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# Technology policy and environmental quality at crossroads: Designing SDG policies for select Asia Pacific countries

Avik Sinha[a,*], Tuhin Sengupta[a,b], Tanaya Saha[c]

[a] Centre for Excellence in Sustainable Development, Goa Institute of Management, India
[b] Department of Information Technology and Operations Management, Goa Institute of Management, India
[c] Department of Comparative Literature, Jadavpur University, India

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ABSTRACT

Since the inception of Sustainable Development Goals (SDGs), the Asia Pacific countries are facing difficulties in attaining the SDG objectives, as maintaining the environmental quality has been a challenge for them. In this study, we have revisited the technology policies of these countries, and in doing so, we have tried to address the problem of environmental degradation, while addressing the issues of sustainable economic growth, clean and affordable energy, and quality education. In this pursuit, we have designed two indices for environmental degradation and technological advancement, and then analyzed the association between them following the Environmental Kuznets Curve (EKC) hypothesis. Following IPAT framework, and by using quantile approach, over a period of 1990–2017, we have found that the turnaround points of EKCs rise with the rise in quantiles, i.e. quantiles with low pollutions are having turnaround points within sample range, whereas quantiles with high pollutions are having turnaround points outside sample range. Using Rolling Window Heterogeneous Panel Causality test, unidirectional causality has been found running from technological advancement to environmental degradation. Following the results obtained from the analysis, we have tried to address the objectives of SDG 13, SDG 4, SDG 8, SDG 9, SDG 7, and SDG 10.

## 1. Introduction

The UN initiative of "*Transforming our world: the 2030 Agenda for Sustainable Development*" was enforced with the aim to initiate 17 global Sustainable Development Goals (SDG's) on 1st January 2016. These SDGs are unique in the sense that they urge all the developed and developing countries to contribute toward a better world for future generations. It is evident that nations around the globe should unite together to formulate sustainable industrial practices and living conditions. *The Sustainable Development Goals Report 2018* suggests contrasting picture about the present progression in the various aspects of SDG's considering 2030 target agenda. For instance, on one hand, there has been a significant decline (35%) in the maternal mortality rate in the Sub-Saharan Africa, about 40% decline in child marriages in South Asia, and accessibility to electricity has become twofold in the least developed countries. On the other hand, more than 2.3 billion people do not have convenience to basic sanitation, 892 million people still practice open defecation and more than 1 billion people living in the villages face dearth of electricity, and 9 out of 10 people of the urban areas inhale contaminated air. Furthermore, the number of malnourished populace increased from 0.777 billion to 0.815 billion during 2015–2016 because of conflicts, droughts, and events associated with climate change. Considering that only 12 years are left to meet the deadline, we must develop a sense of urgency. Ensuring that actions are focused toward the needed urgency and to meet the respective goals, we not only need evidence about our current status, but we also need to forge partnerships between policy makers and different stakeholders at all levels.

Among the 17 SDGs, SDG 13 primarily concentrates on climate change mitigation, and accomplishing it has been a major challenge from the perspective of policy directive in the developed as well as developing nations (Baumeister 2018; Bisbis et al., 2018; Sinha et al., 2018). This is further substantiated by recent research on the concerning carbon emission levels as envisaged for 2018 (Quéré et al., 2018; Figueres et al., 2018). The emissions projections predict that industrial carbon emissions will reach to 37.1 billion tonnes, an all-time high, in 2018. The total carbon emissions (includes emissions from land activities such as deforestation) are expected to touch 41.5 billion tonnes. The "Global Carbon Project" declared the findings on 5 December 2018 at the "24th Conference of the Parties to the United

* Corresponding author.
*E-mail addresses:* f11aviks@iimidr.ac.in (A. Sinha), f13tuhins@iimidr.ac.in (T. Sengupta), tanaya86saha@gmail.com (T. Saha).

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Nations Framework Convention on Climate Change" (COP24) in Katowice, Poland. *The Sustainable Development Goals Report 2018* has recorded the year 2017 to be a hottest year with temperature 1.1 °C above that of the pre-industrial period (United Nations, 2018). In addition, the World Meteorological Organization has shown that the global temperature reached the highest from 2013 to 2017. This calls for urgent and meaningful mitigation actions for tackling the problem of climate change. To fulfill climate change mitigation, a notable outcry is the utilization of clean energy as an effective energy policy around the globe, which shifts our attention for the time being on SDG 7 (Affordable and Clean Energy), which is one of the measures that will help SDG 13 (Climate change) meet its target. According to the current trend presented in the report, it is expected that the share of renewable energy will reach about 21% of the total energy consumption by 2030. The implementation and use of green and clean energy are subjected to various aspects like current economic growth of the country, the amount of foreign direct investments in the form of cleaner technologies, and the domestic policy of the nation toward clean energy use considering their internal micro-economic factors (Amri et al., 2019; Chen et al., 2020). Therefore, it is quite evident that the presence of green technology is an important parameter to promote clean energy and tackle climate change. However, to implement green technology for both short and long run, there is need for investment in R&D and innovation (Avom et al., 2020; Khan et al., 2020). Hence, there is a need to focus on SDG Goal 9 (Resilient Infrastructure, Sustainable Industrialization and Foster Innovation) coupled with environmental awareness through quality education (SDG Goal 4). As per the report, there is 19% reduction in carbon intensity from 2000 to 2015. In addition, of the aggregated global manufacturing value in 2015, about 44.7% (of which 34.6% belongs to the developing economies) is from the medium and high technology sectors. Further, the report states that approximately 617 million children of both the primary and lower secondary schools are not able to accomplish minimum expertise in reading, thereby highlighting the lack of quality education for achieving environmental awareness. Moreover, following the results obtained by Zafar et al. (2020), it can be understood that the deficiency in educational attainment not only lowers the environmental awareness, but also impedes the research and development process within a nation. Without the proper educational infrastructure in place, it might not be possible for the policymakers to enable the public-private partnerships for enhancing the environmental awareness. Hence, it can be said that tackling climate change will not be feasible without understanding the devising policies for SDG 13, rather SDG 7 (affordable and clean energy) and SDG 9 (Innovation and Infrastructure) coupled with SDG 13 should be addressed together to bring in a sustainable policy in the interface of technology, R&D and innovation, environmental quality, and economic growth. This will not only foster long run sustainable economic growth (SDG Goal 8) but also contribute toward reducing inequality among countries in the long run (SDG Goal 10). In this way, integrating SDGs would help policy makers to tackle the pressing issues in a comprehensive manner in the short as well as long run.

Only few studies have attempted to address climate change (Le Blanc, 2015) with a three-pronged SDG (technology, R&D, Innovation, and economic growth) integration approach. The primary intention towards such an approach is direct effect of technology driven progressions on the economic growth, whose subsequent beneficial impacts are evident in the developmental procedures. Hence, technical advancement has indirect effect on the developmental process, and any effort of evaluating this impact is probably far-flanged. Intention of this study is to design a SDG framework for policy designing. The extant studies on SDGs in specific primarily include SDG Index and Dashboards (Sachs et al., 2017), scorecards (Nicolai et al., 2015), and country development diagnostics framework (Gable et al., 2015). This study aims at designing a multipronged policy framework for the Asia Pacific countries, so that they can attain the SDG objectives by 2030. By means of technological innovation and targeting environmental degradation, present study aims touching upon other SDG objectives, and thereafter, designing suitable policies based on the study outcomes. The United Nations report (Asia and the Pacific SDG Progress Report 2017) on Economic and Social Commission for Asia and the Pacific specifically mentions that Southeast Asia have made "no progress towards SDG's on climate action". It is envisaged that the region would experience a 6 °C increase in temperature with the culmination of this century. This could have serious impact on weather, agriculture, population migration etc. The report also finds that the medium and high-tech industry growth in the Asia-pacific region is not sufficient to meet the 2030 SDG target. Therefore, it highlights the importance of technology and infrastructure in meeting the SDG target. Lastly, the current trend of economic growth needs to be reversed for fulfilling SDG Goal 8. For this reason, a comprehensive policy (environmental quality, technology and economic growth) needs to be in place to address the issues of Asia-Pacific region from the perspective of 2030 SDG Goal target. There lies the policy-level contribution of the study.

In order to achieve this policy-level contribution, suitable analytical and methodological frameworks are required, so that the policy-level contributions are complemented. Now, in order to design an effective policy framework, then the analytical framework should be able to capture the evolutionary impact of the policy instruments on the target policy variable, and it is possible through the Environmental Kuznets Curve (EKC) hypothesis framework. Application of this theoretical framework has given the study a tractability to exemplify the contextual development in a much comprehensive manner, and therefore, the anticipated model outcomes might be capable of recommending closely exact consequences for this context, which can be imitated in case of other emerging economies around the globe. Now, this analytical framework needs a suitable methodological adaptation, so that the evolutionary impact captured through analytical framework can be complemented. While considering this aspect, it also needs to be remembered that the design of an effective policy framework necessitates encompassing the entire spectrum of data, so that the policy suggestions can be focused at various levels of the target policy parameters. In order to comply with this requirement, Bootstrap Quantile Regression has been employed, so that the entire spectrum of the data can be encompassed in the analysis, and the policy decisions can be provided at various levels of the target policy variable, defined by quantiles. This is how the methodological and analytical complementarity of the policy-level contribution of the study has been ascertained.

Along with this, two indices have been introduced in this study, i.e., environmental index and technological index, to make the analysis more comprehensive. In the environmental index, we included the major air pollutants, which are $CO_2$, $CH_4$, $N_2O$, PM2.5, and other greenhouse gases, whereas, in the technological index, we did include government expenditure in R&D, amount of technical cooperation grants, number of researchers in R&D, and number of patent and trademark applications.[1] The reasons behind designing these two indices are: (a) the target policy variable in this study is environmental degradation, which is indicated by air pollution. Now, the indicator of air pollution might not be captured through a single variable, and therefore, five air pollution indicators are chosen for building an index. This environmental index might give a clear picture about the air pollution scenario in these nations. (b) The major policy instrument in this study is technological advancement, which also might not be captured through a single variable, and therefore, five technological advancement indicators are chosen for building an index. This technological index might give a clear picture about the technological advancement scenario in these nations. Lastly, this study has utilized the Rolling Window Heterogeneous Panel Causality Test, which has been designed

[1] Due to unavailability of data, we have restricted ourselves within these indicators of technological progression.

in keeping with the application of rolling window estimation (Balcilar et al., 2010) on heterogeneous panel causality test by Dumitrescu and Hurlin (2012). This approach makes use of the bootstrapping of causality test, and thereby, it enhances the explanatory power of the test. Application of this approach is a methodological innovation brought forth in the study.

The paper is organized in the following manner: Section 2 explains the current literature on technology, R&D, and Innovation toward environmental quality and outlines the research gap for our study. The mathematical model followed by theoretical basis is explained in Section 3. The next section documents the results obtained from the analysis. The research, practice and policy implications are explained in Section 5. Section 6 gives the conclusion by highlighting the ways of answering the research questions given in the Introduction.

## 2. Literature review

We triangulated our research gap by segregating the literature into two parts. First, we concentrated on studies related to the impact of technology, population, innovation, economic progression, research and development on ecological features. Second, we focused on studies related to SDGs and technology in one sub-group and climate change and SDGs in another sub-group and argued about the contribution of our paper to the existing literature.

### 2.1. Technology, population, economic progression, and ecology

Numerous works have been conducted on technology and carbon emissions (Wolfram and Lutsey, 2016; Zhang et al., 2016a; Gelenbe and Caseau, 2015; Bond et al., 2004; Shahbaz et al., 2019; Shahbaz and Sinha, 2019). Most of these studies have neglected two aspects: First, the studies did not use the EKC framework for comprehending the consequences associated at the policy level in the short and long run. Second, very few studies have probably incorporated technology, population, economic growth and environmental policy in one single study (Zongzhi, 2010). For instance, Lewis (2016) tried to understand the role of legal and policy framework with technology for minimizing global carbon emissions. de Vries and Ferrarini (2017) scrutinized the role of technology, supply chain, and energy consumption on emission levels in both the developed and emerging economies. Li et al. (2019) conducted a study on 30 provinces in China and employed a spatial model to understand the effect of economic growth and high-technology toward carbon emissions. On similar lines, Yi (2012) studied the crucial role played by environmental regulation and technology innovation and economic growth toward emission levels in China. Shabani and Shahnazi (2019) conducted a causality study to understand the effect of energy consumption, information and communication technology and gross domestic product on carbon emission levels in Iran. The studies discussed so far did consider technology as one of the predictors of emission levels. However, these studies mostly neglected innovation and R&D in their econometric model. Very few studies have incorporated innovation and R&D as one of the technological parameters while evaluating their role in emission levels (Apergis et al., 2013; Álvarez-Herránz et al., 2017a, 2017b; Churchill et al., 2019). For instance, Lee and Min (2015) analyzed the role of eco-friendly innovation and R&D towards carbon emissions and firm performance. Zhang et al. (2016b) highlighted the role of technological innovation while analyzing the emission levels in China. Irandoust (2016) investigated the role of energy-growth nexus and technological innovation in the reduction of carbon emissions in the Nordic countries. Ganda (2019) investigated the role of innovation and technological investments on carbon emissions in the chosen countries. Garrone and Grilli (2010) studied the association between R&D expenditures in the power segment and carbon emissions for 13 advanced nations. However, Lee et al. (2015) explored influence of carbon discharges and expenditures on conservational studies related to firm performance. Fisher-Vanden and Wing (2008) modeled the impact of R&D on economic growth and carbon emissions in the developing countries. It has been stated earlier that these studies neglected a comprehensive EKC analysis for robust policy design. Further, these studies did not incorporate technology, innovation, R&D analysis in their model; so our research tries to fill the void and attempts to analyze a robust technological policy through the implementation of the EKC framework by developing a comprehensive environmental and technological index.

### 2.2. Technology, SDGs, and climate change

Studies have been conducted related to the interface of SDGs and climate change; however, the focus has been divergent in terms of addressing issues and causes of climate change (Ladan, 2018; Major et al., 2018; Rodriguez et al., 2018). Reckien et al. (2017) explored the impact of climate change on urban population and how the impact would ultimately affect other SDGs. Haines et al. (2017) highlighted the measures to mitigate adverse outcomes of pollutants in the short run. Kelman (2017) explored the relation among disaster risk reduction, climate change, and SDGs, and stressed on the necessity of incorporating the strategies associated with climate change alleviation and adversity risk management. Kedir (2017) highlighted the adverse impacts of climate change in Africa toward worsening of food security and emphasized the need to devise mitigation strategies for achieving SDG targets in Africa. Chirambo (2016) emphasized on the need to forge South-South alliances in terms of financial support for mitigating adverse impacts of climate change in Africa, which can have a substantial impact on human development index. Hiller et al. (2016) highlighted the importance of addressing issues concerning climate change and development together and further emphasized the need to include the use and potential of modern effective technologies, development agendas and climate change in business as well as financial models. Balasubramanian (2018) substantiated the same argument by addressing the need to focus on famine in conjunction with climate change in low income population groups as a pressing need thereby positively contributing toward the vital aspects of SDGs. Hence, we observed that very limited focus and importance has been given to technology for addressing climate action and the SDGs associated with it.

Studies concerning technology and SDGs have been limited and have concentrated towards commonly exclusive subjects. For instance, Adams et al. (2018) explored the utility of blockchain technology that could deliver advantageous consequences both ecologically and socially for stimulating business models, thus promoting the UN SDGs. Van der Sanden and Foing (2018) attempted to map the collaboration with space technology for accomplishing sustainability in various facets that are advantageous for life on earth through the scrutinization of numerous crucial regions within the 17 SDGs. Imaz and Sheinbaum (2017) highlighted the need to extend the current understanding and application of technology, i.e., technology transfer toward achieving different SDG's. Dialoke (2017) analyzed the implication of achieving SDGs with the help of technology in the education sector in Nigeria. Hence, we observed that there remains a void in terms of focusing on the need to address the policy directive toward the use of technology in achieving different SDGs.

### 2.3. Research gap

Summarizing the above two subsections, we attempt to address two research gaps in the following sections. First, none of the studies addresses the motivation behind integrating different SDGs at the policy level. Le Blanc (2015) highlighted the need to integrate SDGs in research studies, which substantiates the gap addressed in our study. Second, very few studies have considered the interplay of technology and SDG both at the policy and operational level, thus presenting the

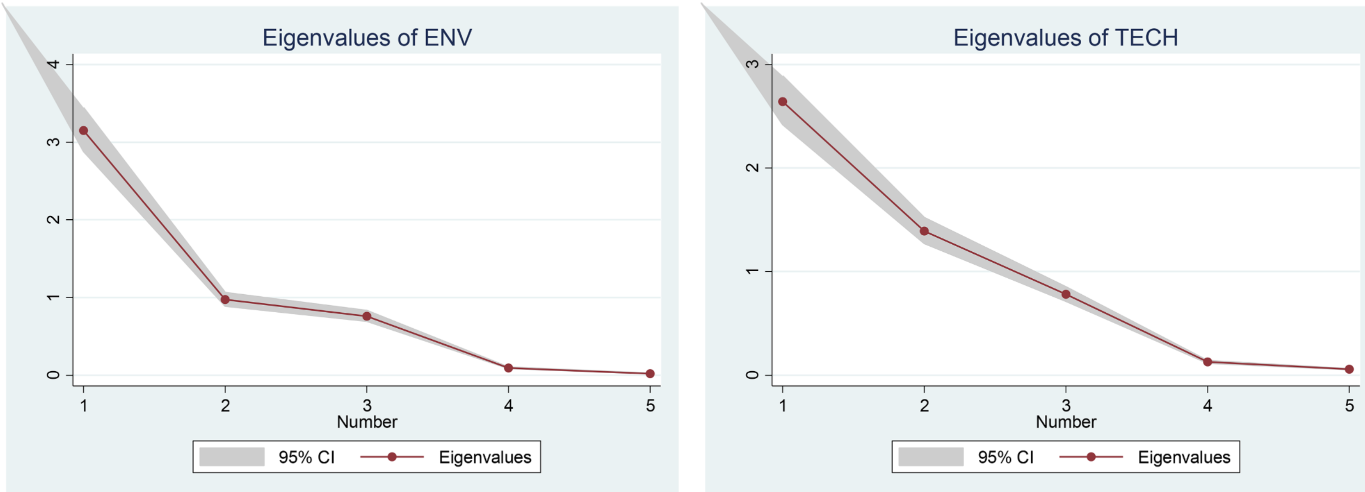



**Fig. 1.** Plot of eigenvalues of the principal component.

opportunity of dealing with the same interaction in this study. Third, there has been no study that specifically analyzes the technological advancement on environmental quality through the overarching framework of EKC. While addressing the given research gaps, our paper attempts to make specific contribution to the literature. First, our paper is amongst those primary studies that attempt and analyze the technology policy and environmental quality by creating two different indices, which consider an inclusive coverage of both environmental degradation parameters and technological advancement features in a single study. Second, our paper presents an opportunity to revisit technology policy both in the short and long run through the lens of EKC in the Asia-Pacific region. Future researchers can replicate similar studies on other nations keeping in mind the interplay of economic growth and cleaner technology in the short as well as long run. We presented our mathematical model and theoretical framework in the next section.

## 3. Empirical framework and data

In this study, our intention is to examine the impact of technological advancements related to environmental quality for certain Asia Pacific countries from 1990 to 2017. For analyzing the effect, we employed the IPAT framework (Ehrlich and Holdren, 1971). The estimation schema is designed depending on the available literature on the EKC hypothesis and IPAT modeling (Paramati et al., 2017; Vélez-Henao et al., 2019; Sinha and Sengupta, 2019). The primary reason for using the IPAT framework for this study is the capability of this framework to capture the evolutionary environmental impact (I) of population (P), economic affluence (A), and technological advancement (T). The objective of this study is to design a policy framework by analyzing the impact of technological progression on environmental quality, in presence of the evolutionary economic growth pattern of the nations. Now, in the empirical model to be analyzed in this study, economic growth pattern in the sample countries denotes the economic affluence of those nations, the environmental impact is captured through the environmental index, and the technological advancement is captured through the technological development index. Thus, the parameterization of IPAT framework has been achieved through the empirical model to be analyzed in the study. The premise of the IPAT framework falls in the similar lines with the research objective, and hence this framework has been chosen for the study.

To empirically estimate the evolutionary impact of economic growth and technological advancement on environmental quality, the following empirical model has been designed:

$$ENV_{it} = f\,(GNI_{it},\, GNI_{it}^2,\, TECH_{it},\, REN_{it},\, POP_{it}) \tag{1}$$

Here, *ENV* represents the indicator of air pollution, *GNI* represents the gross national income, *TECH* stands for the indicator of technological development and R&D, *REN* stands for consumption in renewable energy, *POP* refers to population, and $i$ refers to the selected countries ($i = 1,\ldots,N$), and $t$ stands for the study duration ($t = 1,\ldots,T$).

The index represented by ENV constitutes of five main air pollutants present in the Asia pacific countries, these pollutants are carbon dioxide ($CO_2$), methane ($CH_4$), nitrous oxide ($N_2O$), particulate matter 2.5 ($PM_{2.5}$), and greenhouse gases ($GHG_O$), including hydrofluorocarbons, perfluorocarbons and sulfur hexafluoride. Likewise, the index represented by TECH constitutes of five main R&D indicators, which are the count of trademark submissions (TM) and patent submissions (PAT), number of researchers in R&D per million people (RES), technical cooperation grants (GR), and spending associated with R&D, which is depicted as a percentage of GDP (GOVEX). The indices are developed with the help of principal component analysis (PCA). The primary reason behind the use of these indices is that the focus on neither local nor global pollutants can depict the appropriate picture of different countries degrading ambient air quality. However, the varying levels of development essentially affect the R&D level of these countries; hence, the selection of an indicator for R&D will probably not be able to illustrate the accurate picture of technological innovation and advancement of these nations. Consequently, it is possible to represent these two indices as (We provide the eigenvalues of the indices in Fig. 1):

$$ENV_{it} = \alpha_{0it} + \alpha_{1it}CO_{2it} + \alpha_{2it}CH_{4it} + \alpha_{3it}N_2O_{it} + \alpha_{4it}PM2.5_{it} + \alpha_{5it}GHGO_{it} + \epsilon_{it} \tag{2}$$

$$TECH_{it} = \beta_{0it} + \beta_{1it}PAT_{it} + \beta_{2it}TM_{it} + \beta_{3it}RES_{it} + \beta_{4it}GR_{it} + \beta_{5it}GOVEX_{it} + \epsilon_{it} \tag{3}$$

Before moving on with the analysis, it should be mentioned that while operationalizing the empirical model, we have converted the gross GNI data into per capita terms by dividing them with total population figure. Moreover, data on R&D outflow has been converted into gross terms by multiplying the percentage values with the real GDP in US dollar. Hence, all the parameters used in PCA are expressed in gross terms. The correlation table for the PCA has been provided in Appendix 1.

Considering the IPAT framework for operationalizing the mathematical model as presented in Eq. (1). Following the description of the framework, the relation among echelon of economic activity (A), environmental impact (I), technology (T), and population (P) might be demonstrated as:

$$I = P \times A \times T \tag{4}$$

The implications of this model depict that pollution, economic activity, and technology employed affect the environmental quality. Nevertheless, Dietz and Rosa (1994, 1997) and Rosa and Dietz (1998) formulated the STIRPAT (Stochastic Impacts by Regression on Population, Affluence, and Technology) model for empirical verification. Considering this framework, we designed the model based on Eq. (1), where ENV refers to ambient air pollution, GNI and utilization of renewable power refer to the indicators of economic accomplishments and affluence, and TECH represents technological progression, and POP refers to population. Following the above argument, the testable empirical prototype of Eq. (1) might be depicted as:

$$ENV_{it} = \theta_{0it} + \theta_{1it} GNI_{it} + \theta_{2it} GNI_{it}^2 + \theta_{3it} TECH_{it} + \theta_{4it} REN_{it} + \theta_{5it} POP_{it} + \epsilon_{it} \tag{5}$$

In order to handle the multicolinearity in the data, the variables have been orthogonally transformed before carrying out the analysis (see Appendix 2). While conducting the empirical analysis, first we applied Chudik and Pesaran's (2015) the weak cross-sectional dependence test for checking whether the data has cross-sectional dependence. Considering the obtained results from the above test, we utilized Breitung (2001) and Herwartz and Siedenburg (2008) unit root tests, which undertake the persistence of cross-sectional dependence among model parameters. Upon realizing the integration order present in the variables, we verified the existence of long run cointegration among the variables; however, in this process, the issue of cross-sectional dependence also needed to be addressed. For this reason, we utilized the Westerlund and Edgerton (2008) panel cointegration test.

We can presume that all countries will not have similar level of ambient air pollution; hence, there is need of outlining the consequential developmental strategies with regard to the pattern of emission. Therefore, the necessity of analyzing the effect of prosperity, populace, and technological development on air contamination in varied quantiles has aroused, which can be carried out by employing the quantile regression (Koenker, 2005). For robustness check, we applied three mean group tests, i.e., (a) with augmented effect (AMG), (b) with common correlated effect (CCE-MG), and (c) cross-sectional ARDL (CS-ARDL), for examining the above-mentioned relationship. Finally, to focus on new insights for giving policy-level propositions, we employed the rolling window heterogenous panel causality test (Dumitrescu and Hurlin, 2012). The test analyzed the relation between ENV and TECH, and included another robustness assessment on the ecological effects of evolutions in technology.

We collected data in this study for $N_2O$ emissions in cubic tons of carbon correspondent, average yearly coverage of PM2.5 discharges in μ-grams per meter$^3$, $CH_4$ discharges in cubic tons of carbon correspondent, $CO_2$ discharges in cubic tons, and additional greenhouse gas discharges (i.e., HFC, PFC and $SF_6$) in cubic tons of carbon correspondent, technical cooperation grants in real US dollar, GNI in real US dollar, R&D outflow as% of GDP, per capita renewable power utilization in billion kilo watt hours, number of trademark solicitations, number of patent solicitations, number of researchers in R&D per million individuals, and the total population. The data source for this study is the World Bank indicators (World Bank, 2018), and we gathered data for 35 Asia-Pacific countries[2] for the period 1990–2017. Table 1 records the variables and the pertinent studies associated with them. To conduct the analysis, we transformed the model parameters into natural logarithms to level the data, estimate elasticity with respect to the model parameters, and regulate likelihood of heteroskedasticity. Descriptive statistics of the variables are given in Appendix 3.

## 4. Results

The estimation of the results started with checking the stochastic property of the data by means of applying unit root tests. However, the explanatory power of a unit root test depends on assuming the presence of cross-section amidst the data. The second-generation unit root tests assume the presence of cross-section in the data, which has been ignored by the first-generation unit root tests. Table 2 presents the outcome of weak cross-sectional dependence assessment (Chudik and Pesaran, 2015), which showed the presence of cross-sectional dependence in the data at 1 percent level of significance, thus validating the application of second-generation unit root tests. Table 3 presents the outcome obtained from employing Breitung (2001) and Herwartz and Siedenburg (2008) unit root tests, which showed that the data turn out to be stationary after first difference, thereby, signifying that the model parameters are integrated to unit order.

After confirming the order of integration amongst the model parameters, we analyzed the relation of cointegration and cross-sectional dependence among the variables. In this pursuit, we employed the panel cointegration test developed by Westerlund and Edgerton (2008). Table 4 presents the Lagrange multiplier (LM) statistics, which demonstrates that the variables are cointegrated, and this evidence allows us to proceed with the further estimation process.

Upon discovering the cointegrated relation amid the model parameters and carrying out pre-test diagnostics (see Appendix 4), we carried out the bootstrap quantile regression analysis on the model described in Eq. (5). During the analysis, we stipulated three quantile series, i.e., 10th–30th quantile represents low air pollution, 40th–60th quantile represents medium air pollution, and 70th-90th quantile represents high air pollution. With the help of this categorization, we could segregate the regions with regard to their air pollution patterns. Table 5 demonstrates the outcome of quantile regression analysis, which exhibits presence of inverted U-shaped EKC across all regions. However, the disparity among the achieved turnaround points divulges the nature of environmental degradation prevailing in these nations. First, we will start with the evolutionary impact of economic growth pattern. For all the three categories, the evolutionary impact of economic growth pattern has demonstrated inverted U-shaped form, but the nature of turnaround points arising out of these associations differ across the categories. For the low air pollution region, the turnaround points are within the sample range, and near the mean per capita GNI. Economic growth pattern in these regions is allowing the EKC to reach the turnaround point at a very early stage, and thereby demonstrating the policy-level efficacy achieved to have a control over the issue of environmental degradation. However, for the medium air pollution region, though the turnaround points are within the sample range, the turnaround points are close to the maximum per capita GNI of the sample. It denotes the uncertainty of the policies prevalent in these regions, as further rise in economic growth might make those policies ineffective in controlling the environmental degradation. Lastly, for the high air pollution region, the turnaround points are outside the sample range, and thereby demonstrating the inefficacy of the prevalent policies in these regions to control the issue of environmental degradation. This evolutionary impact of economic growth pattern suggests that the rise in the industrial growth might be a cause of the environmental degradation in these regions, and rise in environmental degradation with higher economic growth substantiates this claim. This impact shows the rationale behind the nations failing to attain the objectives of SDG 13, and this might cause predicament in the way to achieve the objectives of SDG 8.

This segment of results bears more significance, when they are analyzed alongside the impact of technological advancement and renewable energy consumption. For all the three categories, the impact of

[2] The chosen countries are Australia, Bangladesh, Bhutan, Cambodia, China, East Timor, Fiji, French Polynesia, India, Indonesia, Japan, Kiribati, Laos, Malaysia, Maldives, Marshall Islands, Mongolia, Myanmar, Nepal, New Caledonia, New Zealand, Pakistan, Papua New Guinea, Philippines, Russia, Samoa, Singapore, Solomon Islands, South Korea, Sri Lanka, Taiwan, Thailand, Tonga, Vanuatu, and Vietnam.

**Table 1**
Variable description.

| Variables | Description | Source of data | Reference study |
|---|---|---|---|
| $CO_2$ | $CO_2$ emissions in thousand metric tons | World Development Indicator (World Bank, 2018) | Roberts et al. (2019) |
| $CH_4$ | $CH_4$ emissions in thousand metric tons of $CO_2$ equivalent | World Development Indicator (World Bank, 2018) | Yusuf et al. (2012) |
| $N_2O$ | $N_2O$ emissions in thousand metric tons of $CO_2$ equivalent | World Development Indicator (World Bank, 2018) | Sinha and Sengupta (2019) |
| PM2.5 | mean annual exposure of PM2.5 emissions in μg/m$^3$ | World Development Indicator (World Bank, 2018) | Dong et al. (2018) |
| $GHG_O$ | other greenhouse gas emissions (i.e. HFC, PFC and $SF_6$) in thousand metric tons of $CO_2$ equivalent | World Development Indicator (World Bank, 2018) | Mallapragada et al. (2018) |
| PAT | number of patent applications | World Development Indicator (World Bank, 2018) | Lemus and Marshall (2018) |
| TM | number of trademark applications | World Development Indicator (World Bank, 2018) | Hidalgo and Gabaly (2012) |
| RES | number of researchers in R&D per million people | World Development Indicator (World Bank, 2018) | De Rassenfosse and de la Potterie (2009) |
| GR | technical cooperation grants in current USD | World Development Indicator (World Bank, 2018) | Bojnec (2011) |
| GOVEX | R&D expenditure as a percentage of GDP | World Development Indicator (World Bank, 2018) | Vicente and Lopez (2006) |
| GNI | gross national income in current USD | World Development Indicator (World Bank, 2018) | Cranston and Hammond (2012) |
| REN | renewable energy consumption in billion kWHs | World Development Indicator (World Bank, 2018) | Sadorsky (2009) |
| POP | Population | World Development Indicator (World Bank, 2018) | Dalton et al. (2008) |

**Table 2**
Results of Chudik and Pesaran (2015) weak cross-sectional dependence test.

| *Variables* | *Test statistic* | *p-value* |
|---|---|---|
| ENV | 63.374 | 0.000 |
| TECH | 96.470 | 0.000 |
| GNI | 137.074 | 0.000 |
| REN | 114.782 | 0.000 |
| POP | 143.558 | 0.000 |

**Table 3**
Results of second-generation unit root tests.

| *Variables* | Herwartz and Siedenburg (2008) | | Breitung (2001) | |
|---|---|---|---|---|
| | *Level* | *First Diff.* | *Level* | *First Diff.* |
| ENV | 0.1146 | −1.6512[b] | 3.3320 | −10.7029[a] |
| TECH | 0.0507 | −1.1123[c] | 2.5022 | −19.4171[a] |
| GNI | −0.6948 | −1.4989[c] | 16.5956 | −5.6761[a] |
| REN | −0.2827 | −2.6454[a] | 6.2136 | −10.6314[a] |
| POP | −0.8768 | −1.5489[c] | 24.6111 | −4.5944[a] |

[a] significant value at 1%.
[b] significant value at 5%.
[c] significant value at 10%.

**Table 4**
Results of Westerlund and Edgerton (2008) cointegration test.

| | *Test statistic (1)* | *p-value* | *Test statistic (2)* | *p-value* | *Test statistic (3)* | *p-value* |
|---|---|---|---|---|---|---|
| $LM_\tau$ | −5.499 | 0.000 | −5.237 | 0.000 | −2.381 | 0.009 |
| $LM_\phi$ | −6.210 | 0.000 | −5.015 | 0.000 | −2.573 | 0.005 |

Note:
Model (1): model with a maximum number of 5 factors and no shift.
Model (2): model with a maximum number of 5 factors and level shift.
Model (3): model with a maximum number of 5 factors and regime shift.

technological advancement has been found to be positive. This segment of the findings demonstrates that the level of R&D activities in these nations toward the technological developments is having adverse effect on the environmental quality. These countries are characterized by accelerating economic growth, and therefore, environmental protection mostly takes a backseat during the designing of policies for these nations. Acemoglu et al. (2012) discussed this issue while analyzing the impact of endogenous and directed technical change on environmental quality. Song et al. (2018) provided a detailed review on this issue. However, it is surprising to note that the impact of TECH is low in the countries with low pollution, medium in the countries with medium pollution, and high in the countries with high pollution. This also divulges that the level of R&D activities in these nations toward the technological development is a major enabler of the issue of environmental degradation. As the level of industrialization rises, the demand for technological innovation also rises, and therefore, deterioration of environmental quality initiates. This segment of the results falls in the similar lines with the finding of Sinha et al. (2020) for top-10 polluting MENA (Middle East and North African) countries. When the nations direct the innovations towards industrial development and at the cost of environmental quality, the very purpose of SDG 9 is defeated, as the technological innovations are ascertaining short-run economic benefits at the cost of long-run sustainability.

Now, on the other hand, the impact of renewable energy consumption on environmental degradation has been found to be negative across all the three categories of countries. Though the prominence of renewable energy solutions is rising in these nations, it has an optimistic effect on the environmental quality, which is insufficient to cater to the growing energy demand in these nations. Probably for this reason, the influence of renewable energy consumption on ecological feature has not been particularly visible in these nations. Sinha and Sengupta (2019) identified this specific issue in the Asia-Pacific Economic Cooperation (APEC) countries, Sharif et al. (2020a) for Turkey, Sharif et al. (2020b) for top-10 polluted countries around the world, and Zafar et al. (2020) for the OECD countries. Amidst rising environmental issues in these nations, the promising role of the renewable energy consumption is a ray of hope towards not only attaining environmental sustainability, but also helping these nations to make a progression towards achieving SDG 7.

Lastly, these nations are characterized by high industrial growth, which increases the number of vocational opportunities, and therefore, these

**Table 5**
Results of bootstrap quantile regression analysis.

| Variables | Low air pollution | | | Medium air pollution | | | High air pollution | | |
|---|---|---|---|---|---|---|---|---|---|
| | $Q_{0.1}$ | $Q_{0.2}$ | $Q_{0.3}$ | $Q_{0.4}$ | $Q_{0.5}$ | $Q_{0.6}$ | $Q_{0.7}$ | $Q_{0.8}$ | $Q_{0.9}$ |
| GNI | 0.0875[c] | 0.1168[c] | 0.1245[b] | 0.2398[a] | 0.1210[a] | 0.2965[c] | 0.4290[c] | 0.2966 | 0.3596[a] |
| $GNI^2$ | −0.0049[a] | −0.0064[a] | −0.0069[a] | −0.0100[a] | −0.0052[a] | −0.0123[a] | −0.0167[a] | −0.0110[c] | −0.0132[a] |
| TECH | 0.0359[a] | 0.0477[a] | 0.0498[b] | 0.0604[c] | 0.0951[a] | 0.1212[b] | 0.1336[b] | 0.1008[c] | 0.1276[a] |
| REN | −0.0011[b] | −0.0288[a] | −0.0307[b] | −0.0317[c] | −0.0121[b] | −0.0437[b] | −0.0105[b] | −0.0583[b] | −0.0458[b] |
| POP | 0.2420[a] | 0.3013[a] | 0.3369[a] | 0.3809[a] | 0.5617[a] | 0.4802[a] | 0.5682[a] | 0.5501[a] | 0.4288[a] |
| Constant | −3.6723[a] | −4.3063[a] | −4.6405[a] | −6.2054[a] | −3.9451[a] | −7.4535[a] | −8.6227[a] | −7.9506[b] | −7.8359[a] |
| Shape of EKC | Inverted U | Inverted U | Inverted U | Inverted U | Inverted U | Inverted U | Inverted U | Inverted U | Inverted U |
| Turnaround Point | $7544.48 | $9181.99 | $8281.17 | $161135.35 | $112940.38 | $171586.96 | $378628.72 | $716274.09 | $823412.13 |

Note: regressions have been run with 200 bootstrap replications and 95% confidence level.
[a] significant value at 1%.
[b] significant value at 5%.
[c] significant value at 10%.

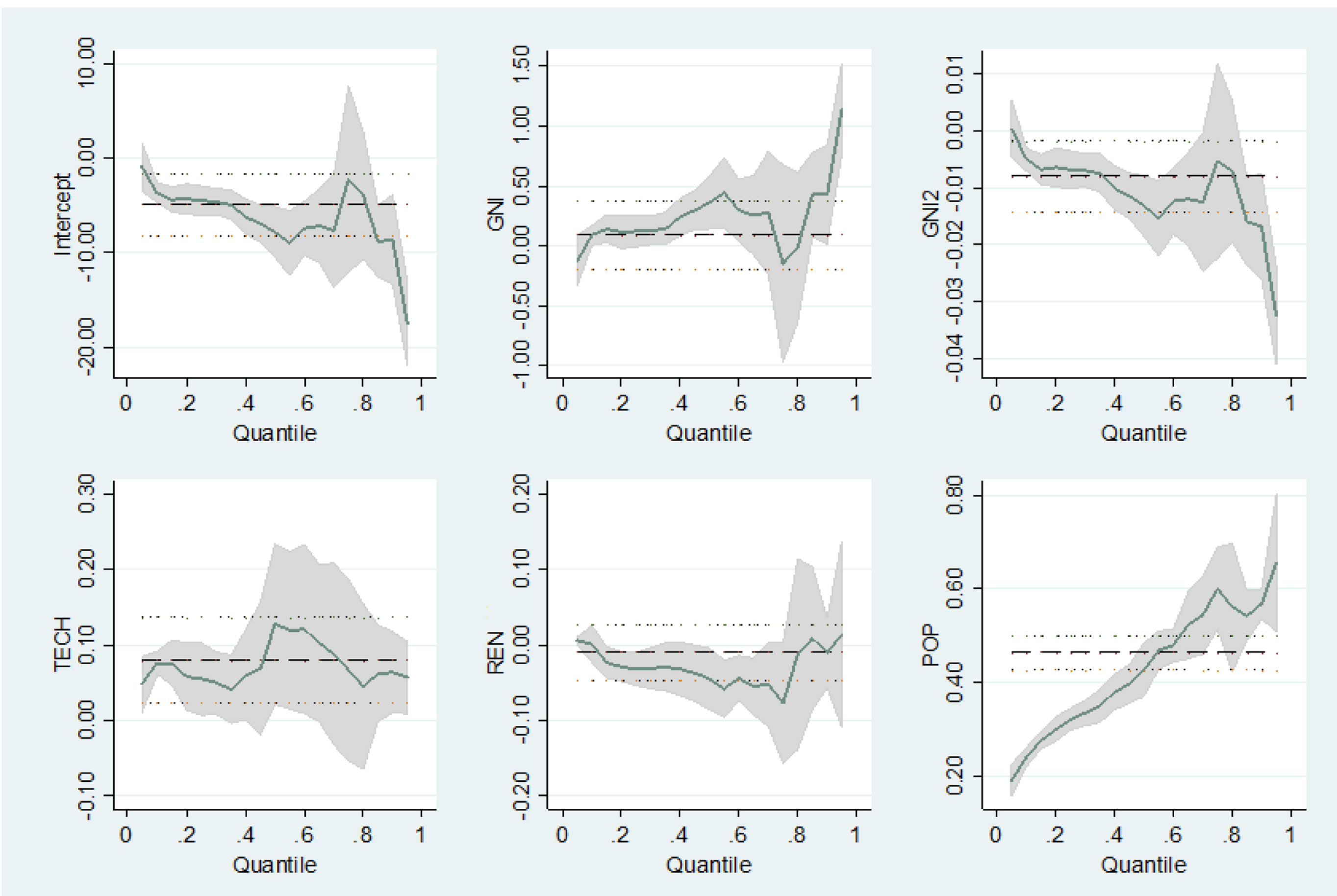



**Fig. 2.** Quantile regression plot at 95% confidence level.

nations are also experiencing a rise in population. Furthermore, the existing urban infrastructure in these nations are not yet capable of handling the issue of rising population; hence, these nations are striving with major incidents of energy poverty issues. In such a situation, the inadequate urban infrastructure not only aggravates the issues of energy efficiency, but also results in space heating, which in turn causes greenhouse gas emissions. Sinha and Bhattacharya (2016a, 2017) identified this issue in the case of Indian cities. This segment of the results indicates that the rising population pressure in the urban center of these countries might restrict them from achieving the objectives of SDG 8. In Fig. 2, the coefficients of the quantile regression analysis are plotted.

To bring forth more robustness in the analysis, we carried out AMG, CCE-MG, and CS-ARDL tests on the aggregate data. Table 6 presents the results, which show that EKC exists for the Asia-pacific countries. However, the direct impact of renewable energy consumption on ecological feature has been offset by the negative effect of technological progression. In this case, it is noteworthy to observe that the turnaround points for the aggregate data are outside the sample range, thus indicating the need of sustainable policy level design.

Finally, we carried out the rolling window heterogeneous panel causality test. For any national level policy towards sustainable development, one of the intrinsic characteristics is bidirectionality (Lu et al., 2014; Sinha et al., 2018). Fig. 3 depicts the results, which shows progression in technology has a positive effect on ambient air pollution; however, there is minimal effect when the direction of the causal relationship changes. However, the result obtained demonstrates that the prevalent research and

**Table 6**
Results of long run estimates.

| *Variables* | *CS-ARDL* | *AMG* | *CCE-MG* |
|---|---|---|---|
| GNI | 1.5770[b] | 1.2029[b] | 1.5769[b] |
| GNI$^2$ | −0.0613[a] | −0.0449[c] | −0.0611[b] |
| TECH | 0.7627[b] | 0.2712[a] | 0.7625[a] |
| REN | −0.1731[c] | −0.1182[c] | −0.1731[b] |
| POP | 0.7355[a] | 0.3108[c] | 0.7354[a] |
| Constant | −2.7159[c] | −5.9775[a] | −5.0098[b] |
| Shape of EKC | Inverted U | Inverted U | Inverted U |
| Turnaround Point | $385759.35 | $656923.56 | $402019.28 |

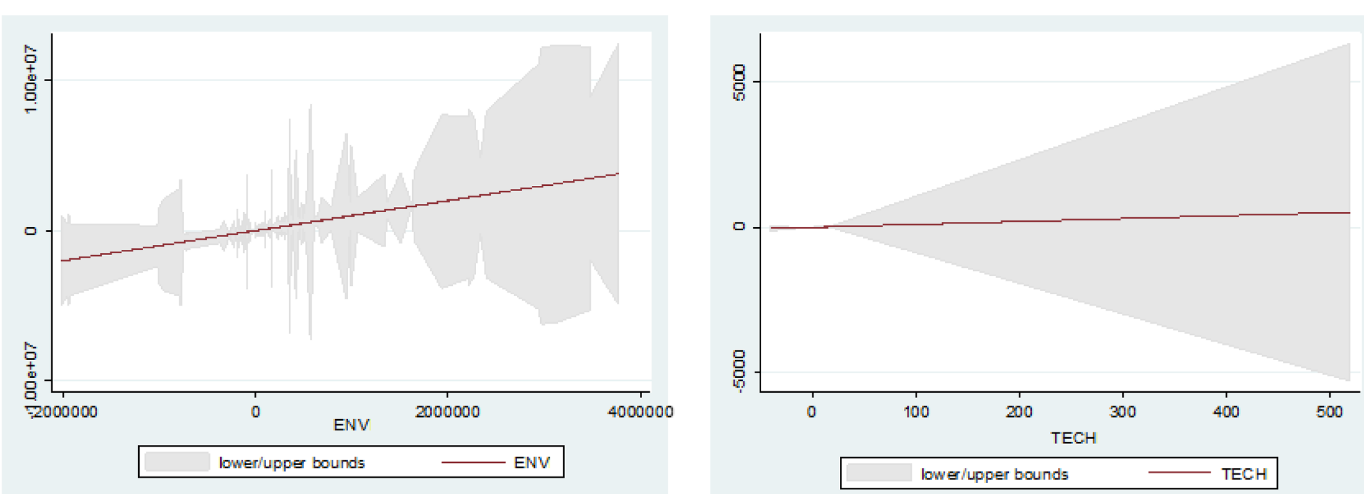
[a] significant value at 1%.
[b] significant value at 5%.
[c] significant value at 10%.

development activities are industrialization driven, but these R&D activities do not consider their negative effects. Saying this, it is both surprising and alarming to find no causal impact of environmental degradation on technological advancement, as the policy-level inefficacies to control the environmental degradation might have not been realized yet on the R&D front. As the technology-driven economic growth pattern in these nations is driving the environmental degradation, therefore, the impact of environmental degradation might be visible on the economic growth pattern, and after certain policy lag, on the technological advancements. Absence of this impact divulges the policy-level myopia in controlling environmental degradation by technological advancements. Hence, policymakers can consider the absence of bidirectionality between these two aspects to be their primary concern.

## 5. Policy implications and discussion

We analyzed the impact of technological advancement, consumption in renewable energy, population and gross national income on air pollution for the Asia-Pacific countries, and further encountered several insights in the course of empirical analysis. Technological progression positively affects ambient air pollution index, whereas, the renewable energy consumption negatively affects the same. These countries have high economic growth and their existing policies are largely pro-industrialization. Therefore, it can be assumed that the R&D activities carried out in these nations largely aim at technological progression and less toward environmental protection. It is probable that the prevailing course of economic growth in these nations is not environment-friendly, and so the persistence of this economic growth pattern might be harmful for sustainable development of these nations. For these reasons, the policymakers should focus on redesigning the energy and educational development policies for safeguarding the developmental future of these nations.

Nevertheless, it is necessary to remembered that, if these nations start implementing thorough renewable energy implementation, then the economic growth will be worse hit, as it will make the existing energy infrastructure completely redundant, and the cost of implementation might push these nations toward the balance of payment crisis. Therefore, based on the endogenous research and development capabilities, these nations need to take small steps toward ensuring environmental sustainability. These steps will be different for nations with low, medium, and high air pollution levels, respectively. Let us begin with the first strata, i.e., nations with low air pollution levels. The policymakers of such nations have to allocate more resources on R&D for creating green solutions to replace the existing production technologies. This initiative should be complemented by enhancing environmental responsiveness midst the populace through modifications in the educational curriculum, and this enhancement in environmental awareness might help the policymakers in encouraging people-public-private partnerships to encounter environmental degradation. In this way, citizens will be more aware about the energy efficiency related issues, and this can shift their preference from fossil fuel to renewable energy solutions. In this situation, the demand of fossil fuel-based energy sources will be lessened, which in turn will upsurge the renewable energy requirement, while compelling the government to take budgetary allocation decisions following a pro-ecological philosophy, rather than the pro-industrialization philosophy. Following this path, these countries might be competent to realize the requirements of SDG 7 and SDG 4, thereby, compliance of such requirements will encourage the attainment of SDG 13. In this way, the shift from fossil fuel-based energy sources and environmentally harmful technologies might be replaced smoothly without damaging the economic growth pattern. Next, we will consider the second strata, i.e., nations with moderate air pollution levels. For these countries, while allocating budgetary resources for R&D in green production technologies, the policymakers have to impose higher tax rate for the polluting industries, although incentivizing the cleaner industries. This will both force and motivate the industries for implementing green energy solutions for production purpose, which will in turn increase the demand for renewable energy solutions. This derived demand-pull strategy needs to be complemented through the modification of educational curriculum by stressing on the environmental awareness, so that citizens become aware of the environmental protection and advantages of green and renewable energy. This will also enable countries to carry out innovations in technology for encountering environmental degradation at the grassroot level, which will not only aggravate the national capacity to innovate but will also lead toward creation of green jobs. This will help these countries to reach a position so as to meet




(a) Causal Impact of TECH on ENV (b) Causal Impact of ENV on TECH

**Fig. 3.** Results of rolling window heterogenous panel causality tests.

the requirements of SDG 8 and SDG 9, in consort with realization of the goals of SDG 7, SDG 4, and SDG 13.

Lastly, we consider the last strata, i.e., nations with high air pollution levels. Along with air pollution, these countries also have high population pressure, low energy efficiency, and social imbalance. Therefore, the policy level interventions in these countries need to be inclusive, keeping the economic growth pattern unharmed. For these nations, the new energy policies should focus on both the industrial and domestic consumers. Industries can avail the renewable energy and cleaner technology solutions at a predetermined rate of interest, which will be payable to the government. Moreover, the domestic consumers can avail the renewable solutions against low-cost loans from the government, and for decreasing the burden of expenses, the households can be given an interest holiday. During this period, the fiscal pressure can be managed by the interest received from the industrial consumers, which in turn will give the households enough time and capacity to repay the price of the renewable energy solutions for domestic usage. Now, this solution needs to be considered for the rising population pressure, and therefore, the interest holiday and pro-rata price for the households might be decided depending on the household income, as it will bring parity in terms of providing the solutions. Such policy interventions might provide the government with several benefits: (a) it will help the policymakers to go for gradual transferal from fossil fuel to renewable energy sources, (b) there will be sufficient time to allocate budgetary resources for R&D activities toward unearthing alternate energy sources and building cleaner technological solutions, and (c) the environmental awareness among the citizens will start rising. Further, it should be remembered that these policy interventions need to be complemented by increasing environmental awareness, which can be done through revision of the educational curriculum in schools and upgradation of the urban infrastructure. Upon considering these policy interventions together, these nations might experience the emergence of green jobs, better living conditions, higher educational attainment along with lower level of environmental degradation, affordable and clean energy, and sustainable growth in income. Once, these things are in place, the social imbalance is likely to come down, as vocational opportunities will rise, along with affordable energy, better education, and robust urban infrastructure, and consequently, the inequality in income can be reduced because the average level of income and living standard of the marginalized population will rise. Sinha and Bhattacharya (2016a, b) also suggested that addressing the energy efficiency issues might have positive social spillover effect. All of these might be possible by enhancing the R&D capacity of these nations and capitalizing the enhanced capacity to encounter environmental degradation, develop cleaner technologies, and create new green vocational opportunities. Thus, these countries should be in a position for ascertaining the requirements of SDG 8, SDG 9, SDG 7, SDG 4, and SDG 13. Furthermore, we have already discussed that the accomplishment of these objectives might habitually result in accomplishment of SDG 10 to some extent.

In a nutshell, these nations need to augment their capacity of conducting the R&D activities for reducing environmental degradation, developing cleaner production technologies, and creating new vocational opportunities. The policymakers need to invest more on R&D activities for capacity building, and they also need to promote the renewable energy solutions by increasing awareness about environmental protection and energy efficiency through the revision of educational curriculum. While carrying this transformation, they will also have to consider about not harming the economic growth pattern; hence, both the industrial and domestic consumers of electricity must be considered. In this consideration, the income level of the domestic consumers also needs to be taken care of. The differential interest rate mechanism for the different levels of consumers needs to be implemented, which will enable smooth transition from fossil fuel to renewable energy sources as well as in maintaining parity in the policy-level impact. The increase in environmental awareness is expected to bring forth people-public-partnerships, which can be a channel for creating new green jobs. It is expected that the new vocational opportunities will help in elevating the living standard, which in turn will reduce the social imbalance occurring due to income inequality. Along these lines, climate change might be mitigated through decline in ecological deprivation (achievement of SDG 13), the alteration of educational curriculum can increase consciousness about the ecology (achievement of SDG 4), R&D activities can foster innovation and create new vocational opportunities (achievement of SDG 8 and 9), citizens will be able to afford clean energy at reasonable prices (SDG 7). Further, the enhancement of living standard can reduce societal disparity and inequality in earnings (achievement of SDG 10) (see Appendix 5).

## 6. Conclusion

Today, the achievement of sustainable development has become one of the major critical issues, and to institutionalize this global issue, SDGs came into existence. Countries with pro-industrialization agenda are finding it difficult to address the objectives, as the policies and practices prevailing in those countries are more growth-oriented. Therefore, the policies in those countries need to be redesigned for fulfilling the objectives of the SDGs, which is the focus of this study. The empirical results of this study investigate the effect of technological progression on environmental degradation, following the EKC framework, which includes consumption in renewable energy, population and gross national income. The next step was to analyze the relationship among the said variable for different country segments as explained in the methodology section through the bootstrap quantile regression analysis. This was followed by robustness checks through CS-ARDL, CCE-MG, and AMG analysis. To obtain further insights between environmental degradation and technological progression, we applied the rolling window heterogenous panel causality test. Based on the results of the analysis, the policies for addressing some of the SDGs objectives have been suggested.

For the Asia-Pacific countries, this study for the first time address the issue of implementation of SDGs, while considering progression in technology as vehicle for sustainable development. With regard to ambient air pollution, the index has given us a wide scope for analyzing the environmental degradation issue, as choosing a single pollutant could not have solved the purpose by narrowing the purpose of policy-oriented study. Similarly, choosing only one single parameter for R&D activities related to the technological progression would have trimmed the scope of the study. Therefore, in methodological terms, the introduction of these two indices is a contribution to the literature on environmental economics. Moreover, the usage of quantile regression in designating the country segmented air pollution has given us the flexibility of suggesting the policies in accordance with the context setting. Now, on policymaking front, the present work contributed to the extant literature of environmental economics by providing indicative ways of addressing the objectives of selected SDGs, and the ways in which the complementarity of research capabilities and the national policies can be used as a vehicle for achieving these objectives.

Lastly, we would like to mention that data support is crucial to come up with sound policy level decisions, and many researchers have identified this issue. During analysis, one of the major problems, we have encountered is the unavailability of data. Because of this specific issue, we could not consider several other Asia-Pacific countries for the analysis. Therefore, the unavailability of data is a limitation for this study, and further it acts as a limitation for these countries to achieve the objectives of SDGs.

## CRediT authorship contribution statement

**Avik Sinha:** Conceptualization, Data curation, Formal analysis, Resources, Software, Validation, Visualization, Writing - original draft. **Tuhin Sengupta:** Conceptualization, Writing - original draft. **Tanaya Saha:** Writing - original draft, Writing - review & editing.

## Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.techfore.2020.120317.

**Appendix 1**
Correlation matrix of the model parameters for PCA.

| *Correlation matrix for the parameters of ENVINDEX* | | | | | |
|---|---|---|---|---|---|
| | $CO_2$ | $GHG_O$ | $CH_4$ | $N_2O$ | PM2.5 |
| $CO_2$ | 1.0000 | | | | |
| $GHG_O$ | 0.6040 | 1.0000 | | | |
| $CH_4$ | 0.9155 | 0.3525 | 1.0000 | | |
| $N_2O$ | 0.8916 | 0.3596 | 0.9770 | 1.0000 | |
| PM2.5 | 0.5633 | 0.9278 | 0.4822 | 0.6698 | 1.0000 |
| *Correlation matrix for the parameters of TECHINDEX* | | | | | |
| | GOVEX | PAT | TM | RES | GR |
| GOVEX | 1.0000 | | | | |
| PAT | 0.9565 | 1.0000 | | | |
| TM | 0.8492 | 0.8139 | 1.0000 | | |
| RES | 0.9196 | 0.7834 | 0.6521 | 1.0000 | |
| GR | 0.8308 | 0.5445 | 0.4813 | 0.9287 | 1.0000 |

**Appendix 2**
Multicolinearity statistics.

| Variables | Before transformation | | After transformation | |
|---|---|---|---|---|
| | VIF | Tolerance | VIF | Tolerance |
| ENV | 2.30 | 0.4356 | 1.00 | 1.0000 |
| TECH | 10.15 | 0.0986 | 1.00 | 1.0000 |
| GNI | 12.24 | 0.0817 | 1.00 | 1.0000 |
| $GNI^2$ | 9.30 | 0.1076 | 1.00 | 1.0000 |
| REN | 1.79 | 0.5598 | 1.00 | 1.0000 |
| POP | 10.41 | 0.0961 | 1.00 | 1.0000 |

**Appendix 3**
Summary statistics of variables.

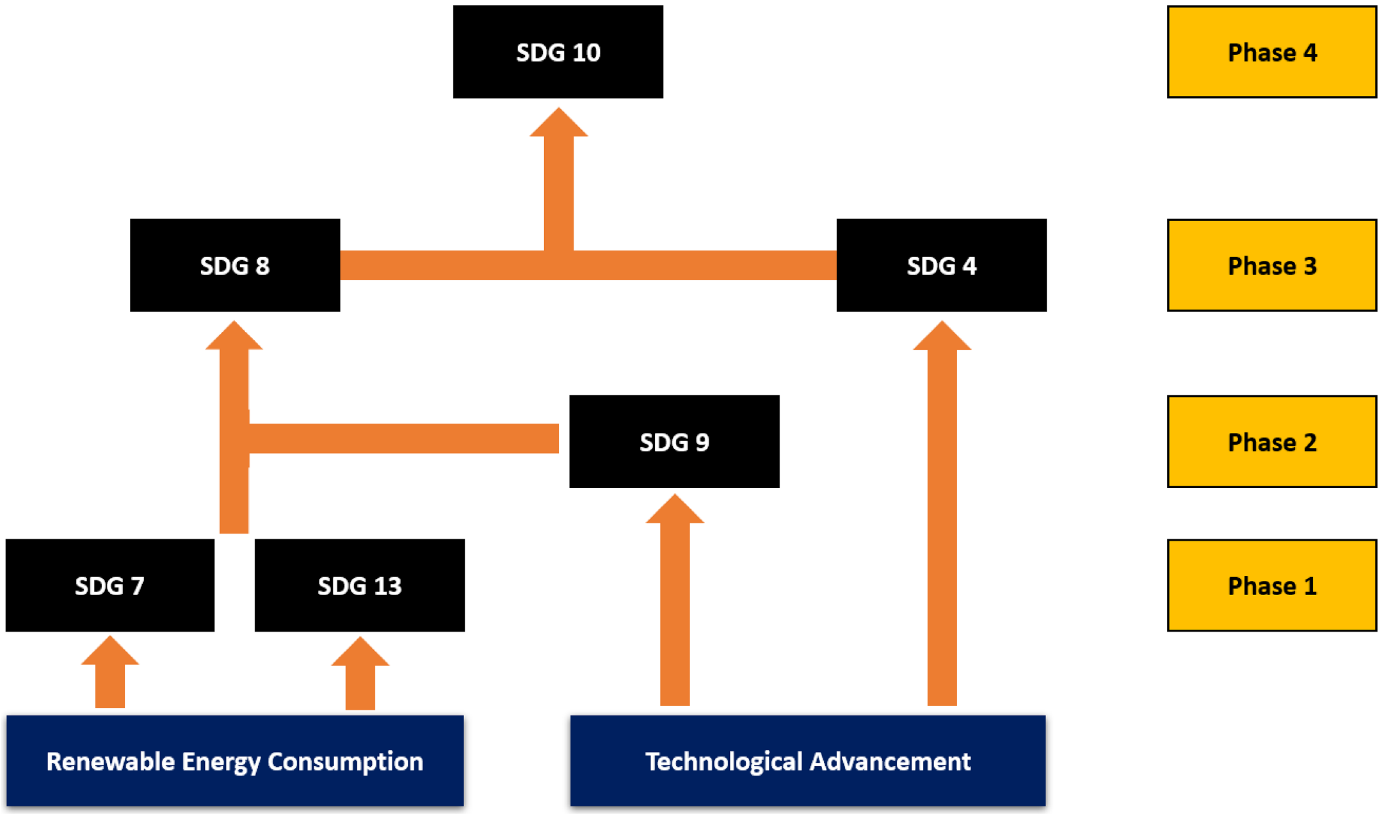
| Variables | Number of observations | Mean | Standard deviation |
|---|---|---|---|
| $CO_2$ | 980 | 3395.80 | 4374.47 |
| $CH_4$ | 980 | 1379.83 | 1538.56 |
| $N_2O$ | 980 | 689.01 | 1163.74 |
| PM2.5 | 896 | 17.95 | 40.85 |
| $GHG_O$ | 896 | 1602.83 | 4240.61 |
| PAT | 980 | 11.14 | 68.15 |
| TM | 924 | 97.92 | 248.09 |
| RES | 896 | 781.84 | 1574.79 |
| GR | 896 | 91.70 | 255.62 |
| GOVEX | 868 | 0.46 | 0.82 |
| GNI | 980 | 10421.42 | 26055.87 |
| REN | 980 | 34.30 | 29.07 |
| POP | 980 | 103723368.23 | 276886235.97 |

Note: All the variables are considered in raw form.

**Appendix 4**
Diagnostic statistics of the empirical model.

| *Diagnostic tests* | *Test statistics* |
|---|---|
| Heteroskedasticity (Breusch and Pagan, 1979) | 1.65<br>(0.1986) |
| Normality (Jarque and Bera, 1987) | 1.28<br>(0.7361) |
| Serial Correlation (Wooldridge, 2002) | 1.12<br>(0.3815) |
| Omitted Variable Bias (Ramsey, 1969) | 0.61<br>(0.1654) |

Note: *p*-values are within parentheses.




**Appendix 5.** Phase-wise SDG implementation.

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**Avik Sinha** is an Assistant Professor in the area of General Management & Economics and also affiliated with Centre of Excellence in Sustainable Development at Goa Institute of Management. He is a Fellow in Economics from Indian Institute of Management Indore. He has published several papers in *Journal of Cleaner Production, Environmental Science and Pollution Research, Renewable and Sustainable Energy Reviews, Ecological Indicators*, etc. His current research interests include Energy Economics, Environmental Economics, and Sustainable Development.

**Tuhin Sengupta** is an Assistant Professor in the area of Information Technology and Operations Management at Goa Institute of Management. He is also affiliated with Centre of Excellence in Sustainable Development at Goa Institute of Management. He is a Fellow in Operations Management & Quantitative Techniques at Indian Institute of Management Indore. He has worked in Larsen & Toubro Ltd. as a senior planning engineer. He has published research papers in international journals such as *Technological Forecasting and Social Change, Journal of Cleaner Production, Environmental Science and Pollution Research, Operations Management Education Review, Journal of Global Operations and Strategic Sourcing*, etc. He has also published teaching cases in Ivey Publishing, Emerald Emerging Market Case Studies, and European Case Clearing House. His-current research interests include sustainable supply chain and retail supply chains in unorganized markets.

**Tanaya Saha** has done M.Phil. in Comparative Literature from the Jadavpur University, M.A. in English from the English and Foreign Language University Lucknow, and B.A. in English from Scottish Church College Kolkata. She has been featured in the prestigious Advantage Woman Programme of ICICI Bank. She has a rich experience of working with SAGE Publications. Her research interest is sustainable development.