economic growth could be expected to complement the long-term environmental welfare goals of the South Asian nations as well. The findings corroborate the results documented in the South Asian context by Sabir and Gorus (2019) and Sabir et al. (2020).

Table 10 Panel long-run elasticity estimates from the CCEMG and AMG panel regression analyses

Model Estimator	(3) CCEMG	(3) AMG	(4) CCEMG	(4) AMG
Dep. var: ecological footprint per capita (EFP_{PC})				
$\ln RGDP_{PC}$	3.748*	4.059*	2.960*	2.076*
	(1.101)	(1.001)	(1.040)	(0.601)
$\ln RGDP^2_{PC}$	− 0.214*	− 0.216**	− 0.258*	− 0.191*
	(0.090)	(0.107)	(0.039)	(0.060)
$\ln REC_{PC}$	− 0.550*	− 0.409*	–	–
	(0.124)	(0.112)		
$\ln RELEC_{PC}$	–	–	− 0.032*	− 0.064*
			(0.010)	(0.012)
lnFD	0.221**	0.201**	0.178**	0.185**
	(0.103)	(0.092)	(0.091)	(0.092)
lnURB	1.797**	1.395*	3.775*	3.716*
	(0.900)	(0.491)	(1.001)	(1.021)
lnOPEN	0.115*	0.104*	0.05**	0.06**
	(0.027)	(0.021)	(0.024)	(0.029)

The standard errors are reported within the parentheses

*, ** and ***denote statistical significance at 1%, 5% and 10% levels, respectively

Moreover, the favorable impacts of RET in safeguarding the welfare of the environmental attributes are once again affirmed by the statistically significant negative elasticity parameters attached to RECpc and RELECpc. A 1% rise in the per capita REC and REO levels attribute to declines in the EFP figures by 0.41–0.55% and 0.03–0.06%, respectively, on average *ceteris paribus*. Hence, it can be claimed that augmenting renewables into the national energy-mixes of the selected South Asian economies would not only improve the overall air quality but would also enhance environmental welfare from a broader perspective. Thus, it is pertinent for the concerned governments to align the economic development policies with the environmental sustainability objectives. However, a major concern for the South Asian economies is the declining shares of renewables in their respective aggregate final energy consumption figures (World Bank 2019). Thus, these concerning issue requires appropriate policy intervention to expedite RET within South Asia. Consequently, liberalizing the trade barriers to promote the cross-border flows of renewable energy across this region could be a plausible solution to the declining REC shares. This, in turn, could also be critically pertinent for improving the overall environment in South Asia. The negative nexus between renewable energy use and EFP was also acknowledged in the studies by Destek and Sinha (2020) and Danish et al. (2020) in the context of the OECD and BRICS countries, respectively.

Besides, financial development is found to boost the EFP levels in South Asia. A 1% rise in the share of the domestic credits to the private sector in the GDP results in a rise in the EFP figures by 0.18–0.22%, on average, *ceteris paribus*. This finding corroborates with the findings by Baloch et al. (2019) for 59 countries under the Belt and Road Initiative of China. On the other hand, urbanization is found to elevate the EFP levels as well. This once again confirms the detrimental impacts of unplanned urbanization on the overall environmental quality of the selected South Asian economies. The marginal impact of a rise in the percentage share of the urban residents in the aggregate population of the respective South Asian nations is found to increase the EFP figures by 1.40–3.78%, on average, *ceteris paribus.* Similar findings in the context of high-income countries were opined by Ozturk et al. (2016) while Charfeddine and Mrabet (2017) found contrasting impacts in the context of oil and non-oil exporting MENA countries. Finally, the results in the context of international trade also exhibit negative impacts on the quality of the environment in South Asia. A 1% rise in the trade openness indices accounts for 0.05–0.12% increments in the EFP figures, *ceteris paribus.* Thus, monitoring the quality and the nature of the traded goods and services is pertinent to limit the associated environmental adversities. In this regard, it is ideal to facilitate the trade of commodities that can utilize renewable energy resources to curb the EFP in South Asia. The positive relationship between international trade and EFP was also reported by Ulucak and Bilgili (2018) in the context of middle and high-income economies while for the low-income economies an opposite correlation was ascertained.

For further robustness check of the elasticity findings across other panel data estimation techniques, this paper also employs the CUP-FM and CUP-BC panel regression estimators to re-estimate all the four econometric models. However, the CUP-FM and CUP-BC techniques account for the cross-sectional dependency problems but are unable to accommodate the slope heterogeneity issues. The corresponding results, as reported in Table 11, conform to the aforementioned elasticity estimates mostly in terms of the predicted signs. Thus, the robustness of the elasticity estimates is further assured. However, it is apparent from the overall findings that although the validity of the EKC hypothesis is confirmed across all the regression approaches, the magnitudes of the elasticities depend on the type of the regression estimator used. Since there are slope heterogeneity and cross-sectional dependency issues in the dataset, the results from the CCEMG and the AMG panel data estimators can be claimed to provide relatively better estimates of the long-run elasticities.

Finally, the possible country-specific heterogeneity of the findings is assessed using the FMOLS regression estimator for the individual South Asian economies. The corresponding long-run elasticities are reported in Table 12. The results validate the EKC hypothesis for both CFP and EFP in the context of all the selected South Asian economies apart from Pakistan. In the context of Pakistan, the economic growth-environmental quality nexus depicts a U-shaped association, thus, invalidating the authenticity of the EKC hypothesis. This result contradicts the conclusion put forward by Hassan et al. (2019) in which the authors found statistical validation of the EKC hypothesis for EFP in the long-run only. This contrasting finding in the current study can possibly be explained from the understanding that the study by Hassan et al. (2019) did not control for renewable energy use within the analysis which could have led to the validity of the EKC hypothesis. Although the heterogeneous economic growth impacts on the environment are ascertained, higher levels of per capita REC and REO are found to unanimously reduce CFP and EFP figures in all five South Asian countries. These results further highlight the pertinence of undergoing RET in South Asia for ensuring environmental sustainability across this region. Thus, it is ideal for the concerned governments to reverse their declining trends in the respective shares of renewables in total final energy consumption figures. Addressing this issue would not only ensure energy security across South Asia, but it would also negate the environmental adversities stemming from the predominant use of non-renewable fossil fuels.

Besides, financial development is found to increase the CFP and EFP figures of Bangladesh, Pakistan, Sri Lanka and Nepal. In contrast, financial development was found to reduce the levels of CFO and EFP of India. On the other hand, urbanization is found to consistently enhance the CFP and EFP figures of all five South Asian nations. Similar adverse environmental impacts are also ascertained in the context of international trade whereby higher trade openness was seen to be associated with higher levels of CFP and EFP across all these economies. Therefore, taking the country-specific heterogeneous findings into cognizance, it is ideal for the concerned governments to design appropriate environmental policies to ensure environmental sustainability across South Asia.

Conclusions and policy recommendations

Aggravation of the global emissions of GHGs has sparked the urgency in mitigating the greenhouse emissions-induced environmental adversities around

Table 11 Panel long-run elasticity estimates from the CUP-FM and CUP-BC panel regression analyses

Dep. var.	Carbon footprint per capita(CFP_{PC})				Ecological footprint per capita (EFP_{PC})			
Model Estimator	(1) CUP-FM	(1) CUP-BC	(2) CUP-FM	(2) CUP-BC	(3) CUP-FM	(3) CUP-BC	(4) CUP-FM	(4) CUP-BC
$lnRGDP_{PC}$	5.089*	5.120*	2.934*	2.937*	4.479*	4.467*	2.131*	2.122*
	(0.512)	(0.402)	(− 0.197)	(0.779)	(0.228)	(0.226)	(0.118)	(0.124)
$lnRGDP^2_{PC}$	− 0.406*	− 0.402*	− 0.196*	− 0.212*	− 0.372*	− 0.371*	− 0.196*	− 0.192*
	(0.035)	(0.034)	(0.051)	(0.060)	(0.015)	(0.162)	(0.008)	(0.010)
$lnREC_{PC}$	− 1.073*	− 1.076*	–	–	− 0.296*	− 0.295*	–	–
	(0.059)	(0.059)			(0.026)	(0.026)		
$lnRELEC_{PC}$	–	–	− 0.504*	− 0.515*	–	–	− 0.191*	− 0.192*
			(0.089)	(0.089)			(0.014)	(0.013)
lnFD	0.230*	0.180*	0.281*	0.198**	0.196*	0.198*	0.148*	0.136**
	(0.049)	(0.015)	(0.051)	(0.954)	(0.065)	(0.059)	(0.051)	(0.653)
lnURB	2.309*	2.326*	2.588*	2.675*	1.387*	1.391*	1.341*	1.401*
	(0.238)	(0.245)	(0.541)	(0.572)	(0.103)	(0.108)	(0.084)	(0.089)
lnOPEN	0.709*	0.737**	0.902*	1.109*	0.332*	0.292*	1.040*	1.018*
	(0.081)	(0.366)	(0.322)	(0.513)	(0.109)	(0.108)	(0.081)	(0.095)

The standard errors are reported within the parentheses

*, ** and ***denote statistical significance at 1%, 5% and 10% levels, respectively

the globe. Consumption of the conventional non-renewable fossil fuels, in particular, is often alleged to be the major attribute of environmental degradation. Against this background, this paper attempted to probe into the validity of the EKC hypothesis in the context of selected South nations controlling for the per capita REC and REO levels within the analysis. To measure environmental quality, the per capita CFP and EFP figures are used instead of the conventionally used CO2E figures. The overall results from the panel econometric analyses, accounting for the cross-sectional dependency and slope heterogeneity issues, validated the authenticity of the EKC hypothesis in the South Asian context. Besides, higher levels of REC and REO were found to reduce the CFP and EFP figures. In contrast, financial development, urbanization and international trade were found to aggravate the CFP and EFP levels in South Asia. Besides, the country-specific findings validated the EKC hypothesis for Bangladesh, India, Sri Lanka and Nepal but not for Pakistan. Moreover, financial development attributed to lower CFP and EFP levels only in the case of India while aggravating them for the other four South Asian countries. However, urbanization and openness to international trade were found to unanimously elevate the CFP and EFP figures.

In line with these finds, the following policy takeaways can be recommended. Firstly, the South Asian economies should focus on persistently enhancing their respective national income levels; since the validity of the EKC hypothesis implied that economic growth is the long-term solution to the environmental problems in South Asia. However, in the context of Pakistan, it is ideal for the government to revisit the nation's economic growth strategies as the EKC hypothesis did not hold for Pakistan. In this regard, economic expansion in Pakistan should be done in a sustainable manner so that the adverse environmental impacts can be contained. Secondly, since the use of renewable energy was found to be effective in mitigating environmental degradation in South Asia, it is ideal for the net-oil importing South Asian economies, in particular, to phase out their traditional fossil fuel-dependencies and facilitate RET instead. In this regard, overcoming the macroeconomic constraints inhibiting RET across South Asia is a credible energy policy intervention for the economies of concern. Simultaneously, the declining shares of

Table 12 Country-specific long-run elasticities from FMOLS regression analysis

Model	Bangladesh				India			
Dep. var.	(1) lnCFP$_{PC}$	(2) lnCFP$_{PC}$	(3) lnEFP$_{PC}$	(4) lnEFP$_{PC}$	(1) lnCFP$_{PC}$	(2) lnCFP$_{PC}$	(3) lnEFP$_{PC}$	(4) lnEFP$_{PC}$
LnRGDP$_{PC}$	3.691*	2.048*	3.010*	2.087*	0.178*	1.223**	4.503*	2.833*
	(1.343)	(0.157)	(1.170)	(0.178)	(0.023)	(0.597)	(1.132)	(0.753)
lnRGDP$^2_{PC}$	− 0.323*	− 0.198*	− 0.204**	− 0.139*	− 0.061**	− 0.081**	− 0.337*	− 0.304*
	(0.094)	(0.004)	(0.081)	(0.005)	(0.030)	(0.0320	(0.082)	(0.041)
LnREC$_{PC}$	− 0.266**	–	− 0.131**	–	− 0.316*	–	− 0.416***	–
	(0.132)		(0.066)		(0.029)		(0.238)	
LnRELEC$_{PC}$	–	0.041	–	0.003	–	0.067**	–	0.086*
		(0.014)		(0.016)		(0.028)		(0.012)
LnFD	0.545*	0.546*	0.557*	0.560*	− 0.135**	− 0.159*	− 0.271*	− 0.289*
	(0.083)	(0.067)	(0.072)	(0.076)	(0.064)	(0.056)	(0.073)	(0.070)
LnURB	3.105*	2.800*	1.345*	1.270*	4.089*	4.444*	1.167*	2.889*
	(0.430)	(0.341)	(0.375)	(0.388)	(1.137)	(0.798)	(0.051)	(0.070)
LnOPEN	0.124*	0.114*	0.109*	0.108*	0.178*	0.156*	0.359*	0.338*
	(0.041)	(0.031)	(0.034)	(0.035)	(0.046)	(0.040)	(0.054)	(0.051)

Model	Pakistan				Sri Lanka			
Dep. var.	(1) lnCFP$_{PC}$	(2) lnCFP$_{PC}$	(3) lnEFP$_{PC}$	(4) lnEFP$_{PC}$	(1) lnCFP$_{PC}$	(2) lnCFP$_{PC}$	(3) lnEFP$_{PC}$	(4) lnEFP$_{PC}$
LnRGDP$_{PC}$	− 0.611	− 1.962*	− 3.601*	− 3.357*	4.478*	4.001*	5.820*	6.871*
	(0.519)	(0.103)	(0.587)	(0.899)	(1.251)	(0.918)	(1.117)	(0.734)
lnRGDP$^2_{PC}$	0.020	0.189*	0.281*	0.272*	− 0.217*	− 0.166*	− 0.336*	− 0.372*
	(0.031)	(0.007)	(0.042)	(0.006)	(0.079)	(0.061)	(0.050)	(0.050)
LnREC$_{PC}$	− 0.662*	–	− 0.083**	–	− 0.371**	–	− 0.623*	–
	(0.191)		(0.041)		(0.151)		(0.137)	
LnRELEC$_{PC}$	–	− 0.111*	–	− 0.049*	–	− 0.267*	–	− 0.267*
		(0.016)		(0.015)		(0.037)		(0.031)
LnFD	0.340*	0.315*	0.265*	0.262*	0.142*	0.141*	0.172*	0.049***
	(0.012)	(0.010)	(0.010)	(0.009)	(0.036)	(0.031)	(0.038)	(0.025)
LnURB	8.247*	5.971*	2.273*	2.515*	6.178*	2.819**	14.201*	10.975*
	(1.651)	(0.125)	(0.534)	(0.120)	(1.112)	(1.183)	(3.119)	(2.490)
LnOPEN	0.173*	0.140*	0.125*	0.143*	0.568*	0.549*	0.402*	0.307*
	(0.045)	(0.022)	(0.012)	(0.021)	(0.094)	(0.092)	(0.083)	(0.075)

Model	Nepal			
Dep. var.	(1) lnCFP$_{PC}$	(2) lnCFP$_{PC}$	(3) lnEFP$_{PC}$	(4) LnEFP$_{PC}$
LnRGDP$_{PC}$	8.580*	6.682*	1.684*	1.495*
	(2.147)	(1.289)	(0.268)	(0.159)
lnRGDP$^2_{PC}$	− 1.286*	− 0.121*	− 0.120*	− 0.109*
	(0.161)	(0.029)	(0.036)	(0.039*)
LnREC$_{PC}$	− 2.533*	–	− 0.150**	–
	(0.323)		(0.075)	

Table 12 continued

Model	Nepal			
Dep. var.	(1) $\ln CFP_{PC}$	(2) $\ln CFP_{PC}$	(3) $\ln EFP_{PC}$	(4) $LnEFP_{PC}$
$LnRELEC_{PC}$	–	1.951*	–	− 0.598**
		(0.672)		(0.295)
LnFD	0.176	0.156**	0.156**	0.859*
	(0.158)	(0.072)	(0.072)	(0.201)
LnURB	1.825*	0.832*	0.832*	0.448**
	(0.183)	(0.277)	(0.277)	(0.223)
LnOPEN	0.183*	0.329*	0.392*	0.824*
	(0.069)	(0.097)	(0.096)	(0.084)

The standard errors are reported within the parentheses

*, ** and ***denote statistical significance at 1%, 5% and 10% levels, respectively

REC in the aggregate energy consumption figures of Nepal should also be addressed. Furthermore, promoting cross-border flows of renewable energy across South Asia, particularly from Nepal and Bhutan to Bangladesh, India, Pakistan and Sri Lanka, should be prioritized. Thirdly, since financial development was found to dampen environmental quality in most of the selected South Asian economies, it is essential for the governments to revisit their financial development policies. It is pertinent to extend larger volumes of credit to the industries that are relatively greener compared to the ones that are predominantly intensive in the use of fossil fuels. Besides, provision for green financing should be ensured to reduce the adverse environmental impacts of financial development in South Asia. Fourthly, it is important for the South Asian nations to avoid unplanned urbanization practices which have been found to deteriorate the environmental quality across South Asia. In this regard, green and sustainable urbanization should be ensured whereby the associated environmental adversities can largely be contained. Finally, the globalization policies of the South Asian economies should also be altered. It is recommended that the South Asian economies reduce their engagements in international trade of goods and services that embody high volumes of greenhouse gases. Besides, the export-oriented industries of the South Asian countries should be incentivized to employ renewable energy resources for production purposes. Additionally, these industries should also be incentivized to invest in pollution control programs which can further limit the international trade-induced environmental problems in South Asia. On the other hand, imports of dirty commodities should also be inhibited using appropriate tariff and non-tariff measures. Furthermore, the South Asian economies need to boost intra-regional trade of renewable energy resources. This would not only facilitate the RET phenomenon in South Asia but would also mitigate the negative impacts of international trade on the environment.

As part of the future scope of research, this analysis can be replicated in the context of similar global economies for comparison purposes. Moreover, the other components of the total EFP figures could also be used as potential measures of environmental quality in exploring the validity of the EKC hypothesis in the context of South Asia. Furthermore, causality exercises can also be performed to assess the causal associations as well.

Compliance with ethical standards

Conflict of interest The authors declared that they have no conflict of interest.

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