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ORIGINAL RESEARCH

Testing the moderating role of trade openness on the environmental Kuznets curve hypothesis: a novel approach

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Abstract

We explore the moderating role of trade openness (TO) by gauging its main and interaction effects on the economic growth and environmental quality nexus. In this direction, we implement a novel approach by using three different measures of pollution emissions (CO_2–CH_4–$PM_{2.5}$) in the environmental Kuznets curve hypothesis and applying a structural equation modelling methodology to 115 countries, grouped into low-, middle- and high-income countries, spanning the period 1992–2018. The evidence suggests that energy consumption has a positive impact on CO_2 emissions for all income panels whilst the moderating effect of TO appears to be a key degrading factor of environmental quality in low- and middle-income countries. In addition, TO's interaction with GDP growth is found to negatively affect environmental quality across all income groups. Given that global economies are on the verge of returning to pre-pandemic levels of industrial operations along with emissions in the wake of the failure of COP26 and that COVID-19 has reminded the world the urgency of developing sustainable approaches in fostering 'green economic growth' models; a host of policy measures are proposed in support of this whilst their likely implications are discussed with reference to different income level countries.

Keywords CO_2–CH_4–$PM_{2.5}$ emissions · Moderation effect in EKC · Income level of countries · Trade openness (TO) · Structural equation modelling (SEM)

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1 Introduction

Existing studies on international trade, postulate that trade openness (TO) is one of the driving forces of economic growth (Emerson et al., 2015). Ever since the introduction of the General Agreement on Tariffs and Trade (GATT), global trade has increased exponentially, hence, compelling liberalization of trade amongst countries. Following GATT's reconstitution and emergence as the World Trade Organization (WTO) and its most recent strategic establishment of the Trade Facilitation Agreement (TFA) (WTO, 2017), global trade has experienced a real growth over the years. With a large pool of countries being members of the WTO, economies are emerging as active participants in the global trade through enhanced export-oriented activities and securing a greater financial stake in the international market. Solid trading relationships are enabling countries to boost industrial production and service activities, hence facilitating higher volumes of trade to galvanise economic growth (Zafar et al., 2020). Following its prevalence as a vital instrument in combatting the recent pandemic, trade growth is now projected to emerge as a significant player in fostering the global economic revival (WTO, 2021b). The recently recalculated WTO projection suggests that the global trade volume will see a 10.8% rise in 2021, accompanied by market-weighted GDP growth of 5.3% in the same year, followed by 4.8% in 2022 (WTO, 2021b).

A large body of the academic literature suggests however that countries prioritizing economic growth based on increasing TO will witness degrading quality of the environment in the form of worsening water quality, deforestation of land, pollution, pandemics and so on due to growing exploitations of natural resources (Emerson et al., 2015; Fang et al., 2018; Wang et al., 2020a, 2020b, 2020c). In this context, accelerated GDP growth is inextricably linked to increased levels of energy usage, emission of pollution into the atmosphere (Chen et al., 2019; Jun et al., 2020) whilst damaging the environment and marring the ecological profile of the country (Kim et al., 2019). Moreover, TO will not only continue to pose environmental threats in the form of higher emissions on the host country but also create a spill-over effect on the bordering countries and long-run externality effects regionally (Gamso, 2018; Halkos & Polemis, 2018; Sam & Zhang, 2020). On the global level, the nature of economic interdependence between countries arisen by the acceleration of globalization is thought to pose additional global threats, due in the main, to the relentless exploitation of natural resources and associated pollutions (Adedoyin et al., 2020). The extant empirical findings however reveal inconclusive connectivity between economic growth and environmental pollution (Kassouri & Altintas, 2020). Also, despite the long-standing debate on the potential environmental ramification of free trade, Emerson et al. (2015) argued that such a relationship is evident, firm and well established whilst Fang et al. (2018) emphasised the need for academics and policymakers to work out possible remedial expedients to this challenge.

In contrast to the above arguments, competing theories of sustainable development (SD) have shown beneficial effects of TO on the environment when different phases of growth are considered (Emerson et al., 2015; Jun et al., 2020), e.g., in the forms of scale-, industrial/structural- and technique/technological- effects (Zhang et al., 2020). In particular, the preponderance of these theories suggests that due to the *scale effect* of producing more and increasing both consumption of energy and exploitations of natural resources, economic growth generally has a negative environmental effect in its first phase and environmental quality worsens with the rise of trade activities (Rafindadi & Usman, 2019). As time passes and further economic growth takes place, countries' increasing wealth enables them to create the *[industry] composition and/or technology/technique effects* and outweigh the *scale effect* on the environment by investing in modernizing the capital stock including green technology, training the workforce, adopting best sustainable management practices, etc. (Emerson et al., 2015; Pothen & Welsch, 2019) and also responding positively to "increased demand for a cleaner environment, better living conditions, and tightened environmental regulations" (Fang et al., 2018, p.1).

The hypothesized quadratic in nature effect or otherwise known as the nexus between economic growth and environmental defilement is called environmental Kuznets curve (EKC) hypothesis (Abbasi & Riaz, 2016) which was empirically advanced by some pioneering works, such as Shafik and Bandyopadhyay (1992), Panayotou (1993), Grossman and Krueger (1995), Seldon and Song (1995) and so on. Since then, the EKC hypothesis has been the dominant theory in explaining an inverted U-shaped relationship between environmental depletion and per capita income/GDP or economic growth (Chen et al., 2020; Jalil & Feridun, 2011; Jalil & Mahmud, 2009; Kanjilal & Ghosh, 2013; Mishra, 2020; Rahman, 2020; Shahbaz et al., 2017). This study argues that the existing literature has yet to reach a consensus on the direction of causality among energy consumption, economic growth, and environmental degradation, in which trade is considered to be a vital component of the solution to environmental degradation due to its prospects "to enhance mitigation as well as adaptation efforts" (Brenton & Chemutai, 2021, p. ix). In light of these backdrops, this paper breaks new ground by exploring the moderating role of trade openness (TO) in the context of the EKC hypothesis, and attempts to fill a gap in literature by gauging its direct and indirect effects in the growth-pollution nexus for 115 WTO-member countries and grouping them into World Bank-classified low-, middle- and high-income panels of countries, spanning the period 1992–2018.

Apart from CO_2 emissions, for robustness, this study also considers CH_4, and $PM_{2.5}$ emissions as major sources and proxies for environmental degradation which to the best of the our knowledge has not been attempted before. This research finds that the impact of the moderation effect of TO differs according to the level of income groups and that TO degrades the quality of environment for low- and middle-income countries. The study also observes that the TO 'interaction' with GDP reduce both CO_2 and CH_4 emissions for high income countries; its 'interaction' with GDP^2 growth increases both types of emissions, hence implying a U-shaped EKC. In light of these findings, this research broadens the current understanding of the relationship between economic growth and each of these types of emissions. It can be argued that the central focus and findings of this study on the moderating role of 'trade' in the growth-pollution nexus are able to offer useful insights in reforming the global governance and incentive systems in the discourse of fostering and sustaining "green economy" (Mishra, 2020), i.e., also known as circular economy, green growth, low carbon, sustainable growth, etc. (Dubey et al., 2018; Fang et al., 2018; Masi et al., 2018; Song et al., 2019; Yu et al., 2017). Moreover, in the wake of the negative growth experience during COVID-19 and expectations that countries will attempt to bounce back stronger to international trading including aviation and exceed the pre-COVID levels of pollution globally, the authors believe that the evidence produced in this study will be of paramount importance for policy formations or reformations by all stakeholders who strive to materialise the sustainable development (SD) agenda in the above nexus.

The rest of the paper is organized as follows: Sect. 2 provides a brief overview of the pertinent literature whilst Sect. 3 touches upon the empirical strategy implemented in this study. Section 4 presents and discusses the emerging evidence in light of the existing literature whilst Sect. 6 summarizes the findings by providing some policy implications.

2 Literature review

Given that trade is considered to be "a central element of the solution to climate change" and "a critical node to mobilize to achieve green, resilient, and inclusive development in the coming years" (Brenton & Chemutai, 2021, p. ix), this paper: (a) examines causal relationships between trade openness (TO), economic growth and environmental degradation, and (b) explores the moderating role in main and interaction effects of TO in the context of the EKC. Environmental economists have long debated the validity of this hypothesis and researchers (e.g., Halkos & Polemis, 2018; He et al., 2017; Jayanthakumaran et al., 2012; Jun et al., 2020) showed a divergent variety of nexus between economic growth/development (e.g., GDP growth, urbanization) and environmental degradation (as a consequence of CO_2 emissions, $PM_{2.5}$ concentration, NOx emissions, wastewater discharge, air quality, industrial soot emissions, etc.) in the EKC hypothesis (Xu et al., 2020). Some of them reinforced the inverted U-curve between the nexus (e.g., Balezentis et al., 2020; Chen et al., 2020; Kanjilal & Ghosh, 2013; Mishra, 2020; Rahman, 2020; Shahbaz et al., 2017) whilst others challenged its existence in various contexts (e.g., Al-Mulali et al., 2016; Caviglia-Harris et al., 2009; Jaunky, 2011). Another group of researchers observed a repeat of the rise in environmental degradation following its drop to a certain level, suggesting various patterns of the nexus, such as an inverted-V shape (Kijima et al., 2010), an N shape (Halkos & Polemis, 2018), or a S shape (Pothen & Welsch, 2019). In light of this backdrop, this study conducts a comprehensive review of the major empirical studies on the economic growth-pollution nexus and sets a logical background for attempting a further investigation of the EKC and checking its variability in various income panels of 115 active member countries of the WTO.

A number of studies produced evidence of the existence of the EKC hypothesis at the global, national or subnational levels. For example, using the ARDL methodology, Jalil and Mahmud (2009) and Jalil and Feridun (2011) observed a quadratic relationship between economic growth and CO_2 emissions, and a positive significant impact of TO on CO_2 emissions in China. Kanjilal and Ghosh (2013) studied the long-run association between energy consumption (EC), economic growth, TO and CO_2 emissions for India, and confirmed the existence of the EKC hypothesis where EC causes CO_2 emissions, but TO has a negative impact on CO_2 emissions. Shahbaz et al. (2017) shared similar results for different panel income groups of 105 countries over the period 1980–2014. Overall, their findings confirmed the existence of the EKC hypothesis in most of the income groups of countries and suggested that TO does not affect environmental quality equally when different income levels are considered. In a more recent study, Rahman (2020) used 1971–2013 annual data of the top-10 electricity consuming countries (except Russia), seven of which (i.e., Canada, China, Germany, India, Japan, South Korea, the USA) also belong to the list of top-10 CO_2 emitting economies, and confirmed the presence of the EKC phenomenon in the economic growth and CO_2 emission nexus. Chen, Xian and Li (2020) assessed the impact of foreign trade, EC and income inequality on CO_2 emissions for G20 countries over the period 1988–2015. The simultaneous quantile regression results suggested that the increase of income and EC propel CO_2 emissions whilst TO positively affects CO_2 emissions in the short run. In the long run however, TO appears to be reducing CO_2 emissions.

On the contrary, there are also a number of studies that do not lend support to the EKC hypothesis. For example, on the global level, Caviglia-Harris et al. (2009) used panel data for 146 countries for the period 1961–2000 and failed to verify the existence of the EKC hypothesis. Al-Mulali et al. (2016) investigated 58 advanced and developing economies for the years 1980–2009 and noticed no sign of the EKC. Abid (2017) applied GMM-system method to test the EKC phenomenon across 58 MENA (Middle East & North Africa) and 41 EU countries for the 1990–2011 time period and observed a monotonically rising nexus between CO_2 emissions and GDP (income) in both the countries and also no sign of the EKC presence. The study argued that an inverted-U curve cannot be an automatic outcome, rather a result of the presence of strong environmental policies and strict institutional practices. Likewise, Sarkodie and Strezov (2018) suggested a monotonic shape of the nexus between CO_2 emissions and economic growth. Pursuing a different approach, Pothen and Welsch (2019) used the Material Footprint (MF) panel data as an indicator of the materials that are extricated to manufacture the final demand in a country, including imports for 144 countries, and revealed a S-shaped (cubic) and monotonically positive relationship between GDP per capita and MF for most income panels of countries. On the national/country level, Inglesi-Lotz and Bohlmann (2014) and Nasr et al. (2015) used South African data for the 1960–2010 and 1911–2010 time periods respectively, and found no evidence in favour of the EKC hypothesis. Likewise, Nasir et al. (2021) used Australian data for economic growth, TO, CO_2 emissions for the period 1980–2014 but found no sign of the EKC phenomenon.

Some scholars obtained mixed results on investigating the validity of the EKC hypothesis. For example, Shafik (1994) examined the relationship between economic growth and pollution (proxied by nine diverse sources of pollution), using a sample of 149 countries over the period 1960–1990. The outcomes of the OLS-based panel data analysis indicated the EKC phenomenon for only sulfur dioxide (SO2) and suspended particles matters (SPM). Later, Aslanidis and Xepapadeas (2006) analysed panel data of 48 states of the USA for the period 1929–1994 using nitrogen oxide (NOx) and SO2 as proxies of emissions. The researchers found no evidence of the EKC for NOx but confirmed the presence of the EKC and a robust smooth inverse-V shaped nexus for SO2. Vehmas et al. (2007) examined the nexus between income and Direct Material Input (DMI), and also income and DMC (DMI excluding exports) in the EU15 for the period 1980–2000. In the first case (DMI), they reported evidence supporting the EKC in case of Germany only. In the second case (DMC), they found the EKCs for the entire EU15 and five countries on the national levels. In a recent study, Shahbaz (2019) employed panel regression and cointegration models to investigate the EKC presence in the Next-11 countries and the empirical findings indicated variable relationships between globalisation and CO2 emissions in the EKC hypothesis. Table 5 in the appendix provides an effective summary of the key studies in the area.

The above review indicates that the studies that are conducted on investigating the empirical implications of the EKC in the economic growth—pollution nexus witness diverse results due to differences in "samples, pollutants, and methodologies" (Fang, et al., 2018, p.4), and as a result create some degree of ambiguities with varying conclusions and unclear causal linkages in the nexus in question (Busa, 2013; Xu et al., 2020). This backdrop, as also stressed by Amar (2021), justifies the need to revisit of the earlier findings in the EKC literature using contemporary econometric methods, and this is done in this study on a set of more recent panel data of global economies for the period 1992–2018, applying Structural Equation Modelling (SEM) method and also considering two additional proxies of environmental degradation (CH_4 emissions and $PM_{2.5}$ emissions), besides the most commonly used proxy (i.e., CO_2 emissions) to enhance the validity of the empirical findings. Moreover, in view of the fact that "although much theory and evidence indicate that trade is closely related to income and economic growth, the environmental effect of trade differs systematically from that of economic growth" (Fang, et al., 2018, p.1), this study justifies one of the objectives of conducting an empirical investigation of the role of TO in the economic growth-pollution nexus.

3 Empirical investigation

3.1 Sample and data

Given that "a variety of time series, cross-section and panel data analyses indicate that the empirical results are sensitive to the sample of countries chosen and to the time period considered" (Kijima et al., 2010, p. 1188), the study's initial intention was to cover all countries of the world (i.e., 270), as listed in the World Development Indicators (WDI) (2018). However, in alignment with the research aim of investigating the role of TO in the growth-pollution relationship, the list of countries is filtered based on their active WTO memberships and accordingly deduced the target population to be 164 (as of year 2021). The resulting sample size of 115 countries is based on the complete availability of the continuous data for our study variables. Also, to examine the presence of the EKC hypothesis in different income panels of these countries, the official World Bank classifications were followed to segregate the list of countries into 39 high income, 35 upper middle-income, 32 lower middle-income and 9 low-income groups (see Appendix Table 8). Moreover, given that the panel data effectively reflects the dynamics of empirical variables and a large majority of the empirical research on the EKC hypothesis have used country-level panel data to analyse long-run nexus between growth and pollution (Fang et al., 2018; Xu et al., 2020), the same is followed in this study and the period 1992–2018 was covered. Since a number of countries from Central Asian and Baltic regions secured Independence from the former Soviet Union (USSR) and emerged as sovereign countries on the globe during 1988–1991, pre-1992 data were not available for these countries. Therefore, it was logical to consider the 1992–2018 data corresponding to the variables in this study, i.e., CO_2 emissions, CH_4 emissions, $PM_{2.5}$ emissions; real GDP per capita, energy consumption (EC), transportation (TR) and trade openness (TO).

3.2 The variables

In order to investigate the existence of the EKC hypothesis in the economic growth -pollution nexus in classified income panels of countries and the moderating role of TO in their relationship, environmental degradation is used as the dependent variable, and three different measures of environmental degradation, i.e., carbon dioxide (CO_2), methane (CH_4) emissions and concentration of fine particulate matter ($PM_{2.5}$) are considered to ensure robustness. CO_2 and CH_4 emissions are directly related to global greenhouse effect while $PM_{2.5}$ causes cardiovascular and respiratory problem and regional climatic change (EPA, 2017, 2021; Forabosco et al., 2017; Wu et al., 2020). Table 6 in appendix provides a summary of the statistics of the variables used in the estimation.

Among all types of pollutants, CO_2 is empirically the most influential element in global warming and climate change (Adedoyin et al., 2020; Wang et al., 2020a). The latest estimates suggest that CO_2 emissions in the production and marketing of traded goods and services have resulted in a 4–6 °C increase in the global temperature (Wang et al., 2020a, 2020b, 2020c), in contrast to the COP21 target of limiting the warming preferably to 1.5 °C. The G7 countries, BRICS economies, China and its the Belt and Road Countries (BRCs), the Asia Pacific region, and the top-10 electricity consuming countries (except Russia) account 27.3%, 37%, 50%, 50%, and 61.07% of the global CO_2 emissions respectively (Lin et al., 2021; Mahadevan & Sun, 2020, Rahman, 2020; Wang et al., 2020a, 2020b, 2020c; Zafar et al., 2020).

CH_4 is the second global greenhouse gas (GHG) and it is 80 times more potent than CO_2 in acting as a cause of global warming over the next two decades, besides currently causing about 1 million premature deaths annually (UNEP, 2021). Mainly, various anthropogenic activities like agricultural cultivation, rearing livestock, organic and municipal waste landfills are responsible for CH_4 emissions (Datta et al., 2012). Although there was about 7% decline in the CO_2 emissions during the COVID-19 lockdowns last year, the volume of CH_4 emissions accelerated (NOAA, 2021).

Besides CH_4 emissions, other anthropogenic activities like transport exhausts, biomass burning, urbanization, coal-fired manufacturing activities and natural procedure cause $PM_{2.5}$ emissions (Wu et al., 2020). $PM_{2.5}$ has significant impact for causing cardiovascular diseases, vascular inflammation, lung cancer, asthma, emphysema, or chronic bronchitis. Children and adults are comparatively more vulnerable to $PM_{2.5}$ concentration. Sometimes it affects regional climate, lessening visibility and adulterate food and vegetables (Li et al., 2016a, 2016b).

The key independent variable is TO, which is perceived to be acting not only as a standalone factor but also as a moderating factor that affects environmental quality. It is evident that countries, especially developing countries, that are reliant on trade have degraded the quality of environment, mostly due to the lack of proper regulations and implementation of existing environmental rules and regulations (Jobert et al., 2016; Yunfeng & Laike, 2010). Farhani et al. (2013) found 1% increase in TO increased CO_2 emissions by 0.043% from dirty industries in the MENA region. Researchers (e.g., Gamso, 2018; Halkos & Polemis, 2018; Sam & Zhang, 2020) warned that TO can not only damage the environmental quality in the host countries but also has "spillover effects" on the surrounding states. Conversely, Jayanthakumaran et al. (2012) found no effect of TO on environmental degradation in the cases of China and India. Rather, some studies (e.g., Onafowora & Owoye, 2014; Pothen & Welsch, 2019; Rafindai & Usman, 2019) suggested that TO reduces environmental degradation through the enhancement of the capacity of the countries for using advanced technologies in the production process (technology effect). In light of these mixed evidence, the impact of TO appears to be inconclusive, and hence justifies the need for further investigation to revisit its potential contribution to environmental quality (Wang et al., 2020a, 2020b, 2020c). Given that this study also seeks to capture the moderating effect through GDP growth, it makes an interaction of TO with GDP. Also, given the inconclusive results in the extant literature this research makes any a priori assumptions about the hypothesized sign as it can transpire to be either positive or negative.

Economic growth is the most widely used variable in the growth-environmental pollution nexus (e.g., Abdouli & Hammami, 2016; Rahman, 2020; Umar et al., 2020). Typically, it is measured in real gross domestic product (GDP) or income per capita in most of the studies. Based on the existing evidence, a strong and positive relationship is expected between economic growth and environmental degradation (Jayanthakumaran, et al., 2012). Increasing economic growth enhances not only the integration power and ensure the quality of life but also causes many environmental hazards (Bergasse et al., 2013; Masi et al., 2018). Sustainable path of development hence becomes an imperative prerequisite for the existing and future generations with profound understanding (Song et al., 2019). It should also be noted that the square term of GDP growth will be used to test for potential non-linearities.

Energy consumption (EC), the next explanatory variable here are strong interactions and links between EC and socio-economic development. As a global commodity and cornerstone, EC has a crucial and significant role for most kinds of development (Bergasse et al., 2013). Researchers found divergent results in growth-energy consumption nexus due to time or methodological differences, patterns of energy or economy and heterogeneous climatic conditions (Shahbaz, et al., 2013). However, EC has a direct link with economic growth and environmental degradation (Li et al., 2016a). For example, growth of an economy depends on the expansion of economic activities and these involve relentless consumption of non-renewable energy (e.g., oil, coal, and gas). This leads to convergence into by-products which then contribute into emission of pollution into the atmosphere, resulting in degrading environmental quality in the form of global warming, depletion of ozone layer, etc. (Adedoyin et al., 2020; Wang et al., 2020a). In light of the above backdrop, we expect a significant positive impact of EC on all measures of environmental degradation, i.e., emissions of CO_2, CH_4, and $PM_{2.5}$.

Many scholars have exposed the relationship between economic growth and transportation (TR) sector since TR acts as a facilitator to enhance economic growth and economic growth assists reversely to the TR intensity (Lean et al., 2014; Liddle & Lung, 2013). Also, from the social SD point of view, the transports play a vital role in facilitating a balanced development of the socio-economic systems of a country (Farhadi, 2015). Another aspect of TR is the relationship with GHG emissions as a by-product of fossil fuels. It involves road, railway, aviation and navigation subsectors (EPA, 2021) and as an individual sector it is responsible for 24% of global emissions (Wang & Ge, 2019), 29% of the GHG emissions in the US (EPA, 2021) and 25% of the EU's GHG emissions (EEA, 2020). The transportation-led pollutants such as $PM_{2.5}$, NO_2, and volatile organic compounds (VOCs) cause cardiovascular and respiratory problems, asthma, bronchitis and allergic rhinitis (EEA, 2020; EPA, 2017; Wu et al., 2020). Moreover, "while most other economic sectors, such as power production and industry, have reduced their emissions since 1990, those from transport have risen" (EEA, 2020, p.1). It is because of its persistent role as an "essential connector" to all varieties of industrial activities and operations including logistics, supply chain and human mobilities, contributing potentially to as much as 60% in the global GHGs by 2050 (World Bank, 2020). In light of the above backdrop, this study anticipates a significant positive impact of TR on the alternative measures of emissions considered.

3.3 Model specification

In view of the above, economic degradation in the context of the traditional EKC hypothesis is expressed as follows:

$$ED = f(GDP, EC, TR, TO) \tag{1}$$

where ED stands for environmental degradation and consists of three measures (i.e., CO_2 emissions, CH_4 emissions, and $PM_{2.5}$ emissions); GDP denotes GDP growth; EC stands for energy consumption; TR is transportation; and TO stands for trade openness. CO_2 emissions are measured in metric tons per capita, CH_4 emissions in kilotons of CO_2 equivalent, $PM_{2.5}$ emissions in microgram per cubic meter; real GDP per capita in constant 2010 US$, EC in kg of oil equivalent per capita, TR is measured as percentage of total exports and imports of commercial service and TO is measured as percentage of total trade volume of GDP from the WDI, and adjusted the data for inflation where necessary.

In the recent EKC literature, various econometric methods have been used to investigate the causality between growth and pollution, such as fully modified (Cup-FM) estimates (Chen & Fang, 2018), the fully modified OLS (FMOLS) (Kasman & Duman, 2015), generalized method of moments (GMM) (Li et al., 2016a), the spatial panel model (Espoir & Sunge, 2021), among others. However, in developing an understanding and in order to be able to explain the forms and extent of correlation, variation and covariation among the above set of variables (Brommer et al., 2014), a structural equation modelling (SEM) approach is adopted. The methodological review suggests that among 146 relevant publications on SEM applications in ecological studies, SEM was highlighted as a powerful and an increasingly popular technique in scientific investigations for testing various hypotheses with multiple variables having complex webs of causal relationships (Richter et al., 2016). Shah and Goldstein (2006) emphasized SEM as a more appropriate inference framework for most types of causal analyses including mediation. Unlike traditional methods that offer default model, SEM requires development of a priori specification of the forms of directional and non-directional interactions among observed (measured) and unobserved (latent) variables to endorse hypotheses, with research and/or theory (MacCallum & Austin, 2000). It also investigates "whether the proposed causal relationship is consistent with the patterns [forms] found among variables in the empirical data" (Bollen & Pearl, 2013, p.12). Moreover, as "quantifying behaviour often involves using variables that contain measurement errors and formulating multi-equations to capture the relationship among a set of variables" (Bollen & Noble, 2011, p. 15,639), unlike the traditional methods, SEM explicitly indicates error to detect the imperfect nature of the measures. Also, SEM requires multiple measures to explain unobserved variables and hence resolves the occurrence of multicollinearity problems by identifying distinct latent constructs (Stein et al., 2017). In light of these observations, the selection of SEM is deemed to be well justified.

As a platform of conducting the empirical analysis, the effects of regressors on environmental degradation can be expressed in the following equation forms:

$$CO_{2it} = \beta_0 + \beta_1(GDP_{it}) + \beta_2(GDP_{it}^2) + \beta_3(EC_{it}) + \beta_4(TR_{it}) + \beta_5(TO_{it}) + \varepsilon_{it} \tag{2}$$

$$CH_{4it} = \beta_0 + \beta_1(GDP_{it}) + \beta_2(GDP_{it}^2) + \beta_3(EC_{it}) + \beta_4(TR_{it}) + \beta_5(TO_{it}) + \varepsilon_{it} \tag{3}$$

$$PM_{2.5it} = \beta_0 + \beta_1(GDP_{it}) + \beta_2(GDP_{it}^2) + \beta_3(EC_{it}) + \beta_4(TR_{it}) + \beta_5(TO_{it}) + \varepsilon_{it} \tag{4}$$

where β_0 refers to intercepts and $\beta_{1,}\beta_{2,}\beta_{3,}\beta_{4,}\beta_5$ indicate coefficients of explanatory variables and ε_{it} indicate error terms in Eqs. (2)–(4).

TO is envisaged to have a moderating effect on the relationship between economic growth and environmental degradation. The main purpose of a moderator variable is to modify the form or strength of the relationship between independent and dependent variable in regression analysis. As per literature, two kinds of effects can be measured in moderation effect model: (a) the main effect which is presented in Eqs. (2)–(4), and (b) the moderating effect (Fig. 1) estimates including interaction variables, which is in line with the findings of Chen and Myagmarsuren (2013) and Katircioğlu and Taşpinar (2017). To estimate the main and interaction effects of regressors on the dependent variables of CO_2, CH_4 and $PM_{2.5}$, the variables are normalised and the Eqs. (5)–(7) expressed as follows:

$$\begin{aligned} CO_{2it} =& \beta_0 + \beta_1(GDP_{it}) + \beta_2\left(GDP_{it}^2\right) + \beta_3(EC_{it}) + \beta_4(TR_{it}) \\ &+ \beta_5(TO_{it}) + \beta_6[(GDP_{it}) \times (TO_{it})] \\ &+ \beta_7\left[(GDP_{it}^2) \times (TO_{it})\right] + \beta_8[(EC_{it}) \times (TO_{it})] + \beta_9[(TR_{it}) \times (TO_{it})] + \varepsilon_{it} \end{aligned} \tag{5}$$

$$\begin{aligned} CH_{4it} =& \beta_0 + \beta_1(GDP_{it}) + \beta_2\left(GDP_{it}^2\right) + \beta_3(EC_{it}) + \beta_4(TR_{it}) \\ &+ \beta_5(TO_{it}) + \beta_6[(GDP_{it}) \times (TO_{it})] \\ &+ \beta_7\left[(GDP_{it}^2) \times (TO_{it})\right] + \beta_8[(EC_{it}) \times (TO_{it})] + \beta_9[(TR_{it}) \times (TO_{it})] + \varepsilon_{it} \end{aligned} \tag{6}$$

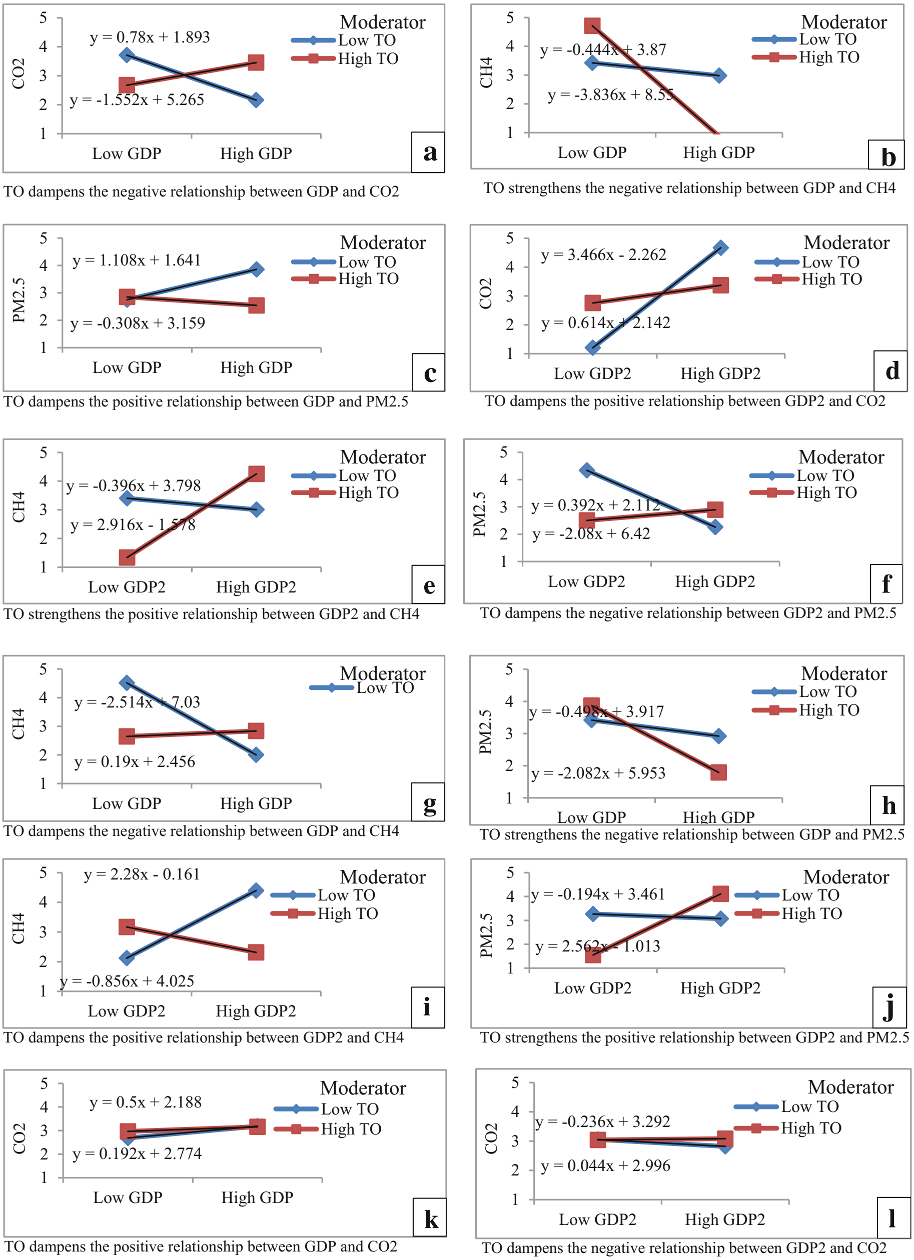

Fig. 1 **a–p** Two-way interaction relationship between gross domestic product (GDP & GDP^2) and selected indicators (CO_2, CH_4 & $PM_{2.5}$) of environmental pollution in different panel income groups

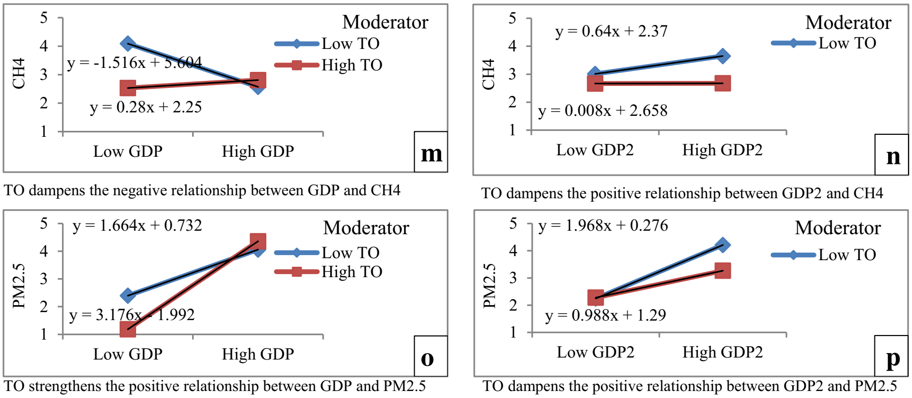

Fig. 1 continued

$$
\begin{aligned}
PM_{2.5it} = {} & \beta_0 + \beta_1(GDP_{it}) + \beta_2\left(GDP_{it}^2\right) + \beta_3(EC_{it}) + \beta_4(TR_{it}) \\
& + \beta_5(TO_{it}) + \beta_6[(GDP_{it}) \times (TO_{it})] \\
& + \beta_7\left[\left(GDP_{it}^2\right) \times (TO_{it})\right] + \beta_8[(EC_{it}) \times (TO_{it})] + \beta_9[(TR_{it}) \times (TO_{it})] + \varepsilon_{it}
\end{aligned}
\tag{7}
$$

The Eqs. (5)–(7) propose that TO exerts influences on the relationship between the independent variables and the dependant variables (i.e., the indicators of environmental degradation). These influences are known as moderating effect in statistical analysis (Cohen et al., 2003). Analysis of Moment Structures (AMOS 25) is used to test the moderation effect in this study.

4 Results

4.1 Validity analysis and CFA

In order to assess the validity of the measurement model, prior to the empirical assessment, reliability analysis and confirmatory factor analysis (CFA) are conducted using the maximum likelihood estimation technique and items are reconstructed based on the results of CFA. Reliability analysis is a procedure used to estimate the consistency of the measured items and the appropriateness of the model.

The recommended good fit indices are represented in Table 1 which is in line with the findings of Shah and Goldstein (2006) and Hasan et al. (2014). The Chi^2 test depends directly on the sample size while CFI, GFI, NFI and TLI are of acceptable fit if > 0.95, poor fit if > 0.90 and SRMR if < 0.06 (Hu & Bentler, 1998), RMSEA if < 0.05 good fit, adequate fit if < 0.08 (Browne & Cudeck, 1993).

4.2 Long-run coefficients of the main effect in path analysis

The value of the coefficients in main and interaction effects differ in classified income groups, particularly in low-income countries where GDP reduces but GDP^2 increases CO_2 emissions

Table 1 Results of model fit indices

Income Groups /measures	Absolute fit measures				Incremental fit measures				Parsimonious fit		
	χ^2/d. f	GFI	SRMR	RMSEA	CFI	IFI	NFI	TLI	AGFI	PGFI	PNFI
Aggregate data of the countries (N = 3105)	11.516	0.997	0.006	0.058	0.998	0.998	0.998	0.979	0.952	0.064	0.076
Low-income countries (N = 243)	1.599	0.989	0.012	0.050	0.998	0.998	0.994	0.986	0.917	0.127	0.151
Lower-middle income countries (N = 864)	4.202	0.998	0.010	0.061	0.999	0.999	0.998	0.970	0.937	0.038	0.045
Upper-middle income countries (N = 945)	7.899	0.991	0.009	0.085	0.995	0.995	0.994	0.949	0.896	0.089	0.105
High-income countries (N = 1053)	5.435	0.991	0.010	0.065	0.996	0.996	0.995	0.974	0.935	0.140	0.166

GFI goodness-of-fit index, *SRMR* standardized root mean residual, *RMSEA* root mean square error of approximation, *AGFI* adjusted goodness-of-fit index, *IFI* incremental fit index, *NFI* normed fit index, *TLI* Tucker Lewis index, *PGFI* parsimonious goodness of-fit index, *PNFI* parsimonious normed-fit-index, *CFI* comparative fit index

Table 2 Estimation of long-run coefficients in EKC with main effects in Path analysis

			Coefficient	S.E	Z-value				Coefficient	S.E	Z-value
Low income countries						*Lower-middle income countries*					
ZCO_2	←	ZGDP	− .193	.091	− 2.12**	ZCO_2	←	ZGDP	.037	.128	.29
ZCH_4	←	ZGDP	− 1.07	.256	− 4.21***	ZCH_4	←	ZGDP	− .115	.145	− .79
$ZPM_{2.5}$	←	ZGDP	.200	.056	3.58***	$ZPM_{2.5}$	←	ZGDP	.295	.139	2.13**
ZCO_2	←	$ZGDP^2$	1.02	.098	10.50***	ZCO_2	←	$ZGDP^2$	.209	.125	1.68*
ZCH_4	←	$ZGDP^2$	.630	.260	2.42**	ZCH_4	←	$ZGDP^2$	− .044	.142	− .31
$ZPM_{2.5}$	←	$ZGDP^2$	.017	.302	.06	$ZPM_{2.5}$	←	$ZGDP^2$	− .422	.136	− 3.11***
ZCO_2	←	ZEC	.282	.025	11.31***	ZCO_2	←	ZEC	.330	.038	8.65***
ZCH_4	←	ZEC	.073	.081	.90	ZCH_4	←	ZEC	.135	.043	3.11***
$ZPM_{2.5}$	←	ZEC	− .636	.058	− 10.88***	$ZPM_{2.5}$	←	ZEC	− .119	.042	− 2.87***
ZCO_2	←	ZTR	− .022	.021	− 1.05	ZCO_2	←	ZTR	.082	.030	2.68***
ZCH_4	←	ZTR	.055	.064	.86	ZCH4	←	ZTR	− .179	.035	− 5.17***
$ZPM_{2.5}$	←	ZTR	.472	.055	8.62***	$ZPM_{2.5}$	←	ZTR	.074	.033	2.24**
ZCO_2	←	ZTO	.063	.021	3.04***	ZCO_2	←	ZTO	.096	.030	3.19***

Table 2 (continued)

			Coefficient	S.E	Z-value				Coefficient	S.E	Z-value
ZCH_4	←	ZTO	− .204	.063	− 3.24***	ZCH_4	←	ZTO	− .360	.034	− 10.54***
$ZPM_{2.5}$	←	ZTO	− .303	.058	− 5.25***	$ZPM_{2.5}$	←	ZTO	− .300	.033	− 9.17***
Upper-middle income countries						*High income countries*					
ZCO_2	←	ZGDP	.080	.046	1.74*	ZCO_2	←	ZGDP	− .010	.018	− .544
ZCH_4	←	ZGDP	− .581	.122	− 4.75***	ZCH_4	←	ZGDP	.067	.031	2.15**
$ZPM_{2.5}$	←	ZGDP	− .645	.131	− 4.92***	$ZPM_{2.5}$	←	ZGDP	− .745	.098	− 7.60***
ZCO_2	←	ZGDP2	− .140	.046	− 3.05***	ZCO_2	←	$ZGDP^2$	.012	.065	.18
ZCH_4	←	ZGDP2	.356	.122	2.91***	ZCH_4	←	$ZGDP^2$	− .090	.119	− .75
$ZPM_{2.5}$	←	ZGDP2	.592	.131	4.50***	$ZPM_{2.5}$	←	$ZGDP^2$	.515	.108	4.76***
ZCO_2	←	ZEC	.943	.011	89.47***	ZCO_2	←	ZEC	.655	.017	39.02***
ZCH_4	←	ZEC	.218	.031	7.01***	ZCH_4	←	ZEC	.112	.029	3.83***
$ZPM_{2.5}$	←	ZEC	.208	.033	6.31***	$ZPM_{2.5}$	←	ZEC	.528	.028	18.84***
ZCO_2	←	ZTR	.029	.011	2.68***	ZCO_2	←	ZTR	.091	.016	5.71***
ZCH_4	←	ZTR	− .273	.030	− 9.05***	ZCH_4	←	ZTR	− .168	.029	− 5.79***

Table 2 (continued)

			Coefficient	S.E	Z-value				Coefficient	S.E	Z-value
$ZPM_{2.5}$	←	ZTR	.186	.032	5.78***	$ZPM_{2.5}$	←	ZTR	.097	.028	3.44***
ZCO_2	←	ZTO	.003	.011	.25	ZCO_2	←	ZTO	.045	.018	2.49**
ZCH_4	←	ZTO	− .259	.029	− 8.89***	ZCH_4	←	ZTO	− .405	.031	− 13.11***
$ZPM_{2.5}$	←	ZTO	− .170	.031	− 5.47***	$ZPM_{2.5}$	←	ZTO	− .011	.030	− .37
Aggregate data income countries											
ZCO_2	←	ZGDP	.173	.031	5.65***	ZCO_2	←	ZEC	.916	.010	89.21***
ZCH_4	←	ZGDP	− .309	.064	− 4.81***	ZCH_4	←	ZEC	.225	.027	8.19***
$ZPM_{2.5}$	←	ZGDP	− 1.21	.057	− 21.25***	$ZPM_{2.5}$	←	ZEC	.487	.022	21.88***
ZCO_2	←	$ZGDP^2$	− .048	.012	− 4.03***	ZCO_2	←	ZTR	.018	.008	2.28**
ZCH_4	←	$ZGDP^2$	.162	.063	2.56***	ZCH_4	←	ZTR	− .155	.018	− 8.52***
$ZPM_{2.5}$	←	$ZGDP^2$	.739	.056	13.16***	$ZPM_{2.5}$	←	ZTR	.118	.016	7.29***
ZCO_2	←	ZTO	.062	.009	6.54***	$ZPM_{2.5}$	←	ZTO	− .228	.018	− 12.36***
ZCH_4	←	ZTO	− .330	.021	− 15.97***	$ZPM_{2.5}$	←	ZTO	− .228	.018	− 12.36***

*, ** and *** indicate statistical significance at the 1%, 5%, and 10% level, respectively

Table 3 Long-term coefficients in EKC with interaction effects in Path analysis

			Coefficient	S.E	Z-value				Coefficient	S.E	Z-value
Low income countries						*Lower-middle income countries*					
ZCO_2	←	GDPxTO	.583	.086	6.76***	ZCO_2	←	GDPxTO	− .068	.114	− .60
ZCH_4	←	GDPxTO	− .848	.285	− 2.97***	ZCH_4	←	GDPxTO	.092	.129	.71
$ZPM_{2.5}$	←	GDPxTO	− .354	.081	− 4.38***	$ZPM_{2.5}$	←	GDPxTO	− .219	.124	− 1.77*
ZCO_2	←	GDP^2xTO	− .713	.093	− 7.64***	ZCO_2	←	GDP^2xTO	.259	.119	2.17**
ZCH_4	←	GDP^2xTO	.828	.288	2.87***	ZCH_4	←	GDP^2xTO	.077	.135	.57
$ZPM_{2.5}$	←	GDP^2xTO	.153	.285	.53	$ZPM_{2.5}$	←	GDP^2xTO	.618	.129	4.78***
ZCO_2	←	ECxTO	.113	.032	3.49***	ZCO_2	←	ECxTO	.027	.040	.67
ZCH_4	←	ECxTO	− .138	.110	− 1.26	ZCH_4	←	ECxTO	− .161	.046	− 3.52***
$ZPM_{2.5}$	←	ECxTO	.503	.082	6.13***	$ZPM_{2.5}$	←	ECxTO	− .199	.044	− 4.54***
ZCO_2	←	TRxTO	.003	.016	.184	ZCO_2	←	TRxTO	.084	.028	2.96***
ZCH_4	←	TRxTO	.009	.055	.18	ZCH_4	←	TRxTO	.089	.032	2.77***
$ZPM_{2.5}$	←	TRxTO	.015	.050	.29	$ZPM_{2.5}$	←	TRxTO	.048	.031	1.55
Upper-middle income countries						*High income countries*					

Table 3 (continued)

			Coefficient	S.E	Z-value				Coefficient	S.E	Z-value
ZCO_2	←	GDPxTO	.007	.044	.17	ZCO_2	←	GDPxTO	− .261	.048	− 5.39***
ZCH_4	←	GDPxTO	.676	.117	5.75***	ZCH_4	←	GDPxTO	− .194	.095	− 2.05**
$ZPM_{2.5}$	←	GDPxTO	− .396	.121	− 3.26***	$ZPM_{2.5}$	←	GDPxTO	.338	.083	4.06***
ZCO_2	←	GDP^2xTO	.067	.014	4.69***	ZCO_2	←	GDP^2xTO	.224	.036	6.16***
ZCH_4	←	GDP^2xTO	− .784	.139	− 5.64***	ZCH_4	←	GDP^2xTO	.352	.070	5.02***
$ZPM_{2.5}$	←	GDP^2xTO	.689	.149	4.66***	$ZPM_{2.5}$	←	GDP^2xTO	− .261	.064	− 4.04***
ZCO_2	←	ECxTO	− .047	.013	− 3.65***	ZCO_2	←	ECxTO	− .042	.029	− 1.45
ZCH_4	←	ECxTO	− .131	.035	− 3.72***	ZCH_4	←	ECxTO	− .642	.060	− 10.67***
$ZPM_{2.5}$	←	ECxTO	− .074	.038	− 1.95*	$ZPM_{2.5}$	←	ECxTO	− .059	.058	
ZCO_2	←	TRxTO	− .052	.011	− 4.85***	ZCO_2	←	TRxTO	− .044	.021	− 2.16**
ZCH_4	←	TRxTO	.175	.028	6.17***	ZCH_4	←	TRxTO	.311	.035	8.76***
$ZPM_{2.5}$	←	TRxTO	− .092	.031	− 3.01***	$ZPM_{2.5}$	←	TRxTO	− .006	.035	− .16
Aggregate data income countries											
ZCO2	←	GDPxTO	− .077	.021	− 3.67***	ZCO2	←	ECxTO	− .054	.016	− 3.36***

Table 3 (continued)

			Coefficient	S.E	Z-value				Coefficient	S.E	Z-value
ZCH4	←	GDPxTO	.449	.048	9.36***	ZCH4	←	ECxTO	− .308	.037	− 8.32***
ZPM2.5	←	GDPxTO	.378	.029	12.87***	ZPM2.5	←	ECxTO	.010	.033	.32
ZCO2	←	GDP^2xTO	.070	.011	6.37***	ZCO2	←	TRxTO	.006	.009	.629
ZCH4	←	GDP^2xTO	− .158	.026	− 6.06***	ZCH4	←	TRxTO	.122	.019	6.35**
ZPM2.5	←	GDP^2xTO	− .245	.021	− 11.8***	ZPM2.5	←	TRxTO	− .051	.017	− 3.04***

*, **, and *** indicate statistical significance at the 1%, 5%, and 10% level, respectively

(see Table 2), indicating U-shaped EKC. Again, GDP growth shows positive impact but GDP^2 growth reveals the significant negative impact in reducing CO_2 emissions in upper-middle-, and aggregated-income groups, supporting the inverted U-shaped EKC. In CH_4 emissions, GDP growth shows significant negative impact for low, upper-middle-, and aggregated-income groups and positive impact on emissions for high income group. However, GDP^2 has significant positive impact on CH_4 for low, upper-middle-, and aggregated-income groups depicting a U-shaped EKC, meaning that further economic growth raises CH_4 emissions in these income groups. Furthermore, in $PM_{2.5}$ emissions, GDP has a significant positive impact for low and lower-middle income groups while it reduces $PM_{2.5}$ emissions for upper-middle, high income and aggregated income groups. Again, GDP^2 increases $PM_{2.5}$ emissions for low, upper-middle, high income and aggregated income groups implying that $PM_{2.5}$ raises along with further economic growth.

4.3 Long-run coefficients of interaction effect in path analysis

The results of interaction effects differ from the main effect significantly. GDP interaction with TO reveals the significant negative impact on CO_2 emissions for high income and aggregated income groups while it shows significant positive impact on the emissions for low-income group (see Table 3). However, GDP^2 interaction with TO depicts a significant positive impact on CO_2 emissions for all the income groups except low-income group meaning that TO causes CO_2 emissions with further GDP growth.

In CH_4 emissions, TO interaction with GDP reveals the significant negative impact for low, and high-income groups while it shows positive impact for upper-middle, and aggregated-income groups. However, TO interaction with GDP^2 shows the positive impact for low, and high-income groups depicting U-shaped EKC while TO interaction with GDP^2 indicates significant negative impact on CH_4 emissions in upper-middle-, and aggregated-income groups depicting an inverted a U-shaped EKC.

Finally, in $PM_{2.5}$ emissions, TO interaction with GDP shows negative impact for low, lower-middle, and upper-middle income groups while it shows positive impact for high income and aggregated income groups. Moreover, GDP^2 interaction with TO leads to positive impact on $PM_{2.5}$ emissions in lower and upper-middle income groups but it reduces $PM_{2.5}$ emissions for high income and aggregated income groups portraying EKC hypothesis.

4.4 Two-way interactions

The two-way interaction effect demonstrates that the independent variable (IV) as the one whose relationship with the dependent variable (DV) is being moderated whereas the moderator is the other IV doing the moderating effect. The interaction is the product variable and the intercept/constant indicates the vertical position for the graph (see set of Fig. 1a–p). In this study, two-way interaction shows the relationship between IV (i.e., GDP) and each of the DVs is moderated by the other IV (i.e., TO) as the moderator. The two-way interactions highlight some dampening and strengthening relationships in respective to high and low flow of moderator (i.e., TO) in different income panel countries on the EKC. "Dampening" means weakening negative or positive relationship between the two IVs (i.e., GDP and CO_2) and strengthening means intensifying positive or negative relationships between the variables.

The set of Figures depicts that TO dampens the negative relationship between GDP and CO_2 (Fig. 1a) and dampens the positive relationship between GDP^2 and CO_2 for low-income group (Fig. 1d) in support to the EKC. TO dampens the negative relationship between

GDP and CH_4 emissions for upper-middle income (Fig. 1g) and aggregated income groups (Fig. 1m), meaning that TO interaction with GDP degrades the quality of environment. While the interaction effect of TO dampens the positive relationships between GDP^2 and CH_4 for upper-middle (Fig. 1i) and aggregated income groups (Fig. 1n), it leads to reduces CH_4 emissions in support to the EKC.

In $PM_{2.5}$ emissions, the interaction effect of TO dampens the positive relationship between GDP growth and $PM_{2.5}$ emissions for low-income group (Fig. 1c), between GDP^2 growth and $PM_{2.5}$ emissions for aggregated income group (Fig. 1p) and strengthens negative relationship between GDP and $PM_{2.5}$ for upper-middle income group (Fig. 1h). However, TO strengthens the positive relationship between GDP^2 and $PM_{2.5}$ for upper-middle income group (Fig. 1j) and dampens the negative relationship between GDP^2 and $PM_{2.5}$ for lower middle-income group (Fig. 1f) and again strengthens positive relationship between GDP and $PM_{2.5}$ for aggregated income group (Fig. 1o), implying that further GDP growth causes environmental degradation emitting $PM_{2.5}$.

4.5 Standardized total effect

The estimated standardised total effect, which is the summation of the standardised direct and indirect effects, enable us to understand the strength of the relationship between the dependent and independent variables. Since AMOS 25 cannot estimate results when there are gaps in the panel data, only a balanced panel data for the period 1992–2018 is considered (for further justifications, see Sect. 3.1).

Table 4 illustrates the results of standardized total effects. In low-income group, GDP growth shows the standardized total negative impact while GDP^2 growth shows the total significant positive impact on CO_2 emission. In interaction effect, GDP interaction with TO shows standardised positive impact while GDP^2 growth interaction with TO depicts the total significant negative impact, meaning that after attaining a threshold point of economic growth, TO helps to develop the quality of environment in low income countries. In CH_4 emissions, GDP growth has the total negative impact for upper-middle and aggregated data income groups while GDP^2 growth has positive impact indicating further economic growth that leads to greater CH_4 emissions. But in interaction effect, although TO interaction with GDP growth causes positive impact, its interaction effect with GDP^2 shows the significant negative impact on CH_4 emissions for both the income groups in support to the EKC. Moreover, in $PM_{2.5}$ emissions, GDP of upper-middle, high income and aggregated income groups, show significant negative impact while GDP^2 reveals the positive impact meaning that further economic growth intensifies $PM_{2.5}$. In interaction effect, although TO interaction with GDP growth demonstrates standardized total positive impact, GDP^2 interaction with TO depicts the total negative impact on $PM_{2.5}$ emissions for high income and aggregated income groups.

5 Discussion

The impact of the moderation effect of TO differs according to the level of income groups. GDP significantly causes CO_2 emissions (see Table 7 in the appendix) for aggregated income groups, while GDP^2 has a significant negative impact on reducing CO_2 emissions for upper-middle and low-middle income groups and significant positive impact for low-income group. The moderation effect suggests that TO interaction with GDP reduces CO_2 emissions for high income and aggregated income groups while it increases CO_2 for low income group,

Table 4 Results of standardized total effect

Incomepanels	Dependent variables	ZGDP	$ZGDP^2$	ZEC	ZTR	ZTO	GDPxTO	GDP^2xTO	ECXTO	TRXTO
LIC	ZCO_2	− .176	1.028	.230	.039	.038	.428	− .562	.117	.003
	ZCH_4	− 1.07	.630	.000	.000	− .204	− .654	.653	.000	.000
	$ZPM_{2.5}$	.200	.000	− .636	.472	− .303	− .273	.000	.382	.000
LMIC	ZCO_2	.037	.209	.330	.082	.096	− .071	.243	.029	.098
	ZCH_4	− .115	− .044	.135	− .179	− .360	.096	.072	− .169	.104
	$ZPM_{2.5}$	.295	− .422	− .119	.074	− .300	− .227	.580	− .209	.056
UMIC	ZCO_2	.000	.000	.943	.029	.000	.000	.057	− .044	− .053
	ZCH_4	− .790	.547	.285	− .214	− .314	.546	− .476	− .123	.148
	$ZPM_{2.5}$	− .645	.592	.208	.186	− .170	− .394	.580	.000	− .094
HIC	ZCO_2	− .230	.159	.818	.121	.000	− .261	.321	.000	.000
	ZCH_4	.067	.000	.112	− .168	− .405	− .324	.787	− .410	.345
	$ZPM_{2.5}$	− .745	.515	.528	.097	.000	.563	− .583	.000	.000
ADIC	ZCO_2	− .147	.041	.975	.033	.034	− .062	.121	− .056	− .007
	ZCH_4	− .309	.162	.225	− .155	− .330	.899	− .471	− .323	.143
	$ZPM_{2.5}$	− 1.218	.739	.487	.118	− .228	.758	− .729	.000	− .060

LIC low-income countries, *LMIC* lower-middle income countries, *UMIC* upper-middle income countries, *HIC* high income countries, *ADIC* aggregate data income countries hence aligning with the results of Mahadevan and Sun (2020) for the Belt and Road Countries (BRCs) on the regional level and Ergun and Rivas (2020) for Uruguay on the national level. Furthermore, the results pertaining to the TO interaction with GDP^2 growth that increases CO_2 emissions for lower-middle, upper-middle, high income and aggregated income groups are in line with the studies of Sin-Yu and Njindan (2019) for Central and Eastern European countries and Bernard and Mandal (2016) for 60 emerging and developing countries (excluding the low income panel).

The impact of CH_4 emissions in low-, upper-middle-, and aggregated-income groups is found to be significant, and negative and positive in high-income group. The fact however, that GDP^2 causes CH_4 emissions for low, upper-middle-, and aggregated-income groups suggests a U-shaped EKC. When TO is interacted with GDP, a positive impact for upper-middle-, and aggregated-income groups is observed whilst a negative impact on the emissions for low, and high-income groups is established. Conversely, the interaction effect between TO with GDP^2 shows a significant and positive impact for low- and high-income groups but a negative impact on the emissions for upper-middle-, and aggregated-income groups.

When $PM_{2.5}$ emissions are considered, GDP^2 has significant positive impact on upper-middle, high income and aggregated income groups implying that further economic growth degrades the quality of environment. However, the interaction effect of TO with GDP reduces $PM_{2.5}$ for low and upper-middle income groups whilst it increases $PM_{2.5}$ emissions for high income and aggregated income groups. Moreover, TO interaction with GDP^2 reduces $PM_{2.5}$ for high income and aggregated income groups is in line with our hypothesis, however it has significant positive impact on $PM_{2.5}$ emissions for lower-middle and upper-middle income groups which is in line with the results of Le et al. (2016) for 98 countries, classified into low-, middle- and high-income panels, covering 1990–2013 panel data. The finding of this study thus ascertains the existence of the pollution haven hypothesis (PHH), reiterating the perception that the rich economies relocate their heavily polluting industrial operations to the developing world.

As a major energy consuming sector and growing contributions in global emissions largely in the forms of CO_2 and $PM_{2.5}$ emissions, this study incorporated transportation (TR) in the econometric equation due to its strong influence on the economic growth and environmental pollution nexus. Findings in this study suggest that in the main effect, TR has significant positive impact on both CO_2 and $PM_{2.5}$ emissions for all the income groups while it shows negative impact on CH_4 emission. However, in interaction effect, TR has significant negative impact in reducing both CO_2 and $PM_{2.5}$ emissions in the upper-middle and high income countries. This finding is indicative of efficiencies in energy consumption (EC) and adoption of advanced and/or green technologies in these income groups, as pointed out by Frondel et al. (2010), Demirel and Kesidou (2011) and Arvanities and Ley (2013) in the contexts of Germany, the UK and Switzerland respectively. Moreover, TO interaction with EC helps to reduce pollution emissions in lower-middle and upper-middle income countries, and this is indicative of the possibility of successful transfers of better technologies in managing efficiency of EC towards reducing pollutions, as emphasised earlier by World Bank (2007).

6 Concluding remarks

"Both theory and evidence suggest that trade promotes growth" (Le et al., 2016, p. 45) and countries prioritizing economic growth based on trade witness degrading environmental quality (Wang et al., 2020a, 2020b, 2020c).

However, "both theoretical and empirical researchers have provided mixed and conflicting evidence on the effect of trade on economic growth and on the environment" (Hakimi & Hamdi, 2016, p. 1447). In this study, the relationship between economic growth and environmental degradation in the EKC framework is investigated. A panel data empirical investigation applied to 115 active WTO member countries for the period 1992–2018 is used and the World Bank classifications are followed to study them in three major income groups. The main and interaction effects of TO in the growth-pollution nexus is estimated using Structural equation modelling (SEM), and CO_2 emissions and additionally CH_4, and $PM_{2.5}$ emissions as major sources and proxies of environmental degradation are utilized to ensure further robustness of the analysis. The contribution of this study is threefold in that a) a novel methodological approach has been adopted, (b) an investigation of both main and interaction effects of TO has taken place and (c) a combination of three major pollutants to study the growth-pollution nexus in the context of EKC has been considered.

The findings suggest that TO degrades the quality of environment for low- and middle-income countries. When interaction effects were explored, TO interaction with GDP is found to reduce both CO_2 and CH_4 emissions for high income countries; its interaction with GDP^2 growth increases both types of emissions, hence implying a U-shaped EKC. In lower-middle income countries, GDP growth has significant positive impact while GDP^2 growth has significant negative impact on $PM_{2.5}$ emissions, meaning that further economic growth reduces $PM_{2.5}$ emissions and hence supports the EKC hypothesis. In both upper-middle, and high-income groups a U-shaped EKC is observed indicating that additional economic growth degrades the quality of environment emitting $PM_{2.5}$. The interaction between TO and GDP^2 growth shows the significant negative impact in reducing $PM_{2.5}$ emissions for high income group. Moreover, TO interaction with EC helps to reduce pollution emission in middle income countries by transferring better technologies for efficient use of energy. In addition, the interaction effect of TO with transportation (TR) helps to reduce CO_2 emissions by adopting efficiencies in energy consumption and advanced technologies in upper-middle- and high-income groups. Countries in this regard can hope to be benefitted with the upcoming Fourth Industrial Revolution innovations towards facing the world's most tenacious environmental issues (as warned by PWC, 2018).

The evidence produced on the two-way interaction effects suggests that TO dampens the negative relationship between GDP and CO_2 for low-income group and strengthens the positive relationship between GDP^2 and CH_4 for lower-middle income group which, according to the "pollution haven hypothesis" (PHH) (Jun et al., 2020), would be indicative of worsening quality of environment due to liberalization of trade. Moreover, the standardized total effect shows that TO interaction with GDP^2 growth increases CO_2, CH_4 and $PM_{2.5}$ emissions in lower-middle income countries; CO_2 and $PM_{2.5}$ emissions in upper-middle income countries, and CO_2 and CH_4 emissions in high income countries.

In light of the mix of evidence generated in this study, potential expedients of enacting the "enabling environment" and nullifying the "pollution haven hypothesis" (PHH) are proposed. All-out efforts of the high, middle, and low-income countries to improve the quality of their environments can facilitate a better quality of environment to the world inhabitants. It would therefore be necessary that all countries from various income groups come together and establish a common set of environmental policies to cease tricky practices like migrating dirty industrial operations to the developing world. These policies will compel large trading countries like China and the USA to push its partners to adopt more environment friendly practices (Gamso, 2018), e.g., integrating environment-friendly provisions in the trade agreements (Le et al., 2016), and also compel countries seeking larger global market share to follow suit. The common set of policy measures would however require a serious attention as earlier initiatives on developing multilateral agreements, e.g., the Doha Climate Change Conference in 2012, and accomplishing the global warming target (below 2 °C) of the Paris Agreement of 2015 (Wang et al., 2020a) have shown persistent signs of struggles towards yielding the desired outcomes.

On the policy front, it is commonly argued or typically expected that developed countries should provide financial and technological supports for mitigation and adaptation efforts in developing countries in the wake of the PHH and this seems to have not worked. Realistically, attempts to transform the "enabling environment" (PWC, 2018) such as removing trade barriers for environment-friendly technology, negotiating international agreements on climate change, setting sectoral and sub-sectoral contribution limits, etc. would be required to face the global environmental challenges and support fostering the notion of "green economy". Also, given that open trade does not affect environmental quality uniformly across different income groups (Le et al., 2016), it is imperative that policy measures are tailored so as to take into account the specific country characteristics to improve environmental quality and enhance sustainable economic growth. For example, whether the manufacturers or the consumers would bear the burden of the emission/carbon tax would depend on a country's political system of governance, e.g., as cited in Ren and Chen (2020), the tax burden is borne by manufactures in Chile and customers in Sweden, and either way a similar net environmental outcome is achieved by the country.

The findings of this paper have policy and managerial implications in the national economies and on the global institutional levels in the backdrops of the global pandemic as well as the changing political and economic scenarios in the recent times. For example, the COVID-19 pandemic has channelled more households into the poverty net, and it has raised the possibility of higher CO_2 emissions due to more reliance on traditional fossil fuels. Moreover, following short-term reduction in emissions due to severe lockdowns, countries will rapidly bounce back to a trade-led growth path where emissions will significantly rise to exceed the global warming threshold, i.e., "a necessary step towards a green society" (Wang et al., 2020b). Henceforth, the results associated with the mediating role of trade in growth-pollution nexus corresponding to different income panels of countries will support reforming current policies and their applications in various initiatives and/or schemes related to "green economy", e.g., to mention a few: (a) The introduction of carbon pricing systems in the USA to secure the Natural Climate Solutions (NCS) including green aviation and clean electricity; (b) The government plan to kick off trading in nationwide emissions trading system (ETS), enhancing sectoral coverages to chemical, petrochemicals, paper and steel in China; (c) The upcoming carbon pricing mechanism in Japan and Taiwan, and similar follow suits in Colombia, Indonesia, Mexico, Thailand and Vietnam between 2022 and 2026; (d) The likely launch of Border Carbon Adjustment Mechanism (BCAM) in the EU, as part of their target to be a "net zero" region by 2050; (e) Potential reformations of policies on trade and the environment in the low- and middle-income countries to applying their nationally defined contributions (NDCs) under the Paris Agreement to achieve climate goals while grabbing opportunities for trades.

The extant literature tends to consider manufacturing, energy, transport and food processing industries as the major pollutants on earth, and often misses out investigating the fashion industry which is believed to be the second most polluting industry globally, accountable for more than the sum of pollution made by maritime shipping and international aviation (UN, 2019). This is an industry which continues to flourish due to its "fast fashion" model of consumerism in the developed economies whereas its manufacturing activities are increasingly relocated in the developing countries, many of which rely pre-dominantly on coal and/or gas. Since "the past two years have witnessed unprecedented global shocks from deepening trade tensions related to the COVID-19 pandemic" (Brenton & Chemutai, 2021, p. 8) and henceforth countries are projected to bounce back stronger in the post-COVID recovery stage, at an estimated rate of 8.0–11.0 percent rise in the volume of world merchandise trade in 2021 (WTO 2021a, 2021b), it is necessary to investigate the role of the fashion industry in the growth-pollution nexus, aiming to contribute to the potential formulations of policy measures to ensure that garments are manufactured and consumed as ethically and sustainably as possible. Moreover, since transportation (TR) plays a significant role in global pollutions due to its inter-connectivity with all major industrial activities and operations, it would be vital to investigate the moderation role of TR in an EKC framework.

As an empirical analysis on the nexus of economic growth and environment has the privilege of considering a wide variety of sources of pollution such as manufacturing, transport, agriculture, food processing, etc., arguably a possible limitation of this research could be the parsimonious specification of the empirical model. In this context, a more holistic analysis can be made on the degree and nature of polluting activities as well as the corrective measures that are applied in various income panels of countries to produce insightful evidence on the impact of the synergetic relationships between urban form, land-use, built environment, transportation, and environmental degradation, in pursuit of a collective convergence of countries to green economic growth. Henceforth, potential future research can also be directed at aspects of spatial planning and its ensuing implication for the environment.

Appendix

See Tables 5, 6, 7 and 8.

Table 5 Summary of selective literature and findings on the nexus between TO and environmental effluences. *Sources*: Authors' summary

Study	Countries	Periods	Methods	Variables	Findings and Results
Abid (2017)	58 MENA countries and 41 EU countries	1990–2011	GMM-system method	TO, CO_2, GDP	Monotonically rising nexus between CO_2 emissions and GDP (income) in both the set of countries. No indication of the EKC presence
Bernard and Mandal (2016)	60 emerging countries	2002–2012	Panel model	TO, EQ, GDP	GDP and TO increase CO_2 emissions. The EKC hypothesis exists Pollution haven with greater volume of trade in developing region
Farhani et al. (2013)	MENA countries	1980–2009	Panel model	TO, CO_2, EC GDP, UR	1% increase of TO leads to 0.043% rise in CO_2 emissions Countries have dirty industries that release a worrisome amount of CO_2
Chen et al. (2020)	G20 countries	1988–2015	OLS regression	TO, Gini Coeff., CO_2	TO positively affects CO_2 emissions in the short run. in the long run, TO appears to be reducing CO_2 emissions. The EKC hypothesis valid
Jobert et al. (2016)	55 developed and developing countries	1970–2013	Panel model	TO, CO_2	Cross-country heterogeneity problem in the panel observed. Countries having similar features regarding trade-environment nexus

Table 5 (continued)

Study	Countries	Periods	Methods	Variables	Findings and Results
Shafik (1994)	149 countries	1960–1990	OLS panel regression	CO_2 and 6 other pollutants	Mixed evidence for the EKC hypothesis: valid only for SO2 and SPM, and not valid for other pollutants
Shahbaz et al. (2019)	N-11 countries	1972–2013	Panel regression Cointegration	GDP, EC, CO_2	The unique order of integration of variables and cointegration of variables for long-term linkages are confirmed
Shahbaz et al. (2017)	105 countries	1980–2014	Granger causality	TO, CO_2	TO unidirectionally causes CO_2 i.e. when TO increase CO_2 also increases. TO negatively affects the environmental quality in long-term
Belloumi and Alshehry (2020)	KSA	1971–2016	ARDL Cointegration	TO, GPD, EC, CO_2	Trade unidirectionally causes CO_2 i.e. when TO increase CO_2 also increases. TO negatively affects the environmental quality in long-term
Nasir et al. (2021)	Australia	1980–2014	DF-GLS, Phillips-Perron, KPSS tests	TO, GDP, EC, CO_2	Strong causal association of GDP, TO, and EC (Energy) with CO_2 The EKC hypothesis not valid

Table 5 (continued)

Study	Countries	Periods	Methods	Variables	Findings and Results
June et al. (2020)	China	1982–2016	Breitung & Candelon (2006) causality	TO, CO_2	TO unidirectionally causes CO_2 in short, medium and long runs Pollution haven hypothesis exists. TO forecasts CO_2 in China
Kanjilal and Ghosh (2013)	India	1971–2008	ARDL	TO, EC, CO_2, GDP	GDP, and EC positively cause CO_2 but TO negatively affects CO_2
Rahman (2020)	Top-10 electricity (ELEC) producing countries	1971–2013	Panel cointegration, Dumitrescu and Hurlin causality test	ELEC, GDP, TO, CO_2	ELEC and TO have significant impact on CO_2 emissions, especially in developing economies due to the lack of proper regulations and implementation. EKC hypothesis exists
Aslanidis and Xepapadeas (2006)	48 states of the USA	1929–1994	Granger causality	NOx, SO2, TO	No evidence of the EKC for NOx but the presence of the EKC and a robust smooth inverse-V shaped nexus confirmed for SO2

In 'Variables' column, EC, CO_2, GDP, TO, UR, and EQ refer to energy consumption, CO_2 emissions, gross domestic product, trade openness, urbanisation, and environmental quality, respectively
In 'Methodology' column ARDL, VECM, GC, and VAR denote autoregressive distributed lag procedure, vector error correction model, Granger causality, vector autoregression, respectively

Table 6 Summary statistics of panel data (1992–2018)

Variable	CO2	CH4	PM2.5	GDP	GDP2	EC	TR	TO
Low income countries								
Mean	0.286970	22,196.65	37.8712	582.6367	424,517.5	418.8007	87.1764	60.4970
Std. Dev.	0.351332	24,314.26	14.2973	292.0880	402,333.3	159.9355	27.5487	20.9800
Min	0.017276	2157.31	19.5385	131.6464	17,330.77	206.8734	22.6000	14.3257
Max	1.676519	189,678	74.9978	1342.543	1,802,421	952.6127	157.131	125.033
Observations	N = 315	N = 297	N = 90	N = 324	N = 324	N = 314	N = 283	N = 292
Lower middle-income countries								
Mean	1.361956	48,051.59	40.2913	1645.056	3,492,944	531.3031	74.8060	68.1484
Std. Dev.	2.46E + 00	106,743.8	20.1100	887.3730	3,638,859	266.0668	27.4189	33.0369
Min	4.27E-02	500.235	14.4999	190.9118	36,447.34	102.4145	4.57982	0.16741
Max	1.91E + 01	912,857	105.672	4684.72	2.19E + 07	2317.919	162.376	199.675
Observation	N = 1086	N = 1056	N = 320	N = 1131	N = 1131	N = 1068	N = 1023	N = 1078
Upper middle-income countries								
Mean	4.025735	82,331.85	24.6851	5860.387	4.31E + 07	1497.379	66.5690	75.8927
Std. Dev.	3.050156	212,525	11.4737	2965.323	4.25E + 07	967.5308	27.9511	40.1842
Min	0.0285129	175.067	10.2113	347.8874	121,025.6	384.595	- 321.65	11.5456
Max	16.08	1,752,290	79.2002	14,778.91	2.18E + 08	5928.661	146.352	280.361
Observations	N = 1169	N = 1155	N = 350	N = 1195	N = 1195	N = 1114	N = 1107	N = 1183
High income countries								
Mean	11.6708	41,316.06	22.6196	32,684.49	1.42E + 09	4939.411	63.2619	92.4490
Std. Dev	8.921216	93,604.37	26.0215	18,759.20	1.72E + 09	3343.773	27.3734	67.8945
Min	1.048911	125.556	5.14745	3699.850	1.37E + 07	663.3058	0.43090	16.0117
Max	70.13564	637,636	135.554	111,968.4	1.25E + 10	21,959.44	150.992	441.603
Observations	N = 1329	N = 1287	N = 390	N = 1359	N = 1359	N = 1380	N = 1204	N = 1370

Table 7 Testing the hypothesis and the summary of the results

Hypothesis	Standardized β					Z-value					Results			
	A	L	LM	UM	H	A	L	LM	UM	H	A	L	LM	UM
H1a: Economic growth (GDP) has significant positive effect on CO_2 emission	.173	− .193	.037	.080	− .010	5.65	− 2.12	.290	1.74	− .544	Accept	Reject	Reject	Reject
H1b: Economic growth (GDP) has significant positive effect on CH_4 emission	− .309	− 1.07	− .115	− .581	.067	− 4.81	− 4.21	− .790	− 4.75	2.15	Reject	Reject	Reject	Accept
H1c: Economic growth (GDP) has significant positive effect on $PM_{2.5}$ emission	1.21	.200	.295	− .645	− .745	− 21.25	3.58	2.13	− 4.92	− 7.60	Reject	Accept	Accept	Reject
H2a: Squared economic growth (GDP^2) has significant negative effect on CO_2 emission	− .048	1.02	.209	− .140	.012	− 4.03	10.50	1.68	− 3.05	.180	Accept	Reject	Reject	Accept
H2b: Squared economic growth (GDP^2) has significant negative effect on CH_4 emission	.162	.630	− .044	.356	− .090	2.56	2.42	− .310	2.91	− .754	Reject	Reject	Reject	Reject
H2c: Squared economic growth (GDP^2) has significant negative effect on $PM_{2.5}$ emission	.739	.017	− .422	.592	.515	13.16	.060	− 3.11	4.50	4.76	Reject	Reject	Accept	Reject
H3a: Energy consumption has significant positive impact on CO_2 emission	.916	.282	.330	.943	.655	89.21	11.31	8.65	89.47	39.02	Accept	Accept	Accept	Accept

Table 7 (continued)

Hypothesis	Standardized β					Z-value					Results			
	A	L	LM	UM	H	A	L	LM	UM	H	A	L	LM	UM
H3b: Energy consumption has significant positive impact on CH_4 emission	.225	.073	.135	.218	.112	8.19	.900	3.11	7.01	3.83	Accept	Reject	Accept	Accept
H3c: Energy consumption has significant positive impact on $PM_{2.5}$ emission	.487	− .636	− .119	.208	.528	21.88	− 10.8	− 2.87	6.31	18.84	Accept	Reject	Reject	Accept
H4a: Transportation has significant positive impact on CO_2 emission	.018	− .022	.082	.029	.091	2.28	− 1.05	2.68	2.68	5.71	Accept	Reject	Accept	Accept
H4b: Transportation has significant positive impact on CH_4 emission	− .155	.055	− .179	− .273	− .168	− 8.52	.860	− 5.17	− 9.05	− 5.79	Reject	Reject	Reject	Reject
H4c: Transportation has significant positive impact on $PM_{2.5}$ emission	.118	.472	.074	.186	.097	7.29	8.62	2.24	5.78	3.44	Accept	Accept	Accept	Accept
H5a: TO interaction with GDP growth has significant negative effect on CO_2 emission	− .077	.583	− .068	.007	− .261	− 3.67	6.76	− .600	.170	− 5.39	Accept	Reject	Reject	Reject
H5b: TO interaction with GDP growth has significant negative effect on CH_4 emission	.449	− .848	.092	.676	− .194	9.36	− 2.97	.710	5.75	− 2.05	Reject	Accept	Reject	Reject

Table 7 (continued)

Hypothesis	Standardized β					Z-value					Results			
	A	L	LM	UM	H	A	L	LM	UM	H	A	L	LM	UM
H5c: TO interaction with GDP growth has significant negative effect on $PM_{2.5}$ emission	.378	− .354	− .219	− .396	.338	12.87	− 4.38	− 1.77	− 3.26	4.06	Reject	Accept	Reject	Accept
H6a: TO interaction with GDP^2 growth has significant negative effect on CO_2 emission	.070	− .713	.259	.067	.224	6.37	− 7.64	2.17	4.69	6.16	Reject	Accept	Reject	Reject
H6b: TO interaction with GDP^2 growth has significant negative effect on CH_4 emission	− .158	.828	.077	− .784	.352	− 6.06	2.87	.570	− 5.64	5.02	Accept	Reject	Reject	Accept
H6c: TO interaction with GDP^2 growth has significant negative effect on $PM_{2.5}$ emission	− .245	.153	.618	.689	− 2.61	− 11.8	.530	4.78	4.66	− 4.04	Accept	Reject	Reject	Reject
H7a: TO interaction with energy use has significant negative effect on CO_2 emission	− .054	.113	.027	− .047	− .042	− 3.36	3.49	.670	− 3.65	− 1.45	Accept	Reject	Reject	Accept
H7b: TO interaction with energy use has significant negative effect on CH_4 emission	− .308	− .138	− .161	− .131	− .642	− 8.32	− 1.26	− 3.52	− 3.71	− 10.47	Accept	Reject	Accept	Accept
H7c: TO interaction with energy use has significant negative effect on $PM_{2.5}$ emission	.010	.503	− .199	− .074	− .059	.320	6.13	− 4.54	− 1.96	− 1.02	Reject	Reject	Accept	Accept

Table 7 (continued)

Hypothesis	Standardized β					Z-value					Results			
	A	L	LM	UM	H	A	L	LM	UM	H	A	L	LM	UM
H8a: TO interaction with transportation has significant negative effect on CO_2 emission	.006	.003	.084	− .052	− .044	.629	1.84	2.96	− 4.85	− 2.16	Reject	Reject	Reject	Accept
H8b: TO interaction with transportation has significant negative effect on CH_4 emission	.122	.009	.089	.175	.311	6.35	.180	2.77	6.17	8.76	Reject	Reject	Reject	Reject
H8c: TO interaction with transportation has significant negative effect on $PM_{2.5}$ emission	− .051	.015	.048	− .092	− .006	− 3.04	.290	1.55	− 3.01	− 1.65	Accept	Reject	Reject	Accept

A aggregate data for all the countries, *L* lower income countries, *LM* lower-middle income countries, *UM* upper-middle income countries, *H* high income countries. Results are estimated at best 5% significance level

Table 8 The list of investigated countries based on their income level

Low-income countries: Benin, Congo Dem. Rep., Ethiopia, Mozambique, Nepal, Senegal, Tanzania, Togo and Zimbabwe

Lower-middle-income countries: Angola, Armenia, Bangladesh, Bolivia, Cambodia, Cameroon, Congo Rep., Cote d'Ivoire, Egypt, El Salvador, Ghana, Guatemala, Honduras, India, Indonesia, Jordan, Kenya, Kyrgyzstan, Mongolia, Morocco, Myanmar, Nicaragua, Nigeria, Pakistan, Philippines, Sri Lanka, Sudan, Syrian Arab Republic, Tajikistan, Tunisia, Yemen and Zambia

Upper-middle-income countries: Albania, Algeria, Argentina, Azerbaijan, Belarus, Botswana, Brazil, Bulgaria, China, Colombia, Costa Rica, Croatia, Dominican Republic, Ecuador, Gabon, Guyana, Iran, Jamaica, Kazakhstan, Lebanon, Libya, Malaysia, Mauritius, Mexico, Namibia, Panama, Paraguay, Peru, Romania, Russia, South Africa, Suriname, Thailand, Turkey, Venezuela

High-income countries: Australia, Austria, Bahrain, Belgium, Brunei, Canada, Chile, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Italy, Japan, Korea Republic, Kuwait, Luxembourg, Malta, Netherlands, New Zealand, Norway, Oman, Poland, Portugal, Qatar, Saudi Arabia, Singapore, Spain, Sweden, Switzerland, Trinidad and Tobago, UK, US and Uruguay

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