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RESEARCH ARTICLE

What matters for environmental quality in the Next Eleven Countries: economic growth or income inequality?

Hemachandra Padhan[1] · **Ilham Haouas**[2] · **Bhagaban Sahoo**[3] · **Almas Heshmati**[4]

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Abstract

This study uses panel data for the period 1971–2013 to explore the implications of growth, wealth disparities, and per capita energy consumption on carbon emissions in a sample of Next Eleven (N-11) countries. It uses the first-generation (Pedroni and Kao) and second-generation (Westerlund) cointegration techniques to highlight a long-run interplay between the selected variables in carbon emission functions for all the N-11 countries. It also analyzes the long-run interactions among the series. Contrastingly, it also shows that economic growth, income inequalities, and per capita energy consumption accelerate CO_2 emissions. Besides examining the effects of wealth disparity square, the study also uses the environmental Kuznets curve hypothesis in the context of the N-11 countries and discusses the policy implications of its findings.

Keywords CO_2 emissions · Income inequality · Panel cointegration · Next-11 countries

JEL classification codes Q57 · O15 · C23

Introduction

As emerging economies grow at the expense of massive energy consumption (EC), they face several difficult challenges in various areas. Among these, environmental quality is one of the biggest concerns as it impacts climate change and poverty levels through a range of effects on agriculture productivity and people's health (Hallegatte and Rozenberg 2017). Countries require greater volumes of energy to sustain their economic growth and development. Given the inelastic nature of the supply of natural resources such as land, drinking water, and clean air, as human activities increase with increasing populations, the accumulated goods and services and externalities produced in the form of pollution and greenhouse gas emissions (GHGs) grow disproportionately in relation to the planet's capacity. An increase in economic activities is reflected in higher growth rates and gross domestic product (GDP) per capita which leads to additional environmental concerns as emission levels increase along with increasing demands for energy. The environmental repercussions of these activities are not only a matter of concern for domestic economies but also for the world at large, as all the countries are

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✉ Almas Heshmati
heshmati@sogang.ac.kr

Hemachandra Padhan
hs18d008@smail.iitm.ac.in

Ilham Haouas
ilham.haouas@adu.ac.ae

Bhagaban Sahoo
sahooeconomics@gmail.com

[1] Humanities and Social Sciences (HSS), Indian Institute of Technology (IIT), Madras, Chennai 600036, India

[2] College of Business Administration, Abu Dhabi University, P.O. Box 59911, Abu Dhabi, UAE

[3] Anandapur College, Keonjhar, Anandapur, Odisha 758021, India

[4] Department of Economics, Room GN702, Sogang University, 35 Baekbeom-ro, Mapo-gu, Seoul 121-742, South Korea

interconnected due to globalization; hence, all countries are likely to be affected by GHGs and face the risk of climate change although with differing impacts in different regions.[1]

Going by theoretical discourses in economic theory on poverty alleviation, it is apparent that the developing world needs significant government efforts along with sustainable economic progress for poverty reduction policies to be efficient and successful. In practice, most of the industrialized and developing countries are expanding their economic activities and output levels. At the same time, they are also aspiring to reduce their carbon emissions. As production and income differences are profoundly intertwined, these in turn will lead to large wealth disparities both in the short and long run. Thus, the developing world is faced with various challenges. Climate change (for example, rising sea levels, storms, droughts, and floods) is one of the most severe of these; it is driven by substantial CO_2 emissions that lead to global warming. Environmental degradation because of rising carbon emissions and climate change is also a pressing problem as it threatens sustainable economic progress in the long-term and also the quality of living standards. It is generally recognized that climate change is a vital issue that needs to be addressed in energy and ecological economics.

Recent available data from the UN climate summit in Poland shows that CO_2 emissions were estimated to rise by 2.7% in 2018. Specialists noted that global carbon emissions in 2018 were expected to reach an all-time high level of 37.1 billion tonnes (Le Quéré et al. 2018). A mix of fossil fuels, deforestation, and other factors contributed substantially to these rising levels. Hence, rising per capita CO_2 emissions are commonly used as proxy for environmental pollutants often linked with higher per capita incomes. As suggested by various scholars (inter alia, Holtz-Eakin and Selden 1995; Kijima et al. 2010; Raza et al. 2015), carbon emissions are a main source of global warming and climate change. Changes in climatic conditions have risen to alarming levels raising governments' attention across the world. The governments all across the globe should work to protect environmental health by implementing a number of policy tools such as taxes and reliance on renewable energy. Some guidelines proposed by policymakers have generated extensive intergovernmental debates, particularly in developing nations. The Kyoto Protocol, which was adopted in Kyoto, Japan on 11 December 1997, is a relevant example of the efforts being made to reduce the carbon footprint that leads to global warming. The protocol entered into force on 16 February 2005 and represents a binding agreement to the UN Framework Convention on Climate Change (UNFCCC).

Given the fact that global warming is on the rise and there are increasing concerns about scarce energy sources, we believe that exploring the interplay between carbon emissions, progress, and wealth disparities in the context of N-11 countries[2] is a scientific endeavor worth undertaking by both scholars and policymakers. It is important to empirically validate the causality, if any, between economic development and income differences on the one hand and environmental degradation on the other in the N-11 countries. This is essential because understanding the direction of causality will provide valuable insights into the best ways of preserving environmental health; such an exercise will also offer examples of best practices for other developing economies to follow. If environmental degradation persists in N-11 countries, amid increased production levels and the associated massive energy consumption, it will have a domino effect throughout the globe. Hence, N-11 and other developing economies seeking to mitigate climate change will need to strengthen collaborations to address the implications of higher progress and higher energy consumption domestically.

Our methodological approach examines the interaction between the different economic series. It is based on an innovative model of the panel cointegration test developed by Pedroni (2004), the panel cointegration test developed by Kao (1999), the fully modified OLS (FMOLS) proposed by Phillips and Hansen (1990), and the dynamic OLS (DOLS) created by Stock and Watson (1993). Existing literature does not apply the panel cointegration, FMOLS, or DOLS methodologies in the context of environmental quality in relation to economic growth and income inequalities in the Next-11 countries. This is a major limitation of these studies because scholars only elude to empirical investigations of the relationships between carbon emissions, growth, and wealth disparities which can lead to inaccurate results on the environmental Kuznets curve's (EKC) assumptions and misguide policymakers whose aim is to protect environmental health worldwide.

The economic rationale behind using these models is that the interplay between selected variables fluctuates as a result of changing economic parameters, natural calamities, energy and environmental strategies, and regulatory and technological innovations.

Our study uses annual data from 1971 to 2013 on a per capita basis for wealth disparities, growth, and carbon emissions in the context of N-11 countries because based on their contributions to global GDP, share of energy demand, and CO_2 emissions to world energy demand and their carbon footprint, they have the potential of becoming some of the largest

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[1] Climate change is a huge threat to human health, global food security, and economic development, as well as to the natural environment. In light of its severe consequences for global well-being, international organizations and governments need to work together to mitigate its risks and cut greenhouse gas emissions that are leading to climate change.

[2] The N-11 countries are Bangladesh, Egypt, Indonesia, Iran, Mexico, Nigeria, Pakistan, the Philippines, Turkey, South Korea, and Vietnam.

economies in the twenty-first century. The N-11 states are increasingly recognized as major influencers in the global open economy and environmental policies next to Brazil, Russia, India, China, and South Africa (BRICS) economies but dissimilar to these in terms of their economic growth patterns accompanied by a greater degree of trade and financial openness. N-11 countries could surpass their rivals and become major market participants despite being exposed to a larger number of challenges relative to BRICS nations as a result of their strong economic reforms targeted at sustainable economic growth in the long term.

N-11 countries are enjoying rapid growth and are participating in global trade and investment projects (except for Iran which is a closed economy impacted the USA's imposed sanctions). They are faced with rising energy demands triggered by investment and industrialization activities that use less energy-efficient technologies to boost economic progress; this is a major reason for environmental degradation. To limit their carbon footprint, Mexico and Nigeria introduced incentives for businesses to enhance national production via more efficient energy technologies. The dynamics of GDP per capita in the N-11 countries in relation to global trends between 1980 and 2013 shows that the average GDP per capita for the N-11 group was lower than the worldwide average (Esfahani and Rasoulinezhad 2015); however, during this period, the growth rate of GDP per capita in the N-11 nations was higher at 4.9% than the aggregate world growth rate (at around 3.2%).

Looking beyond the N-11 individual countries, it is important for academics and business professionals to understand that the N-11 group had a growth rate of nearly 4.5% during the last decade compared to almost 4.0% over the previous decade (data as of 2018) (O'Neill 2018). Considering the volume of its output, it is obvious that the N-11 group makes a significant contribution to the world economy. Nevertheless, despite substantial potential for growth, there are still some issues that can prevent N-11 countries from enjoying BRICS nations' development trends. One factor is represented by the swings in global commodity prices, which effect N-11 producers. Another is political events that may also distress growth prospects. Although N-11 countries cannot rival the BRICS nations in scale, estimates reveal that by 2050, N-11 countries' GDP could reach two-third the size of the Group of Seven (G7) countries, meaning that N-11 nations could have a major impact on the global political, economic, energy, and environmental landscape (Sachs et al. 2007; ALOnaizi and Gadhoum 2017). Given stable parameters for progress, the N-11 countries have the ability to grow at a rate of 4.0% over the next two decades; in addition, incremental demand for these countries could exceed that of G7 and be two times that of the G7 countries by 2050 (ALOnaizi and Gadhoum 2017). Hence, the N-11 group's contribution to global GDP will increase faster.

In 1980, the N-11 group was responsible for over 6.3% of the global carbon emissions because of their petroleum consumption (Esfahani and Rasoulinezhad 2015). By 2013, this had increased to 12.0%, driven by higher population density, heavy reliance of the domestic economies on the manufacturing sector, and substantial share of fossil fuels in the electricity generation mix. The upward trend in economic progress increased the per capita energy consumption's share to 11.0% of global consumption which further aggravated environmental degradation (Yıldırım et al. 2014). CO_2 emissions measured in kilogram per capita and income inequality measured as the Gini coefficient for the N-11 nations from 1971 to 2013 is presented in Figs. 1 and 2, respectively. The pattern differs among the nations more in the case of income inequalities than in the case of CO_2 emissions (Figs. 3 and 4 of the Appendix).

The rest of this study is organized as follows. Section 2 reviews major scholarly work in this field. Section 3 details the methodology and the data used for our analysis. Section 4 gives the results of our study and discusses their significance. Section 5 provides concluding remarks and policy implications and indicates future research directions.

Review of related studies

Kuznets' (1955) landmark study linking the inverted U-shaped interplay between wealth disparities and progress[3] prompted many researchers to empirically investigate the role of growth in income inequality leading to many cross and individual country studies.

Dollar and Kraay (2002) argue that growth is good for the poor as there is evidence of a trickledown effect of the production process that not only creates employment opportunities and increases agriculture productivity but also reduces income inequalities by improving income distribution among the poorest. However, Kashwan's (2017) findings contradict this. Kashwan is of the view that development does not favor the poor because it does not benefit the entire population (haves and have-nots) equally. As a consequence, preference for environmental quality declines over time. In contrast, Sachs (2015) postulates that rising concerns about the impact of economic growth on environmental quality are driven by higher income inequalities. This implies that economies in the globalized world may be good at achieving higher progress, but they fail to maintain an equitable distribution of income with sustainable environmental quality. Therefore, some scholars (for example, Boyce 1994; Magnani 2000; Jorgenson et al. 2017) stress that challenges of environmental quality are a result of social issues mainly generated by wealth disparities and power inequalities. Hence, it is essential to

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[3] The inverted U-shaped hypothesis shows the non-linear relationship between the series indicating that economic growth initially increases income inequalities but narrows them after reaching a particular level.

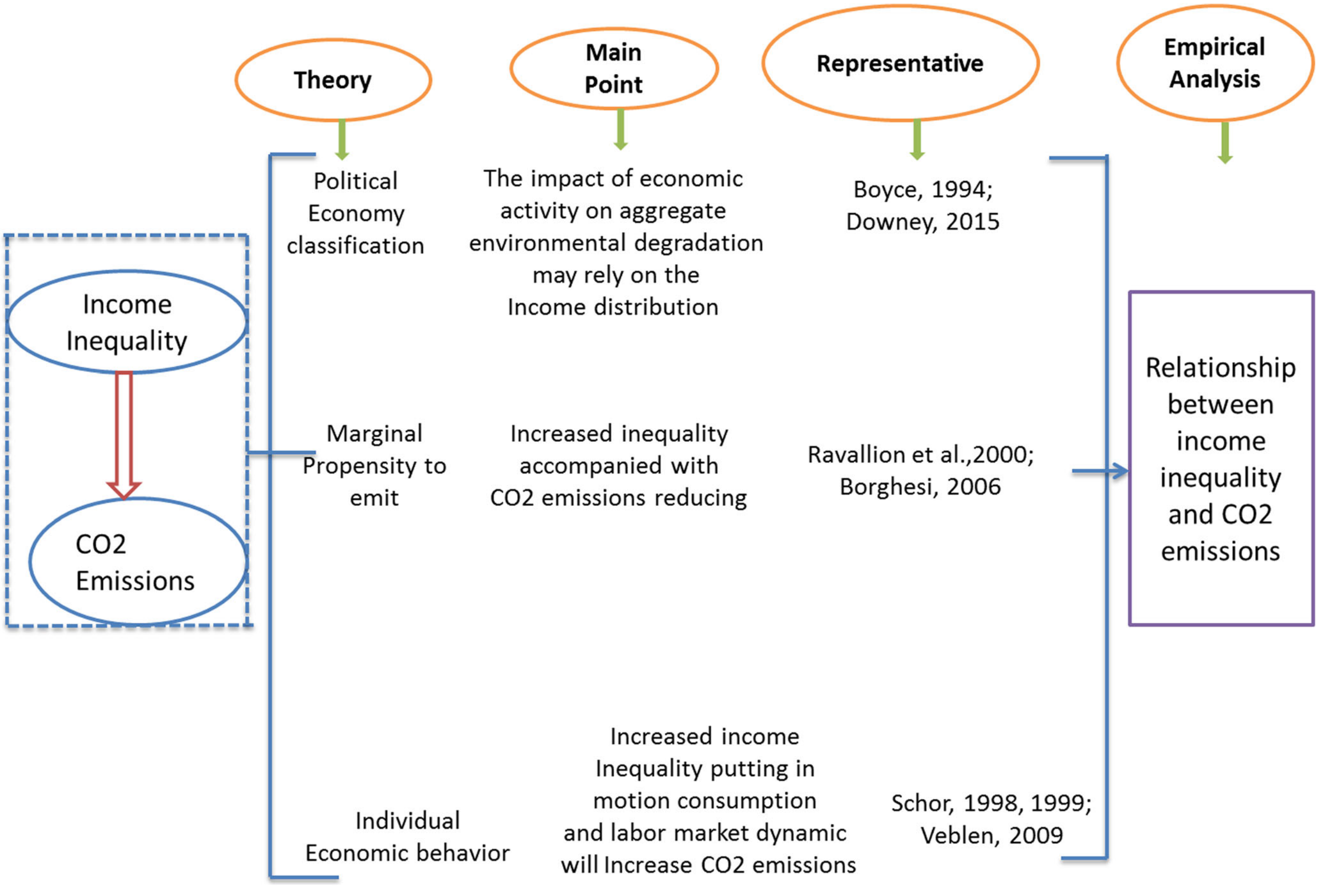

Fig. 1 Theoretical analysis of the income inequality-CO$_2$ emission nexus. Source: authorial adaptation after Liu et al. (2018)

explore major academic achievements on the effects of income inequalities, energy consumption, progress, and urbanization on CO$_2$ emissions. Table 1 provides a summary of the findings of previous studies on the link between income inequalities and economic growth.

CO$_2$ emissions and the income inequality nexus

The interplay between income inequality and climate change has received a great deal of attention from the international community in recent years (Jorgenson et al. 2017). Practical evidence indicates that growth fails to ensure environmental sustainability and instead diminishes it. This is a topic extensively debated by the academia (Wolde-Rufael and Idowu 2017; Kashwan 2017). The nexus between wealth inequality and environmental degradation has been examined by a number of theoretical and empirical analyses (Torras and Boyce 1998; Laurent 2015). As of date, theoretical studies on this relationship are grounded in three distinct approaches (Fig. 1).

The *first* approach provides a political explanation for the impact of income inequalities on environmental degradation. It relies on the distribution of wealth and power between those who have what is needed to better shield themselves from pollution activities and those who cannot exert any influence on such processes. The rich cohorts are also more predisposed towards higher levels of degradation as they possess resources that lead to greater energy consumption and environmental damage (Torras and Boyce 1998). This group is also more

Fig. 2 Dumitrescu-Hurlin (D-H) Granger causality test

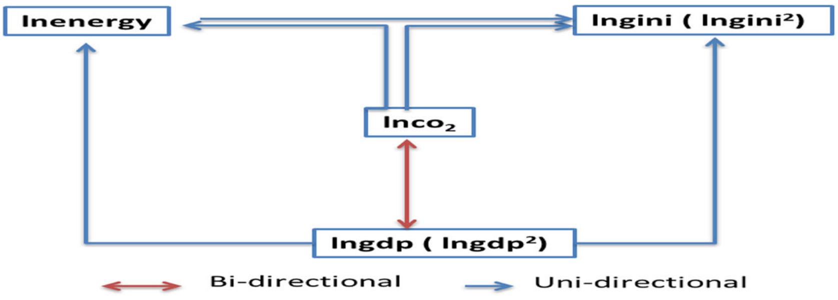

Table 1 Summary of findings from the previous studies on the link between income inequality and economic growth

Authors	Period	Region/country	Methods	Findings
Magnani 2000	1980–1991	Selected OECD countries	Regression analysis	Income inequality shows an expected negative correlation with environmental care
Dollar and Kraay (2002)	4 decades to 1990	92 countries	Regression analysis	Growth is good for the poor as it reduces income inequalities by improving income distribution to the poorest
Binatli (2012)	1970–1985 and 1985–1999	For 1970–1985, 42 countries For 1985–1999, 49 observations	Empirical cross-country analysis	A negative effect of income inequality on growth in the 1970s but, although statistically insignificant, a consistently positive effect in the 1990s
Wahiba and Weriemmi (2014)	1984–2011	Tunisia	Econometric analysis/regression analysis	Inequality had a negative effect on economic growth, particularly ex post the acceleration of opening exchange
Hao et al. (2016)	1995–2012	23 provinces in China	GMM	CO_2 emissions per capita rise as the income gap enlarges nationwide
Kashwan (2017)	1995–2005	137 countries	Regression analysis	Failure of growth to ensure environmental sustainability and diminish income inequality
Madsen et al. (2018)	1870–2011	21 OECD countries	Two-stage least squares (2SLS) approach	A negative effect of income inequality on economic growth
Vo et al. (2019)	1960–2014	A full sample of 158 countries and a sample of 86 middle-income countries	Granger causality test and a system GMM	Causality from economic growth to income inequality and vice versa in both samples of countries Income inequality contributes negatively to the economic growth in the middle-income countries
Nwosa (2019)	1981–2017	Nigeria	Autoregressive distributed lag estimation technique	Economic growth had positive but insignificant impact on income inequality

GMM generalized method of moments technique reluctant to engage in environmental protection, emphasizing the attached significant costs of such measures and their own capacity to avoid environmental hazards, thus shifting this responsibility to the poor (Scruggs 1998). Hence, the prevalence of one group or the other influences the degree of observed environmental damage.

The *second* approach gravitates around the concept of marginal propensity to emit (MPE), which states that pollution levels swing with changes in income distribution (Ravallion et al. 2000; Borghesi 2006). Ravallion et al. (2000) were the first to explain how low emissions are triggered by severe domestic inequalities. This was a very controversial finding and was heavily disputed by many academics, who argued that MPE actually diminished with income (Heil and Selden 2001; Schmalensee et al. 2006). These scholars also suggested that MPE's dominant component was represented by consumption needs. This assumption ignores the Keynesian impact that points to lower income groups having a higher MPE compared to higher income groups. An increase in income inequality makes the poor damage the environment to meet their living standards (Boyce 1994). Deforestation by the poor in the emerging world is a relevant example as this has reduced the forest area and subsequently its ability to absorb CO_2. Jorgenson et al. (2017) advocated that an increase in incomes for the poor will most likely reduce environmental degradation.

The *third* theoretical perspective is rooted in advancing individual economic behavior (Liu et al. 2018). This stream seeks to prove that greater inequalities generate augmented energy consumption levels, which enhance CO_2 emissions (Schor 1999). Some authors (for example, Schor 1998; Veblen 2009) explain the presence of a Veblen effect according to which the rich engage in expensive consumption to satisfy their living standards. According to Bowles and Park (2005), income inequalities lead to working long hours, resulting in significant energy consumption and degradation of the environment (Fitzgerald et al. 2015).

In addition to these theoretical analyses, more and more empirical studies use the Gini coefficient to examine the interplay between income disparities and CO_2 emissions. However, their conclusions are conflicting (Liu et al. 2018). Ambiguities in Boyce (1994) arguments and other authors' findings (for example, Ravallion et al. 2000; Borghesi 2006; Grunewald et al. 2017) led to a dialogue on the empirical validity of a significant relationship between inequality and environmental damage. Table 2 presents summary findings of previous studies worldwide on the link between CO_2 emissions and income inequalities.

The interplay between CO_2 emissions and energy consumption

Global energy consumption and environmental degradation have been rising constantly, and understanding the mechanisms and drivers of these emissions is important for guiding the process of policymaking and forecasting to mitigate their effects. In parallel, energy demand, similar to that of most other goods, shows significant fluctuations across income categories. For instance, emerging nations are expected to register a rapid increase in energy consumption as households enjoy middle-income levels (Wolfram et al. 2012). However, empirical arguments from high- and middle-income states seem to point the other way, as the rich spend a smaller income share on energy.

As of date, there are no clear images of the aggregate consequences of per capita energy consumption and the aggregate interplay between income, consumption trends, and environmental degradation (Caron and Fally 2018). This nexus directly influences the GDP's CO_2 intensity which is an essential factor in estimating emissions and also understanding the magnitude of climate change. With the quality of the environment constantly deteriorating, understanding the determinants of CO_2 emissions and energy use is as relevant as ever. According to Caron and Fally (2018), spending on energy and energy-intensive goods reduces with income across a large sample of states. Their projection models point out that income increase changes the patterns of consumption in a manner that generally reduces environmental damage. However, increasing emissions in emerging nations, coupled with a shift from direct to indirect energy consumption, means that their impact on global emissions is only modest. EKC-based analyses have been attacked for lacking structure or causal interpretations (Levinson and O'Brien 2019; Caron and Fally (2018) and for identifying the impact that income has environmental degradation via changes in consumption. Table 3 gives a summary of the findings of previous studies on the link between CO_2 emissions and energy consumption.

The nexus between CO_2 emissions and economic growth

Nnaji et al. (2013) reported a positive impact of fossil fuel consumption and development on CO_2 emissions in Nigeria. Wang (2013) found a reducing effect of differentiated output growth on CO_2 emissions in the USA and China. Salahuddin and Gow (2014) claim that progress had no long-term implications for environmental degradation in the Gulf Cooperation Council countries. Kivyiro and Arminen (2014) emphasize the long-run economic growth-CO_2 emissions nexus for six sub-Saharan African states, while Lau et al. (2014) found that CO_2 emissions stimulated economic growth in Malaysia and Allali et al. (2015) showed that development had a positive impact on CO_2 emissions in Algeria. Similarly, Abid (2015) observed both a short-run and a long-run interplay between growth and the carbon footprint in Tunisia, in addition to unidirectional causality running from progress to CO_2 emissions. Moreover, based on data covering the period 1960–

Table 2 Summary of findings from the previous studies worldwide on the link between CO_2 emissions and the income inequality

Authors	Period	Region/country	Methods	Findings
Torras and Boyce (1998)	1977–1991	A panel of countries	GEMS data originally adopted by Grossman and Krueger (1995)	Income levels enhanced environmental quality in low-income nations and deteriorated in high-income states
Ravallion et al. (2000)	1975–1992	42 countries	Pooled estimations	Pollution levels swing with changes in income distribution
Eriksson and Persson (2003)	1998	World	Augmented Stokey (1998) model	Income inequality decrease via greater democracy is beneficial for environmental quality as it lowers pollution levels
Golley and Meng (2012)	2005	China	Cross-sectional regression analysis	Richer households drive more CO_2 emissions per capita Rising marginal propensity to emit (MPE) over income
Borghesi (2006)	1988–1995	A panel of 126 countries/37 countries without inequality included as explanatory variable	FE model	Inequality has always a statistically not significant impact on CO_2 emissions
Drabo (2011)	1970–2000	90 developed and emerging states	A simple theoretical model based on Magnani (-2000)/regression analysis	Income inequalities were detrimental to environmental quality
Baek and Gweisah (2013)	1967–2008	USA	ARDL approach	Wealth differences and economic growth increase environmental quality, whereas energy consumption harms the US economy
Kasuga and Takaya (2017)	1990–2012	Japan	Reduced-form EKC equations	A harmful impact of wealth disparities on air quality in commercial zones but no significant consequences of income inequalities in the industrial areas
Grunewald et al. (2017)	1980–2008	158 countries	Fixed effects model and group fixed effects model	For low- and middle-income economies, higher income inequality is linked to lower carbon emissions, while in the upper middle-income and high-income economies, higher income inequality increases per capita emissions
Knight et al. (2017)	2000–2010	26 high-income countries	Two-way fixed effects longitudinal models	Wealth inequality is consistently positive and relatively stable
Hübler (2017)	1985–2012	149 countries	Simultaneous-quantile regressions approach	No significant nexus between the two variables income inequality and environmental safety
Jorgenson et al. (2017)	1997–2012	U.S.	Longitudinal analysis/Prais-Winsten fixed effects	The income share of the top 10% increases CO_2 emissions The effect of the Gini coefficient on CO_2 emissions is not significant
Baloch et al. (2018)	1966–2011	Pakistan	ARDL bounds testing approach	Positive effects of income inequalities and income per capita on environmental health
Demir et al. (2018)	1963–2011	Turkey	Autoregressive distributed lag bounds test	A negative relationship between CO_2 emissions and income disparities, which indicates that a higher level of income inequality diminishes environmental damage
Mader (2018)	Various years	USA	FE panel regression models/in in-depth investigation of the empirical validity of the two most recent contributions	No reliable empirical evidence for strong interplay between inequality and environmental degradation

GEMS global environment monitoring system, *FE* fixed effect, *ARDL* autoregressive distributed lags model

Table 3 Summary of findings from previous studies worldwide on the link between CO_2 emissions and energy consumption

Authors	Period	Region/country	Methods	Findings
Halicioglu (2009)	1960–2005	Turkey	Bounds testing to cointegration procedure	First form of long-run relationship: CO_2 emissions are driven by energy consumption, income, and foreign trade Second long-run relationship: income is driven by CO_2 emissions, energy consumption, and foreign trade
Acaravci and Ozturk (2010)	1970–2005 for Germany, 1965–2005 for Hungary and 1960–2005 for the rest of countries	19 European states	ARDL bounds testing approach of cointegration	A long-run positive association among CO_2 emissions and energy consumption along with evidence of an inverted U-shaped EKC hypothesis
Al-Mulali et al. (2012)	1980–2008	East Asia and Pacific, East Europe and Central Asia, Latin America and the Caribbean, Middle East and North Africa, South Asia, sub-Saharan Africa, and Western Europe	FMOLS model	A long-run positive association among CO_2 emissions and energy consumption
Saboori and Sulaiman (2013a)	1980–2009	Malaysia	ARDL methodology/Johansen–Juselius maximum likelihood approach/Granger causality tests	Long-term interaction between CO_2 emissions and energy consumption
Saboori and Sulaiman (2013b)	1971e2009	A number of ASEAN countries	ARDL methodology and VECM Granger causality test	Long-run positive nexus among CO_2 emissions and energy consumption
Shahbaz et al. (2014)	1975–2011	United Arab Emirates	ARDL bounds testing approach/VECM Granger causality tests	Long-run positive nexus among CO_2 emissions and energy consumption/deterioration in environmental quality was driven by energy consumption
Mercan and Karakaya (2015)	1970–2011	11 OECD countries	Structural breaks dynamic panel data analysis	Long-term positive impact of energy consumption on CO_2 emissions
Bilgili et al. (2016)	1982–2011	USA	Asymmetric causality test developed by Hatemi (2012)	Biomass energy consumption mitigates CO_2 emissions per capita and increases GDP per capita
Caron and Fally (2018)	2007	109 countries	General equilibrium model with non-homothetic preferences	Spending on energy and energy-intensive goods diminishes with income

ARDL autoregressive distributed lags model, *FMOLS* fully modified ordinary least square, *VECM* vector error correction model

2005 and a bounds test for the cointegration procedure, Halicioglu (2009) found two forms of long-run interplay between carbon emissions, energy consumption, income, and foreign trade in the context of Turkey. The first one indicates that CO_2 emissions are driven by energy consumption, income, and foreign trade and the second one highlights that income is driven by CO_2 emissions, energy consumption, and foreign trade. Esso and Keho (2016) also identified a positive long-term relationship among CO_2 emissions and progress and a bidirectional causal link between the variables in the Nigerian economy. Table 4 provides a summary of the findings of previous studies on the link between CO_2 emissions and economic growth.

Model building and data description

Model

Given our research objective and the context of theoretical and empirical literature discussed earlier, we specified the basic CO_2 emission function as noted below to understand the nature of the interaction and the effects of the key variables on the CO_2 function (CO_2 emissions). We estimated different versions of our basic models to avoid estimation problems as the addition of a larger number of variables in the same model could result in over parameterization, that is, consumption of degrees of freedom on the one hand and the inclusion of related variables that would trigger multicollinearity issues on the other:

$$\mathrm{lnco}_{2t} = \alpha_0 + \beta_1 \mathrm{lnenergy}_t + \beta_2 \mathrm{lngdp}_t + \beta_3 \mathrm{lngini}_t + \mu_t \quad (1)$$

By adding GDP square in Eq. 2 and Gini square in Eq. 3, the EKC functional form can be represented as:

$$\mathrm{lnco}_{2t} = \alpha_0 + \beta_1 \mathrm{lnenergy}_t + \beta_2 \mathrm{lngdp}_t + \beta_3 \mathrm{lngini}_t + \beta_4 \mathrm{lngdp}_t^2 + \mu_t \quad (2)$$

$$\mathrm{lnco}_{2t} = \alpha_0 + \beta_1 \mathrm{lnenergy}_t + \beta_2 \mathrm{lngdp}_t + \beta_3 \mathrm{lngini}_t + \beta_4 \mathrm{lngini}_t^2 + \mu_t \quad (3)$$

where lnco_2 emissions represent CO_2 emissions per capita as a proxy of environmental quality, lnenergy denotes per capita energy consumption, lngdp is gross domestic product per capita as a proxy of economic development, lngdp^2 is the gross domestic product squared, lngini is the net Gini coefficient proxy of income inequality, lngini^2 is the Gini coefficient squared, which is used to understand whether there is an inverted U-shaped relationship or not, and μ_t is the error term. In addition, for the smoothness of the variables, we used the natural logarithmic for all variables like lnco_2, lnenergy, lngdp, lngdp^2, and lngini^2. α_0 is the fixed effect and β_1, β_2, β_3, and β_4 are slope coefficients. β_1 represents the elasticity of carbon emissions with respect to per capita energy consumption, that is, for every 1% increase in per capita energy consumption, the per capita carbon emissions increase by β_1 percent. Similarly, β_2 and β_3 in Eqs. 2 and 3 measure the elasticity of carbon emissions with respect to income and the elasticity of carbon emissions with respect to income inequality, respectively. The elasticity of emissions with respect to income in Eq. 2 can be formulated as $\partial \ln co2/\partial \mathrm{lngdp} = \beta_2 + 2\beta_4 \ln \mathrm{gdp}$ which can be verified by the existence of the EKC hypothesis. The elasticity of emissions with respect to income inequality can be formulated as $\partial \ln \mathrm{co2}/\partial \ln \mathrm{gini} = \beta_3 + 2\beta_4 \ln \mathrm{gini}$. The turning point[4] of the EKC occurs at a level of income inequality in Eq. 3.

According to the EKC hypothesis, the long-term interplay between per capita energy consumption, wealth disparities, and economic growth on CO_2 emissions can be captured by Eqs. 2 and 3. The EKC hypothesis describes an inverted U-shaped link among environmental degradation and economic growth. We are interested in identifying an inverted U-shaped connection between environmental degradation and income inequalities which can be obtained mathematically by embedding the squared value of the Gini coefficient in the regressors.

Methodological approach

We seek to explore the causal interactions among carbon CO_2 emissions, per capita energy consumption, income inequalities, and economic development using modern econometric techniques. This analysis involves a three-step scientific approach. First, we determine the integration order of the series based on panel unit root tests. Second, we apply panel cointegration tests to verify the existence of any long-term relationships. Finally, we examine the size and direction of any potential causal interactions among our series.

Panel unit root tests/stationarity tests

We apply standard unit root tests to the determinants of CO_2 emissions, total per capita energy consumption, income inequalities, and per capita GDP. Narayan and Smyth (2009) argue that the Augmented Dickey-Fuller (ADF) test has low power in rejecting the null hypothesis of stationarity, particularly for short periods. Hence, recent academic works claim that panel stationarity tests are more powerful compared to individual time series ones (for example, Al-Iriani 2006). We use the panel unit root tests suggested by Levin et al. (2002), Im, Pesaran, and Shin (IPS), Im et al. (2003), Hadri (2002), and Beitung (2001). These are generally more robust than the first generation of panel tests (Narayan and Smyth 2009).

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[4] The turning point is calculated where $\partial \ln \mathrm{co2}/\partial \ln \mathrm{gini} = \beta_3 + 2\beta_4 \ln \mathrm{gini} = 0$ or $\mathrm{Gini} = \mathrm{anti} - \log(\beta_3/2\beta_4)$.

Table 4 Summary of findings from previous studies worldwide on the link between CO_2 emissions and economic growth

Authors	Period	Region/country	Methods	Findings
Nnaji et al. (2013)	1971–2009	Nigeria	ARDL bound test approach to cointegration/Granger causality tests	Positive impact of fossil fuel consumption and development on CO_2 emissions
Wang (2013)	1995–2009(China) 1990–2009(U.S.)	China and the USA	Decomposition and nonparametric statistical analysis	Reducing effect of differentiated output growth on CO_2 emissions in the USA and China
Salahuddin and Gow (2014)	1980–2012	Gulf Cooperation Countries	Pooled mean group estimation	Progress has no long-term implications on environmental degradation
Kivyiro and Arminen (2014)	1971–2009	6 sub-Saharan African states	Autoregressive distributed lag model	Long-run economic growth-CO_2 emissions nexus
Allali et al. (2015)	1990–2100	Algeria	A structural production function/a similar methodology as Cobb-Douglas	Positive impact of development on CO_2 emissions/bidirectional causality between CO_2 emission and electric power consumption
Abid (2015)	1980–2009	Tunisia	VECM model specification and accounting for structural breaks	A short-run and a long-run interplay between growth and the carbon footprint and unidirectional causality running from progress to CO_2 emissions
Begum et al. (2015)	1970–2009	Malaysia	ARDL bound testing approach	CO_2 emissions are negatively linked with economic growth
Esso and Keho (2016)	1971–2010	Nigeria	ARDL bound test to cointegration and Granger causality test	A positive long-term relationship among CO_2 emissions and progress and a bidirectional causal link between variables
Mardani et al. (2018)	1995 and 2017	Various countries globally	Qualitative systematic and meta-analysis method called “PRISMA”	Bidirectional causality between economic growth and CO_2 emission trends

ARDL autoregressive distributed lags model, *VECM* vector error correction model

Moreover, the first-generation panel unit root tests are applied to panel data which neglects both structural breaks and cross-sectional dependence. These are commonly used in the carbon emission-per capita energy consumption literature. These are similar to the ADF-based IPS tests which assume a heterogeneous unit root (Im et al. 2003). In contrast, Breitung and Das (2005) and Levin et al. (2002) point out a homogenous unit autoregressive root. Levin et al. (2002) and IPS test the null hypothesis of time series integration. Hadri (2002) suggests a residual-based Lagrange multiplier test for the null of level or trend stationarity that includes heterogeneous disturbance terms.

Panel cointegration tests and long-run estimations

Using the panel cointegration technique is more powerful than time series models because models estimated from cross-sections of time series have more degrees of freedom and are more efficient than models estimated from individual time series. The panel cointegration techniques are particularly useful when the time series dimension of each cross-section is short.

If all the variables are found to be stationary after taking the first difference, then we proceed to test Pedroni (1999, 2004) and Kao's (1999) panel cointegration tests. To test the existence of cointegration within a heterogeneous panel, Pedroni (1999, 2004) proposed two categories of cointegration tests and seven statistics. The first category is based on four statistics (panel statistics)—the v statistic, rho statistic, the Phillips and Perron (PP) statistic, and the ADF statistic. These statistics are classified in the within-dimension and take into account common autoregressive coefficients across the countries. The second category is based on three statistics (group statistics)—the rho statistic, the PP statistic, and the ADF statistic. These tests are classified in the between-dimension and are based on individual autoregressive coefficients for each country in the panel. The null hypothesis is that there is no cointegration and the alternative hypothesis is that there is cointegration between the variables. Pedroni (1999, 2004) and Kao's (1999) panel cointegration tests are based on the residuals. Deviations from the long-run equilibrium relationship are represented by the estimated residuals. The null hypothesis, of no cointegration, $\rho_i = 1$, is tested via the following unit root test of the residuals:

$$\varepsilon_{it} = \rho_i \varepsilon_{it-1} + \omega_{it} \tag{4}$$

where ε_{it} is defined as the autoregressive process.

Panel cointegration test allowing for cross-sectional dependence

After having confirmed the non-stationarity of the variables for the panel data as a whole, it is natural to test the existence of a structural long-run relationship among the variables. To assess the robustness of our findings, we also implement the bootstrap panel cointegration test proposed by Westerlund (2007)[5]:

$$\Delta y_{it} = \phi_i^{'} d_t + \alpha_i y_{i,t-1} + \lambda_i^{'} x_{i,t-1} + \sum_{j=0}^{\rho_i} \alpha_{ij} \Delta y_{i,t-j} + \sum_{j=0}^{\rho_i} \gamma_{ij} \Delta x_{i,t-j} + e_{it} \tag{5}$$

where $\phi_i = (\phi_{0i}, \phi_{1i})^{'}$, $d_t = (1, t)^{'}$, $\lambda_i = -\alpha_i \beta_i,$. To derive the two-panel statistics, first the lag order ρ_i for each cross-section should be determined and the common error correction parameter α and its standard error σ_α are estimated. Hence, the estimates of α and σ_α can be estimated as:

$$\hat{\alpha} = \left(\sum_{i=1}^{N} \sum_{t=2}^{T} \tilde{y}_{i,t-1} \right)^{-1} \sum_{i=1}^{N} \sum_{t=2}^{T} \frac{1}{\hat{\alpha}_i(1)} \tilde{y}_{i,t-1} \Delta \tilde{y}_{i,t} \tag{6}$$

$$\hat{\alpha}_{\hat{\alpha}} = \left[\left(\frac{1}{N} \sum_{i=1}^{N} \left(\frac{\hat{\alpha}_i}{\hat{\alpha}_i(1)} \right)^2 \right)^{-1} \sum_{i=1}^{N} \sum_{t=2}^{T} \tilde{y}^{2}_{\;i,t-1} \right]^{-1/2} \tag{7}$$

The term $\hat{\alpha}_i$ is the estimated standard error obtained by applying OLS to Eq. 5. Thus, the panel statistics are:

$$P_\tau = \frac{\hat{\alpha}}{\hat{\alpha}_{\hat{\alpha}}} \tag{8}$$

$$P_\alpha = T\hat{\alpha} \tag{9}$$

Further, Westerlund (2007) formulated the group mean test statistics as:

$$G_\tau = \frac{1}{N} \sum_{i=1}^{N} \frac{\hat{\alpha}_i}{\hat{\alpha}_{\hat{\alpha}}} \tag{10}$$

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

where $\hat{\alpha}_{\hat{\alpha}_i}$ is the standard error of $\hat{\alpha}_i$. Under the null hypothesis, all P_τ, P_α, G_τ, and G_α test statistics have limiting normal distribution as T and N go to infinity sequentially. In other words, the statistics are standard and normally distributed when standardized with appropriate moments. Hence, the asymptotic distributions and the moments are dependent on the deterministic terms and the number of regressors included in the regression model. Under the alternative hypothesis, the group mean statistics G_τ and G_α and the panel statistics P_τ and P_α diverge to negative infinity, which means that the test decision is made on the left tail of the standard normal distribution. Additionally, Westerlund (2007) proposed using

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[5] The first-generation cointegration tests (Pedroni 1999, 2004 and Kao 1999) examine the long-run relationships between the variables without cross-sectional dependence and putting common factor restrictions. Thus, we test for cointegration using the test suggested by Westerlund (2006, 2007). The cointegration test proposed by Westerlund (2007) can accommodate cross-sectional dependence and does not impose any common factor restrictions.

Chang's (2004) bootstrap approach for panel cointegration testing which accommodates for cross-sectional dependence.

The Dumitrescu-Hurlin panel Granger causality test

It is important for policymakers to know the directions of causality among the variables so that they can formulate appropriate policies. Therefore, this study employs the Granger causality test developed by Dumitrescu and Hurlin (2012) to demonstrate the causality relationship. This test has very flexible use both in case of T > N and T < N as well as for heterogeneous panels. One of the major advantages of this test is that it can be used for panel data in the presence of cross-sectional dependence. Moreover, this test solves the problems posed by the homogeneity assumption in the standard Granger causality test (Engle and Granger 1987). This test considers the following linear heterogeneous model:

$$y_{it} = \alpha_i + \sum_{i=1}^{k} \gamma_i^{(k)} y_{i,t-k} + \sum_{i=1}^{k} \beta_i^{(k)} x_{i,t-j} + \varepsilon_{it} \qquad (12)$$

where $k \in N^+$ and $k \in N^*$, $\beta_i = (\beta_i^{(1)}, ..., \beta_i^{(k)})$. α_i , $\gamma_i^{(k)}$, and $\beta_i^{(k)}$ indicate a constant term, lag parameters, and slope coefficients, respectively.

Data description

We worked with annual data covering the period 1971–2013 for N-11 countries (Bangladesh, Egypt, Indonesia, Iran, Mexico, Nigeria, Pakistan, the Philippines, Turkey, South Korea, and Vietnam). Our study includes CO_2 emissions (CO_2) in kilogram per capita, per capita energy consumption in kilogram of oil equivalent, and real GDP per capita in constant 2010 US dollars used as a proxy of economic growth borrowed from the World Development Indicators (WDI 2014). The Gini coefficient which measures income distribution is obtained from SWIID (2015).

Table 5 gives the mean values and standard deviations of the data series for N-11 countries.[6] The descriptive statistics show that the data series is fairly dispersed, but the standard deviations are homogeneous. Table 5 also shows that South Korea had the highest means of CO_2 emissions (6677.444) and per capita energy consumption (2670.633), Turkey had the highest GDP mean (6953.612), and Mexico registered the highest mean of the Gini coefficient (47.381). The lowest means of CO_2 emissions (184.668) and per capita energy consumption (131.617) were in Bangladesh and the lowest Gini coefficient (31.088) and GDP were (757.444) in Pakistan. South Korea had the highest volatility in the case of CO_2 emissions (3273.488), energy use (1617.452), and GDP per capita (7000.265). The highest volatility of the Gini coefficient was in Nigeria (3.788).

Results and discussion

Cross-sectional dependence test

This study applied the cross-sectional dependence (CD) test developed by Pesaran (2004) to verify the cross-section dependence across the 11 countries under investigation. Table 6 gives the results of the test applied to CO_2 emissions, per capita energy consumption, income inequalities, and GDP per capita variables. We reject the null hypothesis of cross-sectional independence for all the variables, except for income inequality.

Unit root tests' results

We used the unit root tests developed by LLC, IPS, and Breitung and Das (2005) to verify the existence of unit roots. Levin et al. (2002) proposed the panel-based ADF test and assumed homogeneity in the dynamics of the autoregressive coefficients for all panel units. Under the LLC (2002) unit root test, the null hypothesis indicates the presence of a unit root; the alternative hypothesis claims there is no unit root. The IPS (2003) test which solves the serial correlation problem by accepting heterogeneity between units in a dynamic panel framework shows that under the null hypothesis of non-stationarity the statistics follow the standard normal distribution asymptotically. Table 7 gives the panel unit root tests' results.

Panel cointegration results

After applying panel unit root tests, we proceeded to panel cointegration tests. Cointegration can be described as a systematic long-term interplay among two or more economic variables (Yoo and Goldsmith 2006). Based on the Pedroni test's findings, Table 8 gives the cointegration between selected variables at the 5% level of significance for both the frameworks. Therefore, we have long-run interactions among the series. The Kao (1999) residual cointegration results also support cointegration at the 5% level of significance. Thus, there is strong evidence of a long-term relationship between the series. This is consistent with Lee (2005) and Sadorsky (2009). We used the Westeland test cointegration (2007) to establish a long-run relationship among the series. This also confirms cointegration among selected variables.

Long-run elasticity

We first present the results of the empirical interplay between per capita energy consumption, economic growth, income inequalities, and CO_2 emissions. Pedroni (2004) recommended a superior test relative to single equation methods that can be used for exploring the cointegration vector. We seek to identify a strong interaction between total per capita energy consumption, economic development, income inequalities,

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[6] The data sheet can be obtained in Excel file upon request.

Table 5 Descriptive statistics and pairwise correlation of the variables used (before taking logarithm) 1971–2013

Country		CO_2 emission (kg per capita)	Energy use (kg of oil equivalent per capita)	Gini coefficient	GDP per capita (constant 2010 US $)	Period
Bangladesh	Mean	184.6679	131.6169	35.6024	478.7004	1971–2013
	Std. dev.	111.5216	36.0876	3.6501	153.0717	
Egypt	Mean	1571.8980	565.2152	34.7121	1678.9820	1971–2013
	Std. dev.	591.6827	215.2245	3.1993	567.0324	
Indonesia	Mean	544.1110	570.7360	34.4496	1850.4450	1971–2013
	Std. dev.	63.2482	197.5233	2.4222	811.6094	
Iran	Mean	1003.7160	1601.7570	42.1453	5125.8290	1971–2013
	Std. dev.	265.7120	730.2027	2.3876	1356.7030	
Mexico	Mean	3612.8430	1351.3720	47.3807	7611.2000	1971–2013
	Std. dev.	475.7381	202.9817	2.6974	1091.1430	
Nigeria	Mean	653.8632	690.1914	43.9710	1660.8320	1971–2013
	Std. dev.	182.6912	52.4181	3.7889	390.0648	
Pakistan	Mean	637.2212	402.9434	31.0879	757.4445	1971–2013
	Std. dev.	218.6540	76.2916	1.3293	198.7942	
Philippines	Mean	793.1211	455.8078	42.8155	1651.0720	1971–2013
	Std. dev.	119.4988	25.1957	2.1218	265.2116	
Turkey	Mean	2761.7970	1009.3280	43.3288	6953.6120	1971–2013
	Std. dev.	893.7635	284.4049	3.3541	2028.9190	
South Korea	Mean	6677.4440	2670.6330	31.4508	11,037.9000	1971–2013
	Std. dev.	3273.4880	1617.4520	1.3821	7000.2650	
Vietnam	Mean	819.7588	408.2190	36.1794	807.2760	1984–2013
	Std. dev.	523.8860	145.0561	2.3461	361.5859	
Aggregate	Mean	2570.0630	909.9553	38.5304	3680.1670	
	Std. dev.	2510.8410	898.2884	6.0420	4091.1380	
Pairwise correlation matrix						
CO_2 emissions		1.0000				
Energy consumption		0.9968	1.0000			
Gini coefficient		0.9529	0.9472	1.0000		
GDP		0.9832	0.9855	0.9378	1.00000	

CO_2 emissions are carbon emissions per capita in kilogram. Energy consumption is the energy use per capita in kilogram of oil equivalent. Gini coefficient is the level of income inequality. GDP per capita is the gross domestic per capita in constant 2010 US $ terms

Table 6 Cross-sectional dependence test

Variable	CD test	*P* value	Corr	abs(corr)
lnco_2	25.99	0.000	0.558	0.669
lnenergy	36.88	0.000	0.782	0.791
lngini	0.34	0.736	0.002	0.455
$(\mathrm{lngini})^2$	0.37	0.714	0.003	0.456
lngdp	30.29	0.000	0.651	0.701
$(\mathrm{lngdp})^2$	30.58	0.000	0.657	0.705

All variables are taken in their natural logarithm form to give smoothness to the variables

and CO_2 emissions for all panel countries. Equations 2 and 3 give the regression between these four factors. The dependent variables are carbon emissions, a function of total per capita energy consumption, GDP per capita, and income inequalities.

Table 9 presents the findings of the FMOLS, DOLS, and random effects estimation methods which highlight whether per capita energy consumption, wealth disparities, and level of per capita income stimulate CO_2 emissions in the N-11 countries.[7] The Hausman test confirms the random effects model as a preferred model over the fixed effects model as it helps avoid the cross-sectional effects and also allows us to cross-examine the long-run outcomes returned by FMOLS and DOLS. Both FMOLS and DOLS tests show consistent results that demonstrate a positive interplay running from per capita energy consumption, income inequalities, and level of income to CO_2 emissions at the 1% level of significance.

The long-run elasticity of CO_2 emissions with respect to total per capita energy consumption is estimated at 0.589, 0.626, and 0.584 in model 1 (without EKC) and 0.594, 0.586, and 0.57 in model 2 (with EKC). This means that a 1% increase in per capita energy consumption leads to a 0.58% to 0.59% increase in CO_2 emissions. These findings indicate a monotonic relationship between CO_2 emissions and per capita energy consumption for all N-11 countries. There is no doubt that CO_2 emissions are driven by unsustainable per capita energy consumption patterns.

Our results confirm the presence of an inverted U-shaped relationship between income inequalities and carbon emissions for N-11 countries. Initially, CO_2 emissions increase and they start declining after a threshold level of income inequality has been reached. We identified an environmental EKC interplay among income inequalities and CO_2 emissions. The threshold Gini coefficient level of wealth disparities for all N-11 nations varied from 41 to 45. If a country has a level of inequality below 40, reducing the gap will trigger a decrease in carbon emissions. If inequality is higher than 45, reducing inequality will have no beneficial effects on environmental quality.

Regarding the long-run elasticity of CO_2 emissions with respect to wealth disparity, we found inelasticity coefficients in model 1 (without EKC) but elasticity in model 2 (with EKC) when including the Gini coefficient squared. The coefficient of income inequality is 0.862, 0.437 (insignificant), and 0.78 in model 1. A 1% increase in income inequality drives a 0.78% to 0.86% growth in carbon emissions. Our results illustrate that rising income inequalities force poor people to use low-cost fuels which release more carbon emissions. By contrast, falling income inequalities improve environmental quality. The coefficients for wealth disparity and income inequality square in model 2 are 21.267, 16.94, and 20.00 and − 2.798, − 2.276, and − 2.636, respectively. Further, the estimated threshold levels are 44.66, 41.27, and 44.41.

Our study found an inverted "U"-shaped relation between the level of income inequality and CO_2 emissions. This result shows that wealth disparities decreased CO_2 emissions when the level of income inequalities was more than 45% and increased CO_2 emissions when income inequalities were less than 40%. In countries with more equal distribution of income, an increase in inequalities has a bad effect on the environment. Similarly, countries with more unequal income distribution policies for lowering inequalities will lead to environment degradation. Hence, in both the cases, the level of wealth distribution plays a critical role in environment quality. This indicates that the rich people are more responsible for the degradation of environmental quality as compared to poor people because when the rich become richer, they try to invest their wealth in leading industries to get higher returns without caring about their impact on environmental quality. But in the case of poor people where environment forms a part of their livelihood strategy, they try and protect their environment.

The estimated long-run elasticity of CO_2 emissions with respect to GDP per capita is 0.456, 0.401, and 0.453 for model 1 (without EKC) and 0.449, 0.381, and 0.453 for model 2. This implies that a 1% increase in per capita GDP induces CO_2 emissions of 0.38% to 0.44%. We found a positive long-run interaction among CO_2 emissions and GDP per capita. This shows that an increase in disposable incomes motivates households to consume pollution-free fuels (renewable energy) for their activities.

Finally, the results of the long-run panel Granger causality test are reported in Table 10. There is evidence of bidirectional Granger causality between lngdp and lngdp^2 with lnco_2. However, lnco_2, lnenergy, lngini, and lngini^2 provide a unidirectional causality with lnco_2. Figure 2 gives a graphical illustration of lead-lag causality linkages summarized from the Dumitrescu-Hurlin (D-H) Granger causality test.

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[7] We detected the existence of multicollinearity due to overfitting GDP and Gini square in the models. We do not find the multicollinearity as a problem in the models as all coefficients in the regression Models 2 and 3 are statistically significant. The tests for multicollinearity are VIF = 3.655 for lnergy, 66.932 for lnGDP, 1.147 for lnGini, and 66.081 for lnGDP2 for model 2 and VIF = 2.825 for lnergy, 2.74 for lnGDP, 678.499 for lnGini, and 675.563 for lnGini2 for model 3.

Table 7 Panel unit root tests

	lnco$_2$		lnenergy		Lngini		(lngini)^2		lngdp		(lngdp)^2	
	Statistic	*P* value	Statistic	*P* value	Statistic	*P* value	Statistic	*P* value	Statistic	*P* value	Statistic	*P* value
Variable in level												
Levin, Lin, and Chu *t**	0.7091	0.760	0.5946	0.723	− 0.1377	0.445	− 0.2213	0.412	− 1.2748	0.101	− 0.2244	0.411
Im, Pesaran, and Shin W-stat	− 0.17824	0.429	0.1365	0.554	0.6757	0.750	0.6316	0.736	2.8599	0.997	2.9206	0.998
Breitung t-stat	− 0.1361	0.445	3.0103	0.998	0.7012	0.758	0.7807	0.782	1.8851	0.970	1.1980	0.884
Variable in first difference												
Levin, Lin, and Chu *t**	− 8.4460	0.000	− 8.5669	0.000	− 3.1503	0.001	− 3.2266	0.001	− 5.6860	0.000	− 6.0592	0.000
Im, Pesaran, and Shin W-stat	− 11.075	0.000	− 9.2813	0.000	− 3.9381	0.000	− 3.9489	0.000	− 8.8946	0.000	− 8.7762	0.000
Breitung t-stat	− 4.9581	0.000	− 4.7985	0.000	− 3.5628	0.000	− 4.5079	0.000	− 6.2455	0.000	− 6.7288	0.000

Concluding remarks, policy implications, and future research directions

This research explained the nexus between CO$_2$ emissions, per capita energy consumption, income inequalities, and GDP per capita for the N-11 countries over the period 1971–2013. It investigated whether income levels or income inequalities matter in CO$_2$ emissions. We considered three models: one linearly and two non-linearly specified to verify the environmental Kuznets curve hypothesis for the N-11 countries. Our results show that in the long-run, an increase in income inequalities, economic development, and per capita energy consumption increases CO$_2$ emissions. This is happening in the N-11 states because for the sake of economic growth and poverty reduction, their governments are racing to the bottom leading to weakened environmental regulation policies that follow growth without much attention to the health of the environment.

Our findings also highlight that wealth disparities had both positive and negative effects in the countries that we studied. In countries with equal income distribution, an increase in inequalities had a deteriorating effect on the environment. Similarly, in countries with more unequal income distribution, policies for lowering inequalities and poverty could lead to environment degradation. So, in both cases, the level of wealth distribution played a critical role in environment quality. This indicates that the rich countries are more responsible for deterioration in

Table 8 Panel cointegration test results

	Model 1 lnco$_2$ = f(lnenergy, lngdp, lngini)	Model 2 lnco$_2$ = f(lnenergy, lngdp, lngini, lngdp^2)	Model 3 lnco$_2$ = f(lnenergy, lngdp, lngini, lngini^2)
Padroni cointegration test			
Panel v weighted statistic	− 0.446	− 0.055	− 0.577
Panel σ weighted statistic	− 3.001*	− 2.147**	− 1.887**
Panel $\rho\rho$ weighted statistic	− 4.568*	− 4.959*	− 4.260*
Panel adf weighted statistic	− 2.695*	− 3.035*	− 2.234**
Group σ statistic	− 3.027*	− 2.107**	− 1.682**
Group $\rho\rho$ statistic	− 6.076*	− 6.917*	− 5.530*
Group adf statistic	− 2.806*	− 3.607*	− 2.483*
Westeland cointegration test			
Gt	− 2.715**	− 2.815*	− 2.755*
Ga	− 15.549**	− 12.284	− 14.062 **
Pt	− 8.472**	− 8.621*	− 8.596**
Pa	− 12.823*	− 10.144**	− 11.521*
KAO cointegration test			
ADF test	− 2.749*	− 3.665*	− 2.768*

All are estimated by using Eviews-10 and STATA-12 Software

*$p < 0.01$, **$p < 0.05$, ***$p < 0.1$

Table 9 Panel long-run results

CO$_2$ emissions: dependent variable

	FMOLS			DOLS			Random effect		
	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3
lnenergy	0.589*	0.606*	0.592*	0.626*	0.672*	0.586*	0.584*	0.605*	0.570*
lndgdp	0.456*	2.035*	0.449*	0.401*	2.340*	0.381*	0.453*	2.219*	0.453*
lngini	0.862*	0.510**	21.267*	0.437	0.336	16.94**	0.780*	0.455*	20.005*
lngdp^2		− 0.112*			− 0.112*			− 0.112*	
lngini^2			− 2.798*			− 2.27**			− 2.636*
Adj R^2	0.973	0.978	0.975	0.983	0.990	0.985	0.722	0.756	0.726
Threshold level			44.66			41.27			44.41

Optimum lag obtained from SIC criteria. One asterisk and two asterisks indicate rejection of the null hypothesis at the 1% and 5% levels of significance, respectively. Test for multicollinearity are VIF = 3.655 for lnergy, 66.932 for lngdp, 1.147 for lngini, and 66.081 for lngdp2 for model 2 and VIF = 2.825 for lnergy, 2.74 for lngdp, 678.499 for lngini, and 675.563 for lngini2 for model 3

environmental quality as compared to poor countries because when the rich become richer, they invest their wealth in leading industries to get higher returns without caring for their impact on environmental quality. But in the case of poor countries where the environment forms a major livelihood source and strategy, people try and protect their environment. In most of the sampled N-11 countries, the GDP per capita was below the turning point in development where countries had started investing in the environment.

Therefore, policymakers and governments in N-11 nations can increase environmental protection by applying carbon taxes, emission trading schemes, and various subsidy and technology-based incentive programs. Moreover, governments can promote the development and transfer of clean technology and also encourage both national and foreign investors to employ energy-efficient technologies when increasing production levels. In addition, in an effort to gain a double dividend, N-11 governments should adopt energy use reduction policies not only to preserve their environmental quality and for reducing energy costs but also to distribute the already scarce resources to sectors with high growth potential that are using resource-saving technologies. A shift in taxes from labor to capital under a revenue neutral tax policy will incentivize clean technology development and green jobs.

Future analyses are warranted in terms of applying the quantile-on-quantile regression (Q-Q-R) approach developed by Sim and Zhou (2015), the non-linear autoregressive distributed lag framework detailed by Pesaran et al. (2001), who

Table 10 Dumitrescu-Hurlin Granger causality test

Null hypothesis:	W-stat.	Z-stat.	prob.	Finding
lnenergy does not homogeneously cause lnco$_2$	4.55824	3.56957	0.0004	Unidirectional from lnco$_2$ to lnenergy
lnco$_2$does not homogeneously cause lnenergy	2.45105	0.47925	0.6318	
lngdp (lngdp^2) does not homogeneously cause lnco$_2$	5.67857	5.21260	0.0000	Bidirectional from lngdp (lngdp^2) to lnco$_2$
lnco$_2$ does not homogeneously cause lngdp (lngdp^2)	3.37696	1.83715	0.0662	
lngini (lngini^2) does not homogeneously cause lnco$_2$	2.59263	0.68688	0.4922	Unidirectional from lnco$_2$ to lngini (lngini^2)
lnco$_2$ does not homogeneously cause lngini (lngini^2)	6.54737	6.48675	0.0000	
lngdp (lngdp^2) does not homogeneously cause lnenergy	4.69230	3.76617	0.0002	Unidirectional from lngdp (lngdp^2) to lnenergy
lnenergy does not homogeneously cause lngdp (lngdp^2)	2.35601	0.33987	0.7340	
lngini (lngini^2) does not homogeneously cause lnenergy	2.53512	0.60254	0.5468	Unidirectional from lnenergy to lngini (lngini^2)
lnenergy does not homogeneously cause lngini (lngini^2)	5.46967	4.90624	0.0000	
lngdp^2 does not homogeneously cause lngdp	2.18251	0.08542	0.9319	No
lngdp does not homogeneously cause lngdp^2	2.22432	0.14673	0.8833	
lngini (lngini^2) does not homogeneously cause lngdp	3.15013	1.50448	0.1325	Unidirectional from lngdp to lngini (lngini^2)
lngdp does not homogeneously cause lngini (lngini^2)	8.14550	8.83050	0.0000	
lngini (lngini^2) does not homogeneously cause lngdp^2	3.11037	1.44618	0.1481	Unidirectional fromlngdp^2 to lngini (lngini^2)
lngdp^{2}does not homogeneously cause lngini (lngini^2)	7.98563	8.59604	0.0000	
lngini^2 does not homogeneously cause lngini	2.71893	0.87211	0.3831	No
lngini does not homogeneously cause lngini^2	2.68532	0.82281	0.4106	

postulate the possibility of an empirical examination of nonlinear cointegration, asymmetric dynamic relationships, use of flexible adjustment smooth transition autoregressive (STAR) models (Chen 2003), and flexible policy-based adjustments to achieve targets (Khayyat and Heshmati 2019). Based on these methodologies, academics can examine which groups are the main influencers of environmental quality and assess their capacity to adjust towards targeted development and environmental outcomes.

Our study also provides reliable and consistent empirical findings that can be valuable for policymakers when implementing comprehensive environmental strategies for inclusive and sustainable economic development and growth.

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Appendix

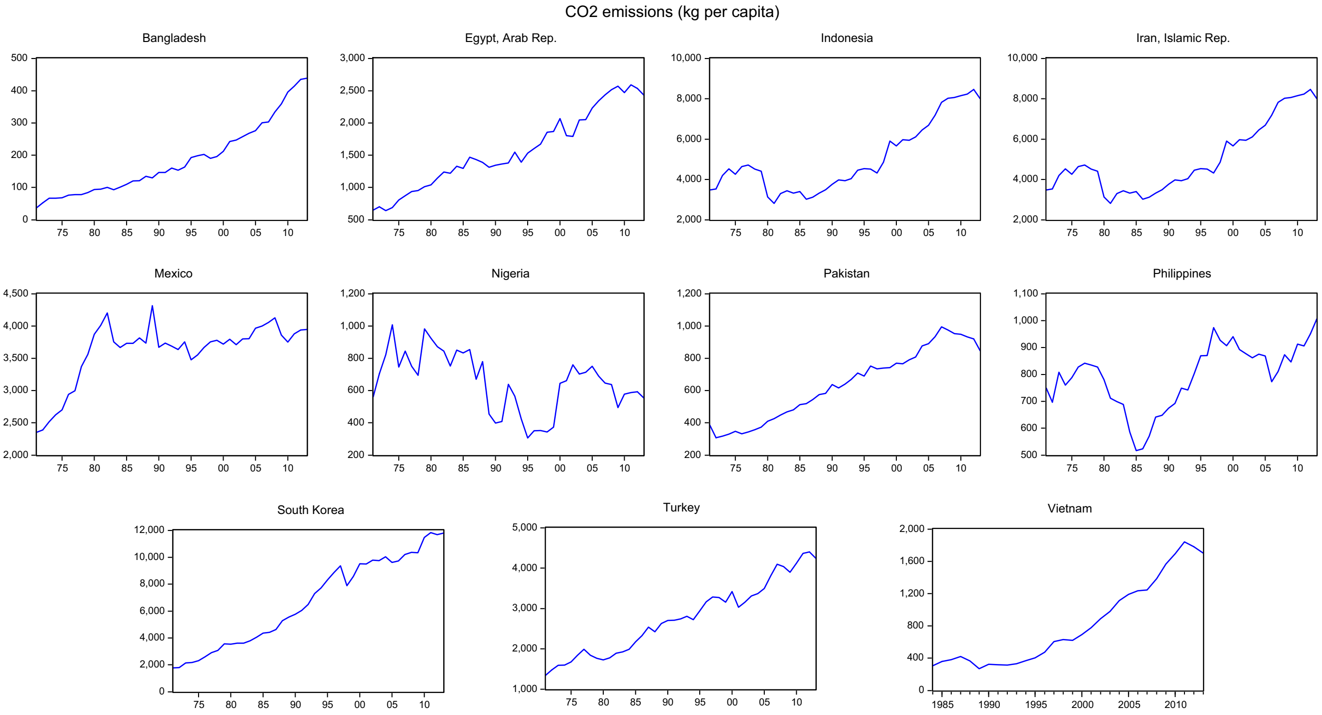

Fig. 3 CO_2 emissions (kg per capita)

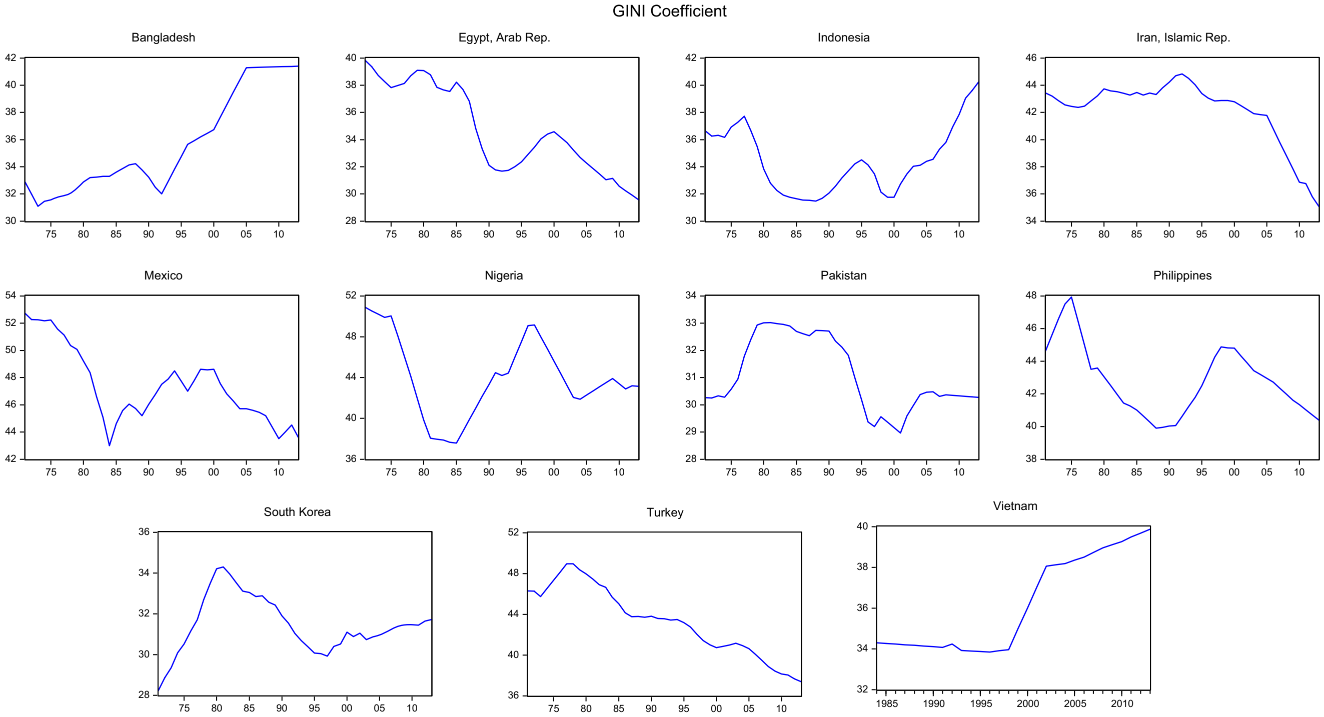

Fig. 4 Income inequality (Gini coefficient)

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