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Research article

Environmental quality and its nexus with informal economy, corruption control, energy use, and socioeconomic aspects: the perspective of emerging economies

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ABSTRACT

This paper explores the impacts of informal economic activities and institutional capacity, particularly, corruption control on the environmental quality degradation of emerging economies under the prevailing socio-economic conditions and energy use patterns of the countries. The study utilizes key environmental degradation indicators: Carbon dioxide (CO_2) emissions, ecological footprints (EFs), and Nitrous Oxide (NO) emissions, and a panel dataset of 15 emerging countries for the period 2002–2019 to undertake an empirical investigation. The pooled mean group (PMG)-ARDL estimator, Fully Modified OLS (FMOLS), Dynamic OLS (DOLS) and Augmented Mean Group (AMG) methods have been applied as empirical investigation techniques. The empirical findings reveal that in the long-run informal economic activities positively affect the environmental quality with fewer recorded emissions of CO_2 and EFs while these activities affect negatively to NO emissions. This study has also found that corruption control improves environmental quality by reducing EFs and NO emissions but works to the opposite by increasing recorded CO_2 emissions. An increase in economic growth and renewable energy consumption improves environmental quality in emerging countries, while consumption of non-renewable energy degrades the environmental quality. The robust empirical findings advocate policy initiatives for intense monitoring of informal activities and implementation of indirect tax policy to regulate informal activities and the pollution they cause. Careful measures of corruption control and initiatives to bring the informal economic activities into a formal framework are suggested to reduce CO_2 and NO emissions. An increase in economic growth with more focus on renewables and phasing out non-renewables can ensure green growth in emerging countries.

1. Introduction

Emerging countries are increasing economic growth by enhancing their industrial activities. The energy-intensive industrial development that is taking place in these countries has turned them into the largest producer of Carbon dioxide (CO_2) in recent decades (Bilgen, 2014; Nguyen and Kakinaka, 2019; Oh et al., 2021). These countries are typically dependent on fossil fuel in their industrialization process due to its low cost. However, the use of fossil fuel-based energy is posing environmental challenges to these countries (Pata and Yilanci, 2020a, 2020b; Li et al., 2021; Le and Sarkodie, 2020; Reilly, 2015). In addition, the increased economic activity encourages the unsustainable use of natural resources that affects bio capacity, increases the countries' ecological footprints (EFs), and poses a threat to the environment (Pata, 2021; Danish and wang, 2019; Oh et al., 2021). To avoid far-reaching consequences on ecology and the environment, these countries are under pressure (both internal and external) to reduce environmental damages (Ahmad et al., 2021b).

Environmental pollution is a multinational concept, and it has links to social issues (e.g., health, education, unemployment, women's employment, electrification rate, and accessibility to energy at fair prices), and governance (e.g., corruption, institutional capacity) in addition to economic growth, energy use, and industrialization (Mohr et al., 2015; Bauer et al., 2016; EIA, 2018). In emerging countries informal economic activities are important aspects that need to be investigated in the context of environmental quality assessment. These countries generally have large informal sector and hence it is suggested to be considered as an economic tool for maintaining energy demand and economic

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development (Medina and Schneider, 2019; Benkraiem et al., 2019; Huang et al., 2020; Elgin and Oztunali, 2014[1]). However, economic activities in this sector are often unregistered, marginal and geographically dispersed in nature that give them the opportunity to be noncompliant with environmental regulations (Elgin and Oztunali, 2014; Pang et al., 2021). Literature shows that the informal economy has largely been ignored into understanding its relationship with environmental quality despite the fact that its expansion increases the discharge of pollutants (Wang et al., 2019).

Under such a backdrop, the present study has focused on the informal economy and related institutional capacity along with economic, social and energy consumption aspects to understand their impact on environmental quality of fifteen (15) emerging countries.[1] Emerging countries are targeted since they have achieved remarkable economic growth in the last two decades and at the same time become liable for worsening the environmental quality, which is evident by their increased ecological footprints up to 3.18 (global hectares per capita) in the year 2017 from 2.36 in the year 1984. These countries have achieved the potentials to influence the global market since they represent 40% of total GDP and almost 60% of total population of the world (Ahmad et al., 2021b). The recent trend of environmental quality degradation (CO_2 emissions and Ecological Footprints) of these selected countries are presented in Figures 1 and 2. The trends of economic growth, informal sector performances and energy consumptions (non-renewable and renewable) of these emerging countries are also presented in Figures 3, 4, 5, and 6.[1]

This paper will add to the literature in several ways; Firstly, this study will provide an insight into environmental quality degradation by employing three indicators: CO_2, EFs, and Nitrous Oxide (NO) to capture the various dimensions of the environmental degradation (see Almeida and das, 2017). Apart from air pollution indicators, CO_2 and NO, of which CO_2 is the most prominent Green House Gas with growth rate 72% and NO with growth rate 42% in last decade (Shokoohi et al., 2022; Sinha and Bhattacharya, 2016), an anthropogenic consumption-based environmental degradation indicator ecological footprints (EFs) is also employed for a comprehensive assessment of total environmental damage. It measures the impact of human pressure on nature in terms of build-up land, cropland, forest products, fishing ground, CO_2 emissions, and water pollution which is capable to assess the sustainability of lifestyle of people, consumption of goods and services, business and production activities, regions and cities (GFN, 2021; Pata and Yilanci, 2020a; Pata and Yilanci, 2020b). Inclusion of EF is important to identify its determining factors since more than 80% of the total population of this world lives in countries with ecological pressure where consumption of natural resources exceeds their ecological reproductive capacity (Pata, 2021). Secondly, the informal sector is utilized in this study as an indication of the level of regulation and governance that an economy experiences (Swain et al., 2020; Goel et al., 2013) to evaluate its impact on environmental quality. Thirdly; since informal economic activities might work through corruption (Goel et al., 2013; Goel and Saunoris, 2020), the corruption control index is accommodated in the study as an institutional capacity indicator to evaluate its role in ensuring environmental quality. Fourthly, this study has added the socioeconomic conditions of emerging countries to understand its influence on environmental quality. Goel et al. (2013) underscores that socioeconomic conditions such as education, employment and demographic characteristics of an emerging economy can impact environmental quality by influencing decision making. Fifthly, the use of empirical investigation technique PMG-ARDL which is robust in finding the common coefficient for the long run and helpful to suggest mutual strategies for the emerging countries.

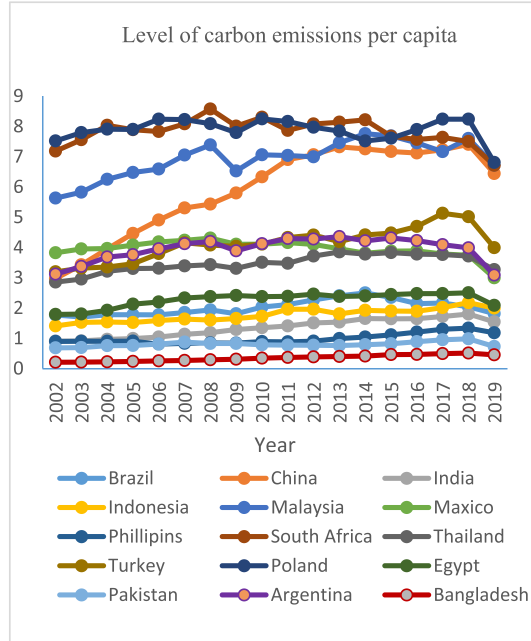

Figure 1. Level of carbon emissions (Source, WDI, 2021).

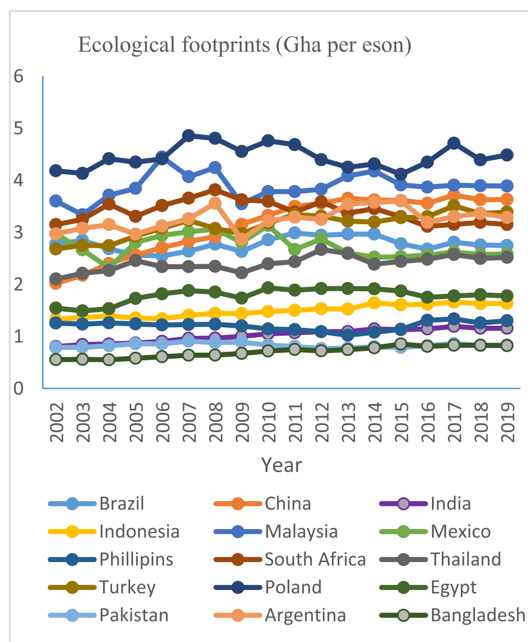

Figure 2. Ecological footprint of countries (Data source: GFN, 2021).

This paper is organized as follows: section 2 presents a brief review of recent literature that links environmental quality measured by various degradation indicators with the variables under investigation in this study. Section 3 describes the data and methodological steps followed in the study to obtain the outcome. Section 4 presents the results in a systematic manner and section 5 discusses the results in brief. Section 6 concludes the study with final remarks and policy suggestions.

2. Literature review

In previous studies, environmental degradation, economic growth and energy consumption were the three most common factors that were investigated. However, this study has extended the analysis by including

[1] Argentina, Bangladesh, Brazil, China, India, Indonesia, Malaysia, Mexico, Philippines, South Africa, Thailand, Turkey, Poland, Egypt, Pakistan (Source: https://worldpopulationreview.com/country-rankings/emerging-countries; https://en.wikipedia.org/wiki/Emerging_market).

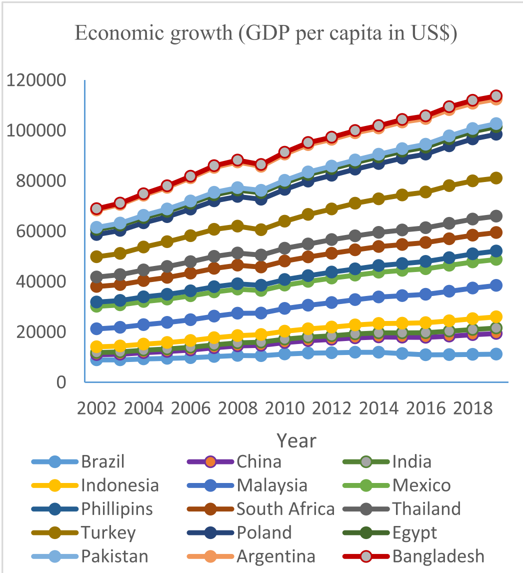

Figure 3. Economic growth in emerging countries (Data source: WDI, 2021).

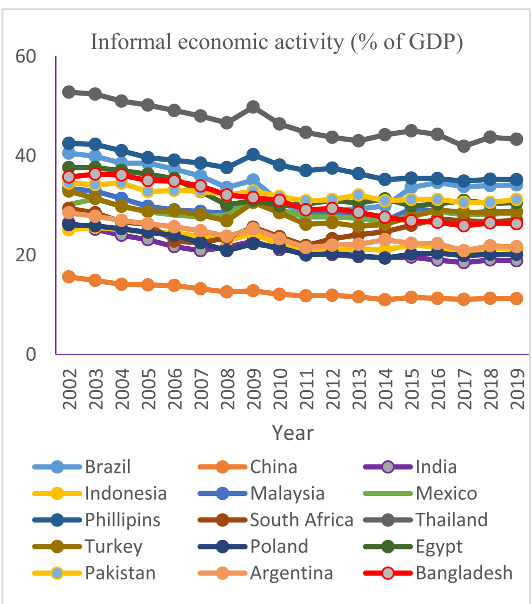

Figure 4. Informal economic activities as percentage of GDP (Data source: Medina and Schneider, 2019).

informal economic activity, corruption control, and socioeconomic conditions. The review of the most recent studies capturing the selected factors mentioned above and their nexus to environmental degradation has been presented below under four sub-sections.

2.1. Environmental quality and economic growth

The relationship between environmental quality and economic growth can be explained by the economic theory widely known as the Environmental Kuznets Curve (EKC) hypothesis. This hypothesis accepts that environmental degradation increases along with an increase in per capita income since more attention is paid to economic growth than environmental quality management at a lower level of income. When the country is at the peak of its development and reaches a certain threshold point, the government pays attention to improving the environmental quality. As a result, environmental degradation declines and form an

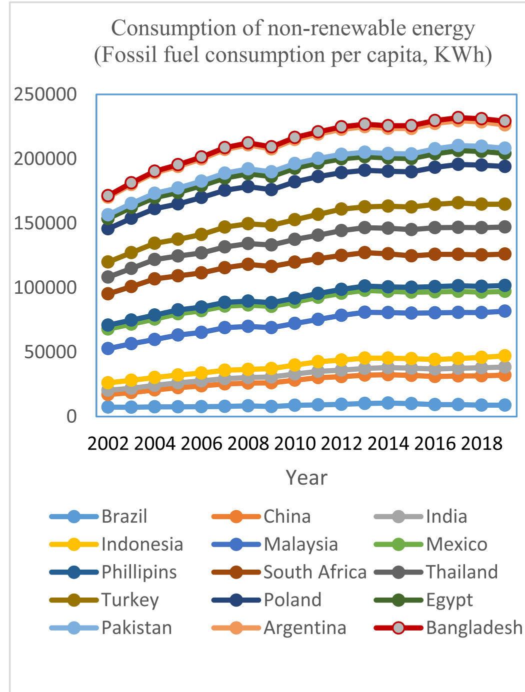

Figure 5. Consumption of non-renewable energy (KWh) per capita (Data source: WDI, 2021).

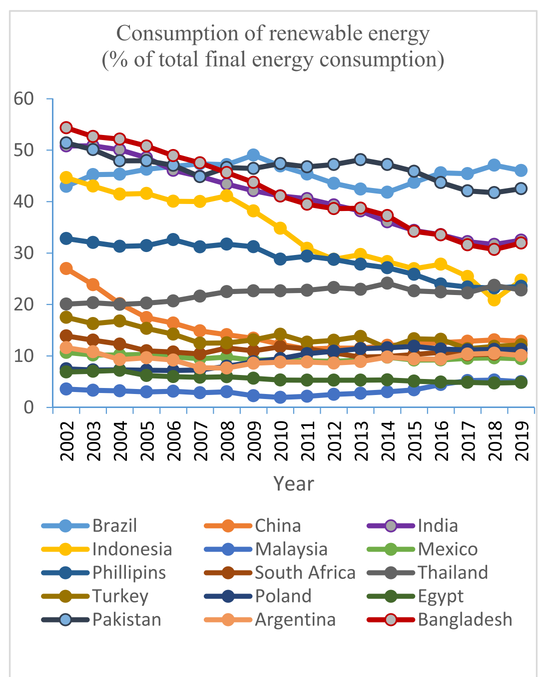

Figure 6. Consumption of renewable energy as percentage of total energy consumption (Data source, WDI, 2021).

'inverted U' shape (Ozcan and Ozturk, 2019; Lawson et al., 2020; Suki and Mohd, 2020; Wen et al., 2021). The phenomena attributed to this shape are the scale, composition, and technique effects through which economic growth contributes to the environmental performance level (Ozcan et al., 2020). Many recent studies have established the validity of the EKC hypothesis by employing both time series and panel data. Rahman (2020) for top 10 electricity consuming countries, Usama et al. (2020) for Ethiopia, Erdogan et al. (2020) for OECD countries, Gü ng ö r et al., 2020 for 9 selected countries, Ahmad et al. (2021a) for 5 China provinces, Suki and Mohd (2020) for Malaysia, Sultana et al. (2021) for Bangladesh all validated the 'inverted U' hypothesis. At the same time, the opposite results U-shaped relations are also found between economic growth and environmental pollution in the recent literature of Usman et al. (2021) for 12 Middle East and North American (MENA) countries, Pontarollo and Serpieri (2020) for Romania, Halliru et al. (2020) for west African countries, Pata and Aydin (2020) for China, and Zhang (2019) for five Central Asian countries. A positive contribution of GDP on environmental degradation indicators was revealed by Taiwo Onifadea et al. (2021) for E7 countries and Ozcan et al. (2020) for OECD countries while increased GDP was found to improve environmental performances in a large panel of countries by Alhassan (2021). A contrast to this result was noted by Danish and wang (2019) for 9 Newly Industrialized (Next-11) countries after integrating economic growth with urbanization. Narayan and Narayan (2010) also found decreasing impact of emissions on economic growth in developing countries.

For emerging countries contradiction prevails in the role of economic growth to Environmental quality. An inverted U-relation between economic growth and EFs has been revealed by Ahmad et al. (2021b) while for Newly Industrialized (Next-11) countries, Destek and Sarkodie (2019) revealed an inverted U relation for Mexico, Philippines, Singapore, and South Africa, and a U-shaped relation for China, India, South Korea, Turkey, and Thailand. A positive impact of increased CO_2 emissions on economic growth was projected by Le and Sarkodie (2020) in their study on emerging markets and developing countries while Acheampong et al. (2021) reveals a negligible effect of CO_2 emissions on economic growth for Sab-Saharan countries.

2.2. Environmental quality and energy consumption

The choice of energy resource of a country depends on a balance between economic growth and environmental degradation (Nguyen and Kakinaka, 2019). In emerging economies, the energy demand is sharply rising for economic development resulting in severe environmental problems (Oh et al., 2021). The negative relation between fossil fuel based energy consumption and environmental quality is revealed in the bulk of energy literature with all its adverse impacts (Ahmad et al., 2021a; Khan et al., 2021; Li et al., 2021; Ozcan et al., 2020, Martins et al., 2019; Destek and Sarkodie, 2019). Sharma et al. (2021) has noticed that energy consumption leads to environmental pollution at a lower income level, whereas its harmful effect becomes weak at a higher level of income.

Given the negative environmental impacts of fossil fuel based energy for economic development, renewable energy has been considered an alternative to those and a potential solution to limit sea-level rise or other climate change problems (Irandoust, 2016; Gani, 2021). Degradation in environmental quality triggers a shift towards renewable energy and energy-efficient technology according to the study of Ibrahiem and Hanafy (2021). The importance of the generation of renewable energy as a less carbon-emitting source is pointed to in a number of studies (Khan et al., 2021; Ingleso-Lotz and Dogan, 2018; Asongu and Odhiambo, 2019; Destek and Aslan, 2017; Wang et al., 2020). Nguyen and Kakinaka (2019) revealed that the relationship between renewable energy consumption and carbon emissions usually associated with the country's level of development. The stimulating role of renewable energy consumption in shaping environmental quality was identified by Zafar et al. (2020) for OECD countries.

By disaggregating energy into renewable and non-renewable categories, many studies reveal that renewable energy is environmentally friendly while non-renewable energy is damaging to the environment (Ahmad et al., 2021; Djellouli et al., 2021 for selected African countries, Khan et al., 2021 for OECD countries, Pata, 2021 for USA). In the study of emerging markets and developing countries (EMDEs), Le and Sarkodie (2020) have revealed that the exploitation of renewable energy offers double dividends by providing economic growth and reducing CO_2 emissions. However, no effect has been found for renewable energy consumption on environmental quality degradation in China by Pata and Caglar (2021).

2.3. Environmental quality and informal economy

While there are ample studies on the influence of the formal economy on environmental quality, the investigation on the impact of the informal economy on environmental quality is largely ignored and unknown although the informal sector includes many pollution-intensive activities and intensifies environmental impact (Wang et al., 2019; Blackman, 2000). Karanfil and Ozkaya (2007) found a link between environmental pollution and informal economic activities. Benkraiem et al. (2019) also found a significant relationship between unrecorded economy, environmental quality, and energy consumption. Elgin and Oztunali (2014) investigated this in a global context and revealed an inverted U relation between the informal economy and environmental pollution in terms of energy use. Their findings suggested that the small and large size of informal sectors were accompanied by a lower level of pollution, and medium-sized informal sectors were linked to a higher level of pollution. The model that was developed in the study identified two channels of informality that might affect environmental pollution: scale effect and deregulation effect. Since these two effects worked in opposite directions, an inverted U relation was created based on the altered relative strength of one with respect to informal sector size.

Literature has identified some features of informal economy that work behind its relation to environmental quality. Canh et al. (2021) underscored that since the activities of the shadow economy are almost free from environmental regulations, the shadow economic activities can be more energy-intensive and less green-oriented. Compliance with official requirements is generally weaker in the informal sector compared to the formal sector. Therefore, the formal sector avoids the costly regulations by outsourcing part of its production to the informal sector. Baksi and Bose (2016) modeled this process and analyzed how stringent regulations affected the size and regulatory compliance status of an endogenous informal sector through the outsourcing decision of formal firms. This study also identified the conditions under which a partially compliant informal sector acted as a source of leakage by permitting the formal sector to outsource polluting production. Bento et al. (2018) showed that energy tax could create welfare gains by allowing substitution from the informal sector. They mentioned two mechanisms through which the informal sector could lower the costs of environmental and energy tax policy: first; an energy tax would impose an indirect tax on the informal sector since informal firms buy energy from the formal sector, such as electricity, natural gas, gasoline, and secondly; a revenue-neutral shift in tax base towards energy that could decrease the tax burden on goods substituted by the informal sector. These mechanisms were found to have considerable potential in welfare-enhancing substitution of informal labor into the formal sector. Therefore, well-judged policies are required to address the damaging impact of informal economy to the environmental quality.

2.4. Institutional arrangements and environmental quality

Institutional arrangements, including policies, acts, and regulations in a jurisdiction, are crucial for protecting environmental quality. The outcome of the study by Ahmad et al. (2021b) has indicated that institutional quality promotes environmental sustainability by moderating the interconnection between economic complexity and ecological degradation. The virtue of institutions for environmental protection in developing countries has been noted by Azam et al. (2021). However, this depends on the enforcement of environmental rules and regulations (Momtaz and Kabir, 2018). The prevalence of corruption often creates difficulties in effectively enforcing the rules and regulations and protecting environmental quality (Du, 2021). Illegal rent seekers are key actors who may influence the implementation of environmental rules and cause environmental degradation during the development of a country. Their illegal activities may make economic development unsustainable as there is a potential to release carbon emissions, degrade forests and land resources, and cause water pollution (Du, 2021; Dogan et al., 2020). Ren et al. (2021) have shown how corruption influences environmental pollution and emphasize the importance of understanding the relation between corruption and carbon emissions for the formulation and implementation of public policies focusing on corruption control and carbon emissions reduction. Paying special attention to MENA countries, Goel et al. (2013) showed with empirical evidence that both more corrupt nations and nations with large shadow sectors projected similar effects in yielding fewer recorded emissions. Their study revealed the negative impact of these two on the recorded pollution level.

From the review of recent literature, it has been observed that the role of the informal sector, corruption control, and the prevailing socio-economic condition of the countries were not investigated in environmental degradation studies of emerging countries. Moreover, contradictions still prevail in the outcome of economic growth-environmental degradation nexus. This study has been initiated to fill these gaps and find some new insights into the economic mechanism of emerging countries that need to be addressed to continue their economic growth at a minimum environmental cost.

3. Data and methodology

3.1. Data

To accomplish the objectives of this study, 15 (fifteen) emerging countries[1] of the world have been selected and panel data set spanning 2002–2019 is used. The details of the used variables are presented in Table 1.

3.2. The method

This study follows the modified STRIPAT (Impact = Population X Affluence X Technology) framework proposed by Rosa and Dietz (1998) to identify the stochastic impact of population, affluence, and technology on environmental issues. Since STRIPAT model allows some additional factors that might influence the environment apart from affluence and demographic characteristics to associate with T (York et al., 2003), the study adds informal sector activities and corruption control in the model to satisfy the aim of this study. The basic form of the STRIPAT model with a required modification can be stated as follows:

$$I = \alpha EG_{it}^{\beta_1} RE_{it}^{\beta_2} NRE_{it}^{\beta_3} SEC_{it}^{\beta_4} IE_{it}^{\beta_5} CC_{it}^{\beta_6} \varepsilon_{it} \quad (1)$$

Here, in Eq. (1), I represents environmental impacts in terms of CO_2 emissions, Ecological footprints, and NO emissions. α refers to the constant, $\beta_1, \beta_2, \beta_3, \ldots\ldots, \beta_6$ are the exponents of A, T, P and two additional variables IE and CC. This study captures affluence by Gross Domestic Product per capita (*EG*), demographic variable is captured by their socioeconomic conditions (*SEC)* and Technology is captured by a disaggregated form of energy (see Appiah et al., 2019), Renewables (*RE*) and Non-renewables (*NRE*) since the use of energy facilitates technological diffusion. This study considers informal economic activities (*IE)* and corruption control (*CC*) that are identified as institutional factors with T to assess their impact on environmental degradation. The variables are transformed into log form, aiming to reduce the heteroscedasticity and to obtain the elasticity of the explanatory variables to the explained variable directly. The model can be specified in the logarithmic model as follows:

$$lnED = \alpha + \beta_1 lnEG_{it} + \beta_2 lnRE_{it} + \beta_3 lnNRE_{it} + \beta_4 lnSEC_{it} + \beta_5 lnIE_{it} + \beta_6 lncc_{it} + \varepsilon_{it} \quad (2)$$

In Eq. (2), impact (*I*) is replaced by environmental degradation (*ED*) measured by CO_2 emissions, EFs, and NO emissions. Specifically, the study estimates the following three models.

$$lnCO_2 = \alpha + \beta_1 lnEG_{it} + \beta_2 lnRE_{it} + \beta_3 lnNRE_{it} + \beta_4 lnSEC_{it} + \beta_5 lnIE_{it} + \beta_6 lncc_{it} + \varepsilon_{it} \quad (3)$$

$$lnEF = \alpha + \beta_1 lnEG_{it} + \beta_2 lnRE_{it} + \beta_3 lnNRE_{it} + \beta_4 lnSEC_{it} + \beta_5 lnIE_{it} + \beta_6 lncc_{it} + \varepsilon_{it} \quad (4)$$

$$lnNO = \alpha + \beta_1 lnEG_{it} + \beta_2 lnRE_{it} + \beta_3 lnNRE_{it} + \beta_4 lnSEC_{it} + \beta_5 lnIE_{it} + \beta_6 lncc_{it} + \varepsilon_{it} \quad (5)$$

Panel econometric approaches have been applied to these models [Eq. (3)-Eq. (5)] that consider the issues of heterogeneity and cross-sectional dependence.

3.3. Pre-estimation investigations

In panel data estimation, the first step is to inspect the 'unobserved common processes' on the error terms and the variables. It may arise from the shocks of unobserved common factors that affect all panel units

Table 1. Description of variables.

Variables	Acronyms	Unit	Source
CO_2 emissions	CO_2	Metric tons per capita	WDI + International energy agency 2020) https://www.iea.org/data-and-statistics
Ecological Footprint	EF	Gha per person	Country trends, Global Footprint Network https://data.footprintnetwork.org/?_ga=2.59590190.2004080785.1636416261-137262501.1627655575#/countryTrends?type=BCpc,EFCpc&cn=9
Nitrous Oxide emissions	NO	Thousand metric tons of CO_2 equivalent per capita	WDI (2021)
Economic Growth	EG	GDP per capita in 2010 constant US$	WDI (2021)
Informal Economy	IE	% share of GDP	Medina and Schneider (2019), Shedding Light on the Shadow Economy: A Global Database and the Interaction with the Official One
Renewable energy consumption	RE	% of total final energy consumption	WDI (2021)
Non-Renewable energy consumption	NRE	Fossil fuel consumption per capita (KWh)	Our World in Data [Ref. Assi et al., 2021] https://ourworldindata.org/fossil-fuels#fossil-fuel-consumption-which-countries-use-the-most-energy-from-fossil-fuels
Socio-economic Condition	SEC	Percentile rank	International Country Risk Guide, WB (2021)
Control of Corruption	CC	Percentile rank	Worldwide Governance Indicator, WB (2021)

and spillover across all panel units (Le and Sarkodie, 2020). It is very likely to have economic assimilation among the countries since they belong to the same economic group. Hence, the study has checked the cross-country interrelationship among the variables by adopting four cross-sectional dependence (CSD) tests: Breusch Pagan LM (1980) test, Pesaran scaled LM (2004) test, Bias-corrected scaled LM (2012) test, and Pesaran (2004) CD test. All these tests provide the yardstick for selecting the next econometric approach suitable for the analysis, i.e., unit root tests and cointegration tests.

To check the stationarity of the variables this study has conducted both the First and Second generation unit root tests. Im, Pesaran and Shin (2003) (IPS) that deals with individual root and Levin et al. (2002) (LLC) that deals with common root problem have been employed as first generation test. The IPS and LLC model can be expressed as follows:

$$\Delta y_{it} = \rho_i y_{i,\,t-1} + \sum_{j=1}^{pi} \delta_i y_{it-j} + \alpha_{mi} d_{mt} + \varepsilon_{it} \tag{6}$$

In Eq. (6), Δ is the first difference operator, j is the optimal lag, α_{mi} and d_{mt} are parameters and vector of coefficients, respectively. The null hypothesis and the alternative hypothesis for LLC and IPS tests can be written as

(Null Hypothesis)	$H_0 : \beta_i = 0$	*for all i*
(LLC)	$H_0 : \beta_i = \beta < 0$	*for all*
(IPS)	$H_0 : \beta_i 0$ *for some* $i,\ \beta_i < 0$	*for atleast one i*

However, these tests do not take into account the cross-sectional dependence. Hence, the Cross-sectional augmented IPS (CIPS) and Cross-sectional Augmented Dickey-Fuller (CADF) tests developed by Pesaran (2007) are employed where the ADF regressions are improved with cross-section averages of lagged values and first differences for each unit (Westerlund et al., 2016). CADF statistics can be formulated as follows:

$$\Delta y_{it} = \alpha_{it} + \beta_i y_{i,t-1} + \gamma_i \overline{y}_{t-1} + \sum_{j=0}^{p} \theta_{ij} \Delta \overline{y}_{t-j} + \sum_{j=1}^{p} \delta_{ij} \Delta y_{i,t-j} + e_{it} \tag{7}$$

In Eq. (7), $\overline{y}_t$ represents the average at time T for all cross sections (Salman et al., 2019). The CIPS test is basically the cross-sectional average of the individual CADF test and can be expressed as

$$CIPS = N^{-1} \sum_{i-1}^{N} CADF_1$$

Once stationarity of the variables are confirmed, in the next step, the study moves for Perdoni (1999) cointegration tests and Kao (1999) cointegration test that are the extension of Engel-Granger two-step residual-based cointegration tests to confirm the existence of long-run relationships among the variables. Kao test is based on homogeneous cointegrating vector assumption on the null proposition. The Perdoni (1999) method for cointegration is a robust framework of heterogeneous errors in cross-section dependence and several regressors (Appiah et al., 2019). The Westerlund (2005) cointegration test, which is more appropriate in the presence of CSD and heterogeneity, has also been employed based on the result of the CSD test. The null hypothesis of the Westerlund (2005) test assumes no cointegration and relaxes the assumptions of common factor restrictions. This test uses structural dynamics rather than residual dynamics to identify the long-run relationship among the variables (Arshad Ansari et al., 2020). The statistic is called panel VR statistic. The statistic is derived based upon a model in which the AR parameter is either panel-specific or is the same over the panels (Appiah et al., 2019). This study uses the same over the panel.

3.4. Model estimation

The model specifications of Eq. (3) to Eq. (5) follow the Pooled Mean Group Autoregressive Distributive Lag (PMG-ARDL) estimation technique taking insight from Ibrahiem and Hanafy (2021), Ahmad et al. (2021b), Sarkodie and Strezov (2019); Appiah et al. (2019); Attiaoui et al. (2017). PMG-ARDL is a standard least squares regression model that is advantageous for estimating the long-run and short-run cointegrating relationships and applicability in large and small panels (Khan et al., 2020). This method is also appropriate for variables integrated to I (0), I (1), and a mix of both but not I (2). Pesaran et al. (1999) proposed this approach that combined pooling and averaging of coefficients employed above the cross-sectional units. PMG estimator hypothesizes long-run slope homogeneity and hence it considers the long-run coefficients common but allows the short-run dynamic specification to differ from country to country. It also reveals the dynamics of adjustment from short-run to long-run. This estimation procedure based on the maximum likelihood method seems consistent since it accounts for individual characteristics and provides an improved evaluation of the long-run relationship. It is also robust to outliers and lag order selection (Pesaran et al., 1999).

The ARDL system of equations for time period $t = 1, 2, \ldots.., T$ and number of cross-sections $i = 1, 2, \ldots.., N$ for the Y is shown in Eq. (8).

$$Y_{i,t} = \sum_{j=1}^{p} \delta_{i,j} Y_{i,t-1} + \sum_{j=0}^{q} \gamma'_{i,j} X_{i,t-j} + \varepsilon \tag{8}$$

Here, $X_{i,t-j}$ is the (kx1) vector of regressors for cross-section *i*. The proposed re-parameterized form of the model by Pesaran et al. (1999) is as follows:

$$\Delta Y_{i,t} = \xi_i \left(Y_{i,t-1} - \theta'_1 X_{i,t-1} \right) + \sum_{j=1}^{p-1} \delta_{ij} \Delta Y_{i,t-j} + \sum_{j=1}^{q-1} \delta'_{ij} \Delta X_{i,t-j} + \varepsilon_{it} \tag{9}$$

In Eq. (9), $(Y_{i,t-1} - \theta'_1 X_{i,t-1})$ is the Error Correction Term (ECT). Y (*lnED*) denotes the dependent variables, CO_2, EFs and NO respectively and X denote the set of regressors ($lnEG_{it} + lnIE_{it} + lnRE_{it} + lnNRE_{it} + lnSEC_{it} + lnCC_{it}$) with the same number of lags q across *i*, the cross sectional units in time t. ξ_i represents the error correction coefficients, θ represents the long run coefficients that produces the δ and γ estimates after convergence is reached.

This study further applies Fully Modified OLS (FMOLS) (Phillips and Hansen, 2016) and Dynamic OLS (DOLS) (Stock and Watson, 1993) for long-run panel estimation, based on the results of the cointegration analysis. The estimation of these cointegration regression models using a parametric approach will check the robustness of the long-run coefficients of PMG model. These methods are advantageous with asymptotic properties and free from endogeneity issues (Arshad Ansari et al., 2020). The estimators of these models are efficient in eliminating the autocorrelation problem in residual terms. They are also unbiased with small samples (Zhang, 2019). The results obtained from estimating the three different models (3–5) are also cross-examined with the Augmented Mean Group (AMG) estimators of Eberhardt and Bond (2009) and Eberhardt and Teal (2010) that deal with cross-section dependence, heterogeneity and endogeneity problems (Ahmad et al., 2021b; Pata et al., 2021).

4. Results

Descriptive statistics of the selected variables are presented in TableS1. Results indicate that there are no major differences between mean and median except *RE*. The correlation matrices are presented in Table S2 and the results of four Cross-sectional Dependence (CSD) tests are summarized in Table S3. The results reject the null hypothesis of cross-sectional independence of the variables at 1% significance level. This indicates that a shock arising in one sample country may influence the same to the other countries. In order to address this problem sufficiently and to ensure the efficiency of estimation, the study has applied second generation unit root tests CIPS and CADF in addition to first generation tests IPS and LLC. The results of the unit root tests that incorporate an intercept and trend are presented in Table S4. Results reveal that the unit root problems of the variables are resolved in their first differences although a few variables are found to be stationary at their levels.

Having confirmed that all series are stationary at the first difference, the panel co-integration tests suggested by Pedroni (1999) and Kao (1999) are conducted. In addition to these two tests, Westerlund (2005) cointegration test has also been performed based on the result of CSD tests. The Cointegration test results for models (3), (4), and (5) are reported in Table 2.

The results of Kao (1999) cointegration tests show that the variables are cointegrated in the models, and hence they have long-run associations among themselves. The results of Pedroni (1999) cointegration tests also reveal the long run association of variables in the models. Since the CD test reveals cross-sectional dependence for model (3), the study has applied the second generation cointegration test Westerlund (2005). Here, the test statistic variance ratio rejects the null theory of no cointegration between CO_2 and the set of explanatory variables in favor of the alternative that all panels are cointegrated in the model.

The results obtained from an estimation of Pooled Mean Group (PMG)-ARDL approach based on the cointegration form of the simple ARDL model are presented in Table 3. Both the short-run and long-run results of the estimated model (3)–(5) are reported in the Table along with their convergence coefficients.

In Table 3, model (3) estimation results reveal that 1% increase in economic growth (EG), consumption of renewable energy (RE), informal economic activities (IE), and socio-economic conditions (SEC) reduce CO_2 emissions in the long run (LR) by 0.48%, 0.88%, 0.07% and 0.13% respectively. As opposed to these coefficient results, a percentage point increase in non-renewable energy (NRE) consumption increases CO_2 emissions by 1.22% while a percentile increase in corruption control (CC) increase CO_2 emissions by 0.11%. The short-run (SR) results project that consumption of non-renewable energy increases carbon emission but controlling corruption can reduce it. The estimation results of model (4) reveal that 1% increase in EG, IE, RE consumption, and CC contribute to improve the ecological footprints (EFs) by 0.31%, 0.34%, 0.1% and 0.06% respectively, while consumption of NRE works to the opposite by increasing EFs 0.75% in the LR. Informal activities are found to be a negatively contributing factor to EFs in the short-run as well. Lastly, the model (5) estimation results have found EG, RE consumption, improvement in socioeconomic conditions (SEC) and CC as improvements over NO emissions, implying 1% increase in EG, RE consumption, SEC and CC decrease NO emissions by 0.42%, 0.23%, 0.05% and 0.04% respectively. Opposing these, 1% increase in IE activity and consumption of NRE deteriorates NO emissions level by 0.12% and 0.63% respectively, in the LR. In the SR, EG increases NO emissions and RE consumption decrease it in a significant manner. The results of Hausman test, which sets the null hypothesis of homogeneity in the long-run coefficients, has justified the selection of PMG-ARDL models. The error correction terms (ECT), presented as convergence coefficients in Table 3, and are found to be negative and statistically significant for all three models.

The long-run results of the PMG model are expected to be identical for the countries and the short-run coefficient results are country-specific. To satisfy the aim, this study emphasizes the long-run outcomes and checks those for robustness with the results of cointegration models estimation presented in Table 4. The FMOLS and DOLS model estimation results report almost similar outcome for EG, RE and NRE and SEC with PMG-ARDL model estimation results. IE activities and CC results are also exactly similar for CO_2 and NO emissions with PMG-ARDL model. IE in FMOLS and DOLS estimation results project negative sign as the main model but CC appears with positive sign for EFs.

The LR regression estimates of AMG model are presented in Table S5. The results reveal that IE activities increase CO_2 emissions and the role of CC is insignificant. For NO emissions, it is weakly significant and negatively associated to IE that contradicts to earlier results. However, the result of IE activities on EFs is similar to the result of PMG-ARDL models. The result for RE, NRE and SEC are also similar in AMG model like other applied models. The slight differences in regression estimates are justifiable and may arise due to the difference in assumptions of the applied models that doesn't nullify the main findings of the study.

5. Discussion

In PMG-ARDL models EG is found to be improving towards environmental quality implying that economic growth reduces all types of emissions in emerging countries. FMOLS and DOLS results have also confirmed that. This result of EG supports the findings of Narayan and Narayan (2010) for the panel of Middle-eastern and South Asian developing countries where long run income elasticities were found to be smaller than the short run income elasticities, suggesting carbon emissions reduction with economic growth. This result is also in line with Alhassan (2021) for 79 countries where economic growth improves environmental performances and Acheampong et al. (2021) for Sub-Saharan African countries where economic growth reduces CO_2 emissions through a mechanism of structural shift towards information industries and services that are less carbon emitting. The result indicates that economic growth is important for reducing emissions since it can bring structural and technological innovations (Acheampong et al.,

Table 2. The results of the test for cointegration.

Test for Cointegration
Ho: No co-integration
H_1: All panels are co-integrated

	Model-3(CO_2)		Model-4 (EFs)		Model-5(NO)	
Kao	Statistic	P-value	Statistic	P-value	Statistic	P-value
Modified Dickey-Fuller t	-4.921	0.000	-4.091	0.000	-1.741	0.041
Dickey-Fuller t	-0.676	0.249	-4.532	0.000	-1.761	0.039
Augmented Dickey-Fuller t	-0.475	0.317	-2.975	0.001	-0.952	0.170
Unadjusted Modified Dickey-Fuller t	-6.004	0.000	-6.674	0.000	-2.828	0.002
Unadjusted Dickey-Fuller t	-1.053	0.145	-5.409	0.000	-2.292	0.011
Pedroni	Statistic	P-value	Statistic	P-value	Statistic	P-value
Modified Variance ratio	-2.431	0.0075	-2.697	0.000	4.192	0.000
Modified Phillips-Perron t	2.996	0.0014	1.500	0.000	-7.751	0.000
Phillips-Perron t	-1.507	0.065	-7.626	0.000	-6.676	0.000
Augmented Dickey-Fuller t	-1.935	0.026	-7.720	0.000	-3.783	0.000
Westerlund	Statistic	P-value	Statistic		Statistic	
Variance ratio	1.538	0.061	-	-	-	-
CD	23.27	0.000	0.781	0.993	0.337	0.736

Table 3. The results of Pooled Mean Group (PMG)-ARDL estimation.

Variables	Model-3(CO_2)		Model-4 (EFs)		Model-5(NO)	
	Coefficient	S.E	Coefficient	S.E	Coefficient	S.E
Convergence coefficient	-0.478***	0.181	-0.516***	0.109	-0.418***	0.049
Long-run coefficient						
lnEG	-0.477***	0.081	-0.307***	0.025	-0.419***	0.047
lnIE	-0.884***	0.162	-0.337***	0.013	0.119*	0.072
lnRE	-0.074***	0.029	-0.100***	0.021	-0.229***	0.050
lnNRE	1.223***	0.055	0.748***	0.019	0.630***	0.045
lnSEC	-0.131***	0.042	0.018	0.013	-0.052*	0.031
lnCC	0.106***	0.017	-0.056***	0.008	-0.045***	0.012
Short-run coefficient						
ΔlnEG	0.146	0.475	-0.146	0.241	0.404**	0.180
ΔlnIE	0.153	0.476	-0.208**	0.105	-0.141	0.120
ΔlnRE	-0.123	0.196	-0.104	0.093	-0.203**	0.092
ΔlnNRE	0.515**	0.284	0.009	0.077	0.083	0.107
ΔlnSEC	0.049	0.284	0.045	0.066	0.061	0.069
ΔlnCC	-0.113***	0.041	0.008	0.041	-0.027	0.041
Constant	-0.687***	0.266	-0.469***	0.109	-2.004***	0.466
Hausman test	Chi-Sq 1.33 (p-value 0.969)		Chi-Sq 0.78 (p-value 0.992)		Chi-Sq 0.51 (p-value 0.944)	
Number of Countries	15		15		15	
Number of Observations	255		255		255	
Log likelihood	787.311		839.252		906.193	
CD test	23.271 (0.000)		7.576 (0.000)		26.318 (0.000)	

Note: AIC criterion is chosen for the lag order.
*** indicates 1%, ** indicates 5% and * indicates 10% significance level.

Table 4. The results of Fully Modified OLS (FMOLS) and Dynamic OLS (DOLS) regressions.

Variables	Model-1(CO_2)		Model-2 (EFs)		Model-3(NO)	
	FMOLS	DOLS	FMOLS	DOLS	FMOLS	DOLS
	Coefficient	Coefficient	Coefficient	Coefficient	Coefficient	Coefficient
lnEG	-0.045*** (4.670)	-0.195*** (3.833)	-0.031*** (3.262)	-0.129*** (2.809)	-0.118*** (0.016)	-0.241*** (0.060)
lnIE	-0.077*** (3.411)	-0.203*** (2.586)	-0.142*** (6.325)	-0.189*** (2.473)	0.077*** (0.030)	0.102 (0.103)
lnRE	-0.129*** (8.749)	-0.082*** (2.664)	-0.105*** (7.082)	-0.051* (1.688)	-0.065*** (0.011)	-0.042 (0.033)
lnNRE	0.929*** (50.751)	1.105*** (14.373)	0.511*** (27.863)	0.597*** (8.856)	0.249*** (0.025)	0.456*** (0.086)
lnSEC	0.018 (0.602)	-0.026 (0.949)	0.033 (1.082)	0.043* (1.673)	0.041*** (0.009)	0.060 (0.032)
lnCC	0.053*** (2.670)	0.068*** (2.988)	0.119*** (6.057)	0.008 (0.325)	-0.015* (0.008)	-0.009 (0.026)
R-squared	0.997	0.998	0.991	0.996	0.991	0.996
Adjusted R-squared	0.996	0.997	0.990	0.993	0.990	0.995
S.E of Regression	0.023	0.021	0.025	0.021	0.023	0.016
Long-run variance	0.002	0.000	0.000	0.000	0.000	0.000
Mean dependent var	0.416	0.416	0.323	0.323	-3.462	-3.463
S.D dependent var	0.391	0.392	0.250	0.250	0.235	0.235
Sum squared resid	0.125	0.066	0.144	0.061	0.125	0.046

Note: *** indicates 1%, *8 indicates 5% and * indicates 10% significance level respectively. Std. Errors are reported in the parenthesis.

2021). However, the negative impact of economic growth on CO_2 emission contradicts to the findings of Ahmad et al. (2021b) for emerging countries, Sharif et al. (2020) for Turkey, Danish et al. (2019) for Pakistan.

IE is found to contribute negatively to CO_2 emissions and EFs in LR. However, the result of corruption control that decrease CO_2 emissions in the short run but increase emissions in the long run indicates to the fact that corruption control initiatives encourage polluting firms to swaps their emissions from official to unofficial domain in the long-run. Thus the negative association of informal activities with CO_2 emissions can be justified since informally operated firms can easily pursue the polluting activities even under strict regulations and able to hide them by taking the advantage of their non-compliance nature (Goel et al., 2013; Baksi and Bose, 2016; Wang et al., 2019; Elgin and Oztunali, 2014). Subcontracting polluting activities to unregistered firms are possible in the presence of a large informal sector that helps to keep emissions unrecorded (Goel et al., 2013; Goel and Saunoris, 2020). This result is exactly similar to the findings of FMOLS and DOLS while the result of AMG (in Table S5) reveals its positive association with CO_2 emissions in insignificant Corruption Control scenario. The positive coefficient of corruption control on CO_2 emissions evident the findings of Goel et al. (2013) for Middle East and North American (MENA) countries. This result is also in line with that of Azam et al. (2021), and justifies the argument of Wang et al. (2019) and Ahmad et al. (2021b). For NO pollution, IE reports its positive role while CC contributes positively to emission reduction in the main model and FMOLS model. IE and CC are found to associate negatively to EFs in PMG-OLS and AMG models although their results in FMOLS and DOLS model estimation indicate for emission swap by projecting positive sign for CC. The little contradiction in CC result may arise due to the broader purview of EFs that measures the demand for natural resources and provides an overall picture of resources depletion by human (Pata and Yilanci, 2020a, 2020b). EF captures both direct and indirect effects and tracks not only carbon demand on land by population but also the consumption of productive surface area that encompasses land, air and water (GFN, 2021). Sometimes informal sector activities are involved in waste picking and recycling activities that may also contribute behind this result. These results imply that strong institutions are capable to control corruption and ease implementation of strict environmental laws contributory to improve the overall environmental quality (Ahmad et al., 2021b).

In development process domestic institutional framework is important in controlling CO_2 emissions (Lau et al., 2014). However, CO_2 emissions worsens institutions (Acheampong et al., 2021) and in this study institutional activities against corruption are found to decrease environmental quality by increasing CO_2 emissions. This can be justified under the theoretical arguments of 'scale effect' and 'composition effect' (Baksi and Bose, 2016). Strict regulations reduce the production of harmful goods but also motivates the formal sector firms to produce less in-house and outsource more from informal sector firms ('scale effect and 'subcontracting effect'). This brings a compositional change in production ('composition effect') and increases the size of the informal sector that carries more harm due to the increased proportion of non-compliance firms. The counteracting effect of scale and composition can decrease the damage initially. Still, depending on the intensity and strictness of regulation and enforcement, harm can increase and crosses a turning point value that depends positively on enforcement intensity. This non-monotonic impact of regulations has adverse side effects on the production process that negatively affect social welfare (Baksi and Bose, 2016; Goel and Saunoris, 2020).

Consumption of RE is found to have a stimulating role to improve environmental quality which is similar to the result of Usman et al. (2021), Pata et al. (2021), Zafar et al. (2020), Zhang (2019), Sharif et al. (2020) while NRE contributes negatively to it that is evident in most of the empirical literature on environment (mentioned in literature review section). This result is established with strong statistical significance in all model estimation results of this study. Echoing to the opinion of Le and Sarkodie (2020) the empirical findings of this study supports in promotion of green energy to promote environmental quality in emerging economies.

6. Conclusions and policy implications

This paper explores the impacts of informal sector activities, corruption control, energy consumption and socio-economic conditions on environmental quality degradation of emerging economies. This study employs three degradation indicators: CO_2 emissions, ecological footprints (EFs), and NO emissions to obtain a reliable outcome. The period covered by the study is 2002–2019, and it includes 15 emerging countries. In empirical investigations, the study has checked for cross-country dependency at the beginning. Next, it has employed the first and second generation unit root tests and relevant cointegration tests. After confirming the level of integration, the study has applied the PMG-ARDL model for this dynamic panel and has proceeded to estimate the short-run and long-run dynamics of the variables for three models (3)–(5) employing CO_2, EFs, and NO, respectively. These long-run results have been cross-checked by estimating two widely accepted co-integration models FMOLS and DOLS. This study has also adopted AMG model to examine the validity of long-run results. The results of the PMG-ARDL models estimation are found to be consistent with FMOLS or DOLS or both for most of the variables. The long-run results have revealed that economic growth and renewable energy contributes negatively, and non-renewable energy contributes positively to environmental degradation for all three indicators. Informal sector activities contribute to reduce recorded CO_2 emissions and EFs but appear as a positively contributing factor for NO emissions. Corruption control increases CO_2 emissions but improves EFs and NO emissions by PMG-ARDL results although Corruption control increases EFs by the FMOLS and DOLS results. Improvement in the socioeconomic condition of people reduces air pollution. Since the elasticity of variables is higher in the CO_2 model and corruption control result points to the possible expansion of informal activities that ultimately swap pollution from formal to informal firms and hide those as unrecorded, strategies for CO_2 emissions reduction needs to pay a priority in the environmental management policy. Similarly, NO emissions also need attention for its reduction.

The empirical findings of this study infer that insightful institutional and economic policies are required to minimize CO_2 and NO emissions, and to keep EFs at lower level in emerging countries. Increase in economic growth is not enough to improve environmental quality (Almeida and das, 2017). Promotion of institutional quality across emerging countries is also crucial in order to attain the benefits of economic as well as environmental sustainability. The empirical findings unambiguously demonstrate the need to implement environmental management policies that encourage renewable energy consumption and reduce reliance on non-renewable energy. An increase in the investment and subsidy in renewable energy projects, facilitating the penetration of renewable energy technology in the total energy mix, and gradual phase-out of fossil fuel based energy would be the confirmed solution to environmental degradation. Carbon and environmental tax that are under consideration to many countries can be implemented for the selected countries since it has been getting popular in countries recently (Bento et al., 2018;). Besides all these, the behavior of informal activities needs to be monitored, and corruption control measures should be evaluated and assessed with their effectiveness. Policymakers should understand and evaluate the informality of the economies to avoid poorly informed policy decisions. Indirect tax policy can be implemented to regulate the informal activities. At the same time, corruption control measures should be targeted and well-orchestrated so that the emissions cannot go unrecorded and unregulated. Economies should prevent excessive competition and high price discrimination in the formal sector to avoid leakage favoring the informal sector. In addition to these, countries should ensure high level in socio-economic condition to reduce aerial emissions to some extent.

Environmental degradation negatively affects human well-being, and therefore it is important to create a coherent, consistent and effective environmental framework to prevent its degradation. The analysis of dynamic interrelations among informal activities, economic growth, energy consumption, institutional mechanism, and environmental degradation reveals the coexistence of some possible means towards sustainable development. Although it is acknowledged that data limitation prevents this study from finding more dynamic outcome and the nature of interaction between informal economic activities and corruption control is not exposed elaborately by this study, this study opens up new research opportunity by focusing pollution from an unobserved sector that remains hidden and unrecorded. More comprehensive studies on nature of informal activities and their role in development process of emerging countries can make more accurate inference on environmental pressure. Improvement in socioeconomic aspects of peoples' life is another area of advanced research that can be highlighted in future studies to find strategy of emission reduce. From the outcome of this study it can be concluded that for effective outcomes, environmental regulations should be directed to specific dimensions of pollution control. Control of CO_2 and NO emissions is suggested as the top priority to this end. An effective measure of reducing CO_2 and NO emissions will facilitate improving the other indicators of environmental degradation. Economic growth with proper environmental management will support the overall well-being and ensure long-term economic stability contributory to the green growth of the emerging countries.

Declarations

Author contribution statement

Nahid Sultana: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Mohammad Mafizur Rahman: Conceived and designed the experiments; Contributed reagents, materials, analysis tools or data.

Rasheda Khanam: Conceived and designed the experiments.

Zobaidul Kabir: Conceived and designed the experiments; Wrote the paper.

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Data availability statement

Data will be made available on request.

Declaration of interests statement

The authors declare no conflict of interest.

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