Does renewable energy consumption reduce ecological footprint? Evidence from eight developing countries of Asia

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Abstract

Economic and demographic transitions led by the persistent increase in the per capita income have challenged the environmental conservation drive in most of the developing nations. Therefore, in recent years, policymakers emphasized the need for navigating the harmful impacts of economic growth endeavors on the established ecosystem. In this regard, the widespread usage of renewable energy solutions has helped in restoring the environmental quality in both developed and developing countries. Keeping this in mind, in the present study, we examined the long run and short-run impacts of per capita income, renewable energy, life expectancy, and population density on the ecological footprint in the eight developing countries of South and Southeast Asia from 1990-2015. In the selected nations, these variables appear to be the potential drivers of the ecological footprint. To calculate the common coefficients, we have employed the cross-sectional augmented autoregressive distributed lag (CS-ARDL) approach, as this approach handles the cross-sectional dependency issue efficiently and provides the short-run and long-run coefficients. The long-run results supported the need for low pollution-intense energy resources because the association between per capita income and ecological footprint is found N-shaped. Further, the study established that the increased use of renewable energy has significantly reduced the ecological footprint in the region. However, the increased population density has led to an increase in pollution emissions in these countries. Similarly, the impact of life expectancy on the ecological footprint is found positive but insignificant. Based on the findings, a multipronged policy framework has been designed, so that these nations can attain the objectives of certain sustainable development goals (SDGs).

JEL classification: C23; Q2; Q53; Q56

Keywords: Ecological Footprints; Renewable Energy; Life Expectancy; Per Capita Income; Population Density; SDG

1. Introduction

The economic growth-oriented human activities appear to be a threat to the established ecosystem in developed and developing countries (Bekun et al., 2019). Despite all the efforts of policymakers and environmental protagonists, the level of carbon emissions in the whole world increased by 1.4% in 2017. In absolute terms, this increase is estimated at 460 million tons (Acheampong, 2019). In the overall pollution emissions, the share of the developing regions has remained significantly more than the developed countries. In conformity to this, the International Energy Agency (IEA, 2018) in its report ascertained that carbon-intense energy resources and economic growth endeavors have contributed to raising the level of ecological footprint in both developed and developing countries. Even the associated channels such as energy usage (Ang, 2007), foreign investment (Zhu et al., 2016), urbanization (Afridi et al., 2019), trade expansion (Faiz-Ur-Rehman et al., 2007), and population growth (Shahbaz and Sinha, 2019) have reinforced the distortion of the established ecosystem in the preceding years. The discernible exodus from environmental conservation to economic growth opened the scope to investigate the long-run determinants of the environmental quality (Kanjilal and Ghosh, 2013; Alola et al., 2019).

In this quest, we observed that the South and Southeast Asian countries have witnessed a major shift on the economic and demographic fronts. As per the report of OECD (2018), from 2011-2015, the per capita income in emerging Asian countries increased at a rate of 7.1% annually, which is likely to increase at a rate of 6.3% annually in the coming five years. Saying this, the increased per capita income level caused by policy regime-shift improved the living standard of the people, which in turn might have changed the demographic settings such as life expectancy and fertility rate (Brueckner and Schwandt, 2014). Due to the availability of job opportunities, the population density in the big industrial cities of South and Southeast Asia has increased at a startling rate, which in turn increased the consumption of nonrenewable energy solutions such as crude oil, natural gases, and coal in the preceding years. Undeniably, the amalgamation of economic and demographic transitions fueled the process of economic expansion; but the increased usage of carbon-intense energy resources appeared to be a catalyst to raising the ecological footprint in the developing countries of South and Southeast Asia (Dogan et al., 2020; Sharma et al., 2020). Referring to the report of The Economic Times (2019a), in the list of the top ten most polluted cities across the world, seven are situated in the South Asian region. In support of this statement, the articles published in Bangkok Post (Roengjit, 2019) and Dawn (Agence France-Presse, 2019) reported that the pollution levels of metropolitan cities situated in India, China, Bangladesh, and Pakistan are way above than the standard level.

To reduce the atmospheric pressure, governments of these countries have adopted several direct and indirect measures. For example, Delhi government's odd/even number vehicles movement policy (The Economic Times, 2019b), Nepal's Air Quality Program (Saud and Paudel, 2018), Malaysia's Environmental Quality Act-1974, and Environmental Quality

Regulations-2014 (Chin et al., 2019) are some of the measures adopted by the Asian countries to restore the air quality in the respective countries. It appears from the above discussion that air quality management has been given top priority, whereas these governments ignored land and water quality management. This is evident from the exacerbated rate of water-generated diseases in the given regions (Biswas and Tortajada, 2019). The unfailing increase in deforestation, floods, and soil erosion indicates that the water and land management policies in these regions proved inadequate to restore the natural habitations; and lack of synergy between economic and environmental policies increased the environmental vulnerability (Tyler and Fajber, 2009). By intertwining the water, energy, land, and economic policies, governments can kill two birds with one stone, first, to achieve economic growth, and second, to restore the environment.

The given scenario of the ecosystem signifies the need for cleaner energy (SDG-7)[1], ecosystem restoration (SDG-15), hygienic lifestyle (SDG-3), and sustainable economic growth (SDG-8) in these developing countries. However, due to the emerging nature of these nations, economic agendas might have put the environmental issues at the back seat (Haseeb et al., 2018). Furthermore, the combustion of nonrenewable energy solutions at the household levels has made the situation worst because to carry out the routine activities, people are heavily dependent on the nonrenewable energy resources in these countries. Therefore, to navigate the negative impacts of energy solutions, these nations have to develop less carbon-intense energy solutions where widespread use of renewable energy resources can play a vital role. The literature posits that the renewable energy solutions are superior to fossil fuels because they exert less pressure on the environment (Sarkodie and Strezov, 2019; Jebli et al., 2019) without distorting the growth process (Balsalobre-Lorente et al., 2019). Another possible solution to improve the environmental quality is to reduce the marginal consumption of energy solutions at the production stage so that the harmful impact of energy on environmental quality can be minimized (Bekun et al., 2019). In both cases, governments have to facilitate research and development. Otherwise, the extensive and incessant use of fossil fuel may continue to impose long-lasting challenges such as import dependency, price fluctuations, cost-inefficiency, and most importantly ecological imbalance (Zafar et al., 2019).

Therefore, in terms of policy formulation, it requires to consider renewable energy as a determinant of the ecological footprint, so that its environmental viability can be tested. Further, by examining the ecological footprint at the various levels of income, it can be examined whether the growth endeavors in the selected countries are in line with the global environmental standards. Besides per capita income and renewable energy solutions, we introduced the life expectancy and population density as determinants of the ecological footprint. In terms of sustainable development growth, these demographic indicators can play a crucial role in the long run (Kumar and Stauvermann, 2019). The literature supports their role in determining CO_2 emissions (Abbasi and Riaz, 2016) or EFP (Marquart-Pyatt, 2015; Gazi et al., 2016) in the long run. Even, the proposed SDGs are based on the overall quality of the environment where human

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[1] The detailed list of abbreviations is given in Table A2 (Appendix).

activities are intrinsically woven with the ecosystem. In a simplified manner, in the present study, we examined the impacts of economic (i.e. per capita income and renewable energy solutions) and demographic factors (i.e. life expectancy and population density) on the ecological footprint in the developing countries of Asia for the period of 1990-2015. The selection of countries (i.e., India, Bangladesh, Pakistan, Sri Lanka, Nepal, Malaysia, Thailand, and the Philippines) and study period (1990-2015) appears to be rational and based on the geographical segregation where the purposive sampling approach is followed because the data of some of the countries such as Afghanistan, Cambodia, and Vietnam was not available for the given period.[2] Moreover, owing to the more rural population and low population density in the latter countries (FAOSTAT, 2020), their inclusion could lead to the problem of outliers. In comparison to other selected countries, the size of GDP and population in Sri Lanka and Nepal is relatively small but the increasing ecological footprint stimulated us to include them into the present set of countries (Vadrevu et al., 2017). To compute the common coefficients, we employed the newly introduced approach namely cross-sectional augmented autoregressive distributed lag estimation (CS-ARDL) (Chudik et al., 2013). In the presence of the given commonalities, even the pollution convergence level is expected to be the same. Thus, we can propose a common policy framework that may address the environmental issues across-countries (Yilanci and Pata, 2020). While proposing the policy framework, we advocated the need for a phased multipronged strategy to achieve the SDGs without disturbing the growth pattern of these developing regions.

The study may contribute to the available literature in many ways. Firstly, by adopting the second-generation econometric approaches, we highlighted the need for the cleaner production processes and procedures, because not only air quality but also other ecological indicators might be perturbed by the existing production techniques. Secondly, we projected to intensify the widespread usage of renewable energy resources in a phased-manner. Here lies the major contribution of the study, because the suggested scheme, without disturbing the economic growth may help in restoring the ecological system and provide the solution of the prolonged issue of environmental pollution. Through the proposed system, not only economic costs but also environmental costs can be reduced considerably, if without creating job loss the nonrenewable resources are used at the industrial and domestic levels. Thirdly, we established the need for a hygienic lifestyle, as the increasing population density and life expectancy are exerting negative pressure on the ecosystem in the concerned countries. Lastly, by adopting the CS-ARDL econometric approach, we navigated the possibility of cross-sectional dependency, which is a common problem in the panel data set. The proposed progressive approach may help these nations to realize sustainable development goals by 2030.

The subsequent paper is sectioned into the literature study, research methodology, empirical results and discussion, and policy endorsements with conclusions.

2. Examination of the literature

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[2] More details about the selection of countries are given in the research methodology section.

A systematic examination of the past studies indicates that the association between CO_2 emissions and its possible determinants has regularly been examined in the country-specific and region-specific studies. For example, in a country-specific study, Chen (2001) observed that in Taiwan if carbon emissions to be kept at the 1990 level, the country has to compromise with the GDP growth rate. In other words, for controlling environmental pollution, it is required to reduce the production level in the long run. This kind of tradeoff has often posed a challenge to the policymakers, as the governments have to carry the economic agendas at the cost of the environment. In the case of Spain, the results of Feijoó et al.'s, (2002) study confirmed that the manufactured goods may lose the market competitiveness if for controlling carbon emissions, the energy-efficient techniques of production to be implemented. As the use of energy-efficient techniques beyond a level may add the cost of 20% per product. Therefore, the study suggested a tradeoff level between energy-efficiency measures and CO_2 emissions for the country. Further, studies in the past have quite often considered population growth rate (Pebley, 1998), population size (O'Neill et al., 2001), density (Sharma et al., 2020a), and age structure to determine pollution intensity in a region (Liddle, 2013). Even shifts in demographic indicators may have a substantial impact on environmental quality in the long run (O'Neill and Chen, 2002). Considering the role of economic and demographic factors in determining environmental pollution, the literature survey has focused on both types of attributes to determine CO_2 emissions or ecological footprints.

Ang (2007) in his country-specific study highlighted that increased domestic production and energy consumption significantly intensified the carbon emissions in France. Additionally, in the long run, the association between domestic production and carbon emissions turned into nonlinear and significant. Therefore, the study confirmed that at the higher levels of income, the intensity of the carbon emissions decreased significantly, which might be the outcome of the widespread use of energy-efficient technologies across-industries. However, it is not necessary that the increased income level may always contribute to improving environmental quality. For example, using the time series data of Tunisia, the study carried out by Fodha and Zaghdoud (2010) confirmed the inverted U-kind association between sulfur dioxide (SO_2) emissions and domestic production. However, GDP's association with carbon dioxide emissions is found monotonic and direct during the study period, which indicates that even at the higher level of income, CO_2 emissions continued to increase in the region. Similarly, using the ARDL bound approach, Ghosh (2010) in his study found the absence of the long-run relationship between gross domestic production and carbon emissions in India. However, the study observed the short-run causality between energy usage and carbon emissions. Therefore, the study proposed to adopt the less-carbon intense energy resources in the region. Stephenson et al. (2010) in their study highlighted that the increasing consumption trend in developing countries has had a direct impact on global warming. Further, the study documented that the impact of increasing global warming is more severe on poor people than rich in the long run. In developing countries, the fertility rate is still very high, which leaves extra pressure on available natural and manufactured resources and intensifies environmental pollution. High fertility rate combined with the large population base (i.e., existing size of the population) dilutes the benefits of the increased per capita income. In fact, such kind of environment may pose new challenges such as climate change and environmental degradation in the long run (Stephenson et al., 2010).

While examining the impact of external factors on CO_2 emissions in a country or region, FDI inflows, and trade expansion have regularly been studies in the past (Shahbaz et al., 2015; Zhu et al., 2016). In this regard, using the bootstrap approach, Koçak and Şarkgüneşi (2018) in their study observed that the increased FDI inflows in Turkey have led to an increase in environmental pollution. However, during the whole study period (1974-2013), the relationship between both has not remained linear and direct. Initially, FDI inflows contributed to increasing CO_2 emission, whereas after achieving a level of FDI inflows, the relationship between both turned into negative and significant. Such kind of relationship is termed as Pollution Heaven Hypothesis in the literature. The study also observed the EKC hypothesis during the study period. Similarly, taking a sample of newly industrialized economies, Zhang et al. (2017) confirmed that in the selected countries, trade expansion has contributed to a decrease in the level of environmental pollution. To pursue their growth targets, the selected countries might have made more imports than exports; which in turn, might have increased the pollution level in exporter countries but not in importer countries.

The literature is filled with studies where instead of segregation of energy into renewable and nonrenewable, the overall impact of energy consumption on carbon emissions has been examined (Shahzad et al., 2017; Afridi et al., 2019). Considering the need for sustainable economic growth, most of the countries have started focusing on cleaner and renewable energy resources, as the extensive use of nonrenewable energy is found more carbon-intense (Zaidi et al., 2018). Here, it cannot be denied that the consumption of renewable energy also may intensify environmental pollution (Bulut, 2017). However, in comparison to nonrenewable energy, the impact of renewable energy on climate change is less harmful and more cost-effective (Sinha et al., 2018; Chen et al., 2019). In this regard, using the evidence of China, Long et al. (2015) found that coal energy, which is a nonrenewable energy source, has significantly raised the pollution level in the country. The study proposed to increase the use of hydro and nuclear power based electricity in the long run. Similarly, Dogan and Seker (2016), Bhattacharya et al. (2017), and Inglesi-Lotz and Dogan (2018) in their studies documented that renewable energy usage is comparatively more biologically friendly in the long run.

Besides CO_2 emissions, the monitoring of water, air, and land quality has also become necessary, as the negative impact of economic endeavors on these ecological indicators cannot be denied (Wackernagel and Rees, 1996). Owing to the rapid economic developments, the utilization of these natural resources has increased considerably (Todaro and Smith, 2017). The overutilization of natural resources may pose certain new challenges such as environmental pollution and supply-deficiency. In this regard, Gazi et al. (2016) confirmed that increased income level has intensified the EFP in the selected 22 countries during the study period (1961-2011). Therefore, the study recommended changing the consumption pattern and existing state of technology, as the present lifestyle and production processes have seriously damaged the ecological system. Further, the study proposed to maintain a balance between economic growth and natural resources. Otherwise, the increasing level of EFP may reduce the actual benefits of economic growth. In this regard, The Global Climate Risk Index-2020 has ascertained that India has borne a loss of $37 billion in the year 2018, which is caused by catastrophic climate changes. Ironically, this loss is more than the health budget of the country for the same year (The Times of India, 2019). As far as the nonlinear relationship between per capita income and ecological footprint is concerned, Destek and Sarkodie (2019) in their panel data study found that the relationship between both has established an inverted U-type shape during the study period, which confirms the possibility of the EKC hypothesis. Even the increased consumption of energy has led to a significant increase in the EFP in the selected countries.

While establishing the association between demographic indicators and ecological footprint, Alola et al. (2019) confirmed that the increased fertility rate has intensified the EFP in the long run. Similarly, Wu et al. (2019) in their study documented that the size of the population and energy-types had significantly contributed to increasing the EFP in Tianjin during the study period (1994-2014). As far as the Asian region is concerned, the Asian Development Bank (2012) in its report ascertained that deforestation, use of pesticides, urbanization, dams, industrialization, mining, use of non-degradable products, maladministration of coastal areas, and extensive release of effluents have considerably damaged the land, air, and water quality, especially in the preceding decades. Further, the report suggested that an annual investment of $45 million to conserve the ecosystem could save $5 trillion's damage in the whole world. However, the actual investment to conserve the ecosystem is well below than required and the above-mentioned developments are continuously posing serious threats to the natural habitations.

The above discussion reveals that both economic and demographic transitions may significantly contribute to altering the ecological system of a region. Consequently, the SDGs have provided guidelines that economic pursuits should not be followed in isolation or without considering environmental impacts. Based on the above discussion, a wide range of variables can be considered to determine the environmental quality of a region. However, in relation to the developing economies, the examination of the EKC hypothesis is desirable. As it helps in understanding whether the adopted route of economic growth is environmentally appropriate. Similarly, in the over-populated countries like South and Southeast Asia, consideration of demographic aspects as the EFP determinants appears to be necessary. In the past, South and Southeast Asian regions have not been studied in this fashion. Thus, the study may enable to bridge the potential research gap where the EFP function is to be determined by the per capita income, renewable energy, life expectancy, and population density.

3. Research material and framework

3.1 Theoretical underpinning

To fulfill the energy demand, the developing countries of Asia are heavily dependent on nonrenewable energy solutions. The cross-border transactions of energy resources allowed them to carry their growth agendas uninterruptedly. As a result, these nations have shown exceptional economic growth, especially in the last two decades. However, in terms of environmental conservation, this strategy has enlarged environmental costs (Sharvini et al., 2018). This is evident from the increasing pressure of greenhouse gases led by the combustion of nonrenewable energy resources. Even the demographic transitions such as urbanization, life expectancy have contributed to damage the environmental quality because not only industries but also domestic users have preferred nonrenewable energy solutions over renewable energy. Stating differently, both commercial and domestic users of energy are significantly contributing to polluting the established ecosystem where nonrenewable energy appears to be a major contributor. Therefore, owing to the consistently increasing environmental challenges in the selected eight countries, we included per capita income, renewable energy, life expectancy, and population density as determinants of the ecological footprint for the period of 1990-2015. In doing so, if the impact of renewable energy on the ecological footprint is found negative, we can propose a long-term strategy, wherein the accountability of all stakeholders can be established.

After the 1990s, these countries have gone through major changes, especially on the economic front. Intuitively, demographic changes are the outcomes of economic changes. Therefore, the study is initiated from 1990. Owing to the unavailability of the data after 2015, the data set is limited up to 2015. In this regard, per capita income (constant 2010 US $), renewable energy (percentage of the total final energy consumption), life expectancy (life expectancy at birth, total in years), and population density (people per sq. km of land area) series are taken from the World Bank's (2019) dataset. The ecological footprint series is taken from the global ecological network.[3] For controlling the data sharpness, GDP and ecological footprint are converted into the per capita form; subsequently, all the series are converted into the natural logarithm form. In this regard, we explored the possibility of the N-shaped association between per capita income and EFP where the scale, composition, and technique obsolescence effects are represented by the first, second, and third turn, respectively (Baloch et al., 2020). The expected association between linear, squared, and cubic per capita income and the EFP is direct, indirect, and direct, respectively. Here it can be argued that the intensified usage of energy resources with the semi-advanced production process may widen the level of environmental pollution in the initial stages of economic development. Thereafter, the working of composition effect may reduce the marginal consumption of energy and other needed inputs, which in turn, may reduce the level of pollution emissions. Lastly, the excessive usage of energy resources with the given equipment, once again, may invigorate the level of pollution in the long run. If the association between industrial production and environmental pollution exhibits the same pattern, then it can be named as the N-shaped EKC.

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[3] https://www.footprintnetwork.org/

This study has focused only on 8 Asian countries, and there is a specific reason behind the choice of these countries. The choice has been made in two steps. The SDG progress reports (UNESCAP, 2019; 2020) for the Asian and Pacific countries have demonstrated that these nations are the laggards in terms of attaining the SDG objectives, with a specific focus on SDG 13, SDG 14, and SDG 15. This is why the Asian continent is chosen in the first step. Now, in order to choose the poor performers among the Asian countries, we had gone through the newsletters, opinions, and interviews published by the Centre for South Asian Studies, University of Oxford, over the period of 2015-2019. These documents were chosen based on their focus on SDGs, and these documents have specific mentions of the chosen eight countries. Being an Asian Think Tank, it has been assumed that the specific attribution of these countries as laggards by Centre for South Asian Studies has its rationale imbibed in the policy failures of these nations, and that has given us an opportunity to carry out a purposive sampling based on these two steps.

The expected impact of renewable energy is negative on the EFP, whereas, the expected impact of life expectancy is positive in the long run. Here it needs to ascertain that the life expectancy rate in urban areas may be different from rural areas (Marquart-Pyatt, 2015). At the same time, in terms of environmental pollution, urban areas are found more polluted than rural areas (Rice, 2007). However, we have ignored this kind of segregation in the present study. Secondly, with the growing age, people may start emitting less pollution. In the case of the USA, Zagheni (2011) observed that after reaching the age of 60, the pollution intensity led by people might start decreasing. However, this age limit may vary considerably across regions. Furthermore, irrespective of country and age group, it is difficult to achieve the zero level of the EFP caused by human beings. Therefore, this age-limit has also been ignored while considering the life expectancy as a determinant of the EFP in the present study.

Further, the expected impact of the population density needs to be confirmed. As with the increased density, the marginal use of the total land and other natural resources may squeeze, which may reduce the ecological footprint. On the other hand, the increased population density may enhance the utilization of natural resources in a particular region or locality, which in turn may intensify the EFP in the long run. In this regard, it needs to understand whether the concentration of population is in urban or rural areas, big cities or small cities (Jones and Kammen, 2013), more resource endowed or less resource endowed areas, as owing to these factors, its impact on the EFP may vary considerably (Marquart-Pyatt, 2015). Therefore, its impact on the EFP in the selected countries needs to be established. Based on the studies of Hubacek et al. (2009), Harris, (2010), Liddle (2013), Danish et al. (2019), Alola et al. (2019), and Danish et al. (2020), in the present study, we intended to establish the nonlinear ecological footprint function, which enables us to obtain the common long-run coefficients for each determinant. In most of the Asian countries, economic attributes are visibly dominating environmental pollution (Sabir and Gorus, 2019). In this regard, by identifying the common determinants of the EFP, the study may enable us to extend the existing literature because the variables such as life expectancy and population density may have a significant impact on the established ecosystem (Alola et al., 2019). Equation (1) depicts the association between dependent and independent variables:

$$EFP = f\,(PCI,\ PCI^2,\ PCI^3,\ RENE,\ LEXP,\ DENS) \qquad (1)$$

In equation (1), EFP, PCI, RENE, LEXP, and DENS are used to represent the ecological footprint, per capita income, renewable energy, life expectancy, and population density, respectively. Equation (2) represents the relationship in a more formal manner where *βs* are used to denote the elasticity coefficients and μ represents the error term:

$$EFP_{i,t} = \alpha + \beta_1 PCI_{i,t} + \beta_2 PCI^2_{i,t} + \beta_3 PCI^3_{i,t} + \beta_4 RENE_{i,t} + \beta_5 LEXP_{i,t} + \beta_6 DENS_{i,t} + \mu_{i,t} \qquad (2)$$

For generating the sample homogeneity, the natural logarithmic values are taken in the ecological footprint function. Further, t and i subscript are carried for the time and country, respectively. In mathematical terms, we need to confirm both necessary and sufficient conditions to establish the N-shaped association. The former is based on the sign of coefficients β_1, β_2, and, β_3, which are expected to be positive, negative, and positive, respectively. In the case of the latter (necessary condition), the solution of $\beta_2^2 - 3\,\beta_1\,\beta_3$ should provide positive value.

3.2. Data stationarity

Owing to the long study period, it is required to confirm whether series are stationary at the level or first difference. Due to the weak prediction power of the traditional panel unit-root tests, we have performed the second-generation tests because these tests are more reliable in the presence of a cross-sectional association. The ignorance of the cross-sectional dependency may lead to unreliable results because macroeconomic variables tend to influence across regions and may lead to significant common shocks in the long run (Sabir and Gorus, 2019). If the study period is sufficiently long and the country-panel is relatively small, the Lagrangian multiplier test is apt for the stability examination. Contrarily, if the former (i.e. the study period) is small and the latter (i.e. country-panel) is large, Pesaran's CD test is more appropriate. Owing to the possibility of the inter-country dependency, besides these tests, we employed the Breusch and Pegan's (1980) test to address the stability issue. The econometric procedure to calculate the cross-country dependency (CCD) is given in equation (3) where the significant p-values will reject the absence of interdependence if time (TIME) is sufficiently large and sample (SAM) goes to →∞.

$$CCD = \frac{\sqrt{2TIME}}{\mathrm{SAM}(\mathrm{SAM}-1)}\left(\sum_{i=1}^{\mathrm{SAM}-1}\sum_{q=l+1}^{\mathrm{SAM}} \mathrm{p}_{iq}\right) \qquad (3)$$

Equation (3) needs to be modified if the given panel is unbalanced, which is not a case in our study. Therefore, the mechanism for the unbalanced panel is not addressed here.

3.3. Cross-sectional unit root tests

Considering the possibility of the inter-country dependency, the cross-sectional augmented Dickey-Fuller (hereon CADF) tests is employed. The econometric procedure for the same is mentioned in equation (4)

$$\Delta z_{i,t} = \Phi_i + \gamma_i y_{i,t-1} + \beta_i \overline{y_{t-1}} + \sum_{l=0}^{q} \rho_{i,l} \Delta \overline{y_{it-1}} + \sum_{l=0}^{q} \zeta_{i,l}\, y_{i,t-1} + \mu_{i,t} \qquad (4)$$

In equation (4), the lag-length is denoted by q and $\overline{y_t}$ calculates the cross-sectional dependency, which is time-based. Based on the t-statistics, the CADF test treats the values of ADF separately. Further, given the calculated mean values of the CADF test, we can calculate the values of the Im-Pesaran-Shin test, which is named as CIPS because it handles the cross-section possibility separately. The procedure for calculation is given in equation (5).

$$CIPS = \left(\frac{1}{SAM}\right) \sum_{i=1}^{SAM} t_i(SAM, TIME) \qquad (5)$$

3.4. Westerlund cointegration approach

By understanding the need for a robust panel cointegration test, we adopted an advanced approach, i.e. Weserlund (2007) test. In the presence of possible cross-country dependency, the Westerlund test provides the statistical values (i.e., G_t, G_a, P_t, and P_a); and based on these values, it can be ascertained that whether comprised data series are associated in the long run. The calculation procedure for this test is mentioned in equation (6).

$$\Delta W_{i,t} = \alpha_i T_t + \gamma_i W_{i,t-1} + \rho_i V_{i,t-1} + \sum_{l=1}^{p_i} \gamma_{i,l} \Delta W_{i,t-l} + \sum_{l=-q_i}^{p_i} \beta_{i,l}\, V_{i,t-1} + \mu_{i,t} \qquad (6)$$

In equation (6), the constant term T_t = (1) constant trend. Similarly, (0) is no constant trend, and lastly, (1, t) is constant and trend. Here, the adjustment speed is = γ_i. Through this procedure, Pesaran (2006) considers the possible dependency among variables across-countries and provides a stationary solution. For calculating the error term, the following procedure is followed:

$$\in_{it} = \gamma_i F_t + \mu_{i,t} \qquad (7)$$

In equation (7), F_t denotes the factor matrix of order m into 1(unnoticed). By calculating the averages of cross-sections, equation (7) provides the proxies for the F_t, which are expected to be consistent. By doing so, the issue related to the cross-sectional dependency can be managed and results would be efficient. For example: $\overline{EFP_t} = 1/N \sum_{i=1}^{N} EFP$. Following the same procedure, we can calculate the statistics of other indicators. Thereafter, the final equation would look like:

$$EFP_{it} = \alpha_0 + \alpha_1 PCI_{it} + \alpha_2 (PCI_{it})^2 + \alpha_3 (PCI_{it})^3 + \alpha_4 RENE_{it} + \alpha_5\, LEXP_{it} + \alpha_6 DENS_{it} + b_0 \overline{EPF_{it}} + b_1 \overline{PCI_{it}} + b_2 \overline{(PCI_{it})^2} + b_3 \overline{(PCI_{it})^3} + b_4 \overline{RENE_{it}} + b_5\, \overline{LEXP_{it}} + b_6 \overline{DENS_{it}} + \epsilon_{it} \qquad (8)$$

In equation (8), using the individual coefficients (i.e., b_1 to b_6), the related and common effect to be calculated.

3.4. The CS-ARDL estimation

It is well evident that not only geographical association but also trade-related exchanges may likely generate the cross-sectional dependency among the selected countries (Bello et al., 2018). Owing to the similar growth trajectory and demographic characteristics, the possibility of the common determinants of the ecological footprint cannot be rejected, which encourages employing the CS-ARDL estimation (Chudik et al., 2013). In comparison to the FMOLS, DOLS, and PMG approaches, this approach has certain inherent advantages: firstly, it addresses the problem of cross-sectional dependency, which is a common problem in other approaches; secondly, it provides the short-run coefficients as well, which is not possible in the FMOLS and DOLS approaches; lastly, the CS-ARDL approach circumvents the structural break and autocorrelation issues more efficiently than the FMOLS, DOLS, and PMG approaches (Anderson and Raissi, 2018). However, in comparison to the cross-sectional distributed lag (CS-DL) approach, it is more sensitive to the lag-length selection. Also, it requires a sufficiently large period to compute reliable results (Chudik et al., 2015). In the present study, for measuring the overall degradation of the land, air, water in the selected countries, i.e. the ecological footprint, the study has used the nonlinear terms of the per capita income, which enables us to capture whether with the increased per income, the relationship between both changes the sign in the long run. Equation (9) establishes the relationship between comprised variables where the mechanism to calculate the short-run and long-run coefficients using the basic panel-ARDL (i.e., PMG) approach is mentioned. Later on, the CS-ARDL equation (12) will be derived from equation (9).

$$e_{i,t} = c_i + \sum_{l=1}^{u} \alpha_{i,l} e_{i,t-l} + \sum_{l=0}^{v} \beta_{i,l}\, z_{i,t-l} + \varepsilon_{i,t} \qquad (9)$$

$$\varepsilon_{i,t} = \gamma_i f_t + \mu_i \qquad (10)$$

In equation (9) and (10), (i) represents the selected countries, (t) represents the study period, (e_i) represents the ecological footprint, (z_i) is used for the selected drivers of the ecological footprint, (f_t) represents the unobserved vectors with the common factors, and (γ) is used for the factor loading. The superscript (u) and (v) are used for the lag orders of the dependent and independent variables, respectively, and assuming the absence of serial correlation.

The short run-coefficients ($\alpha_{i,l}$ and $\beta_{i,l}$) to be used to derive the long-run coefficients (ϕ_i), which is given in equation (11). In the case of the CS-DL approach, we can calculate the long-run coefficients even without using the short-run coefficients

$$\phi_i = \frac{\sum_{l=0}^{u} \beta_{i,l}}{1-\sum_{l=1}^{v} \alpha_{i,l}} \tag{11}$$

For calculating the long-run coefficients (ϕ_i), the ecological footprint (e_{it}) to be regressed on independent variables (z_{it}) where $z_{it}{}^{r}{}_{l=0}$. The CS-ARDL approach efficiently handles the exogeneity restriction provided the sample size is sufficiently large (Chudik et al., 2015). After examining the individual long-run coefficients by using the panel ARDL approach, the overall average effects of the variables to be calculated by using equation ($\phi = n^{-1} \sum_{i}^{n} \phi_i$) where units to be averaged across. This approach considers that the calculated errors are free from the cross-sectional dependency. However, in reality, it may not be so because the global factors may tend to get correlated in the long run, which may lead to inconsistent results. Therefore, equation (9) needs to be modified, which should be based on the cross-sectional averages. Even for the dependent variable, the same procedure needs to be applied. Equation (12) provides us the mechanism to calculate the CS-ARDL results, which is an extension of equation (9).

$$e_{i,t} = c_i + \sum_{l=1}^{u} \alpha_{i,l} e_{i,t-l} + \sum_{l=0}^{v} \beta_{i,l}\, z_{i,t-l} + \sum_{l=0}^{1} \Lambda_i\, y_{t-m} + \varepsilon_{i,t} \tag{12}$$

Here, (y_{t-m}) is calculated on the basis of ($\overline{et}, \overline{zt}$). Rest all variables are the same as mentioned in equation (9). This approach will allow us to calculate the CS-ARDL based coefficients. Similar to the ARDL approach, the error correction term in the CS-ARDL estimation allows us to establish the long-run stability in the system if it is negative and significant. The mechanism to calculate the ECT is given in equation (13).

$$e_{i,t} = c_i + \sum_{l=1}^{u} \alpha_{i,l} e_{i,t-l} + \sum_{l=0}^{v} \beta_{i,l}\, z_{i,t-l} + \sum_{l=0}^{1} \Lambda_i\, y_{t-m} + \sum_{l=1}^{u} \theta_{i,l} \overline{et}_{i,t-l} + \sum_{l=0}^{v} \delta_{i,l}\, \bar{z}_{i,t-l} + \varepsilon_{i,t} \tag{13}$$

Here, $\theta_{i,l} = \sum_{l=1}^{N} \frac{e_{i,t-l}}{N}$ and $\delta_{i,l} = \sum_{l=1}^{N} \frac{y_{i,t-l}}{N}$

4. Results and discussion

The basic properties of the compiled data set are given in Table 1. Along with per capita income, the ecological footprint series has depicted a significant standard deviation during the study period. It indicates that the ecological footprint and per capita income have varied significantly in the selected countries during the study period. In addition, all the series are distributed abnormally, as the Jerque-Bera test rejects the null hypothesis of normal distribution at the 1% significance level.

<Insert Table 1 here>

Owing to the long study period, it is required to confirm whether series are stationary at the level or first difference. In this regard, the panel unit-root tests have been performed. The results of common and individual unit-root tests with traditional approaches are mention in Table A1 (Appendix). The augmented Dickey-Fuller, Im et al. (2003) Levin et al. (2002) tests given in Appendix (Table A1) reveal that all the series are stable either at the level or at first differences, which is a prerequisite for examining the long-run relationship. However, in the panel data set, it is necessary to examine whether the comprised series exhibit cross-sectional dependency. The outcomes of Pesaran's and Breush-Pegan tests given in Table 2 display that over the study period, the data series are cross-sectionally dependent. It means, the null hypothesis of the absence of cross-country independence is rejected and data series tend to influence across countries in the long run.

<Insert Table 2 here>

The outcomes given in Table (2) highlight the need for a robust technique that can provide reliable results even in the presence of the cross-sectional dependency, as all the tests confirmed the presence of interdependency among the selected countries with the given variables. In the presence of such kind of association, Westerlund's (2007) cointegration test is more reliable. Because this test even in the presence of cross-country dependency provides efficient results. However, before employing Westerlund's (2007) test, we explained the results of the CADF and CIPS panel stationarity tests, which are given in Table (3).

<Insert Table 3 here>

The results given in Table (3) confirm that all the series are stable at the first difference even in the presence of cross-sectional dependency. In other words, the series are unstable at the level but stable at the first difference. Thus, it allows us to apply the cointegration test of Westerlund.

<Insert Table 4 here>

Westerlund's cointegration test results given in Table (4) reject the null hypothesis of the absence of common coefficients. Even the results of Pedroni's and Kao's tests also reported the absence of no cointegration among comprised series. Stating differently, the comprised set of variables is cointegrated and enables us to provide the long run common coefficients. The results of Pedroni's and Kao's cointegration tests mentioned in the lower panel also confirm the possibility of the association between ecological footprint and its determinants. Its approval allows us to employ the CS-ARDL estimation. The results of the CS-ARDL estimation are given in Table (5). For evaluating the common coefficients through the CS-ARDL approach, the error correction term should have a negative and significant sign and cross-sectional dependency should be addressed.

<Insert Table 5 here>

Growing economic and political interests have improved the synchronization among countries, which in turn has increased the mutual interdependency as well (Benli, 2019). Thus, the interdependency among countries extends the impact of economic shocks through trade channels (Bello et al., 2018). Saying this, Table (5) provides the results of the CS-ARDL estimation, which provides the long-run and short-run coefficients. These results are based on the time-series data (1990-2015) where the eight developing countries of South and Southeast Asia have been considered. The error correction term (ECM) affirms that the ecological footprint establishes the long-run equilibrium with a speed of -0.506 if disequilibrium exists. In other words, the ecological footprint automatically establishes the equilibrium with the per capita income, squared per capita income, cubic per capita income, renewable energy, life expectancy, and population density if it deviates from the long-run equilibrium path.

The relationship between the EFP and the linear, square, and cubic per capita income is found positive, negative, and positive, respectively. This ascertains that the EFP-income association is N-shaped in the long run, which confirms the existence of the EKC in the region. Even, the results of Sinha et al.'s (2017) and Sharma et al.'s (2020) studies found an N-shaped association between CO_2 emissions and per capita income in N-11 and South Asian countries, respectively. Further, the negative and significant coefficients of the renewable energy confirm that the increased use of renewable energy consumption enables us to control the EFP not only in the long run but also in the short run. In conformity of this, Sinha et al. (2017) and Apergis et al. (2018) in their respective studies established that the ecological footprint or CO_2 emissions could be controlled by intensifying the use of renewable energy solutions in the long run. However, Hastik et al. (2016) suggested that without developing energy-saving production processes, renewable energy consumption alone may not be able to address environmental issues. In terms of EFP generation, the impact of life expectancy is observed direct but insignificant, whereas the population density's impact is observed direct and significant in the long run. In a similar line, by using the set of 16 European Union countries, Alola et al. (2019) in their study confirmed a significant association between fertility rate and ecological footprint. Similarly, Sharma et al.

(2020a) in their study reported that the increased population density has contributed to invigorating the EFP in the developing Asian nations.

Based on this, it can be contemplated that not only economic activities but also demographic attributes emanated pressure on the ecological system in the given countries. Following the philosophy of SDGs, economic growth and routine activities can be channeled through renewable energy consumption, as its extensive use may address the issues pertaining to the environment. However, based on the outcomes of Table (5), it can be argued that the region has witnessed economic growth at the cost of environmental pollution. Stating differently, the existing techniques of production, energy resources, and demographic changes might have contributed to increasing the per capita income. However, on the environmental front, their role can be debated. Until now, whether it is for commercial or domestic purposes, the consumption of nonrenewable energy is significantly more than renewable energy in these countries (Sharvini et al., 2018). By finding so, it can be considered that the existing techniques of production unable to clear the tests for energy-efficiency and carbon-intensity, which is not desirable for sustainable economic growth. Therefore, these nations need to re-engineer their long-term growth policy where widespread use of renewable energy on the industrial and household fronts needs to be ascertained. For ensuring the cleaner environment, governments have to identify the pollution-intense sectors where the use of renewable energy resources such as solar, wind, air, water, and biomass can be increased.

Another matter of concern is that despite registering the upward trend in per capita income, people in these countries unable to generate cleaner and healthy processes and lifestyles, as the association of EFP with the population density and life expectancy is found positive. These countries need to learn from Japan where despite having a high population density and life expectancy, the ecological footprint is comparatively very less (Harris, 2010). To address this problem, the enforcement of environmental laws is one of the options. Secondly, governments need to facilitate research and development in the renewable energy sector, which may ensure the widespread use of renewable energy at the household level. Lastly, it requires increasing the use of renewable energy in areas such as agriculture, transportation, domestic lighting, and mundane activities. By doing so, the inclusion of the maximum number of people can be ensured, which in turn may lessen the EFP in the long run. Therefore, to reap the benefits of economic gains, people's conscious participation has to be ensured. Otherwise, the gain caused by the increased per capita income may be neutralized by environmental degradation. As, the increased pollution level may increase the social costs, which in turn may reduce the net benefits of the earned income (Sharma et al., 2020).

Further, by using Dumitrescu and Hurlin's (2012) approach, we intend to assess the direction of the causality among the comprised variables because, in such kind of setting, it may provide additional information on the phenomenon under study. Table (6) reveals that per capita income determines the ecological footprint during the study period. Similarly, squared per capita income also drives to ecological footprint. In terms of policy formation, these results are quite significant. For example, the income-EFP association necessitates the need for cleaner and environmental-friendly techniques of production in the selected developing countries. In failing so, the region would continue to experience a trade-off between economic growth and environmental degradation. Further, the association of the EFP with life expectancy and population density is found bidirectional during the study period. This type of relationship corroborates that the association between environment and human activities is dynamic; therefore, while framing environmental policies and laws, the possible impact of demographic and communal aspects needs to be considered. In the case of renewable energy and EFP association, Table (6) reveals that the EFP drives renewable energy significantly during the study period. It means, environmental issues may enlarge the need for renewable energy resources, which is most desired for the developing countries, as these countries are witnessing an alarming level of environmental pollution. Further, it is observed that life expectancy and population density are bi-directionally associated with per capita income. This association reveals that demographic aspects may have an impact on economic growth and economic growth may influence the EFP.

<Insert Table 6 here>

5. Conclusion and recommendations

By far, the present study investigated the impact of renewable energy consumption on EFP for eight developing countries of South and Southeast Asia during 1990-2015. At the same time, we investigated whether the association between per capita income and EFP has remained nonlinear in the selected countries. Owing to the demographic changes in the region, life expectancy, and population density are also considered as determinants of the EFP.

The study outcomes provide us with significant insights necessary to devise suitable policy implications for these nations. The economic growth pattern in these nations is seemingly unsustainable in nature, and that too from the environmental perspective. The first turnaround point of the EKC is well-within the sample range, whereas the second turnaround point slightly above the sample range. This gives an indication that the economic growth trajectory in these nations might prove to be unsustainable in near future. Now, these nations are characterized by a high level of economic growth, and therefore, the volume of job creations is substantially large in the urban centers of these nations. Therefore, the pressure of urbanization is experienced, owing to the growth in employment opportunities. With the rise in population density in these regions, faster depletion of natural resources takes place, which has a consequent effect on the ecological footprint of these nations. Moreover, the rise in the living standard due to income growth has resulted in raising the life expectancy of the citizens, which might have another impact on the ecological footprint. However, the results of causality analysis demonstrate that ecological footprint might have an impact on life expectancy, as well as on population density.

Moreover, the expectation of better livelihood might attract citizens towards urban centers, while the rise in population density might also have an impact on life expectancy, which might be considered as an indicator of the standard of living. These outcomes have opened several threads for discussion, which might lead to the formulation of policies for enabling these nations to make a progress towards attaining the objectives of SDGs. While the policies will help these nations in attaining SDGs, these policies will also help these nations to prepare a pathway for institutionalizing the cleaner production practices, both at industrial and household levels.

In order to tackle this situation, policies need to be developed for both industrial sectors and households. While implementing these policies, it is needed to be remembered that in pursuit of internalizing the negative environmental externalities, the economic growth pattern should remain unharmed. As the concentration of jobs is exerting pressure on the environmental quality, the initial phase of the policy implementation should look into the urban infrastructure, so that the rise in population can be accommodated. In this pursuit, the local municipal or equivalent local government bodies should take the initiative to expand the border of the cities, and in this way, the initial pressure or population rise can be handled. Once this policy is implemented, the policymakers should look into sustaining the environmental quality. Therefore, in the subsequent phases, the policymakers should consider promoting renewable energy solutions. In the second phase, the policymakers should make the renewable energy solutions available to the households at a pro-rata subsidized rate, and in order to avail the solutions, the households might be given certain interest rate holiday. In this way, the acceptability of renewable energy solutions among the households might be enhanced by means of bringing forth the aspect of affordability. Now, this particular policy move will definitely create fiscal pressure, and this pressure can be tackled through the industrial sector. The renewable energy solutions might be made available to the industrial sector at a higher rate than the one being prescribed for households. Along with this, based on the ecological footprint of the firms, differential pricing mechanism can be adopted, and it might discourage the firms to continue the nonrenewable energy solutions, and having a control over the water and land contaminating activities. This policy action will help these nations in achieving the objectives of SDG 7. In the third phase, the policymakers should aim at sustaining the policy actions being taken up in the previous two phases. One of the earliest policy actions in this phase should be to create the model sustainable villages, which will help the rural population in having suitable employment opportunities. This will not only help the rural population to have a better livelihood, but also the pressure on the urban ecosystem will be reduced. This will help these nations in achieving the objectives of SDG 8, while making a progression for SDG 11, i.e. sustainable cities and communities. On the other hand, the policymakers should promote people-public-private partnerships for enhancing the environmental awareness among the citizens, so that the environmental protection initiatives can be boosted, and the acceptance of renewable energy solutions can be further promoted. Once these policies are in place, these nations will be able to make a progression towards achieving the objectives of SDG 13, i.e. climate action, SDG 14, i.e. life below water, and SDG 15, i.e. life on land.

While prescribing these policies, the necessary caveats should also be prescribed, without which the policies might not function effectively. First, the policymakers should make the environmental regulations more stringent, so that the “tragedy of commons” can be avoided. Second, while promoting renewable energy solutions, workers in the traditional nonrenewable energy generation sector should be provided with adequate skill development and capacity building, so that they can be absorbed in the emerging renewable energy generation sector. This way the pressure of prospective unemployment in these nations can be avoided. Third, while promoting the acceptance of renewable energy solutions, the government agencies should refrain from rent-seeking behavior, as it might discourage the further expansion and diffusion of these solutions.

As the policies designed in this study only assumed the demographic aspects, further robustness in the policy design can be brought forth by considering the aspects of gender and ageing. However, the policies laid out in this study can act as a baseline report, which can be further expanded by considering additional aspects of policy design. Future studies on this aspect can be carried out by considering the spatial dimensions of demographic differences, as this aspect can bring forth several new insights regarding the pattern of changes in the labor force, on the ecological footprint.

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