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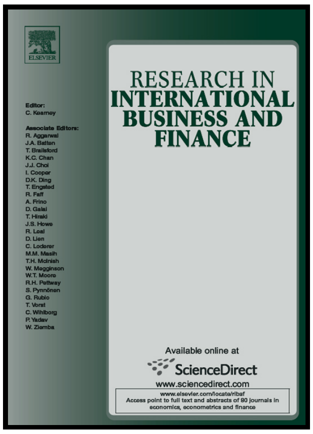

Moderating impact of FDI on the growth-environment nexus

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Moderating impact of FDI on the growth-environment nexus

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ABSTRACT

This paper aims to investigate the moderating presence of FDI in the nexus amid economic progression and quality of environment in 115 countries, and various income panels of countries from 1992 to 2019, based on a theoretical underpinning of the Environmental Kuznets Curve (EKC). The results reveal a significant positive influence of energy consumption on CO2 discharges across all income panels. The interaction between FDI and square of GDP leads to a decrease in CO2 emissions for low and lower-middle income countries, whereas a drop in PM2.5 discharges is distinctively recorded for low, lower middle, high income, and overall income levels. Likewise, the interaction of FDI with manufacturing growth exhibits a negative influence on CO_2 emissions reduction in both low and lower-middle income economies, and a reduction in CH_4 discharges for upper-middle, high income, and overall income levels. All these results support the EKC hypothesis and offer a useful insight for countries that intend to pursue green economic growth with due consideration for energy consumption and environmental pollution.

JEL Classification

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C33

Keywords

Environmental Kuznets Curve (EKC)

Moderation effect

Foreign Direct Investment (FDI)

CO_2-CH_4-$PM_{2.5}$ emissions

Structural equation modelling (SEM)

1. Introduction

The influence of economic progressions on the environment is a serious matter of concern for policymakers and is essential for the development of effective strategies, policies, institutional regulation and settings (Jin et al., 2022; Mushed et al., 2023). There are various theories that explain the nexus of economic growth with the environment, such as limits theory, new toxics and Davidson, race to the bottom, environmental Kuznets curve (EKC), and so on (Everett et al., 2010; Stern, 2004; Uddin et al., 2021). The EKC model, a pioneering work on growth-environment nexus suggested by Grossman and Krueger (1995), hypothesizes an inverted U-shaped association between economic growth and environment, implying that environmental depletion is initially driven by the “scale effect” of economic progression, which requires an enhancement in production inputs, escalating the intensity of pollution (Majumder et al., 2022; Rafindadi and Usman, 2019). However, as countries advance in terms of their economic growth, increased investment in cleaner technologies and environmentally friendly production processes can reduce pollution (Stern and Valero, 2021). In this context, FDI can play a strong role in either supporting the EKC hypothesis or counteracting the negative influence of economic growth by introducing innovative technologies and promoting investment in clean energy (de Vita et al., 2021). In support of this argument, the recent fall in FDI inflows to countries with more vulnerable climate (Shear et al., 2023) can be considered alarming.

Extant literature highlights the potentials of FDI to mandate the host country for adopting environmentally efficient technologies and modern management practices, and hence, improving production efficiency through positive externalities, leading to spillover effects on local firms (the "technique effect"), and subsequently reducing pollution (Pothen and Welsch, 2019; Wang et al. 2013; Zhu et al., 2007). Further, the "composition effects" suggest that as the economy advances through different stages of growth, its structure shifts from agriculture to manufacturing, and from dirty to cleaner industries. Therefore, the final impact of growth on the environment can be either affirmative (positive) or adverse (negative), based on the pattern and composition of growth, determining the final shape of the EKC (Mohapatra et al., 2016). To test these theoretical assumptions, many empirical studies have been conducted using different methodologies, data, and proxies (Sarkodie et al., 2020). Despite evidence suggesting a strong effect of FDI on the environment (To et al., 2019), the association of FDI with the environment remains unclear (Blanco et al., 2013) and has been further complicated by conflicting results (Demena and Afesorgbor, 2020; To et al., 2019). Given this background, it is deemed valuable and pertinent to assess the FDI's moderating presence in the economic growth – environmental quality nexus, and to gain insights into the extent of the "technique effect" of FDI in reducing the CO2 discharges and, therefore, affecting the inverted U-shape of the EKC.

This study contributes to the extant literature in multiple ways. Firstly, extant literature documents a large volume of studies on the relationship of FDI with energy consumption, economic growth, financial development, and so on using the EKC framework. For example, Balibey (2015) evaluated the impact of the nexus amid economic growth, CO_2 emission and FDI on the EKC for Turkey for the 1974-2011 period. He and Yao (2017) analyzed the effect of FDI on the association of per capita income with air pollutant emissions (proxied by soot and dust) in the Chinese Provinces. Ali et al. (2020) examined elasticities among economic development, fossil energy consumption, inward FDI and CO_2 emission for Pakistan using data spanning over

1975 until 2014. Halliru et al. (2020) investigated the links of FDI with economic growth, energy consumption, CO_2 emissions, human capital and bio-capacity in six ECOWAS economies for the 1970-2017 period. Manocha (2021) examined the association of FDI with environmental depletion in 14 developing countries of Asia during 1971–2019. Luo et al. (2022) investigated the effect of FDI and other variables on economic growth and CO_2 emissions in China, Singapore and India for the 1980-2020 period. Saqib et al. (2023) explored the same in 16 European countries for the 1990–2020 period. Tabash et al. (2023) investigated the influence of a range of economic variables including economic and financial developments, FDI, human capital, and energy consumption on CO_2 emissions in six GCC countries from 2001 to 2019. Unlike these studies, the novelty of this paper is its major focus on investigating the moderating role of FDI on the EKC using a large sample of 115 countries. Secondly, previous research has not extensively explored the moderation effect of FDI in different income panels of countries using the EKC framework. Additionally, previous studies (Cole et al., 2011; Demena and Afesorgbor, 2020) have expressed concerns that the economic returns from enhanced FDI flows could be counterweighed by the simultaneous rise in environmental emissions. Bakhsh et al. (2017) have therefore, called for policymakers to not prioritize FDI over environmental quality. However, the "technique and composition effect" suggests that global greenhouse gas (GHG) emissions can be reduced through economic structure changes, innovation, and technological advancement, leading to the EKC (Acharyya, 2009; Liobikienė and Butkus, 2019). Third, the study recognizes the growing significance of FDI flows compared to international trade, and the rising levels of pollution globally. For instance, the manufacturing sector in the USA contributed to a 5.7% increase in emissions in 2018, while Europe's industrial manufacturing became one of the region's major air polluters by 2016. China, being the biggest developing economy in the world (Li et al., 2023), was the largest emitter of GHGs by 2010. In light of this background, the study acknowledges the significance of the manufacturing sector in economic progression and its growing adverse impact on the atmosphere. Therefore, manufacturing is included as one of the key explanatory variables in this research. Fourth, despite numerous studies on the association of economic progression with atmospheric degradation, research on the link between economic growth and PM2.5 emissions is limited for three reasons: (a) PM2.5 emission is not a major concern in developed countries (Yiyi, 2017) because of the existence of the pollution haven hypothesis, postulating wealthy economies' tendency to relocate their highly polluting industries to the developing world; (b) data on PM2.5 emissions is not widely accessible, even though it has significant impacts on human health and nature in many developing economies (Kilian and Kitazawa, 2018); (c) the increasing trend in manufacturing and industrial activities, as noted by Taiwo et al. (2014), is a significant contributor to PM2.5 emissions, including metals and carbonaceous particles. Conducting this study to test the hypotheses related to PM2.5 emissions will expand the scope of research in this area. Fifth, while many research works have explored the FDI–environment nexus, and evaluated the authenticity of theories like the EKC, PHH, and PH, the findings are however, still inconclusive (Sarkodie et al., 2020; Sharif et al., 2022). Moreover, as noted by Erdogan (2014), Pazienza (2014) and Ning and Wang (2018), there is an ambiguity regarding the contribution of FDI on the host country performance in managing the quality of environment. Given this context and perspective, considering the empirical analysis of 115 country experiences, this study will provide valuable insights into this area.

Our study finds a major effect of the interaction effect between FDI and square GDP in lessening CO2 discharges for low and lower-middle income panels. In regard to CH4 discharges, GDP growth shows a substantial positive influence for all income panels except low income. FDI's interaction with manufacturing (MF) shows a positive influence in reducing CH4 discharges for all income panels, except low income, supporting the PH hypothesis for all income groups except low income and the PHH for low income. The association of FDI with square GDP has a positive influence in reducing PM2.5 discharges for all income panels; this indicates an inverted U-shaped EKC. Additionally, energy intake exerts a substantial positive influence on CO2 discharges for all income panels. The two-way interaction impact highlights the prominence of FDI in plummeting pollution discharges by weakening the positive relationships or strengthening the negative relationships in the EKC.

The rest of this study is planned in the following order: Section 2 covers related literature and hypothesis formation. Section 3 outlines data sources, the econometric model, and the methods employed. Section 4 presents the outcomes of the empirical investigation. Section 5 draws conclusions and delves into the policy inferences.

2. Literature review and hypothesis development

The motive of our research is to delve into the association amid FDI, economic progression (growth), and environmental damages, with a focus on exploring FDI's moderating presence in the EKC framework. Given the importance of FDI to achieve sustainable and inclusive development, as highlighted by Brenton and Chemutai (2021), this paper targets to provide insights into the cause-and-effect associations amid these variables. Economic progression – environmental depletion nexus has long been a topic of discussion amongst environmental economists, with a variety of hypotheses emerging. Researchers (e.g., Halkos and Polemis, 2018; He et al., 2017; Jayanthakumaran et al., 2012; Jun et al., 2020) have explored the association of economic growth with worsening environment through CO2-PM2.5-NOx emissions, wastewater disposal, air quality, industrial soot emissions, etc. within the context of the Environmental Kuznets Curve (EKC) hypothesis (Xu et al., 2020). These studies have presented different shapes of the nexus, including an inverted U-curve (e.g., Chen et al., 2013; Kanjilal and Ghosh, 2013; Mishra, 2020; Rahman, 2020; Shahbaz et al., 2017), inverted-V shape (Kijima et al., 2010), N shape (Halkos and Polemis, 2018), and S shape (Pothen and Welsch, 2019). In consideration of this background, we perform an appraisal of the experiential investigations on the relationship between economic advancements and the quality of environment and establish a strong foundation for further exploring the EKC in 115 countries across various income levels and examining the main and interaction impacts of FDI in the relationship.

2.1 Environmental degradation

Against the backdrop of consistent environmental degradation (ED), this paper considers the magnitude of carbon dioxide (CO2) and methane (CH4) emissions as proxies for ED as well as the intensity of fine particulate matter (PM2.5). Such discharges have a direct impact on the greenhouse gas (GHG) effects, while PM2.5 is linked to cardiac and respirational illnesses and regional atmospheric change (EPA 2017). One of the most significant contributors to global warming is CO2 discharge (IPCC, 2014). Different researchers have presented various shapes of the nexus amid economic progression and worsening environment as a result of CO2 emissions, including inverted U-shaped, U-shaped, and N-shaped (Bekhet et al., 2017; He et al., 2017; Jalil and Feridun, 2011; Jayanthakumaran et al., 2012; Saboori and Sulaiman, 2013; Sehrawat et al., 2015; Zi et al., 2016). CH4 is a potent greenhouse gas, second only to CO2 emission in its ability to trap heat. The anthropogenic actions, like farming of rice, rearing of livestock, and waste landfills from organic and municipal wastes constitute main sources of CH4 emissions (Datta et al., 2012; Forabosco et al., 2017; Jovanović et al., 2015; Zhang et al., 2016; Zhou et al., 2015). The sources of PM2.5 emissions include transportation, biomass burning, urban growth, manufacturing, and natural courses. These emissions/discharges not only cause significant health issues (such as cardiovascular diseases, lung cancer, and bronchitis) for adolescents and adults who spend more time outdoors and be susceptible to the effects of PM2.5 emissions, but also affect regional climates, reducing visibility and contaminating food and vegetables (Begum et al., 2013; Li et al., 2016; Liu et al., 2016; Sanderson et al., 2013; Singh et al., 2017).

2.2 Economic growth and environmental depletion

The association of GDP growth (as proxy of economic growth) with atmospheric pollution is widely studied, with many researchers finding a strong and positive correlation. Most of them have used CO2 emissions to represent environmental depletion. Moreover, several studies (e.g., Begum et al. 2015; Bekhet et al. 2017; Elliott et al. 2017; Ertugrul et al. 2016; Jayanthakumaran et al. 2012; Maroufi and Hajilary, 2022; Omri 2013; Saboori and Sulaiman 2013; Sadorsky 2009; Shahbaz et al. 2013) have provided evidence of strong affiliation of energy consumption with socio-economic progressions. Energy acts as a crucial global product in facilitating development in various forms (Bergasse et al., 2013). Economic growth enhances a nation's opportunities for global integration and quality of life, but also results in significant environmental vulnerabilities (Guo and Ma, 2009). However, the nature of the association of economic progression with energy intake is complex and can vary due to time, methodology, energy and economic patterns, and climatic situations (Shahbaz et al., 2013). The EKC hypothesis suggests that GHG discharges intensify as GDP grows until reaching a point when it starts falling as GDP grows further (GDP2) (Begum et al., 2013; Bekhet et al., 2017; Jayanthakumaran et al., 2012; Omri, 2013; Saboori and Sulaiman, 2013). It is crucial to work out a sustainable pathway to economic advancement for both current and future generations by thoroughly understanding the growth – environment nexus.

Considering the above review of literature, we propose the first set of hypotheses below:

H1a: Higher is Economic growth (GDP), significantly higher becomes the CO_2 emissions.

H1b: Higher is Economic growth (GDP) significantly higher becomes the CH_4 emissions.

H1c: Higher is Economic growth (GDP) significantly higher becomes the $PM_{2.5}$ emissions.

H2a: Squared economic growth (GDP^2) affects CO_2 emissions negatively and significantly.

H2b: Squared economic growth (GDP^2) affects CH_4 emissions negatively and significantly.

H2c: Squared economic growth (GDP^2) affects $PM_{2.5}$ emissions negatively and significantly.

2.3 Energy consumption and environmental degradation

The environmental transition theory asserts that the demand for urban infrastructure and energy consumption increases in the transition period from traditional to industrial economic growth with consequences of a decline in the environmental quality (Majeed and Luni, 2019). Numerous empirical studies (e.g., Boutabba, 2014; Chen et al., 2023; Jalil and Feridun, 2011; Li et al., 2016; Omri, 2013; Saboori and Sulaiman, 2013; Sanderson et al., 2013; Sehrawat et al., 2015; Tamazian et al., 2009) have found that environmental degradation is a direct consequence of energy consumption. The persistent use of non-renewable streams of energy (oil, coal, and gas) is leading to a concerning rate of global warming and depleting ozone layer. Shahbaz et al. (2018) observed a direct and affirmative association of energy intakes with CO2 discharges. Munir and Riaz (2020) supports this finding; it reports that increases in consumption of oil and coal in Australia, and the same in oil, gas, and electricity in China and the USA lead to a long-term rise in CO2 emissions. Furthermore, inefficiency in energy use and absence of eco-friendly technology contribute to high emissions. Musibau et al. (2020) studied the recent environmental problems in Africa and revealed that the growing increase in CO2 emissions primarily stems from excessive use of natural resources. Given this backdrop, our paper proposes the second set of hypotheses as follows:

H3a: Energy consumption positively and significantly affects CO_2 emissions.

H3b: Energy consumption positively and significantly affects CH_4 emissions.

H3c: Energy consumption positively and significantly affects $PM_{2.5}$ emissions.

2.4 Manufacturing and environmental depletion

Rapid globalization is driving significant progressions in the manufacturing sector of leading economies. In 2009, the Chinese manufacturing sector overtook the USA in contributing to GDP, followed by Germany, the USA, and Japan in terms of environmental quality (Wu et al., 2015). Energy-focused manufacturing and the consumption of fossil fuels pose a major challenge for global emissions, particularly from power plants producing chemicals, aluminum, pulp and paper, cement, iron and steel, and nonmetallic sources (Huang et al., 2010; Sarker et al., 2012; Vine and Ye, 2018; Xu et al., 2016). The European Environment Agency (EEA, 2019) lists a variety of pollutants emitted from manufacturing plants. These comprise GHGs such as CO2 and acidifying pollutants such as sulphur oxides (SOx). Other pollutants like nitrogen oxides (NOx), particulate matter (e.g., PM2.5) with carbonaceous and metals, non-methane volatile organic compounds (NMVOCs), and heavy metals like cadmium (Cd), lead (Pb), and mercury (Hg) (EEA, 2019; Taiwo et al., 2014) are released into the atmosphere (Baroutian et al., 2006; Bhanarkar et al., 2005). Schuhmacher et al. (2009) illustrated the impact of cement plants, for example, and described how industrial emissions and pollutants such as heavy metals can mix with food chains, vegetation, and water, leading to harm to human and environmental health. Industrial sites also frequently experience high traffic, intensifying dust, and diverse chemical signatures, leading to acute environmental hazards (Charron and Harrison, 2005). Given the discussions above, the paper proposes the fourth set of hypotheses as follows:

H4a: Manufacturing affects CO_2 emissions positively and significantly.

H4b: Manufacturing affects CH_4 emissions positively and significantly.

H4c: Manufacturing affects $PM_{2.5}$ emissions positively and significantly.

2.5 FDI and environmental depletion

The relationship of the inflows of FDI with the environmental situations of host countries is not clear-cut. Table 1 summarizes some important studies on the FDI-environment connection. While some studies find that FDI exerts an adverse influence on the atmosphere (Omri et al., 2014; Seker et al., 2015; Yousaf et al., 2016b; Zheng and Sheng, 2017), others see no harmful impact. For instance, Kirkulak et al. (2011) emphasised FDI's role as a mean of transferring sophisticated technologies that can help reducing air pollution in China. Hao and Liu (2015) studied the FDI, trade and CO2 data for 29 provinces of China for the 1995–2011 period and revealed a positive role of FDI in curbing CO2 discharges in the Chinese territory. On the contrary, Qayoom and Irfan (2014) and Zakarya et al. (2015) observed that FDI strongly promotes economic progression in the BRICS countries while discharging a controlled volume of CO2. Linh and Lin (2015) showed an affirmative and noteworthy influence of FDI inflows on the environmental improvement in the 12 most populous economies in Asia. These studies revealed a significant bearing of FDI on economic progression and suggested that CO2 emissions can be reduced through policy and practice changes in the region, supporting the polluter-haven hypothesis.

Researchers conducted comparative studies to investigate the haven and halo impacts of FDI corresponding to different income panels. For instance, Doytch and Uctum (2016) revealed a negative influence of FDI on the environment in low and middle-income countries, demonstrating the pollution haven effects (PHH). On the contrary, the researchers noted that FDI had affirmative impacts on the environment in high-income economies, illustrating the halo effects (PH). Kostakis et al. (2017) employed a multivariate analysis to make a comparative assessment of the impact of FDI on the CO2 discharges between Brazil and Singapore and discovered that FDI inflows had a detrimental influence on CO2 discharges in Brazil but produced improved results for Singapore. Despite both countries receiving substantial amounts of FDI, the difference in outcomes can be attributed to Brazil still being a developing country, while Singapore, with a higher level of development, uses a majority of its FDI inflows in the service sector to adopt clean technologies. Thus, the FDI experiences in Brazil and Singapore align with the haven and halo effects frameworks, respectively. Another body of literature has proposed a bidirectional and/or unidirectional nexus of FDI with the quality of environment (Chandran and Tang, 2013a; Omri et al., 2014; Peng et al., 2016). Adom et al. (2019) discovered a non-linear association amid FDI and energy demand, where the absorption capacity of technology, level and stage of development, and reconciliation cost vary among panel countries.

Considering the above observations, we propose the following set of hypotheses depicting the influence of FDI on the rapport between growth and environment:

H5a: Interaction Term of FDI and GDP growth affects CO_2 emissions negatively and significantly.

H5b: Interaction Term of FDI and GDP growth affects CH_4 emissions negatively and significantly.

H5c: Interaction Term of FDI and GDP growth affects $PM_{2.5}$ emissions negatively and significantly.

H6a: Interaction Term of FDI and GDP^2 growth affects CO_2 emissions negatively and significantly.

H6b: Interaction Term of FDI and GDP^2 growth affects CH_4 emissions negatively and significantly.

H6c: Interaction Term of FDI and GDP^2 growth affects $PM_{2.5}$ emissions negatively and significantly.

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3. Data and econometric modelling

3.1 Sample and data

Given that the sensitivity of empirical results is subject to the number of countries and the length of time covered in a study sample (Kijima et al., 2010), we aimed to include all 270 countries, corresponding the list suggested by the World Development Indicators (CD-ROM, 2020). In order to align with the research objective of examining the influence (effect) of FDI on the growth-pollution nexus, we narrowed the number of countries down to 164 which are active members of the WTO (as of 2021). Finally, based on full set of data availability, our final sample constitutes 115 countries inclusive of the study variables for real estimation, adjusting for inflation. Further, we grouped the countries were grouped into different income panels using the World Bank classifications: high income (39), upper middle-income (35), lower middle-income (32), and low-income (9) (refer to Appendix A1 for further information). As the panel data accurately captures the dynamics of empirical variables, and much of research on the EKC hypothesis (Fang et al., 2018; Xu et al., 2020) has employed the country-level panel data to analyze the long-run relationship, our study has used the same approach, covering the period from 1992 to 2019. Following Sharif et al. (2022) and Uddin et al. (2021), the decision to consider the 1992-2019 period was influenced by two major considerations. Firstly, the former Soviet Union States came into existence as sovereign countries during 1988-1991, implying non-existence of the pre-1992 data for these countries (Sharif et al., 2022; Uddin et al., 2021), many of which are already covered in our sample of 115 countries. Secondly, the global FDI flows dropped by 35% in between 2019 and 2020, i.e., from $1.5 trillion in 2019 to $1.0 trillion in 2020 due to the COVID-19 pandemic (UNCTAD, 2021), implying an importance of limiting data for our variables: CO2 emissions, CH4 emissions, PM2.5 emissions, real GDP per capita, energy consumption (EC), manufacturing (MF), and FDI, within the pre-COVID-19 eras.

3.2 Variables

In this study, the likely presence of the EKC hypothesis in the association between economic growth and pollution for various income groups of economies is examined and also the moderating role of FDI in the growth-pollution nexus is investigated. Accordingly, a set of dependent and independent variables are selected for the empirical testing.

As the dependent variable, environmental depletion is used and proxied by carbon dioxide (CO_2), methane (CH_4) emissions and concentration of fine particulate matter ($PM_{2.5}$).

CO_2 and CH_4 emissions are the leading contributors to heat-trapping gas or greenhouse gas (GHG) (EPA, 2021; Forabosco et al., 2017; Wu et al., 2020; Yadav et al., 2023). CO2 alone is the source of at least three-quarters of emissions, which are caused by extracting and burning of fossil fuels (Adedoyin et al., 2020; Wang et al., 2020a). Also, since 2005, about three-quarters of the global GHG emissions had been caused variably by twenty countries that commonly included China, the US, and India (Lin et al., 2021; Mahadevan and Sun, 2020; Maroufi and Hajilary, 2022; Rahman, 2020; Wang et al., 2023a; Zafar et al., 2020). CH_4 is the second major contributor to GHG, and this is caused by different anthropogenic activities like cultivations, livestock, organic and municipal waste landfills (Sharif et al., 2022). Likewise, $PM_{2.5}$ emissions are caused by some other anthropogenic activities like transport smokes, biomass burning, urbanization, coal-powered manufacturing and natural causes (Uddin et al., 2021; Wu et al., 2020). Nitrous Oxide (N2O) accounts for about 6% of GHG emissions worldwide (EPA, 2017, 2021; Forabosco et al., 2017; Wu et al., 2020). However, given that the sources of N2O, e.g., agriculture, livestock, and fuel and agro-residue burning, are like the sources of CH4 and $PM_{2.5}$, N2O is not considered in this study.

In this study, FDI, economic growth, manufacturing and energy consumption are used as independent variables. With the fast-proliferating globalization of the world economies, the continued flows of FDI have fostered economic convergences of many host nations, accompanied by rising CO2 emissions, mostly in countries which lacked appropriate policy measures and witnessed poor implications of environmental regulations (Aggarwal and Goodell, 2015; Jobert et al., 2016; Wang et al., 2023b). On the contrary, there have been cases where FDI-hosting countries showed signs of mitigating CO2 emissions by observing environmental regulations, adopting green technologies and producing environment-friendly products (Aggarwal and Goodell, 2014; Ahmad et al., 2019; Bose and Kohli, 2018; Huang et al., 2022). The above two scenarios imply the presence of Pollution Haven Hypothesis (PHH) (i.e., FDI inflows exacerbating environmental depletions) and pollution halo effect (PH) (i.e., FDI inflows enhancing environmental quality) respectively. Given that the extant literature has documented conflicting outcomes on the links between FDI inflows and environmental quality (Raghavendra et al., 2023), we adopt FDI as a key independent variable in this study. Also, given that the empirical studies on growth-environment nexus have endorsed economic growth as a significant contributor to pollution (e.g., Rahman, 2020; Umar et al., 2020), and sustainable trajectory of economic convergence is a vital pre-condition for the safeguarding of a healthy survival of future generations (Sharif et al., 2013; Song et al., 2019; Uddin and Sharif, 2017), we adopt economic growth as an important explanatory variable and, as a proxy, we use the square term of GDP growth to test for potential non-linearities.

Energy consumption (EC) is the next explanatory variable of this study. Historically, EC has played a vital role in facilitating a large variety of economic developments (Bergasse et al., 2013), and demonstrated a direct association of environmental depletion with economic growth as well as socio-economic development (Li et al., 2016). However, due to differences in time period and/or methodological approaches, forms of EC, and heterogeneities in economies and the climatic conditions, prior studies observed conflicting results in connection with the economic growth and EC nexus (Chen et al., 2023; Shahbaz, et al., 2019). Given this backdrop, we anticipate a noteworthy and positive influence of EC on all varieties of environmental depletion, i.e., CO_2, CH_4, and $PM_{2.5}$, and adopt EC as another explanatory variable in this study.

The final explanatory variable in this study is manufacturing. Kaldor's growth law, commonly known as the engine of growth hypothesis, postulated manufacturing as an indispensable element in promoting robust economic growth (Pacheco-López and Thirlwall, 2014; Wan et al., 2022). The global FDI inflows have helped to pursue the export-led growth paradigm which the Washington Consensus prescribed as a vital policy measure of growth, and hence materializing the development agenda of many developing economies (Palley, 2012). This development was reinforced by international regulatory bodies, e.g., IMF and World Bank, and replaced the paradigm of import substitution (Irwin, 2021). The enactments of export-led policy have led to the prosperous industrialization processes and bolstered large scale manufacturing activities in East and Southeast Asian economies. The experience was however not rewarding for many economies in Africa and South America (Rodrik, 2016). In general, during the normal growth periods, manufacturing activities have made substantial contributions to economic progressions (Timmer, 2009; Wan et al., 2022). Considering the above backdrop, this study expects momentous and positive effects of MF on the alternative measures of emissions considered.

3.3 Model specification

It is evident that FDI can amplify economic progression in host countries in several ways, e.g., diffusion of technology, increased production efficiency, and capital accumulation (Bende-

Nabende et al., 2003; Hussain & Haque 2016), supporting the existence of the Halo effect (PH). On the other hand, several studies have observed an affirmative causal association of FDI with environmental pollution, such as in Malaysia (Hitam and Borhan, 2012b), 18 Latin American LDCs (Blanco et al., 2013), and 19 African countries (Ali & Ismail, 2015), indicating the potential for a Pollution Haven (PHH) effect. However, other research has revealed that FDI has an affirmative influence in reducing environmental contaminations (Hao and Liu, 2015; Mert and Boluk, 2016; Seker et al., 2015). Therefore, our study examines the moderation effect of FDI on the dynamic association of economic progression with environmental depletion by applying the EKC framework. To this end, we devise three regression models as below.

$$CO_2 = f(\text{GDP}, GDP^2, EC, MF, FDI) \quad (1)$$

$$CH_4 = f(\text{GDP}, GDP^2, EC, MF, FDI) \quad (2)$$

$$PM_{2.5} = f(\text{GDP}, GDP^2, EC, MF, FDI) \quad (3)$$

In this study, the CO2 emissions data were recorded in per capita metric tons, while CH4 in kilogram tons of CO2 equivalent, and the PM2.5 data in micrograms per cubic meter. The paper measures the energy consumption (EC) data in kilograms of oil equivalent per capita, manufacturing (MF) by the manufacturing value added as a percentage of GDP, and FDI by the net inflows as a percentage of GDP. The GDP per capita was recorded in constant 2010 US dollars.

According to Baron and Kenny (1986), moderation is established when the association amid two variables is dependent on a third variable that facilitates and modifies the relationship. Moderator variable is defined here as its role to alter the nature or intensity of association amid the independent and dependent variables in a regression analysis. We represent the influence of the repressor on environmental depletion in the form of three relevant equations, as below:

$$CO_{2it} = \beta_0 + \beta_1(GDP_{it}) + \beta_2(GDP^2{}_{it}) + \beta_3(EC_{it}) + \beta_4(MF_{it}) + \beta_5(FDI_{it}) + \varepsilon_{it} \quad (4)$$

$$CH_{4it} = \beta_0 + \beta_1(GDP_{it}) + \beta_2(GDP^2{}_{it}) + \beta_3(EC_{it}) + \beta_4(MF_{it}) + \beta_5(FDI_{it}) + \varepsilon_{it} \quad (5)$$

$$PM_{2.5it} = \beta_0 + \beta_1(GDP_{it}) + \beta_2(GDP^2{}_{it}) + \beta_3(EC_{it}) + \beta_4(MF_{it}) + \beta_5(FDI_{it}) + \varepsilon_{it} \quad (6)$$

Where β_0 refer to intercepts and $\beta_{1,}\beta_{2,}\beta_{3,}\beta_{4,}\beta_5$ denote coefficients of explanatory variables and ε_{it} implies error terms in equation (4-6).

We believe that FDI may have played the moderating impact on the association amid economic progression and environmental depletion. Two forms of effects are found in the literature that constitute the moderation effect model. They are the (i) main effect evident from eqs. (4-6), and (ii) moderating effect estimates (shown in Figure 1), which include interaction variables; the later follows the works of Chen and Myagmarsuren (2013), and Katircioğlu and Taşpinar (2017). To measure the main and interaction impacts of the independent variables on the CO2, CH4, and PM2.5 emissions, we have normalized these variables and re-written the following equations (7-9).

$$CO_{2it} = \beta_0 + \beta_1(GDP_{it}) + \beta_2(GDP_{it}^{\;2}) + \beta_3(EC_{it}) + \beta_4(MF_{it}) + \beta_5(FDI_{it}) + \beta_6[(GDP_{it})\times(FDI_{it})] + \beta_7[(GDP_{it}^{\;2})\times(FDI_{it})] + \beta_8[(EC_{it})\times(FDI_{it})] + \beta_9[(MF_{it})\times(FDI_{it})] + \varepsilon_{it} \quad (7)$$

$$CH_{4it} = \beta_0 + \beta_1(GDP_{it}) + \beta_2(GDP_{it}^{\;2}) + \beta_3(EC_{it}) + \beta_4(MF_{it}) + \beta_5(FDI_{it}) + \beta_6[(GDP_{it})\times(FDI_{it})] + \beta_7[(GDP_{it}^{\;2})\times(FDI_{it})] + \beta_8[(EC_{it})\times(FDI_{it})] + \beta_9[(MF_{it})\times(FDI_{it})] + \varepsilon_{it} \quad (8)$$

$$PM_{2.5it} = \beta_0 + \beta_1(GDP_{it}) + \beta_2(GDP_{it}^{\;2}) + \beta_3(EC_{it}) + \beta_4(MF_{it}) + \beta_5(FDI_{it}) + \beta_6[(GDP_{it})\times(FDI_{it})] + \beta_7[(GDP_{it}^{\;2})\times(FDI_{it})] + \beta_8[(EC_{it})\times(FDI_{it})] + \beta_9[(MF_{it})\times(FDI_{it})] + \varepsilon_{it} \quad (9)$$

Equations (7-9) above capture the moderating effects of an influential variable, FDI on the rapport amid independent variables upon various gauges of environmental pollutants, and this is in alignment with statistical analysis (Cohen *et al*., 2003).

INSERT FIGURE 1 ABOUT HERE

3.3 Econometric methods

We used structural equation modeling (SEM) to examine directly the impact of factors (CO2, CH4, and PM2.5) responsible for environmental degradation as well as the main and moderating effects of FDI. SEM is a flexible and widely used statistical technique that models the relationships between variables, both latent and observed. It integrates several multivariate procedures, including regression analysis, confirmatory factor analysis, canonical correlation, and discriminant analysis. As identified by Fan et al. (2016), SEM has become a widely used tool in ecological studies for testing complex hypotheses involving multiple variables and evaluating causal relationships. Given its power and growing importance in the field, we deemed SEM to be the appropriate choice for our research.

4. Empirical results

4.1 Validity and confirmatory factor analysis (CFA)

Before conducting SEM, we employed the maximum likelihood estimation method to carry out reliability analysis to gauge what extent the measured items are consistent and to determine the suitability of the model. Additionally, we utilized confirmatory factor analysis (CFA) and accordingly revised the items based on the study outcomes, to check the validity of our measurement model. The CFA, implemented through the stats tool package, allowed us to test our pre-specified hypothesized relationships and demonstrate the strength and direction of causation between the variables, including both main and interaction effects, across multiple fields (Fan et al., 2016). The results of fit indices demonstrated that the SEM provides an acceptable fit to the data, as indicated in Table 1 and exhibited in Figure 1.

Table 2 presents the results of the goodness of fit to the data, with the Chi2 test being highly impacted by the sample size. Indices such as Goodness of Fit Index (GFI), Comparative Fit Index (CFI), Tucker-Lewis Index (TLI), Standardized Root Mean Square Residual (SRMR), and Root-Mean-Square Error of Estimate (RMSEA) indicate whether our model is valid, and its fitness to the data used. A model is accepted to have (i) a good fit if CFI, GFI, NFI, and TLI are >0.95, (ii) a poor fit if > 0.90. SRMR is considered an acceptable fit if <0.06 (Hu and Bentler, 1998), and RMSEA is considered to have a good fit if <0.05 and, an adequate fit if <0.08 (Browne and Cudeck, 1993).

INSERT TABLE 2 ABOUT HERE

4.2 Long-run coefficients of main effect in path analysis

The results of the main effect (refer to Appendix 3) vary based on the different income panels. GDP growth has a substantial influence on CO2 discharges in the low, upper-middle-, and aggregated-income panels, but has a negative impact on CO2 discharges in the lower middle and high-income panels. Meanwhile, the affirmative influence of square GDP is observed in the low, lower middle, and high-income panels, indicating that a greater volume of GDP accompanies a substantial amount of CO2 discharges. Our study finds dissimilar impact of GDP growth about CH4 emissions; it demonstrates significantly a negative impact for countries that are low, lower middle, and upper-middle, however, with significantly a positive influence on the high-income panel countries. About PM2.5 emissions, we find GDP growth with a positive effect upon countries that are low-income panels however, significantly with a negative effect for countries that are upper-middle and high-income panels. The square GDP shows a significant positive impact in the upper-middle and high-income panels, but a negative impact in the low and lower-middle income panels, resulting in an inverted U-shaped EKC.

The results of the FDI – GDP growth interactions on environmental depletion (as proxied by CO2, CH4 and PM2.5) are shown in Appendix 4. We find FDI contributing positively to the CO2 emissions for countries that are low and lower-middle income panels, but a negative influence when interacting with square GDP in the EKC. These findings corroborate the outcomes of the research by To et al. (2019) on the Tiger economies in Asia. The interaction between FDI and GDP growth has an affirmative influence on CH4 discharges for upper-middle- and aggregated-income panels, and a negative impact on CH4 discharges for the high-income panel. The link between FDI and square GDP has a positive influence on CH4 discharges in the high-income panel. In the case of PM2.5 emissions, the FDI – GDP growth interaction exerts a positive influence whereas the FDI – square GDP interaction has a negative influence for all income panels, indicating an inverted U-shaped EKC. These results suggest that PM2.5 emissions will decrease with further economic growth after the turning point.

Consumption of energy has a significant positive effect on CO2 releases for all income panels, like the findings of Sterpu et al. (2018) in the EU member states. The effect of manufacturing output on CO2 discharges was observed to be positive and significant for the low-income panel, and for CH4 discharges in the lower-middle and upper-middle income panels, supporting the hypothesis. However, in the high-income panel, the effect of MF was negative on both CO_2 and PM2.5 emissions, contradicting the hypothesis. Additionally, the interaction of FDI with MF showed positive results in reducing CH_4 discharges in the upper-middle, high-income, and aggregated income panels, and PM2.5 discharges in the upper-middle income panel, although its effect on CO_2 was not significant.

4.3 Two-way interactions

The results from Gaskin's (2016) stats tools package show that FDI has varying effects based on the income groups in the EKC. Figure 2 illustrates that FDI weakens the positive correlation between square GDP and CO_2, implying that an enhancement in economic progression helps to reduce CO_2 discharges in the low-income (Figure i) and lower-middle-income (Figure iii) panels. Furthermore, FDI decreases or weakens the positive association of GDP with CO_2; alternatively, this indicates that the interaction of GDP growth with FDI helps reduce CO_2 emissions in the aggregated income (Figure viii) panel. Additionally, FDI decreases the positive association of GDP with CH_4, and intensifies the negative affiliation of square GDP with CH_4, indicating that more economic growth reduces CH_4 emissions in the high-income (Figures iv, v) panel. The two-way interaction effect also reinforces the negative association amid square GDP and PM2.5 (Figure ii), meaning that FDI helps reduce PM2.5 in the low-income panel. On the other hand, FDI weakens the positive rapport of square GDP with PM2.5 in the high-income (Figure vi) and aggregated income (Figure vii) panels, showing that further economic growth helps reduce PM2.5 in the EKC through the adoption of eco-friendly technologies. This aligns with the outcomes of an empirical study on the global economy by Gill et al. (2018).

4.4 Standardized total effect

Table 3 presents the outcomes of the standardized total impact, i.e., the sum of standardized direct and indirect impacts. It appears from the table that the association of FDI with GDP growth has affected CO_2 emissions positively in low, lower middle, and high-income panel economies, while its nexus with square GDP shows a negative impact, indicating the existence of an inverted U-shaped EKC.

INSERT TABLE 3 ABOUT HERE

Regarding the CH_4 emissions, our findings seem to be consistent in nature. The association of FDI with GDP growth shows an affirmative influence on emissions in all the different income panels except for the high-income panel. However, in the high-income panel, the standardized total effect of FDI with GDP growth exhibits a significant negative effect, but the association of FDI with the square of GDP shows a positive impact, reflecting a U-shaped EKC.

Finally, the total impact of FDI's interaction with GDP on PM2.5 emissions is positive, while its interaction with square GDP results in a total negative impact for all income panels. This supports the inverted U-shaped EKC, suggesting that after reaching a turning point, emissions of environmental pollution will decrease as economic growth continues with the adoption of energy-efficient and eco-friendly technologies (as noted by Sarkodie and Strezov, 2019).

5. Conclusion and policy implications

The study finds that the square of GDP has a positive influence on CO2 discharges for low, lower-middle, and high-income panels; this suggests that higher GDP levels lead to significant CO2 emissions. However, the interaction effect between FDI and square GDP has a major effect in lessening CO2 discharges for low and lower-middle income panels. In regard to CH4 discharges, GDP growth shows a substantial positive influence for all income panels except low income. FDI's interaction with manufacturing (MF) shows a positive influence in reducing CH4 discharges for all income panels, except low income, supporting the PH hypothesis for all income groups except low income and the PHH for low income. The association of FDI with square GDP has a positive influence in reducing PM2.5 discharges for all income panels; this indicates an inverted U-shaped EKC. Additionally, energy intake exerts a substantial positive influence on CO2 discharges for all income panels.

The two-way interaction impact highlights the prominence of FDI in plummeting pollution discharges by weakening the positive relationships or strengthening the negative relationships in the EKC. The standardized total effect reveals that while manufacturing growth has a positive influence on CO2 discharges, FDI has a negative influence to reduce pollution discharges in the low and lower-middle income panels. Additionally, the interaction between FDI and square GDP corroborates the EKC hypothesis in reducing both types of pollution discharges for low, lower-middle, and high-income panels. The unrestricted and unconscious (non-judicious) use of natural resources to drive economic progression has put the global environment under great stress. To address the growing requirements of energy, particularly in the manufacturing sector, both the developed and the developing world continue to rely heavily on fossil fuels, i.e., a major source of CO2 discharges. In addition, the rising trend of CH4 emissions, particularly from agriculture, presents further sustainability challenges. PM2.5 concentrations from various human activities also cause regional climate change and adverse bearings on human health. While the adoption of renewable energy and greener technologies is a step forward to achieving sustainability, its limited adoptions do not exert enough influence on reducing pollution emissions.

Our findings on FDI highlight the importance of its moderation effect in balancing the growth and environmental degradation. To attain sustainable development at both the national and international levels, we have several policy recommendations to make. Firstly, given the scholarly concerns that the economic returns from enhanced FDI flows could be counterweighed by the simultaneous rise in environmental emissions (Cole et al., 2011; Demena and Afesorgbor, 2020), governments in developing countries should fortify environmental regulations, especially, in pollution-intensive sectors, like industry and manufacturing, to avoid the negative consequences of the pollution haven hypothesis (PHH). Secondly, given that FDI flows to countries with high polluting rates are falling (Shear et al., 2023), the host country governments should enhance environmental quality through FDI inflows by evaluating institutional performance, seeking alternative financing, and committing to environmental improvement prior to fund disbursement (Jin et al., 2022; Mushed et al., 2023). Thirdly, governments should aim to phase out the PHH and promote the pollution haven (PH) by implementing corruption-free trade and energy policies, such as “Green” FDI, which promotes clean technologies and production methods. Fourthly, global cooperation and understanding among governments, multinational corporations, and environmental organizations is needed to establish a strict policy framework towards achieving sustainable development goals (SDGs). Governments can also establish environmental protection funds based on the amount of FDI inflows and pollution intensity in individual countries to support the PH framework. Fifthly, governments should strive to reduce emissions by sourcing renewable energy and facilitating changes in economic structure, innovation, and technological advancement (Acharyya, 2009; Liobikienė and Butkus, 2019). Policymakers can make use of successful examples, like Ghana, Ethiopia, and Nigeria, who have transformed themselves into top renewable energy producers, while attracting significant FDI (Africa Energy Outlook, 2022).

We acknowledge the availability of a wide range of studies on investigating the relationship of FDI with a number of variables such as, fossil energy consumption, economic growth or development, financial development, and so on using the EKC framework in the contexts of China, India, Pakistan, Singapore, Turkey, GCC region, selective ECOWAS and European economies (Balibey, 2015; Ali et al., 2020; Halliru et al., 2020; Luo et al., 2022; Tabash et al., 2023). On the contrary, this study has set its aim on assessing the moderating role of FDI on the growth-environment nexus using a large sample of 115 countries, and also different income panels of countries using the EKC framework, subsequently making a vital contribution to relevant literature. However, although some of the studies applied similar approach of evaluating the influence of FDI on the association economic growth with pollutant emissions, unlike our study, their samples were limited to regional levels, such as Chinese Provinces (He and Yao, 2017) and Asian developing countries (Manocha, 2021).

Despite the best possible efforts, our study is not free from drawbacks. First, the study is constrained by the insufficiency of relevant data on $PM_{2.5}$ emissions. As a complement, data of a similar variable, i.e., N2O could be used, and robustness of the results could be improved. Second, this study has assessed the interactive influence of FDI individually and logically to produce some vital results where more than one moderator is likely to concurrently affect the growth-pollution nexus. Third, subject to data availability, there could have been a potential scope for conducting a comparative study of the moderating effects of FDI amid various income groups of countries, and finally, comparing the outcomes with the extant literature in related areas. Considering the above contexts, a more holistic investigation could be possible on the level and variety of environmentally contaminating activities. In the pursuit of a green and sustainable economic convergence of countries, future research could be directed to explore: (a) the impact of the simultaneous presence of multiple moderators, such as FDI, human capital, trade openness, and so on, in the EKC hypothesis; and (b) comparative variations in the moderating impact in the EKC hypothesis corresponding to various income panels of countries.

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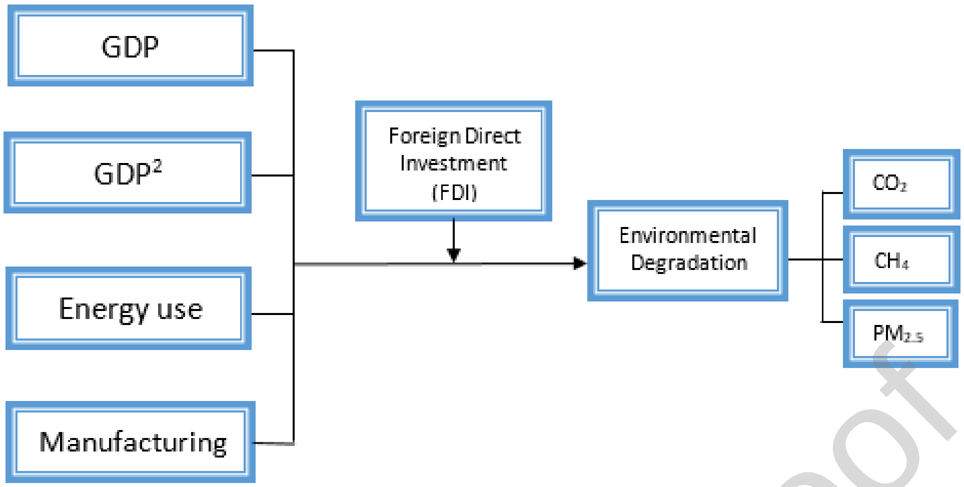


Fig. 1. Moderating role of foreign direct investment (FDI)

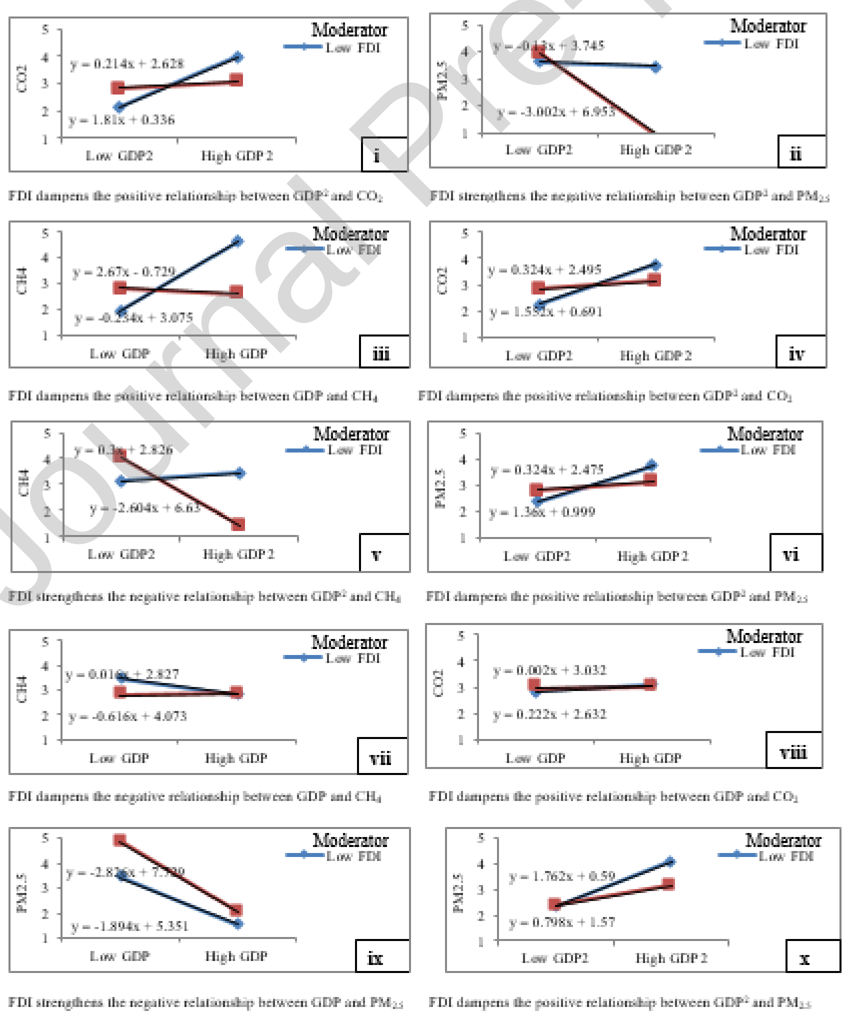


Fig. 2. Two-way interaction relationship between gross domestic product (GDP & GDP^2) and selected indicators (CO_2, CH_4 & $PM_{2.5}$) of environmental pollution in classified income groups.

Table 1. Summary of the existing literatures on FDI and environmental pollution nexus

Study	Region/countries	Study period	Methods	Variable	Main findings
Abdouli and Hammami (2017)	MENA countries	1990-2012	OLS, GMM	FDI, GDP, CO_2	FDI enhances GDP growth, but it reacts negatively to the quality of environment.
Albulesco et al. (2019)	14 Latin American countries	1980-2010	Panel quintiles regression	FDI, CO_2, GDP, Energy, Human capital, Population, Unemployment	Results partially validate the EKC hypothesis and contrast with the finding of Sapkota and Bastola (2017) for the PHH.
AlIyua and Ismailb (2015)	19 African countries	1990-2010	PMG estimation technique	FDI, GDP, EC, CO_2	FDI inflows causes a significant amount of GHGs in the region.
Balibey (2015)	Turkey	1974-2011	Cointegration, IRF	FDI, CO_2, GDP,	FDI have positive and significant impact for reducing the VAR, GC level of CO_2 emissions.
Chandran and Tang (2013a)	Asian 5 countries	1971-2008	Cointegration, GC	FDI, EC, TR, GDP, CO_2	FDI causes CO_2 for Malaysia and Thailand while for Indonesia, there is a bidirectional Causality between the variables.
Kostakis et al. (2017)	Brazil and Singapore	1970-2010	ARDL, OLS, FMOLS	FDI, CO_2, GDP	FDI causes CO_2 for Brazil while it reduces this emission for Singapore because most of FDI goes to service sector & clean technologies in Singapore but industrial production in Brazil.
Linh and Lin (2015)	12 Asian most	1980-2010	Panel model, GC	FDI, CO_2, GDP, EC	FDI decrease the populous countries pollutants by 0.0301% while its inflows by 1%. Simultaneously, FDI and EC cause bidirectionally and CO_2 causes EC unidirectionally.
Liu and Lai et al. (2021)	134 countries	2001-2018	Life cycle assessment (LCA)	FDI, GDP, CO2, Trade openness (TO), Industry, Population, Urbanisation	EKC appears in 68 countries out of 134 countries. Results provide empirical evidence to the "Waste Haven Hypothesis".
Maroufi and Hajilary (2022)	Islamic Republic of Iran	1976-2016	Autoregressive distributed lag (ARDL)	CO_2, GDP, FDI, Income, Gas	CO2 emissions and other outlined variables exhibit short and long- run associations, validating the EKC hypothesis for Iran
Mert and Boluk (2016)	21 Kyoto Countries	1970-2010	PMG, MG	FDI, GDP, EC, CO_2	Economic growth can't ensure environmental protection while FDI inflows and renewable energy consumption can mitigate the emission targets.
Nepal et al. (2021)	India	1978-2016	ARDL, VECM Granger, causality test, EKC model	FDI, GDP, CO2, Trade openness (TO)	There is strong energy-output–CO2–FDI long-run nexus. Energy use is Granger caused by GDP, CO2, FDI and TO in the long-run
Shahbaz et al. (2019)	MENA countries	1990-2005	Generalised Method of	FDI, CO2, GDP, Biomass cons. (BC)	EKC analysis highlights inverted-U and N-shaped links between economic

			Moments (GMM)		growth and CO2. Causality analysis reveals that FDI causes CO_2 emissions.
Wang et al. (2021)	30 Chinese provinces	2004-2016	STIRPAT framework, System-GMM estimation	FDI, ETS, GDP, Energy intensity, R&D, Population, Technical factor	There exists a nonlinear relationship of the “inverted-U” shape between FDI and emissions.
Waqih et al. (2019)	South Asia	1986-2014	Panel ARDL, FMOLS	FDI, CO2, GDP, Energy cons. (EC)	The results confirmed the existence of PHH and EKC in the short run, and the absence of PH effects and of EKC in the long run.
Nasir et al. (2017)	ASEAN-5 economies	1982-2014	Dynamic OLS (DOLS), Fully Modified OLS (FMOLS)	FDI, CO_2, GDP, Financial dev. (FD)	Economic growth, FD and FDI leads to a rise in environmental degradation. The quadratic term for economic growth shows evidence of the EKC hypothesis.
Ojewumi and Akinlo (2017)	33 Sub-Saharan	1980-2013	Panel Vector Auto regressive (PVA), Panel Vector Error Correction (PVEC)	FDI, EQ, GDP	FDI causes GDP and African countries environmental quality (EQ) but EQ does not cause FDI.
Omri et al. (2014)	54 countries	1990-2011	Dynamic simultaneous	FDI, CO_2, GDP	FDI and GDP have regional sub-panels equation and panel model bidirectional causality for all the sub-panels and between FDI and CO_2 have bidirectional causality for all model the sub panels except Europe and North Asian sub-panel.
Peng et al. (2016)	China	1985-2012	Bootstrap panel, GC	FDI, CO_2, GDP	FDI causes CO_2 emissions unidirectionally and concurrently it has bidirectional relationship with GDP growth.
Qayoom and Irfan (2014)	BRICS	1992-2010	Cointegration panel model	FDI, CO_2, GDP, EC	FDI causes GDP and EC, but it does not cause CO_2 emissions.
Yousaf et al. (2016a)	Pakistan	1972-2013	ARDL	FDI, CO_2, EC, GDP	FDI, GDP and EC have momentous contribute to grow CO_2 emissions.
Zakarya et al. (2015)	6 BRICS countries	1990-2012	Panel Cointegration, GC	FDI, CO_2, EC, GDP	FDI causes GDP and it has significant role for reducing CO_2 emissions for BRICS countries.
Zheng and Sheng (2017)	30 Chinese provinces	1997-2009	Panel model	FDI, CO_2	FDI reduces CO_2 emissions in eastern part of China where occurred reform for Market orientation but in western region seems higher CO_2 emissions due to lower market development.

Sources: Author’s summary

Note: In ‘Variables’ column FDI, CO_2, EC, GDP, EQ and TR refers to foreign direct investment, carbon dioxide emissions, energy consumption, gross domestic product, environmental quality and transportation, respectively. In ‘Methodology’ column ARDL, GC, OLS and FMOLS denotes autoregressive distributed lag, Granger causality and ordinary least squares, respectively.

Table 2. Results of model fit analysis

Income Groups	Absolute fit measures				Incremental fit measures				Parsimonious fit measures		
	χ^2/d.f	GFI	SRMR	RMSEA	CFI	IFI	NFI	TLI	AGFI	PGFI	PNFI

Aggregate data of the countries (N=3105)	22.34	0.998	0.011	0.076	0.999	0.999	0.999	0.961	0.934	0.038	0.045
Low-income countries (N=243)	2.761	0.987	0.007	0.080	0.996	0.996	0.994	0.965	0.859	0.089	0.105
Lower-middle countries (N = 864)	9.193	0.993	0.020	0.080	0.996	0.996	0.996	0.937	0.866	0.051	0.060
Upper-middle countries (N = 945)	8.902	0.989	0.009	0.080	0.994	0.994	0.993	0.945	0.882	0.089	0.105
High-income countries (N = 1053)	5.811	0.998	0.009	0.068	0.999	0.999	0.999	0.977	0.929	0.026	0.030

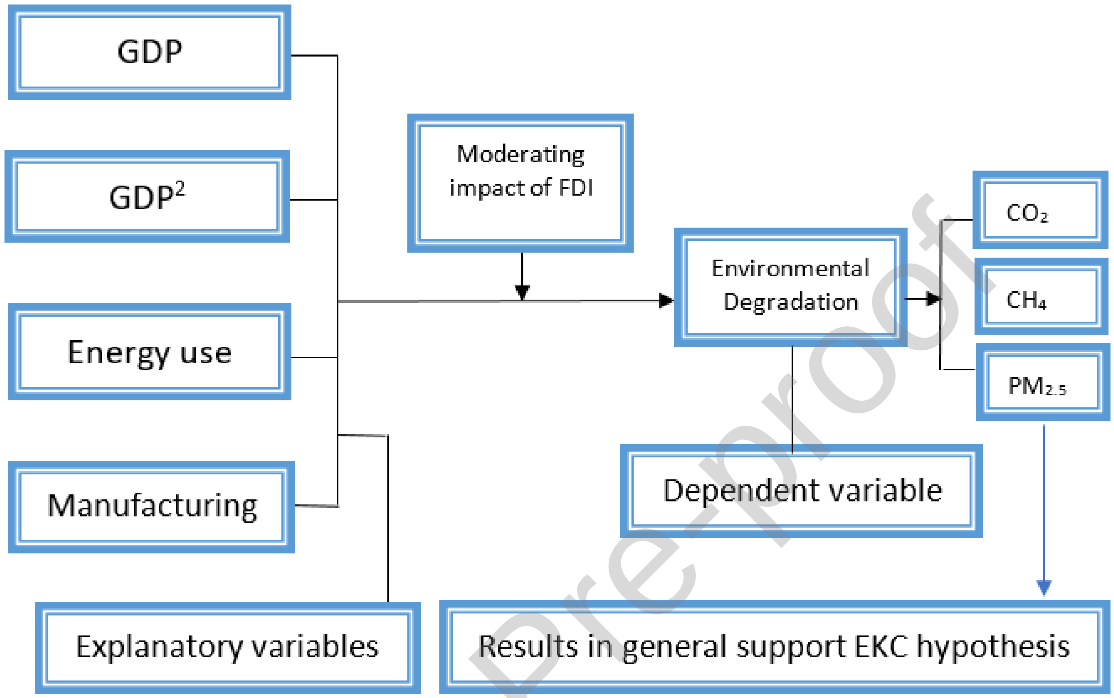
GFI: goodness-of-fit index; SRMR standardized root mean residual; RMSEA: root mean square error of approximation; AGFI: adjusted goodness-of-fit index; IFI: incremental fit index; NFI: normed fit index; TLI: Tucker Lewis Index; PGFI: parsimonious goodness of-fit index; PNFI: parsimonious normed-fit-index;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

Table 3. Results of standardized total effect

Income panels	Dependent variables	ZGDP	$ZGDP^2$	ZEC	ZMF	ZFDI	GDPxFDI	GDP^2xFDI	ECXFDI	MFXFDI
LIP	ZCO_2	.267	.381	.356	.137	-.100	.184	-.281	.017	-.024
	ZCH_4	-.850	.491	.014	.050	.005	-.104	-.009	.000	.356
	$ZPM_{2.5}$	.686	-.783	-.222	-.042	-.550	.006	-.446	.281	.176
LMIP	ZCO_2	-.210	.469	.383	.041	-.019	.378	-.414	.093	.062
	ZCH_4	-.225	.105	-.001	.122	-.215	.375	-.284	.000	-.093
	$ZPM_{2.5}$	.030	-.087	-.238	-.059	-.241	.981	-.675	-.075	.040
UMIP	ZCO_2	.061	-.111	.966	-.029	-.035	-.046	-.003	.050	.012
	ZCH_4	-.436	.409	.183	.253	-.216	.218	-.165	.000	-.258
	$ZPM_{2.5}$	-.594	.401	.259	-.150	-.332	.093	-.163	-.001	-.103
HIP	ZCO_2	-.344	.257	.833	-.095	.027	.089	-.076	.004	.014
	ZCH_4	.609	-.576	.030	-.027	-.276	-1.002	.942	.000	-.126
	$ZPM_{2.5}$	-.710	.421	.462	-.181	-.039	.645	-.458	-.217	.113
AIP	ZCO_2	-.087	.018	.943	-.014	.007	.007	.007	.001	.000
	ZCH_4	-.147	.077	.080	.216	-.171	.357	-.289	-.083	-.109
	$ZPM_{2.5}$	-1.18	.640	.462	-.142	-.233	.827	-.630	-.107	.034

Note: LIP=Low-income panel, LMIP=Lower-middle income panel, UMIP=Upper-middle income panel, HIP=High income panel, AIP=Aggregated income panel

Graphical abstract



Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

HIGHLIGHTS

- There is a significant positive influence of energy consumption on CO2 discharges across all income panels.
- The interaction between FDI and square GDP leads to a decrease in CO2 emissions for low and lower-middle income countries.
- The above interaction leads to a drop in PM2.5 discharges for low, lower middle, high income and overall income levels.
- The nexus of FDI with manufacturing growth exhibits a negative influence on emissions reduction in both low and lower-middle income economies.
- The above nexus leads to a reduction in CH4 discharges for upper-middle, high income, and overall income levels.
- The study in general supports the Environmental Kuznets Curve (EKC) hypothesis.