Environmental Science and Pollution Research (2020) 27:10065–10086
https://doi.org/10.1007/s11356-019-07507-7

RESEARCH ARTICLE

The effects of deforestation and urbanization on sustainable growth in Asian countries

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Received: 10 September 2019 / Accepted: 22 December 2019 / Published online: 13 January 2020

Abstract
This study aims to determine the effects of deforestation, economic growth, and urbanization on carbon dioxide (CO_2) emissions levels in the South and Southeast Asian (SSEA) regions for the 1990–2014 period. The data was divided into five sub-panels. Three of them are income-based groups (namely low-, middle- and high-income panels), and the remaining two are South and Southeast Asian regions. The Pedroni cointegration test confirms a long-run relationship between deforestation, economic growth, urbanization, and CO_2 emissions in the SSEA regions. Further, empirical results reveal the existence of a U-shaped relationship between CO_2 emissions and economic growth for all panels (excepting low-income countries). This means that these countries can grow in a sustainable path, but they must be aware of long-term risks of this economic growth, as this sustainable path could be compromised when reaching the turning point of the "U". Moreover, our results suggest that deforestation and urbanization can aggravate environmental pollution in these regions and can further affect sustainable development in the long run. Besides, the most appropriate and cost-effective method to minimize CO_2 emissions is found to be through the improvement of forest activities.

Keywords Deforestation · Economic growth · Urbanization · CO_2 emissions · Asian countries

Introduction

Forest is one of the essential factors of the earth and survival of humanity (Ciesielski and Stereńczak 2018). The role of the forest evolved over the centuries. Earlier, forests were used only for timber production; however, in recent times, non-production functions of forests grow to be more and more significant (Ciesielski and Stereńczak 2018). The benefits of the forests are long term, and they facilitate the environment in many ways. It provides numerous benefits to humankind (Kishor and Belle 2004), by improving environmental quality, economic opportunities, and aesthetic standards (Coletta et al. 2016; Marziliano et al. 2013). Forest behaves as biodiversity vaults (Christopoulou et al. 2007), and climate change is being affected by carbon storage represented as an ecosystem regulator (Delphin et al. 2016). For all these reasons, forest protection should be considered about political nature, habit, social, and economic conditions (Piussi and Farrell 2000).

In 1990, the world had 4128 million hectares (ha) of the forest, and this area had decreased in 2015 to 3999 million ha. The volume of the forests sector is declining as human population keeps growing and demand for food and land increases. The rate of the net forest area has been lost over 50% since 1990 (FAO 2015). Moreover, there are nearly three million premature deaths related to pollution from firewood (World Energy Outlook 2017). Concisely, forest areas are at risk as a result of climate change, pests, diseases, exploitation, industrialization, and urbanization. Industrialization leads to urbanization by creating economic growth (Liu and Bae 2018). Industrialization influences on the quality of human life and damages the natural environment (Awan et al. 2018).

Shahbaz et al. (2016) explained the urbanization as social and economic capabilities moved from rural to urban areas. Martínez-Zarzoso and Maruotti (2011) focused on the

Responsible editor: Eyup Dogan

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influence of urbanization on carbon dioxide (CO_2) emissions and noted the presence of an inverted U-shaped relationship between CO_2 emissions and urbanization. The global urban population was 1.73 billion in 1980, 39% of the total population which gradually increased to 3.29 billion in 2007 and 3.97 billion in 2015 (almost 54%) which is projected to be 6.42 billion in 2050 (66%) (Urbanet 2018). In 2018, these numbers turned to 4.54 billion with a density of 146 P/km^2, which is equivalent to 59.7% of the total world, standing at first position among all continents. The urban population was 49.7% (a rise of 48.6% since 1955). It will reach 525 billion with a density of 169 P/km^2, and the share of the urban population will be 63% of the total population in 2050 (Worldometer 2018). Among the most populous countries of Asia are China, India, Indonesia, Pakistan, and Bangladesh. Half of the population of the whole world resides in the urban regions. According to the UN estimate in 2050, 64% of the people of developing countries will be urbanized.

Urbanization will increase the demand for necessary infrastructures such as transportation, building, and energy which ultimately increases the level of CO_2 emissions (Liu and Bae 2018).

However, it is a universal consensus that the increasing atmospheric gases (GHG) especially CO_2 emissions are the primary cause of climate change (Wang et al. 2013). Worldwide mesh human-caused CO_2 emissions might need to drop by about 45% from 2010 levels by 2030, attaining 'net zero' around 2050. Robust implementation of CO_2 emissions reduction from the air is essential for mitigating global climate change (Intergovernmental Panel on Climate Change 2018, report Working Group 1 Report, 2018).

In summary, the growing world population, rapid industrialization, and urbanization of the human environment collectively with social and economic changes contribute to rising demands on forest areas. The state of affairs forced the responsible bodies of forest management to pay some special attention to the recreational forest mainly located near the urban areas (Gołos 2013). Moreover, media and political commentaries, by NGOs and in educational literature, the possible adverse environmental effects of growing urbanization had been mentioned see (Lean and Smyth 2010; Mishra et al. 2009).

This study examines the relationship between economic growth, urbanization, deforestation, and CO_2 emissions, taken as a case study of the South Asian and ASEAN regions (SSEA). The SSEA regions are known as one of the highly urbanized areas in the world, struggling underneath the intensity of environmental degradation, CO_2 emissions, and GHG hassle (Behera and Dash 2017). This study moves further than preceding research in several aspects: (i) we examine the impact of deforestation on CO_2 emissions, explicitly addressing the issue of cross-sectional dependence for South and Southeast Asian countries; (ii) the Augmented Ducky-Fuller unit test is applied to check the stationarity properties of the variables and the second-generation panel unit root (Pesaran 2007) test is also applied to assess the robustness of stationarity properties of the variables; (iii) the Pedroni (2001a) and Westerlund (2007) cointegration tests are employed to examine the presence of cointegration between the variables; (iv) to examine, short-run and long-run impact of deforestation, urbanization, and economic growth on CO_2 emissions, we apply the Pooled Mean Group (PMG) regression method, followed by the estimation of error correction approach. The strength of the long-run coefficient is determined by Dynamic Ordinary Least Square (DOLS) and Group Mean Fully Modified Ordinary Least Squares (GM-FMOLS) methods, and (v) the Dumitrescu-Hurlin causality test is applied for examining causal relationship.

We observe that cointegration exists among the variables. Moreover, the relationship between CO_2 emissions and economic growth found to be U-shaped in middle- and high-income countries, deforestation, economic growth, and urbanization are adding in CO_2 emissions. Following policy implications can be considered: (1) the improvement of forest activities is the most cost-effective method to mitigate the CO_2 emissions level; (2) the South and Southeast Asian countries must take the initiative of cross-country settlement to maintain a certain threshold level of pollution and environmental degradation; besides, a vigorous interference for trans-border movement should be applied to regulate the air pollutants and (3) the upcoming projects must declare some green space nearby to offsetting the carbon emissions.

Literature review

Existing literature intends to explain that environmental pollution (as CO_2 emissions) can be divided into three strands: linkage between urbanization and CO_2 emissions, economic growth and CO_2 emissions, and, deforestation and CO_2 nexus.

Urbanization and CO_2 emissions

The economic theory predicts that urbanization is caused by economic growth and social modernization (Martínez-Zarzoso and Maruotti 2011; Poumanyvong and Kaneko 2010). Cities grow because of the continuous flow of human beings into cities. While these flows stop, urbanization involves a standstill (Chaolin et al. 2012). On similar lines, Pacione (2003) states that a boom in the city population accompanies urbanization observed using urban increase and urbanism a period regarding the city's existence style and social, behavioral functions. A comparative look at the procedure of urbanization in different well-known countries shows the truth that the direction of urbanization followed by way of different nations is based totally on their cultural, historical past, and tiers of development (Berry and Lobley 1973). Glaeser and Kahn (2010) surveyed a big frame of literature on urban-pollutants nexus. They focused on city-specific studies, with more recognition of metropolis-precise studies associated with urbanization and air pollutants.

The existing literature shows that researchers reached on different conclusion. Several studies found a positive and negative relationship between CO_2 emissions and urbanization, while some of them also described the inverted U-shaped relation. For instance, He et al. (2017) established the inverted U-shaped relationship between urbanization and CO_2 emissions, while using the provincial level panel estimation in China. They suggested that CO_2 emissions rise with the expansion of urbanization, they declined after reaching a turning point, afterward maintaining an inverse relation with urbanization. Moreover, Zhang et al. (2014) concluded that there is a unidirectional causality moving from urbanization to CO_2 emissions. According to Wang and Zhao (2015), there is a direct relationship found between urbanization and CO_2 emissions in developing, under developing, and developed areas in China and the elasticity coefficients vary in different economic regions. In another study, Miao (2017) suggested that the urban population in a built-up area is one of the contributors to residential CO_2 emissions. Meng et al. (2018) also concluded that urban density contributes to mitigating CO_2 emissions. Besides, Wang et al. (2018b) discussed all forms of urbanization like economic urbanization, population urbanization, land urbanization, social urbanization, and explained that economic urbanization and land urbanization directly affects emissions due to the transformation from underdeveloped to develop areas and wealth growth respectively. In contrast, population urbanization wields an inverse effect on CO_2 emissions while social urbanization decreased emissions due to awareness of energy savings in the surroundings of Pearl River Delta in China. Therefore, it is essential to create a civic sense such as citizenship education, civic awareness, and civic participation in the society about sustainability issues (Awan et al. 2014).

However, Sharma (2011) illustrated an inverse relationship between CO_2 emissions and urbanization in the panel of 69 countries of different income groups around the globe. Ali et al. (2017) also found a negative relationship between CO_2 emissions and urbanization while stated a favorable condition between urbanization and CO_2 emissions in Singapore. Furthermore, the high level of urbanization resulted in a more friendly environment (Chikaraishi et al. 2015). Existing literature also described the urbanization as one of the essential pillars and play a crucial role in social development along with the forest resources (Ünal et al. 2019). Nevertheless, the relationship between urbanization, deforestation, and migrations is not clear because literature lacks the relationship of these variables with other essential factors. Urbanization may require special intentions due to its conversion of forestland into other advancements (De Chant et al. 2010). Limited research focused on the damaging effect of forest on economic activities and decreased recreational opportunities (Christopoulou et al. 2007). Although, Defries et al. (2010) explored that deforestation driven by urban population growth and agriculture trade in 41 countries. Their empirical results show that forest loss is positively related to urban population growth and agriculture products exports. In a recent study about Turkey, Ünal et al. (2019) explored a positive linear temporal relationship between urbanization and deforestation. There is a significant negative relation between forest area and the rural population, which means that the decline of rural population resulted in afforestation.

Economic growth and CO_2 emissions

At the first level, the relationship between environmental pollution and economic growth has been discussed. The economists are analyzing the relationship between per capita income and CO_2 emissions to control the possible anthropogenic CO_2 emissions in the atmosphere since 1991 (Grossman and Krueger 1991). For instance, Grossman and Krueger (1991) developed a connotation between economic growth and environmental degradation. They noted the inverted U-shaped relationship between the variables which is well represented as the Environmental Kuznets Curve (EKC). The EKC hypothesis suggests that during the initial stage of income growth ecological degradation and per capita income increase in parallel and then after achieving the threshold level, environmental degradation decreases with further per capita income (Alvarez-Herranz et al. 2017; Wang et al. 2018a). The EKC has been more significant to understand the effect that economic development has on the environment quality based on past circumstances and present situations to achieve future sustainable development (Uchiyama 2016). EKC reveals the importance of analysis of the specific context of regions or countries, as it evaluates how the economy has developed from the clean agricultural economy to polluted industrial economy, and to clean services economy. On the other hand, it may also allow us to see the tendency of higher-yielding regions to have a higher preference for environmental quality (Dinda 2004). In practical terms, the EKC results have shown that economic growth could be compatible with environmental improvement if appropriate policies are taken (Dinda 2004).

Several contradicting results have been found on such relationships particularly among developed and developing countries. For example, Moomaw and Unruh (1997) reported that the EKC relationship for CO_2 emissions is well defined in countries that are part of the Organization for Economic and Development (OECD). In 106 countries of the different income groups, Antonakakis et al. (2017) verified the existence of EKC because of a continuous process of growth from 1971 to 2011. Koirala et al. (2011) demonstrated the presence of an EKC relationship for CO_2 emissions in high-income countries. Recently, Xie and Liu (2019) also confirmed the inverted U-shaped EKC in the region level study of China throughout 1997–2016 by extended STIRPAT model.

In short, several studies confirmed the existence of the EKC hypothesis some of them are Alam et al. 2016; Apergis 2016; Ben Jebli et al. 2016; Le and Quah 2018; Li et al. 2016; Ouyang and Lin 2017; Shahbaz et al. 2015; Zaman and Moemen 2017.

On the other hand, some of the studies rejected the validity of the EKC hypothesis. For instance, Richmond and Kaufmann (2006) illustrated the invalidation of EKC in the case of non-OECD countries. Al-Mulali et al. (2016) failed to confirm the EKC in Kenya because of urbanization trade openness, GDP, and fossil fuels. Adu and Denkyirah (2018) also found insignificant results in the long run between CO_2 emissions and economic growth in the West African countries with the same income groups, which confirmed the non-existence of EKC. A low level of turning point is a hassle in this case. Moreover, Amri (2018) unable to find the inverted U-shaped relationship between CO_2 emissions and economic growth because of not attaining the requested level of total factor productivity in the Tunisian economy.

Deforestation and CO_2 emissions nexus

The relationship between deforestation and CO_2 emissions is investigated by applying various methods, but few studies have econometric approaches with empirical findings. For instance, Koirala and Mysami (2015) investigated the effect of forest resources on CO_2 emissions in the USA and estimated that forest degradation dominates CO_2 emissions. In the case of Pakistan, Ahmed et al. (2015) developed the relationship between deforestation, economic growth, energy consumption, trade openness, and population and found that there exists a long-run relationship between the mentioned variables. Moreover, the study also found the Granger causality among the variables. According to De Sy et al. (2015), one of the significant sources of CO_2 emissions is the land-use changes in the region of South America. The drivers and indicators of anthropogenic CO_2 emissions is a critical aspect of global climate change commitment. However, few countries monitor the lack of national-level information on deforestation drivers is one of the vital elements. Their results also indicate that remote sensing time series in a systematic way provides the basis for the deforestation and carbon losses drivers in the region of South America. Hewson et al. (2019) also demonstrated the land change to investigate the impact of expert-informed scenarios on deforestation, GHG emissions, particularly CO_2 emissions in the Corridor in eastern Madagascar. Their results illustrate that carbon emissions could be reduced through adequate forest protection and management, whereas, infrastructure advancement in new areas causes a reduction in forest areas. Their results also indicate how land change modeling can enrich the forest policy which ultimately leads the countries to make a settlement among the economic development, forest up-gradation, and climate change commitments.

Recently, Gokmenoglu et al. (2019) developed a relationship between CO_2 emissions and deforestation, energy consumption, urbanization, and fossil fuel energy consumption in ten countries throughout 2000–2015. These long-run equilibrium relationships among the mentioned variables are well established. EKC hypothesis is supported by fully modified ordinary least squares' (FMOLS), and pair-wise DH Granger causality test also proposed the causal relationship among the variables. Their results also confirmed different policies like afforestation grant, exemptions of taxes along with the tariffs on imports regarding forest products are of paramount importance in the reduction of CO_2 emissions in host countries. For different 86 countries Parajuli et al. (2019) also investigated the effects of forest land and agriculture on CO_2 emissions throughout 1990–2014. They proved that the forest is an important determinant to lessen CO2 emissions globally with a dynamic panel data method. The most recent study by Andrée et al. (2019) found inverted *U*-shapes in deforestation, air pollution, and carbon intensities followed by a *J*-shape in per capita carbon output.

Several studies have been done to examine the relationship between environmental pollutants and their determinants (Wang et al. 2016) and we summarize studies in Table 1 demonstrating the association between energy consumption, deforestation and CO_2 emissions, and urbanization in developing and developed countries. Table 1 shows numerous studies on environmental issues, but a limited number of studies, which especially analyzed the relationship between, forestation, urbanization, and CO_2 emissions in South Asian and ASEAN countries.

Methodology and data description

Data

The South Asian[1] and ASEAN,[2] consisting of a panel of 17 countries covering the period of 1990–2014, has been analyzed. The data is divided into six panels: (i) all countries[3]; (ii) lower-income[4] countries; (iii) middle income[5] countries; (iv) high-income[6] countries (as suggested by (World development indicators 2019) economic list); (v) South

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[1] Pakistan, India, Bangladesh, Nepal, Maldives, Iran, Bhutan, and Sri Lanka

[2] Indonesia, Malaysia, Thailand, Cambodia, Philippines, Vietnam, Myanmar, Laos, and Brunei Darussalam

[3] Pakistan, India, Bangladesh, Nepal, Maldives, Iran, Bhutan and Sri Lanka, Indonesia, Malaysia, Thailand, Cambodia, Philippines, Vietnam, Myanmar, Laos, and Brunei Darussalam

[4] Pakistan, Bangladesh, Myanmar, Nepal, Laos, and Cambodia

[5] India, Sri Lanka, Indonesia, Bhutan, Vietnam, and Philippines

[6] Malaysia, Thailand, Brunei Darussalam, Iran, and Maldives

Table 1 Summary of existing studies

No.	Study	Method	Country/ies (period)	Findings
1	Narayan and Narayan (2010)	Panel cointegration and the panel long-run estimation techniques.	43 countries/1980–2004	Rise in income the carbon dioxide emission is fallen in South Asia and Middle East panel when the long-run income elasticity is smaller than the short run
2	Poumanyvong and Kaneko (2010)	STIRPAT	99 countries/1975–2005	Urbanization reduces the energy consumption in low-income countries, while, the urbanization increases the energy consumption in middle and high-income groups. In the case of urbanization on emission is similar in all the sample countries but the middle-income group is higher than the other income groups.
3	Martínez-Zarzoso and Maruotti (2011)	STIRPAT model	88countries/1975–2003	An inverted U-shaped relation between CO_2 emissions and urbanization
4	Li et al. (2012)	STIRPAT model	China province/1990–2010	GDP and urbanization have a higher influence on CO_2 emission
5	Al-Mulali et al. (2012)	FMOLS	East, Pacific, Central and South Asia, East Europe, Latin America and the Caribbean, Middle East and North Africa, Sub- Saharan Africa, and Western Europe countries/1980–2008	84% of countries have the positive long-run relationship between urbanization; energy consumption and carbon dioxide emission and the remaining have the unclear results
6	Zhu et al. (2012)	STIRPAT model, semi-parametric, fixed effect model	20 emerging economies/1992–2008	Urbanization has a nonlinear association ship with CO_2 emission
7	Al-Mulali et al. (2013)	Dynamic OLS technique, panel cointegration, and panel Granger causality	MENA countries/1980–2009	Urbanization, energy consumption, and CO_2 emission have a short and long-run positive relationship
8	Heidari et al. (2015)	panel smooth transition regression model (PSTR)	ASEAN countries/1980–2008	The energy increases the CO_2 emission in the first and second regime. EKC hypothesis and its validity
9	Begum et al. (2015)	ARDL, DOLS, and Sasabuchi–Lind–Mehlum U tests	Malaysia /1980–2009	The GDP per capita and energy consumption have a long-run positive impact on CO_2 emission
10	Saidi and Hammami (2015)	simultaneous equation method	58 countries /1990–2012	The impact of energy consumption on economic growth is positive. Economic growth is negatively affected by CO_2 emission.
11	Rafiq et al. (2016)	STIRPAT and EKC (Environmental Kuznets curve), second-generation heterogeneous linear panel model, nonlinear techniques	22 emerging economies/1980–2010	Population density and affluence increase emissions and energy intensity while renewable energy seems to be dormant in these emerging economies, but non-renewable energy increase CO_2 emissions and energy intensity
12	Li and Lin (2015)	STIRPAT model and dynamic threshold regression model	73 countries/1971–2010	The energy consumption decreases, and carbon dioxide emission increases due to industrialization and urbanization increase the carbon dioxide emission and consumption of energy
13	Shahbaz et al. (2016)	STIRPAT model	Malayshia/1970 Q_1–2011 Q_4	economic growth is a first-rate contributor to CO_2 emissions, the relationship between urbanization and CO_2 emissions are U-shaped
14	Wang et al. (2016)	FMOLS, Pedroni panel co-integration	ASEAN countries/1980–2009	Urbanization, energy consumption, and CO_2 emission have a positive long-run relationship
15	Sheng and Guo (2016)		China provinces/1995–2011	Rapid urbanization increases CO_2 emissions both in the short and long run

Table 1 (continued)

No.	Study	Method	Country/ies (period)	Findings
		STIRPAT model, mean group (MG), pooled mean group (PMG), and dynamic fixed (DFE)		
16	Abdallh and Abugamos (2017)	STIRPAT	MENA countries/1980–2014	The continuation of the urbanization procedure, carbon emissions per capita decreased
17	Zhang et al. (2017)	STIRPAT	141 countries/1961–2011	Inverted *U*-shaped relationship between urbanization and CO_2 emission. Excessive urban attention can declare the benefits of high-level urbanization

Asian region; and (vi) Southeast Asian region. The data for CO_2 emissions (metric tons per capita), real GDP per capita (constant 2010 U.S. dollar), forest area (square Km), the urban population is collected from World Development Indicators (2018). The series of the total population is used to convert urban population and deforestation area km^2 into per capita units (see Fig. 1 in the Appendix).

Empirical models

This paper examines the relationship between deforestation, economic growth, urbanization, and CO_2 emissions. The general form of the function model is as follows:

$$CO_2 = f(\ GDP, \text{Forest}, \text{Urban}) \tag{1}$$

Where, CO_2 is carbon dioxide emissions per capita, GDP measures economic growth via real GDP per capita, forest is forest area per 1000 person, and urban represents urban population per capita.

To estimate the air pollution rate in a country, CO_2 is the most appropriate way to calculate it. The emerging economies with high growth rate could enable the high air pollution in South Asian and ASEAN regions. An increase in urbanization, a high level of manufacturing, and a high-level import of energy can facilitate the growth rate of a country (Behera and Dash 2017). Also, these economies are highly dependent on oil, and others import to stable their economic growth and development. There exist several approaches to find the relationship between urbanization, CO_2 emissions, and economic growth along with the EKC hypothesis. For example Narayan and Narayan (2010) with a panel cointegration and panel long run estimation, Shahbaz et al. (2016) using a STIRPAT model and Zhang et al. (2017) applying IPAT model. However, we follow Grossman and Krueger (1995), Heil and Selden (2001), and Koirala and Mysami (2015) approach to model; our empirical model is as follows:

$$\begin{aligned} CO_{2it} = {} & \alpha_{1it} + \alpha_{yit} GDP_{it} + \alpha_{y^2it} (GDP)^2_{it} \\ & + \alpha_{Uit} \ \ \text{Urban}_{it} + \alpha_{fit} \ \ \text{Forest}_{it} + \epsilon_{it} \end{aligned} \tag{2}$$

We are going to use the log-linear specification for empirical analysis. The standard EKC model represents the quadratic income function provides the base for the inclusion of square GDP in the model (Hui et al. 2007). Furthermore, ϵ_{it} is an idiosyncratic error term, independent, and identically distributed. It represents the standard normal distribution with unit variance and zero mean. Whereas *i* represents the country, *t* stands for a time period, α_{1it} is the intercept, while α_{yit}, α_{Uit}, α_{fit} are the long-run elasticity's estimates of CO_2 emissions per capita with respect to the explanatory variables, such as real GDP per capita, urbanization, and deforestation respectively.

The coefficient α_{y^2it} shows the shape of the EKC curve in the panel countries. After estimation, the following scenarios could be used to analyze the EKC hypothesis: if $\alpha_{yit} = 0$ and $\alpha_{y^2it} = 0$ imply no relationship; $\alpha_{yit} > 0$ and $\alpha_{y^2it} = 0$ imply a monotonically increasing relationship; $\alpha_{yit} < 0$ and $\alpha_{y^2it} = 0$ imply a monotonically decreasing relationship; $\alpha_{yit} > 0$ and $\alpha_{y^2it} < 0$ imply an inverted U-shaped relationship, i.e., EKC hypothesis; $\alpha_{yit}\langle 0$ and $\alpha_{y^2it}\rangle 0$ imply a *U*-shaped relationship (Koirala and Mysami 2015). However, the relationship between CO_2 emissions and explanatory variables cannot be estimated at this stage.

Econometric approach

There are five acquainted steps of a comprehensive analysis concerning an econometric point of view. Unit root testing, cointegration, Pooled mean regression group, FMOLS, DOLS, and Dumitrescu-Hurlin (DH) causality test, we use for empirical analysis.

Unit root testing

The first step employed in this research is known as a stochastic method which could be determined by investigating the unit root problem in the variables of the panel. The panel unit root test is used to determine the presence of the stochastic trends, which is broadly designed to elaborate on the postulation of cross-sectional dependence. Due to several different testing strategies, the aim to apply several unit root tests in the panel is to analyze the reliability of empirical results. Mainly, ADF Fisher and PP Fisher tests have been employed to determine the issues of stationarity. Also, many factors like the trans-border movement of pollutants, general residual interdependence, unobserved common factors, omitted observed common factors, and pollution cross-ways in South Asia and South Asian regions can cause the increased in cross-sectional dependence cross-ways the cross-section units (Behera and Dash 2017). For that reason, to handle the trouble of cross-sectional dependence, it is instructive to use the panel unit root test proposed by Pesaran (2007).

Cointegration testing

The Pedroni test Many panel cointegration tests are suggested by Pedroni (2004). The long-run information in the pool and short-run dynamics of the cross-sectional unit is the significant benefit of cointegration techniques. The pooling can be executed both by employing within and between the dimensional statistics. Pedroni (2001a, b) presents seven-panel cointegration statistics, out of which four considered within dimension statistics and three between-dimension statistics. The computation of the residuals of the hypothesized cointegrating regression by Pedroni (2004) is as follows:

$$Y_{i,t} = \alpha_0 \ + \alpha_{1,i}X_{1i,t} + \alpha_{2,i}X_{2i,t} + \dots\dots\dots\dots\dots\dots + \alpha_{Z,i}X_{Zi,t} + e_{i,t} \tag{3}$$

In equation-3, t denotes the number of observations, Z denotes the number of independent variables, and N represents the number of panel members. It was supposed that a variation between the slope coefficients α_{1i}, $\alpha_{2i}\dots\dots$ α_{Zi}, and the member-specific intercept α_0 can occur across each cross-section. The relevant panel cointegration test statistics could be computed through panel cointegration regression Eq. (2). The existed difference between estimated residuals and original series to compute the panel–ρ and panel-*t* statistics are represented in the following regression:

$$Y_{i,t} = c_{1i} \ \Delta x_{1i,t} + c_{2,i}x_{2i,t} + \dots\dots\dots\dots\dots\dots + c_{Z,i}\Delta x_{Zi,t} + \widehat{\varphi}_{i,t} \tag{4}$$

The Newey-West (1987) estimator represented the residuals of the regression, the variance represented by $\hat{\varphi}^2_{i,t}$ and symbolized as per $\hat{L}^2_{11i}$ was calculated as:

$$\widehat{L}^2_{11i} = \frac{1}{T}\sum\nolimits_{t=1}^{T}\widehat{\varphi}^2_{i,t} + \frac{2}{T}\sum\nolimits_{s=1}^{k_i}\left(1-\frac{s}{k_i+1}\right)1/T\sum\nolimits_{t=s+1}^{T}\widehat{\varphi}_{i,t}\ \widehat{\varphi}_{i,t-s} \tag{5}$$

The regression is estimated for both panel–ρ and group–ρ statistics by using $\hat{\varepsilon}_{i,t} = \hat{\gamma}_i\hat{\varepsilon}_{i,t-1} + \hat{\mu}^2_{i,t}$, using the residuals $\hat{e}_{i,t}$ from the cointegration equation-2. After that the long-run variance ($\hat{\sigma}^2_i$) and contemporaneous variance ($\hat{s}^2_i$) of $\hat{\mu}_{\mathrm{i,t}}$ were computed, where:

$$\hat{s}_i^{\ 2} = \sum\nolimits_{t=1}^{t}\hat{\mu}_{\mathrm{i,t}}\text{And}$$
$$\hat{\sigma}_i^{\ 2} = \frac{1}{T}\sum\nolimits_{t=1}^{T}\hat{\mu}_{\mathrm{i,t}} + \frac{2}{T}\sum\nolimits_{s=1}^{k_i}\left(1-\frac{s}{k_i+1}\right)1/T\sum\nolimits_{t=s+1}^{T}\hat{\mu}_{\mathrm{i,t}}\hat{\mu}_{\mathrm{i,t-s}} \tag{6}$$

Where, k_i stands as lag length and additionally, authors also calculated the term:

$$\tau_i = \frac{1}{2}\left(\hat{\sigma}_i^{\ 2}-\hat{s}_i^{\ 2}\right)$$

However, for panel-*t* and group–*t* again using the residuals of $\hat{\varepsilon}_{i,t}of\,\hat{\varepsilon}_{i,t}$ cointegration regression-1, we estimated $\hat{\varepsilon}_{i,t} = \hat{\gamma}_i\hat{\varepsilon}_{i,t-1} + \sum_t^k = 1\hat{\gamma}_{ik}\Delta\hat{\varepsilon}_{i,t-1} + \hat{\mu}^*_{i,t}$. In this study, the step-down procedure and the Schwarz lag order selection criteria have been applied to determine the lag truncation order of ADF *t*-statistics.

$$\hat{s}_{\mathrm{i}}^{*2} = 1/T\sum_{t=1}^{T}\hat{\mu}_{\mathrm{i},t}^{*2},\ \sim\hat{s}_{\mathrm{i},t}^{*2}\equiv 1/Nt = 1N\hat{s}_{\mathrm{i}}^{*2}$$

The next move was the computation of the relevant Pedroni panel cointegration statistics based on within dimension using the following expressions:

a) Pedroni *v*-statistic:

$$Z_v = \left(\sum_{i=1}^{N}\sum_{i=1}^{T}\hat{L}_{11i}^{-2}\hat{\varepsilon}_{it-1}^{2}\right)^{-1}$$

b) Panel statistic:

$$Z_p = \left(\sum_{i=1}^{N}\sum_{i=1}^{T}\hat{L}_{11}^{-2}\hat{\varepsilon}_{it-1}^{2}\right)^{-1}\sum_{i=1}^{N}\sum_{i=1}^{T}\hat{L}_{11}^{-2}\hat{\varepsilon}_{it-1}^{2}\left(\hat{\varepsilon}_{it-1}\Delta\,\hat{\varepsilon}_{it}-\hat{\tau}_i\right)$$

c) Panel pp-statistic:

$$Z_t = \left(\hat{\sigma}^{2}\sum_{i=1}^{N}\sum_{i=1}^{T}\hat{L}_{11}^{-2}\hat{\varepsilon}_{it-1}^{2}\right)^{-\frac{1}{2}}\sum_{i=1}^{N}\sum_{i=1}^{T}\hat{L}_{11}^{-2}\hat{\varepsilon}_{it-1}^{2}\left(\hat{\varepsilon}_{it-1}\Delta\,\hat{\varepsilon}_{it}-\hat{\tau}_i\right)$$

d) Panel ADF statistic:

$$Z_{*p} = \left(\hat{S}^{*2}\sum_{i=1}^{N}\sum_{i=1}^{T}\hat{L}_{11}^{-2}\hat{\varepsilon}_{it-1}^{2}\right)^{-\frac{1}{2}}\sum_{i=1}^{N}\sum_{i=1}^{T}\hat{L}_{11}^{-2}\hat{\varepsilon}_{it-1}^{*2}\left(\hat{\varepsilon}_{it-1}^{*2}\Delta\hat{\varepsilon}_{it}\right)$$

For Pedroni panel cointegration statistics based on between dimensions, it was used the following expressions:

a) Group-*p* statistic

$$\overline{z}_p = \sum_{i=1}^{N}\left(\sum_{i=1}^{T}\hat{\varepsilon}_{it-1}^{-2}\right)^{-1}\sum_{i=1}^{T}\hat{\varepsilon}_{it-1}^{2}\left(\hat{\varepsilon}_{it-1}\Delta\hat{\varepsilon}_{it}-\Delta\,\hat{\tau}_i\right)$$

b) Group *pp*-statistic

$$\overline{z}_t = \sum_{i=1}^{N}\left(\hat{\sigma}^{2}\sum_{i=1}^{T}\hat{\varepsilon}_{it-1}^{-2}\right)^{-1/2}\sum_{i=1}^{T}\hat{\varepsilon}_{it-1}^{2}\left(\hat{\varepsilon}_{it-1}\Delta\hat{\varepsilon}_{it}-\hat{\tau}_i\right)$$

c) Group ADF statistic:

$$\overline{z}_t^{\,*} = \sum_{i=1}^{N}\left(\sum_{i=1}^{T}\hat{S}^{*2}\hat{\varepsilon}_{it-1}^{-2}\right)^{-1/2}\sum_{i=1}^{T}\hat{\varepsilon}_{it-1}^{*}\left(\hat{\varepsilon}_{it-1}\Delta\hat{\varepsilon}_{it}\right)$$

In the end, to have a standard normally distributed statistics, the appropriate variance and mean adjustment has been applied to each panel cointegration. $\frac{\chi_{N,T}-\mu\sqrt{N}}{\sqrt{v}} => N(0,1\ )$ where $\chi_{N,\,T}$ are the properly standardized technique and functions of moments of the underlying Brownian motion functional. $H_0 : \hat{\gamma}_i = 1$, for all, *I* represents the null hypothesis as no cointegration. Whereas, an alternative hypothesis has two conditions: first, between-dimension-based and second, within-dimension-based panel cointegration test. Condition one $H_a : \hat{\gamma}_i < 1$ for all i. Whereas, common value $\hat{\gamma}_i = \hat{\gamma}$ is not required. However, in the case of within-dimension-based$H_a : \hat{\gamma} = \hat{\gamma}_i < 1$ for all *I*, but the common value $\hat{\gamma}_i = \hat{\gamma}$ is required in this case.

The Westerlund cointegration approach To have validated and more reliable results, Westerlund (2007) test of cointegration has been applied. This test enables the researchers to estimate the diverse forms of heterogeneity along with *p* values. Westerlund (2007) test strengthens the cross-sectional dependence through bootstrapping. Four test statistics are planned in this cointegration test. First, two tests out of four are designed to consider the cointegrated as a whole panel. Second, the remaining two tests are intended to examine the cointegrated panel with at least one cross-sectional unit. The first explained two test statistics based on whole cointegration are referred to as group statistics and denoted by (G_τ and G_α); whereas, the other two are referred to panel statistics which are denoted by (P_τ and P_α). The null hypothesis of this test is no error-correction. It means that if the null hypothesis is rejected, cointegration exists among variables. The Westerlund (2007) tests are based on the following error correction model:

$$\Delta y_{it} = \delta' d_t + \alpha_i\left(y_{it-1}-\beta_i' x_{it-1}\right) + \sum_{j=1}^{p_i}\alpha_{ij}\Delta y_{it-j} + \sum_{j=-q_i}^{p_i}\gamma_{ij}\Delta\,x_{it-j} + e_{it} \qquad (7)$$

In Eq. (7) $t = 1,\ldots, T$ and $i = 1,\ldots\ldots, N$ stand as time-series and cross-sectional units respectively, while d_t contains the deterministic components.

Pooled mean group regression

The mentioned cointegration tests well validate the cointegration relationship between the variables. In a third step, we apply the pooled mean group regression (PMG) recommended by Pesaran (1997) and Pesaran et al. (1999), which enables convergence speed and short-run adjustment to measure the heterogeneity of each country. Pesaran et al. (1999) suggested that this model takes the cointegration form of the simple ARDL model and adapts it for a panel set by allowing the intercepts, short-run coefficients, and cointegrating terms to differ across cross-sections. It further executes the restrictions of the cross-country homogeneity on the long-run coefficients. Hence, the ARDL (*p*, *q*) model is as follows:

$$\Delta(I_i)_t = \sum_{j=1}^{p-1}\rho_j^i\Delta(I_i)_{t-j} + \sum_{j=0}^{q-1}\delta_j^i\Delta(x_i)_{t-j} + \theta^i\left[(I_i)_{t-1}-\alpha_1^i(X_i)_{t-j}\right] + e_{it} \qquad (8)$$

Where, $(I_i)_{t-j}$ and $(I_i)_{t-1}$ describe short and long-run standards regarding CO_2 emissions, respectively; while ρ_j^i and δ_j^i are the short-run coefficients; θ^i is the error correction term; $(x_i)_{t-j}$ and $(X_i)_{t-j}$ are the values of short-run and long-run variables, α_1^i are the long-run coefficients; and $e_{it} = \mu_i + v_{it}$; whereas μ_i and v_{it} represents country-specific fixed and time-variant effects respectively.

The Dumitrescu–Hurlin causality test

A few policy implications can be defined through the analysis of short-run and long-run connections without prior knowledge regarding the causal association between them (Shahbaz et al. 2013). Therefore, in a fourth step, we applied the Dumitrescu and Hurlin (2012) causality test, as this is an appropriate method and represents the more advantages as compared with the traditional Granger (1969) causality test. The DH presents the two important domains of heterogeneity known as the heterogeneity of the regression model and heterogeneity of the casual relationship.

DOLS and GM-FMOLS

Having evidence of both cointegration Pedroni and Westerlund tests on the empirical model, the estimation of the parameters presented in the empirical model is the next and last step. Nevertheless, the desired results may find by applying ordinary least squares (OLS) method on panel data. Also, the fixed effect, random effect, and GMM approach could be a cause of inconsistency and misleading coefficients when applied to cointegrated panel data (Ahmed et al. 2017). To avoid the type of inconsistency concerning the OLS, fixed effect, random effect, and GMM methods, it is instructive to use the Group Mean Fully Modified Ordinary Least Squares (GM-FMOLS) proposed by Pedroni (2001b) and dynamic ordinary least square (DOLS) introduced by Stock and Watson (1993). To test the strength of the long-run coefficient through the PMG method, the GM-FMOLS and DOLS methods are considered the most appropriate techniques. FMOLS is believed to eliminate the hassle of endogeneity in the regressors, and serial correlation within the errors, which might also result in consistent estimate parameters in a relatively small sample. Likewise, the problem of endogeneity, multicollinearity, and serial correlation is solved by using the DOLS estimator. Moreover, the DOLS method gives the cointegrating vector.

Results and their discussion

Table 8 (see in the Appendix) represents the statistics summary of being selected variables presented throughout 1990–2014. According to these statistics, the highest CO_2 emissions (in metric tons per capita) were in Brunei (24.60) in 2011, while the lowest level was in the Maldives (0.6703) in 1991 in the high-income countries list. The average value of CO_2 emissions was in high-income countries (6.98). In the Middle-income countries, the maximum of CO_2 emissions was in Indonesia (2.55) in 2012, and the minimum was in Sri Lanka (0.2232).

Moreover, the average emissions were 0.92 in the middle-income economies. In the case of low-income countries, the maximum value of CO_2 emissions was in Pakistan (0.9910) in 2007 and a minimum in Nepal (0.033835) in 1990 with an average of 0.30. Furthermore, in the case of the South Asian and Southeast Asian region, the highest value of CO_2 emissions was in Iran (8.2830) in 2014 and Brunei (24.60) in 2011 respectively. The minimum value of CO_2 emissions in the South, Southeast region, was in Nepal and Maldives. The mean value of CO_2 emissions was 1.90 and 6.98, in South and Southeast Asian regions respectively.

The highest value of real GDP (in US dollars constant 2010) was in Brunei (37,838.32) in 1992, while the lowest value of real GDP was in Myanmar (193.24 32) in 1991. The average real GDP was 4274.18 over the period 1990–2014 of the selected countries. Regarding the level of forest (km^2) per thousand people, Bhutan has the highest forest area (49.64) in 1995, while the lowest area was covered by Maldives (0.024495) in 2014.

The most top urbanized country per capita was Brunei (0.7633) in 2014, and the minimum migration was in Nepal (0.0885) in 1990. The average value of urbanization per capita was 0.3518. The matrix correlation between our analysis variables shows that CO_2 emissions are positively correlated with GDP and urbanization in all panels. On the other hand, CO_2 emissions are positively correlated with forest in high-income countries and Southeast Asian regions while, negatively correlated in low, middle-income countries and the South Asian region. Furthermore, the forest is positively correlated with urbanization in high-income countries and the Southeast Asian region and has a negative relationship in low, middle income, and south Asian regions. This empirical research estimation begins with the application of several panel-unit root tests to analyze the stationarity properties. ADF Fisher and PP-Fisher tests are used in the variables to measure the integration property.

Along with CO_2 emissions of a country which can affect environmental conditions of another country, the countries of the South and Southeast Asian regions are also suffering from the cross-country heterogeneity, cross-sectional dependence, and transborder pollutants effect (Behera and Dash 2017). A well-known Pesaran (2007) unit root test has been used to manage the ambiguity of cross-sectional dependence.

The results of the PP-Fisher and ADF Fisher panel unit root tests are presented in Table 9 (see in the Appendix). In all the cases of different panels of the countries, almost all the variables are non-stationary at the level. However, variables are stationary at first difference rejecting the null hypothesis at 5% level of significance. This result shows that the variables contain a panel unit root. The literature illustrated that to manage the cross-sectional dependence, the ADF test is not enough. Therefore, the presence of cross-sectional dependence is controlled by applying the Pesaran (2007) unit root test.

The result in Table 2 also shows that all the variables are non-stationary at the level and they are stationary at first difference. So, we can declare that both first-and second-generation unit root tests have similar findings. Hence, after the first order integration of variables, the next step is to analyze the cointegration among different variables. For this reason, we have used two cointegration tests name Pedroni (2004) and Westerlund (2007) known as second-generation.

The Pedroni panel cointegration results are reported in Table 3. In the case of low income, high income, South Asian, Southeast Asian region, and a full panel of the 17 countries, the results indicate that four out of seven statistics are accepting the alternative hypotheses of cointegration. It simply illustrates the long-run relationship of CO_2 emissions with GDP, forest per thousand persons, and urbanization. The results of the cointegration between the variables linked with Wang et al. (2016). But there is no cointegration in the case of middle-income countries. Table 4 reported the second-generation test of cointegration has been employed to overcome this issue of cross-sectional dependence crossways the SSEA regions. Overall, results concluded a long-run relationship between economic growth, deforestation, urbanization, and carbon emissions in the SSEA regions with both methods.

The pooled mean regression group results reported in Table 5. In the case of full countries panel, a long-run association between GDP square and urbanization with CO_2 emissions is observed. The result shows that a 1% increase in the urban population causes a 0.76% rise in carbon emissions. A positive and significant coefficient of GDP square is found which confirmed a U-shaped relationship, and these results align with (Chandran and Tang 2013; Lean and Smyth 2010; Liu et al. 2017; Narayan and Narayan 2010) in case of ASEAN countries, (Sarkodie and Strezov 2019) for India. However, forest and GDP are found to affect CO_2 emissions in the long run negatively. The result concludes a 0.73% increase in CO_2 emissions is due to a 1% decrease in a forest area while economic growth has 1.73% impact on CO_2 emissions in the opposite direction in the SSEA regions. There is no worthy association founded between the short-run variables presented in full panel. The short-run results of GDP per capita and urbanization are linked with Behera and Dash (2017). The negative and statically significant error correction term confirms the long-run relationship between variables. The error correction term − 0.42 shows that the speed of adjustment back towards the equilibrium is corrected by 0.42% each year.

Furthermore, in the case of subpanels' lower-income, high-income countries, South Asia, and Southeast Asian region results indicate that urbanization has a positive relationship with CO_2 emissions although; the coefficients of urbanization vary between 0.98 and 1.57 in all subpanels except middle-income group. However, in the case of middle-income countries, urbanization negatively affects CO_2 emission in the long run.

Moreover, forests and GDP are negatively related to CO_2 emissions in the entire income groups countries with the other two subpanels name as South and Southeast Asian regions in the long run. The forest coefficients vary between − 0.09 and − 3.5 in all panels.

Nevertheless, the GDP and GDP square sign, as well as the significance level, are providing evidence of U-shaped relationship in the middle, high, South, and Southeast Asian region panels. The signs of the GDP and GDP square are consistent with (Begum et al. 2015; Mert and Bölük 2016; Wang et al. 2017). Country specific conditions and policies, and various econometric approaches produced divergent results on the validity of the EKC hypothesis in the Asian economies (Ota 2017). However, our study found insignificant results in the low-income group. The EKC hypothesis is not fulfilled in low-income countries because they are in the stage of early development (income inequality is higher than the income equality) (Al-mulali et al. 2015).

Moreover, the error correction term is significant and confirms the long-run relationship among the variables. There is no association has been reported between the short-run variables presented in all subpanels.

Table 6 reported FMOLS and DOLS results to examine the long-run coefficients to check the robustness of the PMG estimates. The empirical results indicate that that coefficient of forest per thousand people has a negative and significant impact on CO_2 emissions in the case of the full panel as well as low-income, middle-income, and Southeast Asian regions while there is an insignificant relationship exist in South Asian region. The results indicate that these areas are facing deforestation. Moreover, we found a positive impact of forest on CO_2 emissions in the high-income countries. It means that the forest area is also increasing with economic growth in high-income countries. Conversely, we found the same results as well with the DOLS method. GDP per capita has an inverse and significant effect on CO_2 emissions in the case of the full panel of countries along with low-income, high-income, South Asia, and Southeast Asian regions. Our empirical evidence is similar to (Alam et al. 2016; Apergis 2016; Ben Jebli et al. 2016; Le and Quah 2018; Li et al. 2016; Ouyang and Lin 2017; Shahbaz et al. 2015; Zaman and Moemen 2017).

The relationship between urbanization and CO_2 emissions is positive and significant in the full panel as well as in all other sub-panels and results similar to (Sheng and Guo 2016). Moreover, the same results as FMOLS could be found by

Table 2 Unit root analysis with cross-sectional dependence

Economies		Without trend			With trend		
	Variables	*T*-bar	*Z*-*t*-tilde-bar	*P* value	*T*-bar	*Z*-*t*-tilde-bar	*P* value
Low	co2	−0.6987	2.3588	0.9908	−2.0527	1.4039	0.0802
	Δco2	−14.0299	−9.0816	0.0000	−13.8212	−8.6214	0.0000
	for	−8.9129	3.8533	0.0001	−0.6736	3.9803	1.0000
	Δfor	−3.3e+02	−8.6182	0.0000	−6.2e+02	−7.5096	0.0000
	gdp	2.5579	9.8721	1.0000	−1.5299	0.4287	0.6659
	Δgdp	−38.7851	−7.9674	0.0000	−41.7996	−7.7702	0.0000
	urban	−8.2941	−2.4824	0.0065	−1.2090	2.3034	0.9894
	Δurban	−5.0e+02	8.5900	0.0000	2.5e+03	−8.2457	0.0000
Middle	co2	−1.0941	1.1761	0.8802	−1.9038	−1.0813	0.1398
	Δco2	−15.9851	−9.4507	0.0000	−15.1513	−8.8493	0.0000
	for	−3.6954	−2.3114	0.0104	−1.1728	2.6901	0.9964
	Δfor	−2.5e+02	−8.7721	0.0000	−4.0e+02	−8.1931	0.0000
	gdp	0.8125	6.7456	1.0000	−1.7013	−0.1289	0.4487
	Δgdp	−62.0221	−8.6555	0.0000	−64.2276	−8.1657	0.0000
	urban	−2.9564	1.3850	0.9170	1.5991	6.6557	1.0000
	Δurban	−4.3e+02	−8.4632	0.0000	−5.1e+02	−8.2850	0.0000
High	co2	−1.8202	−0.7409	0.2294	−2.9692	−3.0330	0.0012
	Δco2	−18.5212	−9.2953	0.0000	−17.7057	−8.7487	0.0000
	for	−6.7752	−0.0350	0.4860	−1.1105	2.1584	0.9846
	Δfor	−4.0e+02	−8.5070	0.0000	−4.5e+02	−8.3008	0.0000
	gdp	−1.1662	0.7887	0.7849	−2.5264	−2.1930	0.0142
	Δgdp	−31.3966	−9.1109	0.0000	−29.1606	−8.5159	0.0000
	urban	−3.4455	−0.5939	0.2763	−0.6620	2.2967	0.9892
	Δurban	2.5e+03	−8.2457	0.0000	−5.0e+02	8.5900	0.0000
All panels	co2	−1.1681	1.6982	0.9569	−2.2697	−3.1213	0.0009
	Δco2	−16.7288	−8.5252	0.0000	−15.9202	−8.0469	0.0000
	for	−6.4427	−3.6814	0.0001	−0.9783	5.1333	1.0000
	Δfor	−4.7e+02	−7.3951	0.0000	−5.4e+02	−7.3420	0.0000
	gdp	0.8466	10.3001	1.0000	−1.8834	−1.0112	0.1560
	Δgdp	−23.9342	−8.0785	0.0000	−22.2837	−7.5857	0.0000
	urban	−4.9841	−0.9740	0.1650	−0.5700	6.5680	1.0000
South Asia	co2	−0.9365	1.8881	0.9705	−2.2592	−2.0900	0.0183
	Δco2	−20.3392	−10.7264	0.0000	−19.2348	−10.0229	0.0000
	for	−4.0489	0.7307	0.7675	−0.4151	3.6659	0.9999
	Δfor	−5.2e+02	−10.5298	0.0000	−7.5e+02	−9.2918	0.0000
	gdp	1.1654	8.0253	1.000	−1.9150	−0.7964	0.2120
	Δgdp	−48.4027	−4.0792	0.0000	−46.8773	−9.4085	0.0000
	urban	−3.1497	0.2438	0.5963	0.2639	4.9373	1.000
	Δurban	−2.7e+02	−10.3959	0.0000	−4.2e+02	−9.9389	0.0000
Southeast Asia	co2	−1.3741	0.5539	0.7102	−2.2790	−2.3193	0.0102
	Δco2	−22.9334	−11.288	0.0000	−22.0027	−10.534	0.0000
	for	−8.5706	−5.7484	0.0000	−1.4858	3.5989	0.9998
	Δfor	−88.0121	−11.0417	0.0000	−1.6e+02	−10.6638	0.0000
	gdp	0.5232	6.5898	1.0000	−1.8554	−0.6361	0.2624
	Δgdp	−70.8814.	−10.8381	0.0000	−80.3528	−10.1641	0.0000
	urban	−6.6148	−1.5685	0.0584	−0.3423	4.3720	1.0000

Table 2 (continued)

Economies	Variables	Without trend			With trend		
		T-bar	*Z*-*t*-tilde-bar	*P* value	*T*-bar	*Z*-*t*-tilde-bar	*P* value
	Δurban	− 1.1e+03	− 11.9676	0.0000	− 6.6e+03	− 11.6531	0.0000

We report (*T*-bar) and *Z* (*t*-tilde-bar) statistics in the table

applying an alternative DOLS estimator. The mentioned statement illustrates that, in SSEA regions, deforestation and urbanization are the primary cause of increasing CO_2 emissions.

Table 7 reports Dumitrescu and Hurlin (2012) causality results, and we note the presence of feedback effect, i.e., forest, urbanization, and economic growth, are found to have bidirectional causality with CO_2 emissions in case of the full countries, South Asian, and Southeast Asian regions panels. However, the unidirectional causality is seen running from economic growth to CO_2 emissions is confirmed for the case of entire countries and South Asia panels. Moreover, no causal relationship exists between economic growth and CO_2 emissions in the case of the Southeast Asian region.

Furthermore, in low-income countries, CO_2 emissions have a bidirectional causal link with forest and urbanization. The results also illustrated that economic growth and urbanization bidirectional causes forest while; unidirectional causality exists towards CO_2 emissions and urbanization to economic growth. Furthermore, high-income countries have a little different pattern than low-incomecountries—for instance, bidirectional relationships found between the urbanization and forest, economic growth and forest, and urbanization with forest and economic growth. The unidirectional causality is detected running from the forest and economic growth to CO_2 emissions. However, in the case of middle-income countries, a neutral effect is observed between forests, economic growth with CO_2 emissions. A unidirectional casual association running from forest to economic growth is also found. The empirical findings support the implementation of proper management of forest area and control urbanization policy for the long run in the SSEA regions. Dumitrescu-Hurlin causality results indicate that all the variables are interdependent in all cases and our results a line with (Gokmenoglu et al. 2019).

Conclusions and policy implications

This study designed to determine the effects of deforestation, economic growth, and urbanization on carbon emissions in the South and Southeast Asian (SSEA) regions for the period of 1990–2014. This paper has examined the long-run relationship between CO_2 emissions, economic growth, urbanization, and forests by using Pedroni and Westerlund cointegration tests of 17 countries. The data was divided into five sub-panels, three of them are income-based groups (namely, lower, middle and high-income panels) and the other two are South and Southeast Asian regions.

As noted in the introduction and literature review, urbanization and deforestation process in the World and Asian countries in recent decades has been worrying about economic growth and sustainable economic growth. In this sense, the present study sought to assess the relationship between these variables. The conclusions reached allowed us to better understand what the mutual impact between those variables is and how policies can be formulated to promote sustainable growth, with urbanization and forest as presented in this process.

The Pedroni cointegration test yields the confirmation of the long-run relationship between forests, economic growth, urbanization and CO_2 emissions in the SSEA regions. Nonetheless, the results produce by Westerlund cointegration are somehow different as compared to the Pedroni test. Furthermore, in the case of a full panel of 17 countries, low income and South Asian region panel, the Westerlund cointegration test yield the evidence of a long-run relationship between CO_2 emissions, economic growth, urbanization, and forests, thus supporting the Pedroni results. However, in the case of high, middle income and Southeast Asian region panels, we do not find any indication of long-run relationships among the variables throughout 1990–2014. The second major findings were that the existence of a *U*-shaped relationship in the case of a full panel of the 17 countries, Middle, high income and South, Southeast Asian region panels. However, in the case of low-income countries, results did not confirm this relationship. The research has also shown that the bidirectional causality exists among the variables in the SSEA region.

Taken together, these results suggest that deforestation and urbanization are substantially raising the CO_2 emissions in the SSEA region. Also, the result shows that the significance of the relationship between forests, economic growth, urbanization and CO_2 emissions in all income groups and region-wise studies. This study concludes that deforestation is significantly increasing the level of CO_2 emissions in all income level countries and region wise panels resulted in an exaggeration

Table 3 Pedroni panel cointegration analysis

Economies		Low		Middle		High	
		Without trend	With trend	Without trend	With trend	Without trend	With trend
Within -dimension	Panel v-Statistic	0.1589 (0.4369)	0.109186 (0.4565)	0.386035 (0.3497)	− 0.217626 (0.5861)	− 1.338080 (0.9096)	− 1.687644 (0.9543)
	Panel rho-Statistic	− 0.03845 (0.4847)	0.3222 (0.6264)	0.917718 (0.8206)	1.377053 (0.9158)	− 0.108724 (0.4567)	− 0.567505 (0.2852)
	Panel PP-Statistic	− 1.9560 (0.0254)	− 2.4866 (0.0064)	0.500729 (0.6917)	− 0.140307 (0.4442)	− 1.355198 (0.0877)	− 4.640831 (0.0000)
	Panel ADF-Statistic	− 1.5606 (0.0593)	− 3.5751 (0.0002)	− 0.525094 (0.2998)	− 1.960120 (0.0250)	0.226538 (0.5896)	− 1.944049 (0.0259)
Between-dimension	Group rho-Statistic	0.5647 (0.7139)	0.7923 (0.7859)	1.814839 (0.9652)	2.321699 (0.9899)	0.582150 (0.7198)	0.292276 (0.6150)
	Group PP-Statistic	− 2.9326 (0.0017)	− 4.2184 (0.0000)	0.728121 (0.7667)	0.522206 (0.6992)	− 1.466860 (0.0712)	− 12.05880 (0.0000)
	Group ADF-Statistic	− 2.7258 (0.0032)	− 3.9835 (0.0000)	− 0.364402 (0.3578)	− 1.193842 (0.1163)	− 0.368968 (0.3561)	− 3.673069 (0.0001)
Regions		South Asia		Southeast Asia		All countries	
Within-dimension	Panel v-Statistic	− 0.154997 (0.5616)	− 0.097587 (0.5389)	− 0.325699 (0.6277)	− 0.923213 (0.8221)	− 0.337266 (0.6320)	− 0.743840 (0.7715)
	Panel rho-Statistic	− 0.026388 (0.4895)	0.145972 (0.5580)	0.542221 (0.7062)	0.891522 (0.8137)	0.355065 (0.6387)	0.753451 (0.7744)
	Panel PP-Statistic	− 1.829361 (0.0337)	− 4.521192 (0.0000)	− 0.812772 (0.2082)	− 1.387085 (0.0827)	− 1.895021 (0.0290)	− 3.939011 (0.0000)
	Panel ADF-Statistic	− 0.098174 (0.4609)	− 3.302581 (0.0005)	− 1.650802 (0.0494)	− 3.164292 (0.0008)	− 1.291757 (0.0582)	− 4.535434 (0.0000)
Between-dimension	Group rho-Statistic	0.748567 (0.7729)	1.050942 (0.8534)	1.671094 (0.9526)	1.769631 (0.9616)	1.729413 (0.9581)	2.008536 (0.9777)
	Group PP-Statistic	− 1.959334 (0.0250)	− 10.74315 (0.0000)	− 1.046052 (0.1478)	− 1.877356 (0.0302)	− 2.105206 (0.0176)	− 8.735720 (0.0000)
	Group ADF-Statistic	− 0.953525 (0.1702)	− 4.528175 (0.0000)	− 1.899179 (0.0288)	− 2.695894 (0.0035)	− 2.035969 (0.0209)	− 5.067853 (0.0000)

P-values are reported in the parentheses. Automatic selection of maximum lags is based on 0–2 SIC: Newey-west bandwidth selection using Bartlett and Kernel

Table 4 Westerlund (2007) panel cointegration analysis

Economies		G_t	G_a	P_t	P_a
Low income	Without trend	− 3.136 (0.00)	− 0.78 (1.00)	8.537 (0.00)	− 0.986 (0.99)
	With trend	− 3.452 (0.01)	− 0.45 (1.0)	− 8.717 (0.00)	− 0.765 (1.00)
High income	Without trend	− 3.467 (0.00)	− 5.42 (0.9)	− 4.388 (0.46)	− 2.385 (0.95)
	With trend	− 3.096 (0.15)	− 2.83 (1.0)	− 4.195 (0.91)	− 1.633 (0.99)
South Asia	Without trend	− 3.184 (0.002)	− 1.89 (1.00)	− 6.186 (0.238)	− 1.304 (0.996)
	With trend	− 3.321 (0.023)	− 0.90 (1.00)	− 7.997 (0.07))	− 1.212 (1.000)
Middle income	Without trend	− 2.703 (0.11)	− 1.122 (1.00)	− 3.724 (0.82)	− 1.390 (0.98)
	With trend	− 2.432 (0.77)	− 0.872 (1.00)	− 3.570 (0.99)	− 0.941 (1.00)
All countries	Without trend	− 3.080 (0.00)	− 2.267 (1.00)	− 7.354 (0.05)	− 1.454 (1.00)
	With trend	− 2.987 (0.09)	− 1.302 (1.00)	− 7.583 (1.00)	− 0.988 (1.00)
Southeast Asia	Without trend	− 2.988 (0.008)	− 2.601 (1.000)	− 5.030 (0.756)	− 1.541 (0.997)
	With trend	− 2.691 (0.518)	− 1.657 (1.000)	− 4.605 (0.999)	− 0.889 (1.000)

No cointegration taken as the null hypothesis. The test regression is fitted with constant, constant and trend, with one lag and a 0–1 lead. The width of the Bartlett Kernel, the window has been used in the semi parametric estimation of long-run variances. The *p* values are reported in the parentheses

of the greenhouse gas problem along with the destruction of environmental quality. However, it has been observed that industrialized and emerging economies are in the phase of restoration while developing the world in the stage of deforestation. Furthermore, urbanization is also significant in raising CO_2 emissions, but in the case of middle-income countries, we do not find any substantial effect.

Our results do not confirm EKC but evidence a U-shape relationship between CO_2 emissions and economic growth. Some studies found this kind of relationship, as Yandle et al. (2002), Wang et al. (2017), Begum et al. (2015) and Mert and Bölük (2016). The explanation for this result is based on the fact that most pollutants create localized problems like lead and sulfur, and there is a need to cleaning up such pollutants in a fast way. Therefore, as the regions verify economic growth, the marginal value of cleaning up such pollutants improves the quality of citizens' lives largely. On the contrary, reducing emissions

Table 5 Pooled mean group regression (PMG) analysis

Equations	Variables	High	Middle	Low	All	South (Asia)	Southeast (Asia)
Long run	Urban	1.43*** (4.84)	− 3.32** (2.89)	1.570*** (3.82)	0.760* (2.00)	1.191** (2.85)	0.981** (3.49)
	For	− 0.09* (1.66)	− 3.51** (2.98)	− 0.30** (− 2.79)	− 0.737** (3.19)	− 0.650** (2.70)	− 0.593*** (− 4.88)
	Gdp	− 0.58* (− 2.03)	− 9.45** (2.89)	− 0.207 (− 0.49)	− 1.723** (3.54)	− 1.64** (2.97)	− 0.149 (− 0.84)
	gdp^2	0.09** (3.22)	0.720** (3.17)	0.037 (0.71)	0.154 *** (4.28)	0.140 ** (3.51)	0.057 ** (3.18)
Error correction coefficients		− 0.43* (− 1.68)	− 0.26** (2.93)	− 0.39** (− 2.69)	− 0.42*** (5.25)	− 0.519** (3.36)	− 0.409 (4.60) ***
Short run	D. urban	2.433373 (1.00)	19.749 (0.90)	5.31* (1.88)	15.854 (1.01)	5.843 (0.98)	14.880 (− 1.53)
	D. for	3.988690 (1.29)	− 2.387 (0.43)	− 4.11 (− 1.29)	− 2.220 (1.03)	− 1.082 (0.51)	1.428 (0.49)
	D. gdp	75.93329 (1.26)	− 18.212 (1.54)	− 31.76 − 1.28)	25.180 (0.97)	1.479 (0.12)	35.56 (1.25)
	D. gdp^2	− 3.740775 (− 1.31)	1.247 (1.55)	2.671 (1.30)	− 1.168 (0.90)	− 0.192 (0.21)	− 1.79 (− 1.14)
Constants	_cons	− 2.16*** (6.22)	− 7.91** (2.82)	9.68** (3.56)	− 2.158** (6.18)	− 2.49** (4.04)	− 9.91 ** (2.82)
N		120	144	144	408	192	216

Note: *, **, and *** indicates 10%, 5% and 1% level of significance respectively. *T*-values reported in parentheses

Table 6 FMOLS and DOLS analysis

Economies	Variables	FMOLS	DOLS
High (income)	For	6.93*** (0.006)	10.29** (0.04)
	Gdp	−2.56*** (0.00)	−3.00 (0.34)
	urban	26.83*** (0.00)	38.01* (0.10)
	gdp^2	0.204*** (0.00)	0.166 (0.52)
Middle (income)	For	−0.10*** (0.00)	−1.65 (0.75)
	Gdp	0.032 (0.79)	49.39** (0.04)
	urban	0.88*** (0.00)	0.68** (0.02)
	gdp^2	0.013 (0.39)	−3.35** (0.04)
Low (income)	For	−0.09*** (0.00)	−0.137 (0.37)
	Gdp	−0.72*** (0.00)	0.295 (0.52)
	urban	0.96*** (0.00)	2.24*** (0.00)
	gdp^2	0.11*** (0.00)	−0.002 (0.96)
South (Asia)	For	0.030* (0.10)	0.055 (0.59)
	Gdp	−0.074 (0.36)	−0.627* (0.08)
	urban	1.58*** (0.00)	1.45*** (0.00)
	gdp^2	0.042*** (0.00)	0.104*** (0.00)
Southeast (Asia)	For	−0.29 (0.00)	−0.22 (0.09)
	Gdp	−0.55*** (0.00)	−0.87*** (0.00)
	urban	0.63*** (0.00)	−0.41* (0.08)
	gdp^2	0.090*** (0.00)	0.11*** (0.00)
All panels	For	−0.076*** (0.00)	−0.15* (0.09)
	Gdp	−0.192*** (0.00)	−0.53*** (0.00)
	urban	1.37*** (0.00)	0.76*** (0.00)
	gdp^2	0.052*** (0.00)	0.08*** (0.00)

*, **, and *** represents 1%, 5%, and 10% level of significance respectively. *P*-values reported in the parentheses. DOLS regression includes fixed leads and lags specifications. (Lead = 1, lag = 1) coefficient covariance computing with default method, long-run variance (Bartlett Kernel, Newey-west fixed bandwidth) used for coefficient covariance

has not so visible impact at the local level, but improves the environment at the global level.

This leads to the well-known "tragedy of the commons" (Hardin 1968), where no one has the incentive to reduce pollution, and in the end, everyone is worse. So, Yandle et al. (2002) state that even in countries with a high level of income, carbon emissions could not be decreasing following the EKC. Accordingly, as CO_2 is a global pollutant, there is no consensus about its validity within the Kuznets Curve (Uchiyama 2016). Yandle et al. (2002) referred that policies that stimulate growth (for instance trade liberalization) are good for environmental quality.

The existence of a U-shape curve may suggest that for the studied countries the re-linking hypothesis is being verified (CO_2 and yield simultaneously growing) (Sengupta 1996). On the other hand, population pressure in Asian countries may also be contributing to the verification of this assumption, as environmental quality may deteriorate as population pressure increases further. Furthermore, as stated by Ekins (1997), even if there is an EKC, growth in global population income will increase environmental damage. This damage is considered the main obstacle for achieving sustainable development (O'Neill et al. 1996). Thus, if the growth does not automatically lead to higher environmental quality, environmental policies should help in this regard. It should also be noted that when analyzing different countries together, the maximum level of pollution depends on the costs and benefits of reducing pollution, which differ between countries. Different countries will have different absorptive capacity, social preferences, and discount rates, which implies different optimal levels of pollution between countries. This warns of the limitation of collective policies compared to local policies (de Bruyn et al. 1998).

Our results also suggest that deforestation and urbanization could aggravate the environmental pollution and climate change of these regions and it could affect the further sustainable development in the long run.

The findings of our study have several important implications for future practices. We found that deforestation is significantly increasing carbon emissions in the SSEA regions. The conclusion of the study leads to several different questions regarding the forest policy as well as the scientific research also indicate the climate change which can increase the forest fire.

The findings suggest effective forest management to help to reduce CO_2 emissions from deforestation and degradation, so required proper development on forest management would be a policy recommendation in this regard. Although forest managers are aware that their margin of action is limited, the profession and utilization of woodland are by their very nature essentially "residuals" and most depending on what occurs within the different sectors of human activity. As forest development is essential in all aspects of the well-being of local and

Table 7 Pair-wise Dumitrescu-Hurlin panel causality analysis

Economies	Null hypothesis	W-Stat.	Z bar-Stat.	Prob.	Economies	W-Stat.	Z bar-Stat.	Prob.
Low income	LFOR does not homogeneously cause LCO2	7.23717	4.78823	0.0000	High income	3.14450	0.78399	**0.4330**
	LCO2 does not homogeneously cause LFOR	10.9435	8.34670	0.0000		5.71107	3.03348	0.0024
	LGDP does not homogeneously cause LCO2	4.76222	2.41200	0.0159		3.12970	0.77102	**0.4407**
	LCO2 does not homogeneously cause LGDP	2.49473	0.23497	**0.8142**		4.36016	1.84947	0.0644
	LURBAN does not homogeneously cause LCO2	10.3563	7.78295	0.0000		4.94210	2.35951	0.0183
	LCO2 does not homogeneously cause LURBAN	5.58497	3.20193	0.0014		6.53636	3.75681	0.0002
	LGDP does not homogeneously cause LFOR	7.62682	5.16233	2.E-07		5.67328	3.00036	0.0027
	LFOR does not homogeneously cause LGDP	4.24912	1.91938	0.0549		7.33536	4.45710	0.0000
	LURBAN does not homogeneously cause LFOR	11.4952	8.87643	0.0000		7.59784	4.68714	0.0000
	LFOR does not homogeneously cause LURBAN	10.5900	8.00736	0.0000		5.33372	2.70275	0.0069
	LURBAN does not homogeneously cause LGDP	3.86248	1.54816	**0.1216**		6.16823	3.43416	0.0006
	LGDP does not homogeneously cause LURBAN	4.49713	2.15749	0.0310		7.58490	4.67581	0.0000
Middle income	LFOR does not homogeneously cause LCO2	2.66007	0.39371	**0.6938**	South Asia	3.04477	0.88111	0.3783
	LCO2 does not homogeneously cause LFOR	3.83679	1.52349	**0.1276**		7.74611	6.09320	0.0000
	LGDP does not homogeneously cause LCO2	3.85426	1.54026	**0.1235**		4.43957	2.42744	0.0152
	LCO2 does not homogeneously cause LGDP	2.81804	0.54538	**0.5855**		3.45837	1.33965	**0.1804**
	LURBAN does not homogeneously cause LCO2	4.93484	2.57774	0.0099		5.59312	3.70632	0.0002
	LCO2 does not homogeneously cause LURBAN	4.43082	2.09383	0.0363		4.66720	2.67980	0.0074
	LGDP does not homogeneously cause LFOR	23.6029	20.5011	0.0000		20.5428	20.2801	0.0000
	LFOR does not homogeneously cause LGDP	2.60593	0.34173	**0.7326**		4.42401	2.41020	0.0159
	LURBAN does not homogeneously cause LFOR	55.9597	51.5672	0.0000		46.9872	49.5974	0.0000
	LFOR does not homogeneously cause LURBAN	6.25354	3.84384	0.0001		9.01147	7.49603	0.0000
	LURBAN does not homogeneously cause LGDP	9.79717	7.24612	0.0000		8.25107	6.65302	0.0000
	LGDP does not homogeneously cause LURBAN	7.40685	4.95114	0.0000		5.35963	3.44745	0.0006
Southeast Asia	LFOR does not homogeneously cause LCO2	5.63864	3.98466	0.0000	All countries	4.41799	3.50371	0.0005
	LCO2 does not homogeneously cause LFOR	6.14091	4.57528	0.0000		6.89630	7.50890	0.0000
	LGDP does not homogeneously cause LCO2	3.53675	1.51308	**0.1303**		3.96161	2.76614	0.0057
	LCO2 does not homogeneously cause LGDP	2.89005	0.75263	**0.4517**		3.15750	1.46661	**0.1425**
	LURBAN does not homogeneously cause LCO2	7.96805	6.72379	0.0000		6.85043	7.43479	0.0000
	LCO2 does not homogeneously cause LURBAN	6.15988	4.59759	0.0000		5.45744	5.18357	0.0000
	LGDP does not homogeneously cause LFOR	5.71136	4.07017	0.0000		12.6909	16.8735	0.0000
	LFOR does not homogeneously cause LGDP	4.71278	2.89595	0.0038		4.57689	3.76050	0.0002
	LURBAN does not homogeneously cause LFOR	7.42456	6.08471	0.0000		26.0423	38.4508	0.0000
	LFOR does not homogeneously cause LURBAN	6.18204	4.62365	0.0000		7.51354	8.50643	0.0000
	LURBAN does not homogeneously cause LGDP	5.19895	3.46764	0.0005		6.63524	7.08701	0.0000
	LGDP does not homogeneously cause LURBAN	7.38571	6.03903	0.0000		6.43226	6.75897	0.0000

5% level of significance has been used. Insignificant values are highlighted

national communities, the management must indulge them in defending the forests and their sustainable management.

In this regard, countries should be introduced an amendment in laws to protect the forests, and individual actions should be done against timber mafia. Colonization or new housing societies should be ban in the wooded areas, apartments or high buildings should be encouraged, and people would be required special permission before cutting trees. Another important practical implication is to aware people about the importance of trees on traditional media along with social media; especially motivate teenagers at the school level for the long-run sustainability. Moreover, the most appropriate and cost-effective method to minimize anthropogenic CO_2 emissions is the improvement of forest activities.

The second significant finding of the discussion above suggests that urbanization is significantly raising the carbon emissions in the South and Southeast Asian regions. It concludes that sustainable urbanization models should be applied instead of unreliable sustainable urbanization models in SSEA countries. Furthermore, to maintain a certain threshold level of pollution and environmental degradation, SSEA countries must take the initiative of a cross-country settlement. Also, an active interference for the trans-border movement should be implemented to regulate the air pollutants.

The confirmation of a U-shape relationship between CO_2 emissions and economic growth means that these countries can grow in a sustainable path, but they must be aware of long term risks of this economic growth, as this sustainable path could be compromised when reaching the turning point of the "U". Due to lenient environmental policies of the developing countries or ease of doing business and cheap labor together motivates the investor to invest in some Asian countries. This process is called carbon leakage. Conversely, developing countries are also more concern about employment opportunities rather than harmful environmental effects. In this situation, policymakers should revise the environmental policies and encourage environmentally friendly projects and compensate them for the taxes. Besides, it promotes investors to invest in remote areas, especially in the green zone. Every new project must declare some green space nearby to offsetting the carbon emissions.

The generalizability of these results is subject to the following limitations. First, forest per thousand-person data is used instead of per capita because the population is varying in different countries. Second, the data used for this study is bounded only to the country level with annual observations. Third, the study did not evaluate the use of other relevant variables that caused carbon dioxide emissions like energy demand, information, and communication technology (ICT), foreign direct investment, and trade openness.

Future research direction

Finally, and most importantly, the future recommendation is the nonlinear modeling procedures. This study could be possible with other econometric techniques like GMM two-step, or three steps approach, and a panel smooth transition regression model (PSTR). The present study could be tried with STRIPAT model, cubic model approach for EKC hypothesis, etc. Further investigation could focus on the implications at cities or district level. Moreover, this work should be exploited with quarterly data to check the proper short-run effects, or even more including more related variables with forest and urbanization with an extended sample period to capture the impact of deforestation policies by the countries in the SSEA regions.

Funding information This work was financially supported by the research unit on Governance, Competitiveness and Public Policy (UID/CPO/04058/2019), funded by national funds through FCT - Fundação para a Ciência e a Tecnologia.

Appendix

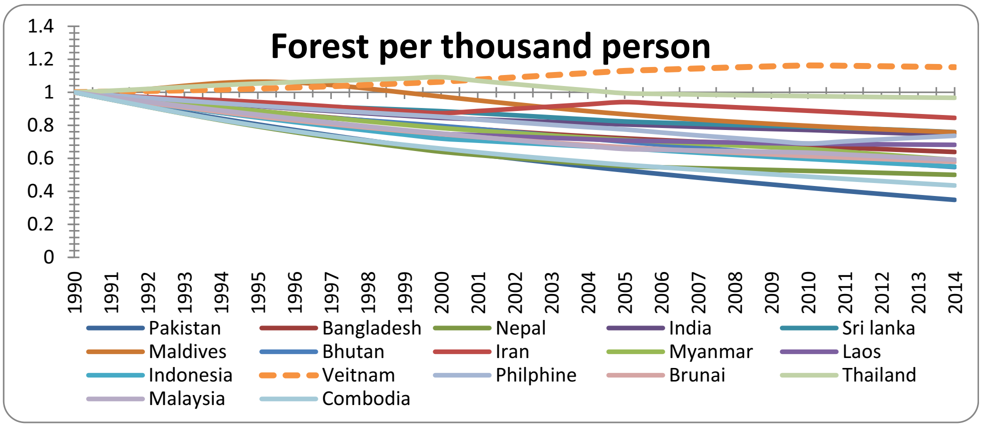

Fig. 1 Forest area per thousand persons

Table 8 Descriptive statistics and correlation matrix

Economies	Variables	Max	Min	Mean	S.D	CO_2	Forest	GDP	Urbanization
High income	CO_2	24.60	0.67	6.98	6.06	1	0.72	0.90	0.73
	Forest	15.96	0.03	5.02	4.79		1	0.74	0.62
	GDP	37,838.3	2502.71	11,808	12,418.07			1	0.57
	Urbanization	0.77	0.25	0.53	0.17				1
Middle income	CO_2	2.56	0.22	0.92	0.44	1	− 0.25	0.46	0.61
	Forest	49.65	0.55	8.63	15.59		1	− 0.08	− 0.17
	GDP	3692.94	431.89	1614.1	758.9			1	0.45
	Urbanization	0.53	0.16	0.31	0.35				1
Lower Income	CO_2	0.99	0.033	0.30	0.24	1	− 0.38	0.61	0.75
	Forest	41.43	0.08	8.46	11.30		1	0.09	− 0.13
	GDP	1470.50	193.24	655.73	268.89			1	0.65
	Urbanization	0.36	0.08	0.23	0.07				1
South Asian	CO_2	8.28	0.03	1.40	1.90	1	− 0.14	0.73	0.92
	Forest	49.64	0.02	6.02	14.11		1	− 0.14	− 0.09
	GDP	8124.70	357.20	2213.15	2127.83			1	0.63
	Urbanization	0.72	0.08	0.30	0.15				1
Southeast Asian	CO_2	24.60	0.67	6.98	6.06	1	0.72	0.90	0.73
	Forest	15.95	0.02	5.02	4.79		1	0.74	0.62
	GDP	37,838.32	2502.71	11,808.35	12,418.07			1	0.57
	Urbanization	0.76	0.25	0.53	0.17				1
Overall	CO_2	24.60	0.03	2.48	4.39	1	0.01	0.93	0.78
	Forest	49.64	0.02	7.51	11.81		1	0.04	− 0.08
	GDP	37,838.32	193.24	4274.18	8318.43			1	0.67
	Urbanization	0.76	0.08	0.35	0.17				1

Note: Authors own calculation based on the data over the period 1990–2014. Mean = simple average, Max = maximum; Min = Minimum; S.D. = standard deviation and right columns presented pair-wise correlations and results reported till second decimal

Table 9 Unit root analysis

Economies		Without trend		With trend		Economies	Without trend		With trend	
	Variables	ADF Fisher	PP-Fisher	ADF Fisher	PP-Fisher		ADF Fisher	PP-Fisher	ADF Fisher	PP- Fisher
Low	co2	5.694 (0.930)	5.040 (0.956)	10.294 (0.590)	9.622 (0.649)	High	8.5416 (0.576)	12.706 (0.240)	11.3814 (0.3286)	19.914 (0.042)
	Δco2	45.432 (0.000)	84.278 (0.000)	33.612 (0.000)	71.369 (0.000)		53.016 (0.000)	111.086 (0.000)	42.229 (0.000)	322.67 (0.000)
	For	12.389 (0.415)	116.319 (0.000)	26.402 (0.009)	9.517 (0.658)		11.494 (0.3203)	27.899 (0.001)	23.415 (0.009)	3.0097 (0.983)
	Δfor	6.701 (0.876)	3.919 (0.984)	27.586 (0.006)	2.564 (0.997)		21.102 (0.010)	7.3107 (0.695)	14.7406 (0.141)	5.4682 (0.857)
	Gdp	0.5072 (1.000)	0.2898 (1.00)	4.595 (0.970)	5.052 (0.956)		3.8101 (0.95)	4.3174 (0.93)	20.98 (0.02)	15.217 (0.13)
	Δgdp	26.158 (0.010)	50.024 (0.000)	27.779 (0.006)	50.670 (0.000)		54.26 (0.000)	87.61 (0.000)	39.38 (0.000)	203.99 (0.000)
	Urban	36.661 (0.000)	53.760 (0.000)	23.3927 (0.024)	5.381 (0.944)		157.49 (0.000)	57.594 (0.000)	29.154 (0.001)	2.797 (0.985)
	Δurban	7.885 (0.794)	5.179 (0.951)	14.913 (0.246)	40.479 (0.001)		7.189 (0.707)	10.591 (0.390)	6.117 (0.805)	71.557 (0.000)
Middle	co2	7.718 (0.806)	8.573 (0.738)	10.650 (0.559)	8.2532 (0.765)	All	21.954 (0.94)	26.32 (0.82)	32.32 (0.54)	37.79 (0.30)
	Δco2	55.790 (0.00)	90.429 (0.00)	41.169 (0.00)	73.000 (0.00)		154.24 (0.00)	285.79 (0.00)	117.0 (0.00)	467.04 (0.00)
	For	12.577 (0.400)	39.664 (0.0001)	249.28 (0.000)	6.846 (0.867)		36.461 (0.354)	183.88 (0.000)	299.09 (0.000)	19.373 (0.979)
	Δfor	44.536 (0.000)	6.954 (0.860)	25.044 (0.014)	2.836 (0.996)		72.34 (0.000)	18.185 (0.987)	67.37 (0.000)	10.86 (0.999)
	Gdp	4.286 (0.977)	1.869 (0.999)	6.167 (0.907)	7.493 (0.823)		8.6038 (1.00)	6.476 (1.000)	31.745 (0.578)	27.763 (0.766)
	Δgdp	37.077 (0.000)	61.734 (0.000)	29.705 (0.003)	53.182 (0.000)		117.50 (0.000)	199.36 (0.000)	96.865 (0.000)	307.85 (0.000)
	Urban	12.467 (0.408)	57.914 (0.000)	8.945 (0.707)	1.796 (0.999)		206.625 (0.000)	169.270 (0.000)	61.492 (0.85)	9.975 (1.000)
	Δurban	3.698 (0.988)	2.350 (0.998)	4.772 (0.965)	4.542 (0.971)		18.773 (0.9840)	18.121 (0.988)	25.802 (0.05)	116.580 (0.000)
South Asia	co2	9.192 (0.905)	9.4688 (0.892)	9.040 (0.911)	20.493 (0.198)	Southeast Asia	12.761 (0.805)	16.851 (0.533)	23.286 (0.179)	17.297 (0.502)
	Δco2	75.150 (0.000)	162.527 (0.000)	56.324 (0.000)	356.35 (0.000)		79.089 (0.000)	123.26 (0.000)	60.686 (0.000)	110.692 (0.000)
	For	11.044 (0.806)	79.638 (0.000)	269.203 (0.000)	6.945 (0.974)		25.417 (0.113)	104.24 (0.000)	29.89 (0.630)	12.428 (0.824)
	Δfor	61.276 (0.000)	9.934 (0.870)	63.598 (0.000)	5.987 (0.988)		11.0635 (0.891)	8.25 (0.97)	48.17 (0.00)	59.11 (0.00)
	Gdp	1.195 (1.000)	1.570 (1.000)	13.240 (0.6551)	15.930 (0.457)		7.981 (0.992)	5.996 (0.998)	23.794 (0.2515)	14.747 (0.790)
	Δgdp	63.245 (0.000)	127.345 (0.000)	51.948 (0.000)	243.87 (0.000)		67.098 (0.000)	94.1594 (0.000)	54.725 (0.000)	81.345 (0.000)
	Urban	75.761 (0.000)	81.609 (0.000)	9.119 (0.908)	5.630 (0.991)		130.86 (0.000)	87.660 (0.000)	28.574 (0.063)	4.345 (0.999)
	Δurban	9.826 (0.875)	5.066 (0.995)	28.94 (0.00)	31.312 (0.012)		8.946 (0.9610)	13.055 (0.788)	58.661 (0.00)	51.424 (0.000)

Note: *P*-values are reported in the parentheses. Automatic selection of maximum lags is based on 0–2 SIC: Newey-west bandwidth selection using Bartlett and Kernel

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