Decomposing scale, technique and composition effects of foreign direct investment on environmental quality

Kong San Chen, Lee Chin, Siong Hook Law, Shivee Ranjanee Kaliappan & Yong Seong Foo

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Author information:

Kong San Chen (First author)
School of Business and Economics, Universiti Putra Malaysia, Serdang, Selangor, Malaysia
Email: chnekong03452@gmail.com

Lee Chin (Corresponding author)
School of Business and Economics, Universiti Putra Malaysia, Serdang, Selangor, Malaysia
Email: leechin@upm.edu.my
ORCID: 0000-0002-8651-2204

Siong Hook Law
School of Business and Economics, Universiti Putra Malaysia, Serdang, Selangor, Malaysia
Email: lawsh@upm.edu.my
ORCID: 0000-0002-6058-4883

Shivee Ranjanee Kaliappan
School of Business and Economics, Universiti Putra Malaysia, Serdang, Selangor, Malaysia
Email: shivee@upm.edu.my
ORCID: 0000-0001-6953-7541

Yong Seong Foo
School of Business and Economics, Universiti Putra Malaysia, Serdang, Selangor, Malaysia
Email: fyseong82@gmail.com

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Decomposing scale, technique and composition effects of foreign direct investment on environmental quality

Abstract: This study aimed to investigate how the decomposing scale effect, technique effect and composition effect of foreign direct investment (FDI) impact on carbon dioxide (CO_2) emissions for 115 nations spanning 1999 to 2019 by employing Generalised Method of Moments (GMM) model. The results indicated that FDI, real GDP per capita, capital-labor ratio, institutional quality and urbanization increase CO_2 emissions while the square of real GDP per capita and trade openness contributed to reducing CO_2 emissions. Also, our findings fail to support Environmental Kuznets Curve (EKC) theory. The outcomes of this research illustrated that scale effect dominates composition effect and followed by technique effect. The interaction effect of FDI and technique effect has the least influence on CO_2 levels in reducing the harmful effects of FDI on CO_2. Furthermore, it should be highlighted that although FDI increases CO_2 emissions, its detrimental impact on CO_2 emissions is moderately mitigated by its interactions with three economic mechanisms. Therefore, it is necessary to enhance the technical processes of production as well as the development of modern technologies. We recommended that policymakers balance sustainable economic development with environmental sustainability by considering the indirect effects of factors on CO_2 emissions.

Keywords: CO_2 emissions; FDI; scale effect; technique effect; composition effect; interaction models

Introduction

Global emissions such as global warming are felt globally. According to data from World bank, global carbon dioxide (CO_2) emissions were 3.88 metric tonnes per capita in 1990. From 1991 through 2019, the values increased at an average rate of between 3.95 and 4.71 metric tonnes per capita. Despite significant efforts have been made to combat CO_2 emissions; however, the level of CO_2 globally continues to rise at an alarming rate. Scholars stated that greenhouse gases emissions are mainly contribute by economic activities resulting from free movement across border such as industrialization (Esmaeili et al. 2023), globalization (Jahanger 2022), trade integration (Zubair et al. 2020), economic growth (Malik et al. 2020), and technological innovation (Xing et al. 2023). Foreign direct investment (FDI) is viewed as one of the causes that contributes to environmental deterioration (Kasimov et al. 2023), and the environmental concerns associated with FDI have emerged as a core issue on the FDI policy agenda of host countries (Esmaeili et al. 2023). While at the same time, numerous countries tend to seek FDI to strengthen the host countries' economy given that FDI serves as a vital engine for achieving economic development. To obtain a compromise within sustainable economic development and environmental sustainability goals, countries may confront a trade-off between FDI and CO_2 emissions reductions.

Through knowledge transfer, spillover effects, the application of advanced technology, and the development of management skills, FDI may provide direct capital finance, produce positive externalities that support economic growth (Lee 2013; Ayappan and Chin 2018). The effects of FDI on CO_2 can be grasped by three effects (Grossman and Krueger 1995; Dinda 2004). First, scale effect refers to FDI increases economic activity, then more inputs are required. Thus, scaling up size of an economy such as increase productivity induces higher energy consumption, in turn more pollution levels.

Second, technique effect which stipulates that FDI is accompanied by the development of new as well as more modern technologies, adoption of green technologies, energy-saving, or low-carbon technology which results in more efficient energy consumption and lowers CO_2 emissions (Zarsky 1999). On the contrary, technological advancement brought about by FDI changes production methods and lowers the prices of energy products or services, which may eventually lead to increased energy demand and consumption, thereby increasing CO_2 emissions (Shahbaz et al. 2016; Wang et al. 2019).

Third, the composition effect might be beneficial or detrimental on CO_2 since it depends on the sectoral distribution of FDI (Grossman and Krueger 1991; OECD 2001; Salim et al. 2017). The composition effect exerted that FDI may drive changes in the economy structure. Increased FDI in the tertiary sector may result in a shift in the energy-consuming sector from heavy industries to services or light industries. As the service sector and light industries lead to the industrial sector to shrink; using more capital-efficient production methods and demanding less energy (Zhang and Zhou 2016; Foo et al. 2023), this suggests a negative composition effect (Stern 2004). Therefore, reducing CO_2 emissions. Conversely, the concentration of FDI in the dirty sectors, such as the secondary sectors, or shifting the structural economic composition of host nations from agricultural to industrial sectors, may result in an increase in energy consumption. The latter requires more energy than the former, which suggests a positive composition effect. Besides that, according to Environmental Kuznets Curve (EKC), technique effect and composition effect decrease CO_2 emissions while scale effect aggravates CO_2 emissions. However, there is equivocal evidence supporting the possibility of EKC.

Indeed, FDI is recognized as a key contributor to the economic development, yet the presence of growing trend of FDI has raised environmental issues and depleted environmental policy requirements. As FDI increases, there will be a change in the scale of economy size, changes in production process and economic structural transformation in the economy due to the transfer of technology. FDI could have direct impacts either positive or negative on CO_2 emissions (Wang et al. 2022; Nguyen et al. 2021). However, limited studies explore the interactive effects of FDI on CO_2 emissions (Liobikienė and Butkus 2019), particularly the interactions of FDI with scale, technique and composition effects. In addition, empirical studies on how FDI affects CO_2 emissions remains unclear, which in turn has contributed to ambiguous findings that require further investigation. Moreover, as a result of the recent increases in energy consumption and CO_2-related emissions, as well as the prediction that greenhouse gas emissions will rise once again, the improvement typically seen as insufficient. To this end, this paper analyzes how FDI affects CO_2 emissions both directly and indirectly.

The contribution of this study adds to the existing literature in several aspects. Firstly, it addresses the pollution-haven hypothesis (PHH) challenge by examining the varied results in the literature regarding the decomposition of the FDI spillover effect. Several studies have explored how the decomposition of FDI—specifically the scale effect, technique effect, and composition effect—affects pollution in host nations. However, these studies often do not explicitly address the indirect impact of the decomposition effect of FDI. It is plausible that the decomposition effect attracts different types of foreign direct investment, thereby influencing environmental quality in diverse ways, which could lead to erroneous conclusions. This study is crucial for extending and filling gaps in previous research by investigating the important role of the decomposition effect in the FDI-environmental quality nexus, along with the pollution halo and pollution haven hypotheses. Second, the present investigation expands on the drivers of environmental quality by illustrating how indirect effect of FDI spillovers influence environmental quality through the moderating effect of three economic mechanisms, namely, scale, technique and composition effect. For policies to be proposed toward efficient and sustainable development that maximize the interaction of foreign and domestic firms, it is essential to understand the function of each channel in the transmission of FDI spillover effects. Third, while many studies have examined the sectoral or country-level effects of FDI spillover, this research provides evidence from a comprehensive analysis and global perspective, using data from 115 countries. This comprehensive approach allows for a more detailed understanding of how FDI impacts environmental quality globally, offering valuable insights that might be missed in more localized studies.

The present study is structured as follows: “Literature review” section expresses the review of pertinent literature and hypothesis development; “Methodology and data” section declares the method and data utilized; “Empirical results and discussion” section

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is the interpretation and discussion regarding the obtained outcomes; "Conclusion" section summarizes the main findings, offers policy implications, discusses the limitations of the study and provides recommendations for future research.

Literature Review

The literature on FDI-CO_2 linkages proposes two primary justifications. First, the pollution-halo theory explains why FDI inflows induce a decrease in CO_2 emissions. For instance, according to Pao and Tsai (2011), the pollution-halo theory suggests that the influx of FDI inflow should be used to transfer green technology from one nation to its partners, thereby enhancing environmental quality (Kisswani and Zaitouni 2023; Demena and Afesorgbor 2020). Second, recent studies address the pollution-haven hypothesis (Copeland and Taylor 1994), which contends that lax environmental regulations in a host economy will attract FDI. This can result in the movement of polluting sector from developed nations to less developed nations, worsening environmental performance and cause environmental degradation in the host nation (Shahbaz et al. 2018; Sun et al. 2017; Dong et al. 2019; Sarkodie and Strezov 2019).

The evidence on the impact of FDI on CO_2 emissions is mixed. Existing findings can be divided into three strands. The first strand of the studies was corroborated by the adverse impact of FDI on CO_2 emissions. For instance, using an imbalanced panel of data, Mert and Bölük (2016) studied how FDIs and the use of renewable energy affect CO_2 emissions. The findings are consistent with the pollution-halo theory, which asserts that FDI advances environmental norms and introduces clean technology, hence reducing carbon emissions. Paramati et al. (2017) postulated that CO_2 emissions are reduced by FDI in the long run in the developing economies but not for developed economies due to FDI bring environmentally friendly technology and energy saving technology to less developed countries. Similar view also supported by Jiang et al. (2018) on 150 Chinese cities; Eluwole et al. (2020) on China; Udemba and Yalçıntaş (2021) on Algeria; Nguyen et al. (2021) on G6 countries who concluded that FDI decrease environmental degradation.

The second strand of studies that find FDI aggravate environmental degradation whose results confirm pollution haven hypothesis. Using country-specific analysis, previous studies manifested that FDI significantly increases CO_2 emissions (Salahuddin et al. 2018 for Kuwait; Seker et al. 2015 for Turkey; Haug and Ucal 2019 for Turkey; Nadeem et al. 2020 and Malik et al. 2020 for Pakistan; Shahbaz et al. 2018 for France). Alternatively, by using panel data analysis, similar results also supported by Paramati et al. (2016) for emerging market economies; Sarkodie and Strezov (2019) for five selected developing countries; Bakhsh et al. (2021) for 40 Asian countries; Pazienza (2019) focus on OECD countries; Farooq (2022) for Asian economies; Wang et al. (2022) for eight newly industrialized countries; Esmaeili et al. (2023) for N-11 economies. However, highlighting potential differences amongst developed and less developed countries, Essandoh et al. (2020) revealed that FDI increase CO_2 emissions in developing countries but insignificant for developed countries. The author further suggested that the increase FDI causes developed countries to transfer high emission-intensive production to developing countries (Sarkodie and Strezov 2019), which results in developed countries achieving decreased emissions at the cost of developing countries.

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The third strand uncovers the nonlinear correlation between FDI and CO_2 emissions by including quadratic and interaction terms in the estimated model. Shahbaz et al. (2015) discovered that FDI initially promotes CO_2 emissions; but, beyond a certain threshold, CO_2 emissions begin to decline. Similar results were also documented by Pazienza (2019); Alshubiri and Elheddad (2020); Omri et al. (2019). However, Jiang (2015) discovered that the squared term of FDI is insignificant influences CO_2 emissions. To further explore the impact of FDI influxes on CO_2, Liobikienė and Butkus (2019) and Sinha et al. (2017) incorporated the interaction term (FDI × Income) to explore the FDI spillover influxes on CO_2 leakages under the constraints of economic growth. Omri and Hadj (2020) confirmed that the interconnections between FDI and institutional and political institutional quality help to reduce CO_2 emissions.

However, a few other studies obtain insignificant and inconclusive results. For instance, the results of an investigation by Albulescu et al. (2019) employing panel quantiles regression analysis into FDI, income, and CO_2 emissions in Latin America was inconsistent. Additionally, it was discovered by Haug and Ucal (2019) and Wu and Li (2011) that FDI is insignificant factor in explaining the FDI-CO_2 emissions nexus in Turkey and Shandong, respectively. Voumik and Ridwan (2023) tweeted that FDI has failed to explain the rise in pollutant emissions levels in Argentina. A study conducted by Chandran and Tang (2013) on five ASEAN nations, the majority of FDI inflows are directed towards the services sector, particularly the financial services, leaving little room for any significant impact on CO_2 emissions. This is especially true for Singapore. In addition, Mahmood et al. (2020) worked on five North African nations ultilising data from 1990 to 2014. They discovered that FDI insignificantly affects CO_2 emissions.

It's worthy to note that the discussion over the EKC is sparked by the economic growth. The environmental deterioration predicted by an expansion in an economy's scale is true, but only to a certain extent. According to a number of works, when a certain level of turning point is achieved, environmental quality improvements are noticed, demonstrating an inverted U-shaped correlation between economic growth and the environment. However, the EKC hypothesis' validity reached different findings. Among them, EKC hypothesis was proven existed for the studies of Al-Mulali and Ozturk (2016), Leitão et al. (2023) and Kostakis et al. (2023) while Rahman (2017), Shahbaz and Sinha (2019), and Fakih and Marrouch (2019) all challenge the EKC hypothesis.

Hypothesis Development

Based on the above discussion of relevant previous literature, FDI may influence CO_2 emissions in both positive and negative ways. A stance with the similar perspective concurs with that of Shahbaz et al. (2019), who assert that FDI inflows on environmental degradation can be positive or negative, contingent upon whether the country attract FDI from energy-intensive sectors or technology-intensive sectors. Accordingly, we propose the following verification for Hypothesis 1.

Hypothesis 1: FDI significantly impacts CO_2 emissions.

To determine whether a host country involves PHH or Pollution halo hypothesis, the effects of FDI on CO_2 can be grasped by three effects (Grossman and Krueger 1995), namely scale effect, technique effect and composition effect as discussed in the two primary rationales, trade perspective and neo-technology trade perspective.

First, based on trade perspective, the scale effect corresponds to increased economic activity, which requires more inputs (Grossman and Krueger 1991; Le and Ozturk 2020; Khan and Safdar 2023), escalating energy consumption and degrading environmental quality. Similarly, Saqib et al. (2023) state that economic development, which leads to increase in the industrial sector, exacerbates environmental quality. Thus, the expansion of an economy activity such as increase productivity induces higher energy consumption, which leads to higher pollution levels. This study argues PHH is highly related to the scale effect in the host countries. Thus, we propose Hypothesis 2 as follows.

Hypothesis 2: Scale effect significantly impacts CO_2 emissions.

Second, based on neo-technology trade perspective, FDI may lead to the development, transfer, and diffusion of more modern and effective technology leading to the changes in the production process (technique effect) which eventually may support either PHH or Pollution halo hypothesis (Rezek and Rogers 2008; Shahbaz et al. 2019). The Pollution halo hypothesis was backed by improvements in production techniques that increased domestic production while emitting less carbon per unit. Udeagha and Breitenbach (2023) reveal that implementing advanced and environmentally friendly manufacturing techniques greatly improves environmental quality. However, according to Tsurumi and Managi (2010), the technique effect is not always favourable for the environment, with the potential that new technologies are more polluted than older technologies. In addition, technological advancement drives up demand and consumption of energy (Ouyang et al. 2018), resulting in the pronounced rise in CO_2 emissions. Based on the literature reviews provided, we hypothesized Hypothesis 3 as follows.

Hypothesis 3: Technique effect significantly impacts on CO_2 emissions.

Third, whether composition effect supports the PHH or Pollution halo hypothesis (Grossman and Krueger 1991) depends on how countries change their production composition in response to structural economic change. This is influenced by the country's level of development of the country, whether the economy is more energy-intensive or more technologically-intensive (Shahbaz et al. 2019), and the country's comparative advantages (Jalil and Mahmud 2009). Higher capital-labor ratio (capital intensity) associated with the expansion of energy-intensive sectors, which would lead to a higher production levels, more consumption and greater pollution (Cole et al. 2005; Cole 2006). Therefore, we propose the following Hypothesis 4 as follows.

Hypothesis 4: Composition effect significantly impacts on CO_2 emissions.

Methodology and data

Model specifications

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According to Shahbaz et al. (2019); CO_2 emissions are influenced by foreign direct investment (*FDI*), real gross domestic product per capita (*RGDPC*), the square of real gross domestic product per capita (*RGDPC*^{2}), and capital-labor ratio (*K/L*). The benchmark model equation is constructed based on the study objectives as follows:

$$CO_{2it} = f(FDI_{it}, RGDPC_{it}, RGDPC^2_{it}, K/L_{it}) \tag{1}$$

To make Eq. (1) estimable, we converted all of the variables to natural-log form. Furthermore, in accordance with Kostakis et al. (2023), this study incorporated the square of real GDP per capita in the model to determine if these parameters may contribute to the generation of the nonlinear connection between pollution and income, hence supporting the validity of the EKC hypothesis. The estimated equation is as follows:

$$\ln CO_{2it} = \beta_0 + \beta_1 \ln CO_{2i,t-1} + \beta_2 \ln FDI_{it} + \beta_3 \ln RGDPC_{it} + \beta_4 \ln RGDPC^2_{it} + \beta_5 \ln K/L_{it} + \beta_6 \ln INS_{it} + X_{it} + \varepsilon_{it} \tag{2}$$

The GMM equation is presented in Eq. (2). It is simply a dynamic panel series equation with dynamic effects ($\ln CO_{2i,t-1}$) and X_{it} is control variables which is trade openness (*TOP* and urbanisation (*URB*); an error term (ε_{it}). The nations are represented by the subscript i ($i=1, ...,N$), whereas the time period is represented by the subscript $(t=1, ...,T)$.

Following Liobikienė and Butkus (2019), we transform Eq. (2) to account for interaction term in order to estimate the potential indirect influence of FDI on CO_2 emissions via scale, technique and composition effect. The empirical model Eqs. (3) - (5) for examining the interaction impact on carbon emissions is as follows:

$$\ln CO_{2it} = \beta_0 + \beta_1 \ln CO_{2i,t-1} + \beta_2 \ln FDI_{it} + \beta_3 \ln RGDPC_{it} + \beta_4 \ln RGDPC^2_{it} + \beta_5 \ln K/L_{it} + \beta_6 \ln INS_{it} + \beta_7 (\ln FDI \times \ln RGDPC)_{it} + X_{it} + \varepsilon_{it} \tag{3}$$

$$\ln CO_{2it} = \beta_0 + \beta_1 \ln CO_{2i,t-1} + \beta_2 \ln FDI_{it} + \beta_3 \ln RGDPC_{it} + \beta_4 \ln RGDPC^2_{it} + \beta_5 \ln K/L_{it} + \beta_6 \ln INS_{it} + \beta_7 (\ln FDI \times \ln RGDPC^2)_{it} + X_{it} + \varepsilon_{it} \tag{4}$$

$$\ln CO_{2it} = \beta_0 + \beta_1 \ln CO_{2i,t-1} + \beta_2 \ln FDI_{it} + \beta_3 \ln RGDPC_{it} + \beta_4 \ln RGDPC^2_{it} + \beta_5 \ln K/L_{it} + \beta_6 \ln INS_{it} + \beta_7 (\ln FDI \times \ln K/L)_{it} + X_{it} + \varepsilon_{it} \tag{5}$$

In Eqs. (3) - (5), we explore the indirect influence of FDI on CO_2 emissions through scale, technique, and compositions effects. To do this, our analysis incorporate the interactions of the FDI with the variables of *RGDPC*, *RGDPC*^{2}, and *K/L* into the equation and evaluate the importance of the interacted coefficients. For instance, the interaction variable of $\ln FDI \times \ln RGDPC$ in Eq. (3). If $\beta_2 > 0$ and $\beta_7 < 0$, which illustrates that increased FDI has an adverse effect on CO_2, but *RGDPC* mitigates that adverse effect. If $\beta_2 < 0$ and $\beta_7 > 0$, this illustrates that increased FDI has a moderating

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impact on CO_2 and that *RGDPC* strengthens that mitigating effect. If $\beta_2 < 0$ and $\beta_7 < 0$, increasing FDI decreases CO_2 emissions and *RGDPC* amplifies this impact. Lastly, if $\beta_2 > 0$ and $\beta_7 > 0$, this illustrates that increased FDI contributed to an increase in CO_2 emissions and *RGDPC* adds to this adverse effect. Additionally, the interaction term serves to estimate the marginal impacts of FDI on CO_2 emissions at different values (at the mean, minimum and maximum) of *RGDPC*. Depending on the influence of *RGDPC* on CO_2 emissions, the expected sign of the interaction variable (β_7) might be positive or negative. As a consequence, by calculating the partial derivatives of FDI in Eqs. (3) - (5), the entire effect of FDI on CO_2 emissions at various levels of *RGDPC*, *RGDPC*^{2}, and *K/L*, can be computed in Eqs. (7) - (9). A positive marginal effect demonstrates that rising *RGDPC* and FDI will lead to increased CO_2 emissions, while a negative marginal effect shows the opposite.

From Eq. (3) $$\frac{dCO_{2it}}{dFDI_{it}} = \beta_2 + \beta_7 RGDPC_{it} \tag{7}$$

From Eq. (4) $$\frac{dCO_{2it}}{dFDI_{it}} = \beta_2 + \beta_7 RGDPC_{it}^2 \tag{8}$$

From Eq. (5) $$\frac{dCO_{2it}}{dFDI_{it}} = \beta_2 + \beta_7 K / L_{it} \tag{9}$$

To sum up, the explanation of the interactive terms is provided in Table 1 as follows:

Table 1. Interaction terms and explanations.

Eq.	Interaction terms	Expected sign	Explanations
(3)	*FDI ×RGDPC*	+/-	FDI through the scale effect accelerates economic expansion and leads to an increase in CO_2 emissions in which multinational FDI operations are associated with higher inputs and an increase proportion of polluting sectors thus increase in the production scale, thereby raising energy consumption and pollution since scaling up economic activity is associated with higher energy use and generates negative environmental externality. However, the scale effect of FDI, when accompanied by high-quality labour mobility and the introduction of advanced managerial experience to domestic firms can increase the production efficiency, reduce the level of energy intensity, which in turn reduces CO_2 emissions.
(4)	*FDI × RGDPC*^{2}	+/-	FDI's impact through the technique effect can minimize emissions by transferring eco-friendly technologies such as energy-saving or low-carbon technology, developing new as well as more modern technologies, and by encouraging competitors in the domestic market to upgrade their technology (technology intensive), resulting in reducing CO_2 emissions. On the contrary, there are circumstances where technological advancement might lead to an increase in energy demand and consumption (rebound effect), which in turn would increases

			CO_2 emissions.
(5)	*FDI × K/L*	+/-	FDI through composition effect could contributes to shifts in economic structure towards industry (capital intensive) and relocation of dirty industries (comparative advantage), which increases CO_2 emissions. In contrast, FDI might potentially shift the economic structure towards the service sector or utilize more capital-efficient or labour intensive production methods, leading the industrial sector to shrink and, as a result, reducing CO_2 emissions.

Data description

This study utilized a panel of 115 nations to analyze the decomposition effect of scale, technique and composition effects of FDI on CO_2 emissions. The data were taken from the World Development Indicators (WDI) and Worldwide Governance Indicators (WGI) databases, covering the period from 1999 to 2019 with 3 years non-overlapping averages. The study's time span is constrained by the availability of data for variable selection. Table 2 reported an overview of the variable descriptions and sources.

Dependent variable

CO_2 represents the total carbon dioxide emissions from fossil fuel usage, calculated in metric tonnes per capita. Similar to Voumik and Ridwan (2023) and Khan and Safdar (2023), this proxy is adopted to denote environmental degradation.

Independent variable

FDI : The net FDI inflows as a proportion of GDP sourced from the WDI. Typically, FDI can have both positive and negative externalities. FDI is presumed to lead an increase carbon emission (Salahuddin et al. 2018; Nadeem et al. 2020; Farooq 2022; Wang et al. 2022) because FDI boosts economic activity that is focused more in energy-intensive businesses as environmental regulations as relaxed (Grimes and Kentor 2003; Musah et al. 2022). Contrarily, nations attract FDI from technology-intensive industries, which encourage technology transfer, improved productivity and the development of management abilities, ultimately contributing to a cleaner environment in the host nations (Jiang et al. 2018)

RGDPC : The real GDP per capita which is calculated as the gross domestic product divided by midyear population (constant 2015 US$) obtained from the WDI online database. Multinational FDI operations are associated with higher inputs and, thus increase in the production scale in the host country, which may raise energy consumption and CO_2 emissions since scaling up economic activity is associated with higher energy use and generated negative environmental externality by causing environmental degradation (scale effect). Therefore, *RGDPC* is predicted to increase carbon emissions (Pao and Tsai 2011; Udeagha and Breitenbach 2023).

$RGDPC^2$: The square of *RGDPC* is to assess the technique effect (Ling et al. 2015; Shahbaz et al. 2022; Shahbaz et al. 2023). Changes in the production process, such as a technological shock or the adoption of low-carbon technologies, can result in a detrimental effect on carbon emissions (Zarsky 1999), which may then lead to the

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development, transfer, and diffusion of more modern and effective technology. It also examines whether the relationship between CO_2 and economic growth is inverted U-shaped or U-shaped (Shahbaz et al. 2018) and to conform the existence theory of EKC as proposed by Kostakis et al. (2023), if slope coefficients of $RGDPC > 0$ and $RGDPC^2 < 0$, which implies that economic growth increases environmental degradation but declines after attaining a certain point. Therefore, $RGDPC^2$ is expected to adversely affect CO_2 emissions (Zarsky 1999).

K/L: The capital-labor ratio is calculated by dividing gross capital formation (in real US$) by total labour force (in thousands), which is used to figure out the composition effect (Tsurumi and Managi 2010; Pazienza 2019). Countries change their production composition in respond to structural economic change; therefore, depending on the degree of development of the country, whether the economy is more energy-intensive or more technologically-intensive, we anticipate either a positive or negative effect (Shahbaz et al. 2019). Higher capital-labor ratio (capital intensity) associated with the expansion of energy-intensive sectors, which would lead to a higher production level, more consumption and greater carbon emissions (Cole 2006), or it may signal the expansion of capital-efficient companies, which would lead to lower CO_2 emissions.

INS: institutional quality as determined by WGI. Even if well-funded, the development programme would fail under the weight of weak institutional quality. (Lehnert et al. 2013; San and Chin 2023). It is computed by taking the average of the six governance indicators. Institutional quality anticipates a favourable relationship between institutional quality and CO_2 emission reduction (Zhang et al. 2020; Omri and Hadj 2020; Khan and Rana 2021). However, weak environmental regulations or corruption erodes the efficacy of institutions, which can result in environmental degradation (Le and Ozturk 2020; Liu et al. 2020; Naz and Aslam 2023). Therefore, the impact of institutional quality may influence CO_2 emissions in both positive and negative ways.

In the model estimation, this study additionally includes trade openness and urbanization as control variables. This analysis used trade openness (% of GDP) and urban population (% of total population) from WDI as proxies for openness and urbanization. One the one hand, trade openness (*TOP*) is expected to influence CO_2 emissions inversely (Acheampong 2018; Opoku and Aluko 2021), whereby trade openness allows for the transfer of technologies, which promotes environmental conservation, but on the other hand, trade openness precedes a surge in manufacturing activity, which contaminates the environment (Khan and Safdar 2023). Regarding urbanization (*URB*), Ali et al. (2020) and Sikder et al. (2022) demonstrate that urbanization leads to an increase in CO_2 emissions. Thus, trade openness is expected to have both a positive and negative impact on CO_2 emissions while urbanization has a negative impact on CO_2 emissions. Although previous research suggested that energy consumption carried a significant direct association on CO_2 emissions, this study excluded energy consumption in the estimation because the data is generated from energy consumption and both variables have a high correlation (Itkonen 2012), which may the cause for the biased-estimation of the parameters and resulting incorrect inference concerning the statistical significance of parameters (Jaforullah and King 2017; Malik et al. 2020; Mahmood et al. 2020; Frodyma et al. 2022)

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Table 2. Summary of Variables Description and Source

Variable	Symbol	Measurement	Data Source	Expected Sign
Carbon Emissions	CO_2	CO_2 emissions (metric tons per capita)	WDI	-
Foreign Direct Investment	*FDI*	Foreign direct investment, net inflows (% of GDP)	WDI	Positive/negative
Real Gross Domestic Product per capita	*RGDPC*	RGDPC (constant 2015 US$)	WDI	Positive
Square of Real Gross Domestic Product per capita	$RGDPC^2$	Squared of RGDPC (constant 2015 US$)	WDI	Positive/negative
Capital-labor ratio	*K/L*	Ratio = Gross Capital Formation (in real US$) / total work force (in thousands).	WDI	Positive/negative
Institutional quality	*INS*	Six broad dimensions of governance (%)	WGI	Positive/negative
Urbanization	*URB*	Urban population (% of total population)	WDI	Positive
Trade openness	*TOP*	Sum of exports and imports of goods and services (% of GDP)	WDI	Positive/negative

Research method

To gauge empirical results, System GMM estimator was utilized as suggested by Blundell and Bond (1998). First, GMM works to eliminate serial correlation and heteroskedasticity in the error structure by using the consistent estimator. Second, GMM is efficient when we have less time periods and more cross section (T < N) (e.g.: we have many observed individual but few observations over time). Third, the System GMM technique used to describe CO_2 as a dynamic process in which prior CO_2 effects present CO_2. The linkage of FDI and CO_2 is believed to be impacted by reverse causality as well as endogeneity, which might lead to estimators with downward biased parameters. (Nickell 1981). To deal with these concerns, Arellano and Bond (1991) proposed a difference GMM estimator, whereby the differenced endogenous explanatory variables are instrumented with appropriate lags to ensure the instruments are uncorrelated with the error term. Fourth, the existence of a lagged dependent variable in the model will give rise to autocorrelation problems, therefore, the System GMM estimator has advantage to deal with the issue of autocorrelation problems by employs lagged differences instruments for level series and lagged levels of instruments for differenced series to integrate regressions in levels and differences in the equations. The risk of having too many instruments, however, might result in the parameter estimates overfitting the endogenous regressors, invalidating the test for overidentifying limitations (Roodman 2009). Therefore, the Hansen J-test, as introduced by Roodman (2009), is used to detect

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overfitting of endogenous regressors and over-identification in which to fulfil the condition for the lack of instruments to be serial correlation in the error term. In order to guarantee the consistency of estimates, the Arellano–Bond (AR2) as proposed by Arellano and Bond (1991) which is used to test for second order correlation in the error term is applied in this work. Finally, the consistency of the System GMM estimators must also meet the requirement that there be fewer instruments than groups (countries) in the regression.

Empirical results and discussion

Table 3 displays the descriptive statistics and correlation matrix. The average value of per capita CO_2 emissions, FDI net inflows as share of GDP, real gross domestic product per capita (constant 2015 US$), squared of real gross domestic product per capita (constant 2015 US$), capital-labor ratio, institutional quality measured as average of six broad dimensions of governance (%), urbanization measured as urban population (% of total population) and trade openness measured as sum of exports and imports of goods and services (% of GDP) in logarithm are respectively, 0.73, 2.76, 8.63, 76.67, 7.99, 3.78, 4.00 and 4.26. In comparison to other variables, the standard deviations of squared of real gross domestic product per capita is rather high. The FDI indicator is the least volatile, which suggests that FDI is stable from 1999–2019. From the correlation's findings, we discover a highly positive associations between CO_2 emissions and real per capita GDP, squared of real per capita GDP, capital-labor ratio, and urbanization, and the lowest positive link with FDI, which further encourages this study to explore the FDI's indirect impact on CO_2 emissions. These findings indicate that real per capita GDP, squared of real per capita GDP, capital-labor ratio, and urbanization significantly contribute to rising CO_2 emissions. Surprisingly, CO_2 emissions are positively connected with institutional quality, which implies that institutional quality have increasing carbon emissions.

Table 3. Descriptive statistics and correlation matrix (1999–2019).

	CO_2	FDI	RGDPC	$RGDPC^2$	K/L	INS	URB	TOP
Mean	0.73	2.76	8.63	76.67	7.99	3.78	4.00	4.26
Std. Dev	1.56	0.33	1.47	25.19	1.48	0.62	0.46	0.53
Min	-3.81	0.03	5.61	31.51	3.28	0.59	2.11	0.28
Max	3.31	5.99	11.37	129.17	11.26	4.60	4.58	5.75
CO_2	1.0000							
FDI	0.1268***	1.0000						
RGDPC	0.8887***	0.1199***	1.0000					
$RGDPC^2$	0.8633***	0.1169***	0.9965***	1.0000				
K/L	0.8655***	0.1268***	0.9445***	0.9336***	1.0000			
INS	0.6886***	0.1507***	0.7775***	0.7780***	0.6912***	1.0000		
URB	0.8185***	0.1435***	0.7978***	0.7722***	0.7630***	0.5583***	1.0000	
TOP	0.4054***	0.3838***	0.3254***	0.3140***	0.3202***	0.3871***	0.3045***	1.0000

Note: *** indicate significance at 1%

In this study, we employed System-GMM to examine how different factors affect CO_2 emissions. Tables 4 provides the empirical findings of System-GMM. To satisfy the

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information criteria, two different tests need to be evaluated. First, the absence of second-order Arellano and Bond test (AR (2)) in residuals must be detected. Second, Hansen tests, which are used to validate that the instrumental variables is orthogonal with the error terms, and must be insignificant. The estimation results for Model 1 is passed AR(2) test and Hansen test. The lagged coefficient of CO_2 (ln$CO_{2i,t-1}$) is significant in Model 1 which confirmed of dynamic effects.

In Table 4, the System-GMM results revealed that the FDI is positively significant, signifying that increased FDI contributes to experience environmental deterioration on CO_2 emissions in which FDI boosts economic activity that is related more in energy-intensive businesses or possibly to polluting industries (high emission-intensive production) as well as environmental regulations relaxed (Grimes and Kentor 2003; Essandoh et al. 2020; Musah et al. 2022) and therefore FDI leads an increase carbon emissions (Salahuddin et al. 2018; Ali et al. 2020; Nadeem et al. 2020; Alshubiri et al. 2021; Farooq 2022; Wang et al. 2022; Ding et al. 2023a), which supported the pollution haven hypothesis. However, the findings contradict those of Zhang and Zhou (2016) and Pujiati et al. (2023), who conjectured that FDI that transferring technology might encourage domestic enterprises to innovate and embrace new technologies, hence increasing energy efficiency and advancing low-carbon economic growth. Therefore, based on the findings, Hypothesis 1 is validated.

Meanwhile, the System-GMM results for the linear *RGDPC* (scale effect) is positive, implies increases CO_2 emissions; while the quadratic term of $RGDPC^2$ (technique effect) is negative, implies decrease CO_2 emissions. This finding indicates that the presence of inverted U-shaped relationship between *RGDPC* and CO_2 emissions. In other words, the association between income level (RGDPC) and CO_2 emissions is favourable at an early stage of development (scale effect), while it is detrimental at a later stage of development (technique effect). With respect to *RGDPC* (scale effect), the multinational FDI operations are associated with higher inputs and, thus increase in the production scale in the host country, which may raise energy consumption and CO_2 emissions since scaling up economic activity is associated with higher energy use and generated negative environmental externality by causing environmental degradation (scale effect). Therefore, *RGDPC* is increasing carbon emissions (Pao and Tsai 2011; Mert et al. 2019; Opoku and Aluko 2021). Thus, Hypothesis 2 is empirically supported. In regard with $RGDPC^2$ (technique effect), changes in the production process, such as a technological shock or adoption of green technologies, effective technology as well as the introduction of newer can have a negative effect on CO_2 emissions (Zarsky 1999; Udeagha and Breitenbach 2023). Hypothesis 3 is empirically verified. In terms of the composition effect, the *K/L* variable is positive and significant explain on CO_2 emissions; implies that countries change their production composition in respond to structural economic change; therefore, higher capital-labor ratio (capital intensity) associated with the expansion of energy-intensive sectors anticipate a positive effect, which would lead to a higher production level, more consumption and greater CO_2 emissions (Cole et al. 2005; Cole 2006; Khan and Safdar 2023). Based on empirical findings, Hypothesis 4 is empirically validated. In light of the three economic mechanisms, scale effect and composition effect are positive, however technique effect is negative, which results are consistent with the study of Nejati and Taleghani (2022). Moreover, the result illustrated that scale effect dominates composition effect, which is followed by technique effect. Consequently, it is necessary to enhance the technical processes of production in order to minimize carbon emissions. In this context, low-carbon technology investment, technological advancements, and capital consumption reduction are significant in national policy implementation.

Besides that, institutional quality has favourable and significant influence on CO_2 emissions at 1%. The positive effect implies that the institutional quality failure or even powerless such as absence of control corruption, lax environmental regulations and poor political stability contribute to reduce environment degradation. The nexus can be explained by the fact that corruption or weak environmental regulations worsens the effectiveness of institutions which can lead to environmental deterioration (Le and Ozturk 2020; Naz and Aslam 2023). This result corroborates well with the findings of Liu et al. (2020) who found that economic governance such as regulatory quality positively affects CO_2 emissions; Samimi et al. (2012) who suggested that policies to improve governance indicators. Apart from that, a more relaxed regulatory environment or tax reductions or exemptions might attract more inward FDI, where investors can bribe the bureaucratic system to speed up legal permission for setting up a foreign plants and making FDI host countries easy prey, especially for those relying on FDI inflows to sustain economic development. Thus, investors or multinational companies that prioritize output and profits may relocate their polluting industries to nations with less stringent regulatory environments, leading to a rise in environmental contamination to rise. The results, however, are at contrast with the findings of Ali et al. (2019), who suggested that good institutional functioning results in appropriate rules, regulations, and property rights, as well as strategies to combat corruption, thereby reducing CO_2 emissions. In terms of the control variables, the findings reveal that the coefficient of urbanization is positive and significant in explaining on CO_2 emissions which is in line with Ali et al. (2020) and Musah et al. (2022) who explained that due to residents migrate towards the main urban cities. Similarly, Gyamfi et al. (2023) claimed that the positive influence of urbanization on CO_2 emissions increases over time, from the short term to the long term. Therefore, urban planners need to improve urban planning, which causes environmental problems (Sikder et al. 2022). Regarding the trade openness variable, trade openness is negative but insignificant explain on CO_2 (Ali et al. 2021).

In order to validate the consistency of the variables, this study conducted a fixed effect model and a placebo test (Ding et al. 2023b), as shown in Table 4 (Model 2 and Model 3). The results show that FDI remained has a positive impact on CO_2 emissions. In addition, the linear and square terms of RGDPC in Model 2 and Model 3 are positive and negative, respectively, indicating the existence of an inverted U shape and supporting the EKC theory. The signs of the institutional quality coefficients of the fixed-effects model and the placebo test are negative and significant, which contradicts the results estimated by the GMM estimates. Overall, the results are consistent with the GMM estimates.

Table 4. Baseline estimation results of two-step System-GMM and robustness checks.

	Baseline Model	Robustness checks	
	GMM	Fixed effect	Placebo test
	Model 1	Model 2	Model 3

FDI	0.2137**	0.0665***	0.0064
	(0.0833)	(0.0221)	(0.0154)
RGDPC	1.4737*	2.9455***	3.0345***
	(0.8529)	(0.2390)	(0.2388)
$RGDPC^2$	-0.0895**	-0.1384***	-0.1443***
	(0.0425)	(0.0138)	(0.0138)
K/L	0.1599*	0.0583**	0.0640***
	(0.0894)	(0.0226)	(0.0227)
INS	0.6119***	-0.2627***	-0.2635***
	(0.1986)	(0.0397)	(0.0400)
URB	0.2013	1.1435***	1.1424***
	(0.1893)	(0.1118)	(1.1126)
TOP	-0.0820	-0.1002***	-0.1005***
	(0.0723)	(0.0282)	(0.0284)
Constant	-10.1879***	-17.7840***	-17.9687***
	(3.7332)	(0.8956)	(0.8993)
CO_2 (-1)	0.6075***		
	(0.1301)		
Observations	690	805	805
Number of country	115	115	115
Country FE		Yes	Yes
Year FE		Yes	Yes
AR (2)	0.333		
Hansen - test	0.608		
Number of Instruments	22		

Note: ***, **, and * indicate significance at 1%, 5% and 10%, respectively. Numbers in parentheses are standard errors; Hansen test and AR (2) which is p-values. All variables are log variables.

Table 5 presented that the lagged value of CO_2 (ln$CO_{2i,t-1}$) is positive and significant which illustrates that the dynamic nature of the CO_2 emissions and the accumulated past CO_2 emissions has an positive impact on current CO_2 emissions. Addressing the indirect effect of FDI on CO_2 emissions, this study incorporated interaction term in the analysis where FDI interacted with the three economic mechanisms namely, scale effect (measured by *RGDPC*), technique effect (measured by $RGDPC^2$) and composition effect (measured by *K/L*) which presented in Table 5. In order words, the interaction term play an essential role in order to capture whether FDI lead to aggravate or mitigate CO_2 emissions through scale effect, technique effect and composition effect. Firstly, the coefficient on interaction term (ln*FDI* × ln*RGDPC)* is -0.0947 and significant at 1% level, indicating that improvements in scale effect (*RGDPC*) mitigates the adverse effect of FDI on CO_2 emissions through production efficiency (De Vita et al. 2021), which shows that foreign investors bring with their own high quality labour mobility as well as advanced managerial skills that increases the host country's production efficiency (Blalock and Gertler 2008) and therefore accelerates economic expansion and adds to a decrease in CO_2 emissions, supporting Pollution halo hypothesis.

Secondly, $RGDPC^2$ individually fails to explicate the nexus, however, the coefficient on interaction variable (lnFDI × ln$RGDPC^2$) is -0.0063 and significant at 5% level, signifying that greater $RGDPC^2$ modulates the negative effect of FDI on CO_2 emissions, which indicate that FDI through technique effect transfers the application of green or low-carbon technologies and advanced technology can have a negative influence

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on carbon emissions (Zarsky 1999). Aside from that, FDI impact through technique effect can minimize emissions by transferring eco-friendly technologies to recipient countries (Albulescu et al. 2020), creating renewable energy sources (Liobikienė and Butkus 2019), and as well as encouraging competitors in the domestic market to upgrade their technology (Shahbaz et al. 2019), supporting the Pollution halo hypothesis. Similar findings were made by Liobikienė and Butkus (2019), but they deemed to be insignificant in explaining the nexus.

Lastly, the coefficient on interaction term (ln*FDI* × ln*K/L)* is -0.1380 and significant at 10% level, exhibits that enhancing *K/L* moderates the negative effect of FDI on CO_2 emissions, which indicate FDI through composition effect potentially lead the economy to restructure or move the economic structure towards the service sector where optimizing the industrial structure in the tertiary industry has an essential impact in lowering CO_2 emissions (Zhang and Zhou 2016). Besides that, the expansion of capital-efficient or labour intensive production methods (Tsurumi and Managi 2010) in presence of technique effect, leading the industrial sector to shrink and, as a result, reducing CO_2 emissions. Furthermore, the comparative advantage hypothesis argues that cheap labour attracts less-polluting sectors, resulting in lower CO_2 emissions (Zhang and Zhou 2016). The result is also corroborated by the study of Liobikienė and Butkus (2019), but the author's finding found insignificant explain the linkage. In a nutshell, inferred from the findings is that although FDI harms CO_2 emissions but it's mitigated by the scale effect, technique effect and composition effect which support the pollution halo hypothesis as well. In light of the findings, the interaction term demonstrated that, when compared to other interaction terms, the moderating effect of $\ln FDI \times \ln RGDPC^2$ has the least influence on CO_2 levels in reducing the deleterious effects of FDI on CO_2. Therefore, countries acting as the primary censored should draw more FDI that accompanied by the transfer of advanced technologies and innovations to minimize CO_2 emissions.

However, the coefficient signs for both linear and quadratic term of *RGDPC* are consistent across Model 1 - Model 3, which is positive and negative, but insignificant explain on CO_2 emissions when interaction term included in the model estimation except Model 1. The coefficients of linear RGDPC and RGDPC squared are not statistically significant at conventional levels, hence we cannot draw the conclusion that the EKC hypothesis is supported across the entire panel. This result is in line with Antonakakis et al. (2017) and Xing et al. (2023), who did not discover evidence to support the EKC theory.

With respect to the control variables, although the estimation model includes the interaction term, the explanation of urbanization coefficient on CO_2 emissions is still positive (albeit insignificant). Nevertheless, the trade openness variable is negative and enters a significant sign; implying that trade openness is associated with improved environmental performance. This result is consistent with that of Opoku and Aluko (2021), who postulated countries will be encouraged to embrace modern, more environmentally friendly technology (Acheampong 2018) as a result of the intense competition that comes with openness.

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Lastly, the marginal impacts of FDI on CO_2 emissions were also calculated in this study to further explore the roles of scale effect, technique effect, and composition effect. From minimum to maximum, the marginal effect is significant but getting smaller. It is consistent throughout the three models. The marginal effect of FDI on CO_2 at maximum is lower than the marginal effects at mean and minimum. The positive marginal effect of scale, technique and composition effect in both minimum and mean level suggests that at FDI increases CO_2 emissions. However, the marginal effect at maximum is insignificant.

For robustness checks, this study incorporated financial development index (FD) (Omri et al. 2019) in the interaction model as additional control variable for sensitivity check which measured by overall financial institutions and financial markets while accounting depth, access, and efficiency. The coefficient of FDI persisted positively and has a significant impact on CO_2 emissions in Model 4 to Model 6. Meanwhile, the linear and squared term of RGDPC remain intact but insignificant except Model 4, which is consistent to results of GMM estimates. Moreover, the control variable for FD was negatively and positively associated with CO_2 emissions, but the connection between the two was only weakly supported. Turning to the view of interaction term, the results remain unchanged and conclude that there is evidence to support the moderating role of scale effect, technique effect and composition effect in the FDI-CO_2 linkages. In addition, the marginal effect of FDI is positive and significant at the minimum and mean value, but insignificant at the maximum value; which is also consistent with the baseline interaction results of GMM estimates.

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Table 5. Results of interaction term based on the two-step System-GMM.

	Baseline interaction regression			Robustness checks		
Variable	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Constant	-5.9061**	-6.1950*	-7.3908**	-6.7535***	-6.0561*	-7.9484**
	(2.4150)	(3.3231)	(3.1701)	(2.4044)	(3.5119)	(3.6294)
CO_2 (-1)	0.7898***	0.7456***	0.7820***	0.9066***	0.7904***	0.7988***
	(0.1237)	(0.1479)	(0.1544)	(0.1235)	(0.1658)	(0.1729)
FDI	1.1221***	0.8187**	1.3974*	1.5831***	0.6890***	1.7765***
	(0.3134)	(0.3470)	(0.7485)	(0.4595)	(0.2401)	(0.6322)
RGDPC	0.6967*	0.7508	0.2275	0.9932**	0.7221	0.3257
	(0.3629)	(0.6439)	(0.7894)	(0.4673)	(0.6586)	(0.8699)
$RGDPC^2$	-0.0342**	-0.0309	-0.0293	-0.0421**	-0.0376	-0.0326
	(0.0160)	(0.0325)	(0.0413)	(0.0183)	(0.0339)	(0.0463)
K/L	0.2463***	0.2287*	0.5879***	0.2159***	0.2577***	0.6526***
	(0.0784)	(0.124)	(0.2010)	(0.0805)	(0.0889)	(0.1910)
INS	0.3133***	0.2960***	0.3417***	0.1631	0.2820***	0.2595***
	(0.0914)	(0.1044)	(0.1191)	(0.1415)	(0.0990)	(0.0907)
URB	0.1013	0.0609	0.6595*	-0.1300	0.1594	0.5818
	(0.1215)	(0.2662)	(0.3904)	(0.1969)	(0.3133)	(0.3792)
TOP	-0.4011***	-0.4267***	-0.3694***	-0.2788*	-0.3955***	-0.3568***
	(0.1031)	(0.1174)	(0.1210)	(0.1499)	(0.1042)	(0.1255)
FD				-0.0141	-0.0018	0.0824
				(0.0522)	(0.0744)	(0.1064)
FDI × RGDPC	-0.0947***			-0.1472***		
	(0.0291)			(0.0482)		
FDI × $RGDPC^2$		-0.0063**			-0.0052**	
		(0.0031)			(0.0023)	
FDI × K/L			-0.1380*			-0.1802***
			(0.0818)			(0.0687)
Observations	690	690	690	690	690	690
Number of country	115	115	115	115	115	115
AR (2)	0.232	0.191	0.192	0.389	0.245	0.224
Hansen - test	0.130	0.167	0.156	0.115	0.113	0.115
Number of Instruments	21	19	18	21	20	19
Min	0.5907***	0.6196*	0.9444*	0.7568***	0.5251***	1.1846***
Mean	0.3049***	0.3343**	0.2962*	0.3123***	0.2903***	0.3376***
Maximum	0.0463	0.0024	-0.1548	-0.0899	0.0173	-0.2518*

Note: ***, **, and * indicate significance at 1%, 5% and 10%, respectively. Numbers in parentheses are standard errors; Hansen test and AR (2) which is p-values. All variables are log variables.

Conclusion

Summary of the findings and policy implications

This study investigates the decomposing scale effect, technique effect and composition effect of FDI on CO_2 emissions in 115 nations. To achieve this aim, a pollution model was established for the period of 1999–2019. The results from the Generalized Method of Moments (GMM) showed that FDI, real GDP per capita, capital-labor ratio, institutional quality and urbanization increase CO_2 emissions while the square of real GDP per capita and trade openness contributed to reducing CO_2 emissions. Also, this study cannot infer that the EKC hypothesis is validated across the entire panel. The results pertaining to the three economic mechanisms illustrated that the scale effect dominates composition effect, which is followed by the technique effect. In regard to the interaction term, the moderating effect of $\ln FDI \times \ln RGDPC^2$ has the least influence on CO_2 levels in reducing the harmful effects of FDI on CO_2. As a result, it is necessary to enhance the technical processes of production in order to minimize carbon emissions. In this context, countries acting as the primary recipients should attract FDI accompanied by the development and transfer, modern and advanced technologies, as well as investments in low-carbon technology and reductions in capital consumption. Moreover, it can be noted that although FDI increase CO_2 emissions, these interaction term with three economic mechanisms, namely: scale effect (measured by RGDPC), technique effect (measured by $RGDPC^2$) and composition effect (measured by K/L) play moderate's role in mitigating the negative effect of FDI on CO_2 emissions.

To attain sustainable economic development through FDI in the host country and at the same time ensuring environmental sustainability, policymakers should take into account the indirect effects of factors on CO_2. This will enable them to strike a compromise between sustainable economic development and environmental sustainability, as explained below:

1. The implications of our study stem from the findings regarding the important role play by scale, technique and composition effects on environmental quality. In our case study, although FDI is beneficial from an economic growth perspective, its impact of FDI degrades on environmental quality is detrimental. Governments should gauge the activity of FDI on environmental quality. The interaction of FDI and scale effect is negatively influences on CO_2. These results can be explained in two ways. First, in the presence of multiplicative effects of FDI and scale effect, countries with stringent rules may force countries forced investors to relocate their polluting industries to host countries with laxer regulations, a phenomenon known as comparative advantage. Consequently, the governments, as the primary border authorities, should impose stringent requirements on foreign investors and establish higher standards to attract international businesses with environmentally friendly technologies. This approach would promote FDI investments in technological advancement and efficient production ultimately increasing the scale of the economy and promoting economic growth. Inadvertently, this would result in lower CO_2 emissions. Second, foreign investors bring with them high quality labour mobility as well as advanced managerial skills which increase the host country's production efficiency (Blalock and Gertler 2008). This accelerates economic expansion and contributes to achieving the halo effect, leading to a decrease in CO_2 emissions.

2. Considering the negative interaction effect of FDI and technique effect, FDI activities facilitate the transfer of new, modern, and energy-saving technologies, as well as low-carbon technology, to host countries. This leads to changes in production process, resulting in more efficient energy consumption and enhanced productivity, ultimately reducing CO_2 emissions. Furthermore, FDI accompanied by technological improvement has the least impact on CO_2 levels, lowering the negative impacts of FDI on CO_2. In this regard, governments should attract FDI directed toward green technology production techniques that utilize fewer inputs and advanced technology. Further, governments should implement incentive policies, such as tax reduction, to encourage enterprises to innovate. In this sense, the governments need to promote FDI geared towards advanced technology that utilizes minimal inputs and green technology production techniques.

3. In respect to the negative joint effect of FDI and composition effect, FDI has the potential to shift the economic structure towards the service sector, which typically consumes less energy compared to energy-intensive industries or manufacturing sector. With the rapid improvement in energy-efficient and capital-efficient production methods facilitated by the technique effect, there is an increase in high-skilled labour and a shrink industrial sector, ultimately resulting in reduced CO_2 emissions. In this case, the energy sector could possibly be the key underlying factor detrimental to environmental quality. First, the government should substitute conventional energy sources with renewable or alternate energy by encouraging FDI to expand its renewable energy sector. Second, the government should promote FDI into the tertiary industry, particularly energy intensive industries or technology-intensive industries, as well as imposed stricter environmental regulations. Third, the government should levy an environmental pollution tax or impose an emissions ceiling system on emission-intensive industries. This will propel industrial policy towards green production, reducing the economy's carbon intensity.

Limitation of Study and Recommendations for Future Research

To perform this empirical study precisely, despite efforts have been made, there are certain constraints that cannot be addressed in this research. First, although CO_2 is the main driver of greenhouse gas emissions, the ecological footprint can be employed in the future to assess pollution. Furthermore, the FDI in this study does not distinguish between types of FDI, such as those directed towards the primary, secondary, or tertiary sectors. The precise type of FDI is useful for determining what sort of FDI contributes to environmental quality.

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References

Acheampong, AO (2018). Economic growth, CO2 emissions and energy consumption: what causes what and where?. Energy Economics 74: 677-692. https://doi.org/10.1016/j.eneco.2018.07.022

Albulescu CT, Artene AE, Luminosu CT, Tămășilă M (2020) CO2 emissions, renewable energy, and environmental regulations in the EU countries. Environmental Science and Pollution Research 27: 33615-33635. https://doi.org/10.1007/s11356-019-06155-1

Albulescu CT, Tiwari AK, Yoon SM, Kang SH (2019) FDI, income, and environmental pollution in Latin America: Replication and extension using panel quantiles regression analysis. Energy Economics 84: 104504. https://doi:10.1016/j.eneco.2019.104504

Ali HS, Zeqiraj V, Lin WL, Law SH, Yusop Z, Bare UAA, Chin L (2019) Does quality institutions promote environmental quality?. Environmental Science and Pollution Research 26: 10446-10456. https://doi:10.1007/s11356-019-04670-9

Ali S, Yusop Z, Kaliappan SR, Chin L (2020) Dynamic common correlated effects of trade openness, FDI, and institutional performance on environmental quality: evidence from OIC countries. Environmental Science and Pollution Research 27(11): 11671-11682. https://doi:10.1007/s11356-020-07768-7

Ali S, Yusop Z, Kaliappan SR, Chin L (2021) Trade-environment nexus in OIC countries: fresh insights from environmental Kuznets curve using GHG emissions and ecological footprint. Environmental Science and Pollution Research 28(4): 4531-4548. https://doi:10.1007/s11356-020-10845-6

Al-Mulali U, Ozturk I (2016) The investigation of environmental Kuznets curve hypothesis in the advanced economies: the role of energy prices. Renewable and Sustainable Energy Reviews 54: 1622-1631. https://doi:10.1016/j.rser.2015.10.131

Alshubiri F, Elheddad M (2020) Foreign finance, economic growth and CO2 emissions Nexus in OECD countries. International Journal of Climate Change Strategies and Management 12(2): 161-181. https://doi:10.1108/ijccsm-12-2018-0082

Alshubiri F, Elheddad M, Jamil SA, Djellouli N (2021) The impacts of financial depth and foreign direct investment on the green and non-green energy consumption of OPEC members. SN Business & Economics 1(6): 77. https://doi.org/10.1007/s43546-021-00075-4

Antonakakis N, Chatziantoniou I, Filis G (2017) Energy consumption, CO2 emissions, and economic growth: An ethical dilemma. Renewable and Sustainable Energy Reviews 68: 808-824. https://doi:10.1016/j.rser.2016.09.105

Arellano M, Bond SR (1991) Some tests of specification for panel data : Monte Carlo evidence and application to employment equations. Review of Economic Studies 58(2): 277-297. https://doi:10.2307/2297968

Ayappan P, Chin L (2018) Intellectual property rights, foreign direct investment and economic growth. International Journal of Economics and Management 12(2): 535-548.

Bakhsh S, Yin H, Shabir M (2021) Foreign investment and CO2 emissions: do technological innovation and institutional quality matter? Evidence from system GMM approach. Environmental Science and Pollution Research 28(15): 19424-19438. https://doi:10.1007/s11356-020-12237-2

Blalock G, Gertler PJ (2008) Welfare gains from foreign direct investment through technology transfer to local suppliers. Journal of international Economics 74(2): 402-421. https://doi:10.1016/j.jinteco.2007.05.011

Blundell R, Bond S (1998) Initial conditions and moment restrictions in dynamic panel data models. Journal of Econometrics 87(1): 115-143. https://doi:10.1016/s0304-4076(98)00009-8

Chandran VGR, Tang CF (2013) The impacts of transport energy consumption, foreign direct investment and income on CO2 emissions in ASEAN-5 economies. Renewable and Sustainable Energy Reviews 24: 445-453. https://doi:10.1016/j.rser.2013.03.054

Cole MA (2006) Does trade liberalization increase energy use? Economics Letters 92: 108-112. https://doi:10.1016/j.econlet.2006.01.018

Cole MA, Elliott RJ, Shimamoto K (2005) Industrial characteristics, environmental regulations and air pollution: an analysis of the UK manufacturing sector. Journal of Environmental Economics and Management 50(1): 121-143. https://doi.org/10.1016/j.jeem.2004.08.001

Copeland B and Taylor M S (1994) North-South trade and the environment. Quarterly Journal of Economics 109(3): 755-787. https://doi.org/10.2307/2118421

De Vita G, Li C, Luo Y (2021) The inward FDI-Energy intensity nexus in OECD countries: A sectoral R&D threshold analysis. Journal of Environmental Management 287: 112290. https://doi:10.1016/j.jenvman.2021.112290

Demena BA, Afesorgbor SK (2020) The effect of FDI on environmental emissions: Evidence from a meta-analysis. Energy Policy 138: 111192. https://doi:10.1016/j.enpol.2019.111192

Dinda S (2004) Environmental Kuznets curve hypothesis: a survey. Ecological economics 49(4): 431-455. https://doi:10.1016/j.ecolecon.2004.02.011

Ding Y, Chin L, Taghizadeh-Hesary F, Abdul-Rahim AS, Deng P (2023a) How does government efficiency affect carbon emission intensity? A comprehensive empirical study. Environmental Science and Pollution Research 1-16. https://doi.org/10.1007/s11356-023-31069-4

Ding Y, Lee C, Lu M (2023b) Does market sentiment push up China's housing prices? An empirical study based on the data of 45 mainstream cities in China. Journal of Housing and the Built Environment 38(2): 1119-1147. https://doi.org/10.1007/s10901-022-09985-7

Dong Y, Shao S, Zhang Y (2019) Does FDI have energy-saving spillover effect in China? A perspective of energy-biased technical change. Journal of Cleaner Production 234: 436-450. https://doi:10.1016/j.jclepro.2019.06.133

Eluwole KK, Saint Akadiri S, Alola AA, Etokakpan MU (2020) Does the interaction between growth determinants a drive for global environmental sustainability? Evidence from world top 10 pollutant emissions countries. Science of The Total Environment 705: 135972. https://doi:10.1016/j.scitotenv.2019.135972

Esmaeili P, Lorente DB, Anwar A (2023) Revisiting the environmental Kuznetz curve and pollution haven hypothesis in N-11 economies: Fresh evidence from panel quantile regression. Environmental Research 228: 115844. https://doi.org/10.1016/j.envres.2023.115844

Essandoh OK, Islam M, Kakinaka M (2020) Linking international trade and foreign direct investment to CO2 emissions: any differences between developed and developing countries? Science of the Total Environment 712: 136437. https://doi:10.1016/j.scitotenv.2019.136437

Fakih A, Marrouch W (2019) Environmental Kuznets curve, a mirage? A non-parametric analysis for MENA Countries. International Advances in Economic Research 25: 113-119. https://doi:10.1007/s11294-019-09724-9

Farooq U (2022) Foreign direct investment, foreign aid, and CO 2 emissions in Asian economies: does governance matter? Environmental Science and Pollution Research 1-16. https://doi.org/10.1007/s11356-021-16115-3

Foo YS, Chin L, Chen KS, Allayarov P (2023) The determinants of international reserves in developing countries. Terra Economicus 21(3): 133-142. https://doi:10.18522/2073-6606-2023-21-3-133-142

Frodyma K, Papież M, Śmiech S (2022) Revisiting the environmental Kuznets curve in the European Union countries. Energy 241: 122899. https://doi.org/10.1016/j.energy.2021.122899

Grimes P, Kentor J (2003) Exporting the Greenhouse: Foreign Capital Penetration and CO? Emissions 1980 - 1996. Journal of World-Systems Research 261-275. https://doi.org/10.5195/jwsr.2003.244

Grossman GM, Krueger AB (1991) Environmental impacts of a North American free trade agreement. Cambridge, MA. https://doi.org/10.3386/w3914

Grossman GM, Krueger AB (1995) Economic growth and the environment. The Quarterly Journal of Economics 110(2): 353-377. https://doi.org/10.2307/2118443

Gyamfi BA, Onifade ST, Ridzuan AR, Shaari MS, Jena PK (2023) An environmental assessment of the impacts of corruption, foreign investment inflow and trade liberalization in the rapidly emerging Malaysian Economy. Environmental Science and Pollution Research 30(41): 93667-93685. https://doi.org/10.1007/s11356-023-28868-0

Haug AA, Ucal M (2019) The role of trade and FDI for CO2 emissions in Turkey: Nonlinear relationships. Energy Economics 81: 297-307. https://doi:10.1016/j.eneco.2019.04.006

Itkonen JV (2012) Problems estimating the carbon Kuznets curve. Energy 39(1): 274-280. https://doi:10.1016/j.energy.2012.01.018

Jaforullah M, King A (2017) The econometric consequences of an energy consumption variable in a model of CO2 emissions. Energy Economics 63: 84-91. https://doi:10.1016/j.eneco.2017.01.025

Jahanger A (2022) Impact of globalization on CO2 emissions based on EKC hypothesis in developing world: the moderating role of human capital. Environmental Science and Pollution Research 29(14): 20731-20751. https://doi.org/10.1007/s11356-021-17062-9

Jalil A, Mahmud SF (2009) Environment Kuznets curve for CO2 emissions: a cointegration analysis for China. Energy Policy 37(12): 5167-5172. https://doi.org/10.1016/j.enpol.2009.07.044

Jiang L, Zhou HF, Bai L, Zhou P (2018) Does foreign direct investment drive environmental degradation in China? An empirical study based on air quality index from a spatial perspective. Journal of cleaner production 176: 864-872. https://doi:10.1016/j.jclepro.2017.12.048

Jiang Y (2015) Foreign direct investment, pollution, and the environmental quality: a model with empirical evidence from the Chinese regions. The International Trade Journal 29(3): 212-227. https://doi:10.1080/08853908.2014.1001538

Kasimov I, Wencong L, Saydaliev HB (2023) Unlocking the potential of foreign direct investment to reduce energy intensity. Environmental Science and Pollution Research 1-19. https://doi.org/10.1007/s11356-023-27525-w

Khan M, Rana AT (2021) Institutional quality and CO2 emission–output relations: The case of Asian countries. Journal of Environmental Management 279: 111569. https://doi:10.1016/j.jenvman.2020.111569

Khan A, Safdar S (2023) Symmetric and asymmetric analysis of trade and environment in Pakistan. Environmental Science and Pollution Research 30(5): 11399-11416. https://doi.org/10.1007/s11356-022-22669-7

Kisswani KM, Zaitouni M (2023) Does FDI affect environmental degradation? Examining pollution haven and pollution halo hypotheses using ARDL modelling. Journal of the Asia Pacific Economy 28(4): 1406-1432. https://doi.org/10.1080/13547860.2021.1949086

Kostakis I, Armaos S, Abeliotis K, Theodoropoulou E (2023) The investigation of EKC within CO2 emissions framework: Empirical evidence from selected cross-correlated countries. Sustainability Analytics and Modeling 3:100015. https://doi.org/10.1016/j.samod.2023.100015

Lee JW (2013) The contribution of foreign direct investment to clean energy use, carbon emissions and economic growth. Energy Policy 55: 483-489. https://doi:10.1016/j.enpol.2012.12.039

Le HP, Ozturk I (2020) The impacts of globalization, financial development, government expenditures, and institutional quality on CO 2 emissions in the presence of environmental Kuznets curve. Environmental Science and Pollution Research 27: 22680-22697. https://doi:10.1007/s11356-020-08812-2

Lehnert K, Benmamoun M, Zhao H (2013) FDI inflow and human development: analysis of FDI's impact on host countries' social welfare and infrastructure. Thunderbird International Business Review 55(3): 285-298. https://doi:10.1002/tie.21544

Leitão NC, Dos Santos Parente CC, Balsalobre-Lorente D, Cantos Cantos JM (2023) Revisiting the effects of energy, population, foreign direct investment, and economic growth in Visegrad countries under the EKC scheme. Environmental Science and Pollution Research 30(6): 15102-15114. https://doi.org/10.1007/s11356-022-23188-1

Ling CH, Ahmed K, Binti Muhamad R, Shahbaz M (2015) Decomposing the trade-environment nexus for Malaysia: what do the technique, scale, composition, and comparative advantage effect indicate? Environmental Science and Pollution Research 22: 20131-20142. https://doi:10.1007/s11356-015-5217-9

Liobikienė G, Butkus M (2019) Scale, composition, and technique effects through which the economic growth, foreign direct investment, urbanization, and trade affect greenhouse gas emissions. Renewable energy 132: 1310-1322. https://doi:10.1016/j.renene.2018.09.032

Liu X, Latif K, Latif Z, Li N (2020) Relationship between economic growth and CO_2 emissions: does governance matter? Environmental Science and Pollution Research 27: 17221-17228. https://doi:10.1007/s11356-020-08142-3

Mahmood H, Alkhateeb TTY, Furqan M (2020) Exports, imports, foreign direct investment and CO_2 emissions in North Africa: Spatial analysis. Energy Reports 6: 2403-2409. https://doi:10.1016/j.egyr.2020.08.038

Malik M Y, Latif K, Khan Z, Butt HD, Hussain M, Nadeem MA (2020) Symmetric and asymmetric impact of oil price, FDI and economic growth on carbon emission in Pakistan: Evidence from ARDL and non-linear ARDL approach. Science of the Total Environment 726: 138421. https://doi:10.1016/j.scitotenv.2020.138421

Mert M, Bölük G (2016) Do foreign direct investment and renewable energy consumption affect the CO_2 emissions? New evidence from a panel ARDL approach to Kyoto Annex countries. Environmental Science and Pollution Research 23: 21669-21681. https://doi:10.1007/s11356-016-7413-7

Mert M, Bölük G, Çağlar AE (2019) Interrelationships among foreign direct investments, renewable energy, and CO_2 emissions for different European country groups: a panel ARDL approach. Environmental Science and Pollution Research 26: 21495-21510. https://doi.org/10.1007/s11356-019-05415-4

Musah M, Mensah IA, Alfred M, Mahmood H, Murshed M, Omari-Sasu AY, Boateng F, Nyeadi JD, Coffie, CPK (2022) Reinvestigating the pollution haven hypothesis: the nexus between foreign direct investments and environmental quality in G-20 countries. Environmental Science and Pollution Research 1-18. https://doi.org/10.1007/s11356-021-17508-0

Nadeem AM, Ali T, Khan MT, Guo Z (2020) Relationship between inward FDI and environmental degradation for Pakistan: an exploration of pollution haven hypothesis through ARDL approach. Environmental Science and Pollution Research 27: 15407-15425. https://doi:10.1007/s11356-020-08083-x

Naz A, Aslam M (2023) Green innovation, globalization, financial development, and CO_2 emissions: the role of governance as a moderator in South Asian countries. Environmental Science and Pollution Research 30(20): 57358-57377. https://doi.org/10.1007/s11356-023-26527-y

Nejati M, Taleghani F (2022) Pollution halo or pollution haven? A CGE appraisal for Iran. Journal of Cleaner Production 344: 131092. https://doi.org/10.1016/j.jclepro.2022.131092

Nguyen DK, Huynh TL D, Nasir MA (2021) Carbon emissions determinants and forecasting: Evidence from G6 countries. Journal of Environmental Management 285: 111988. https://doi:10.1016/j.jenvman.2021.111988

Nickell S (1981) Biases in dynamic models with fixed effects. Econometrica: Journal of the Econometric Society 1417-1426. https://doi:10.2307/1911408

OECD (2001) Environmental Outlook. OECD Publishing, Paris, France. https://doi.org/10.1787/9789264188563-en.

Omri A, Hadj TB (2020) Foreign investment and air pollution: do good governance and technological innovation matter?. Environmental Research 185: 109469. https://doi:10.1016/j.envres.2020.109469

Omri A, Euchi J, Hasaballah AH, Al-Tit A (2019) Determinants of environmental sustainability: evidence from Saudi Arabia. Science of the Total Environment 657: 1592-1601. https://doi:10.1016/j.scitotenv.2018.12.111

Opoku EEO, Aluko OA (2021) Heterogeneous effects of industrialization on the environment: Evidence from panel quantile regression. Structural Change and Economic Dynamics 59: 174-184. https://doi:10.1016/j.strueco.2021.08.015

Ouyang X, Gao B, Du K, Du G (2018) Industrial sectors' energy rebound effect: An empirical study of Yangtze River Delta urban agglomeration. Energy 145: 408-416. https://doi.org/10.1016/j.energy.2018.01.009

Pao HT, Tsai CM (2011) Multivariate Granger causality between CO2 emissions, energy consumption, FDI (foreign direct investment) and GDP (gross domestic product): evidence from a panel of BRIC (Brazil, Russian Federation, India, and China) countries. Energy 36(1): 685-693. https://doi:10.1016/j.energy.2010.09.041

Paramati SR, Mo D, Gupta R (2017) The effects of stock market growth and renewable energy use on CO2 emissions: evidence from G20 countries. Energy Economics 66: 360-371. https://doi:10.1016/j.eneco.2017.06.025

Paramati SR, Ummalla M, Apergis N (2016) The effect of foreign direct investment and stock market growth on clean energy use across a panel of emerging market economies. Energy Economics 56: 29-41. https://doi:10.1016/j.eneco.2016.02.008

Pazienza P (2019) The impact of FDI in the OECD manufacturing sector on CO2 emission: Evidence and policy issues. Environmental Impact Assessment Review 77: 60-68. https://doi:10.1016/j.eiar.2019.04.002

Pujiati A, Yanto H, Dwi Handayani B, Ridzuan AR, Borhan H, Shaari MS (2023) The detrimental effects of dirty energy, foreign investment, and corruption on environmental quality: New evidence from Indonesia. Frontiers in Environmental Science 10: 1074172. https://doi.org/10.3389/fenvs.2022.1074172

Rahman MM (2017) Do population density, economic growth, energy use and exports adversely affect environmental quality in Asian populous countries? Renewable and Sustainable Energy Reviews 77: 506-514. https://doi:10.1016/j.rser.2017.04.041

Rezek JP, Rogers K (2008) Decomposing the CO2-income tradeoff: an output distance function approach. Environment and development economics 13(4): 457-473. https://doi:10.1017/s1355770x08004385

Roodman D (2009) How to do xtabond2: An introduction to difference and system GMM in Stata. The Stata Journal 9(1): 86-136. https://doi:10.2139/ssrn.982943

Salahuddin M, Alam K, Ozturk I, Sohag K (2018) The effects of electricity consumption, economic growth, financial development and foreign direct investment on CO2 emissions in Kuwait. Renewable and Sustainable Energy Reviews 81: 2002-2010. https://doi:10.1016/j.rser.2017.06.009

Salim R, Yao Y, Chen G, Zhang L (2017) Can foreign direct investment harness energy consumption in China? A time series investigation. Energy Economics 66: 43-53. https://doi:10.1016/j.eneco.2017.05.026

Samimi AJ, Ahmadpour M, Ghaderi S (2012) Governance and environmental degradation in MENA region. Procedia-Social and Behavioral Sciences 62: 503-507. https://doi:10.1016/j.sbspro.2012.09.082

San CK, Chin L (2023) Impact of Public Debt on Economic Growth: A Quantile Regression Approach. South Asian Journal of Macroeconomics and Public Finance 12(2): 250-278. https://doi.org/10.1177/22779787231207218

Saqib N, Ozturk I, Usman M, Sharif A, Razzaq A (2023) Pollution haven or halo? How European countries leverage FDI, energy, and human capital to alleviate their ecological footprint. Gondwana Research 116: 136-148. https://doi.org/10.1016/j.gr.2022.12.018

Sarkodie SA, Strezov V (2019) Effect of foreign direct investments, economic development and energy consumption on greenhouse gas emissions in developing countries. Science of the Total Environment 646: 862-871. https://doi:10.1016/j.scitotenv.2018.07.365

Seker F, Ertugrul HM, Cetin M (2015) The impact of foreign direct investment on environmental quality: a bounds testing and causality analysis for Turkey. Renewable and Sustainable Energy Reviews 52: 347-356. https://doi:10.1016/j.rser.2015.07.118

Shahbaz M, Gozgor G, Adom PK, Hammoudeh S (2019) The technical decomposition of carbon emissions and the concerns about FDI and trade openness effects in the United States. International Economics 159: 56-73. https://doi:10.1016/j.inteco.2019.05.001

Shahbaz M, Loganathan N, Muzaffar AT, Ahmed K, Jabran MA (2016) How urbanization affects CO2 emissions in Malaysia? The application of STIRPAT model. Renewable and Sustainable Energy Reviews 57: 83-93. https://doi:10.1016/j.rser.2015.12.096

Shahbaz M, Nasir MA, Roubaud D (2018) Environmental degradation in France: the effects of FDI, financial development, and energy innovations. Energy Economics 74: 843-857. https://doi:10.1016/j.eneco.2018.07.020

Shahbaz M, Nasreen S, Abbas F, Anis O (2015) Does foreign direct investment impede environmental quality in high-, middle-, and low-income countries? Energy Economics 51: 275-287. https://doi:10.1016/j.eneco.2015.06.014

Shahbaz M, Sinha A (2019) Environmental Kuznets curve for CO2 emissions: a literature survey. Journal of Economic Studies 46(1): 106-168. https://doi:10.1108/jes-09-2017-0249

Shahbaz M, Sinha A, Ahmad S, Jiao Z, Wang Z (2023) Role of foreign direct investment in decomposing of scale and technique effects on China's energy consumption. International Journal of Finance & Economics 28(3): 3370-3385. https://doi.org/10.1002/ijfe.2597

Shahbaz M, Sinha A, Raghutla C, Vo XV (2022) Decomposing scale and technique effects of financial development and foreign direct investment on renewable energy consumption. Energy 238: 121758. doi:10.1016/j.energy.2021.121758

Sikder M, Wang C, Yao X, Huai X, Wu L, KwameYeboah F, Wood J, Zhao Y, Dou X (2022) The integrated impact of GDP growth, industrialization, energy use, and urbanization on CO2 emissions in developing countries: evidence from the panel ARDL approach. Science of the Total Environment 837: 155795. https://doi.org/10.1016/j.scitotenv.2022.155795

Sinha A, Shahbaz M, Balsalobre D (2017) Exploring the relationship between energy usage segregation and environmental degradation in N-11 countries. Journal of Cleaner Production 168: 1217-1229. https://doi:10.1016/j.jclepro.2017.09.071

Stern D I (2004) The rise and fall of the environmental Kuznets curve. World Development 32(8): 1419-1439. https://doi:10.1016/j.worlddev.2004.03.004

Sun C, Zhang F, Xu M (2017) Investigation of pollution haven hypothesis for China: an ARDL approach with breakpoint unit root tests. Journal of Cleaner Production 161: 153-164. https://doi:10.1016/j.jclepro.2017.05.119

Tsurumi T, Managi S (2010) Decomposition of the environmental Kuznets curve: scale, technique, and composition effects. Environmental Economics and Policy Studies 11: 19-36. https://doi.org/10.1007/s10018-009-0159-4

Udeagha MC, Breitenbach MC (2023) Revisiting the nexus between fiscal decentralization and CO2 emissions in South Africa: fresh policy insights Financial Innovation 9(1): 50. https://doi.org/10.1186/s40854-023-00453-x

Udemba EN, Yalçıntaş S (2021) Interacting force of foreign direct invest (FDI), natural resource and economic growth in determining environmental performance: a nonlinear autoregressive distributed lag (NARDL) approach. Resources Policy 73: 102168. https://doi:10.1016/j.resourpol.2021.102168

Voumik LC, Ridwan M (2023) Impact of FDI, industrialization, and education on the environment in Argentina: ARDL approach. Heliyon 9:e12872. https://doi.org/10.1016/j.heliyon.2023.e12872

Wang L, Liu G, Alkhatib S, Wang X, Dai J, Abbas SZ, Khan YA (2022) The impact of foreign direct investment on environment: evidence from newly industrialized countries. Environmental Science and Pollution Research 29(47): 70950-70961. https://doi.org/10.1007/s11356-022-20781-2

Wang S, Zeng J, Liu X (2019) Examining the multiple impacts of technological progress on CO2 emissions in China: a panel quantile regression approach. Renewable and Sustainable Energy Reviews 103: 140-150. https://doi:10.1016/j.rser.2018.12.046

Wu X, Li N (2011) Impact analysis of the foreign investment on environmental quality of Shandong. Energy Procedia 5: 1143-1147. https://doi:10.1016/j.egypro.2011.03.200

Xing L, Udemba EN, Tosun M, Abdallah I, Boukhris I (2023) Sustainable development policies of renewable energy and technological innovation toward climate and sustainable development goals. Sustainable Development 31(2): 1178-1192. https://doi.org/10.1002/sd.2514

Zarsky L (1999) Havens, halos and spaghetti: untangling the evidence about foreign direct investment and the environment. Foreign direct Investment and the Environment 13(8): 47-74.

Zhang C, & Zhou X (2016) Does foreign direct investment lead to lower CO2 emissions? Evidence from a regional analysis in China. Renewable and Sustainable Energy Reviews 58: 943-951. https://doi.org/10.1016/j.rser.2015.12.226

Zhang M, Liu X, Sun X, Wang W (2020) The influence of multiple environmental regulations on haze pollution: Evidence from China. Atmospheric Pollution Research 11(6): 170-179. https://doi:10.1016/j.apr.2020.03.008

Zubair AO, Samad ARA, Dankumo AM (2020) Does gross domestic income, trade integration, FDI inflows, GDP, and capital reduces CO2 emissions? An empirical evidence from Nigeria. Current Research in Environmental Sustainability 2: 100009. https://doi:10.1016/j.crsust.2020.100009

Appendix

Table A1. List of countries

1 Albania	30 Congo, Rep.	59 Jordan	88 Paraguay
2 Algeria	31 Costa Rica	60 Kazakhstan	89 Peru
3 Argentina	32 Croatia	61 Kenya	90 Philippines
4 Armenia	33 Cyprus	62 Korea, Rep.	91 Poland
5 Austria	34 Czechia	63 Kyrgyz Republic	92 Portugal
6 Bahamas, The	35 Denmark	64 Latvia	93 Romania
7 Bahrain	36 Dominican Republic	65 Lebanon	94 Russian Federation
8 Bangladesh	37 Ecuador	66 Lithuania	95 Rwanda
9 Belarus	38 Egypt, Arab Rep.	67 Madagascar	96 Saudi Arabia
10 Belgium	39 El Salvador	68 Malaysia	97 Senegal
11 Belize	40 Estonia	69 Mali	98 Sierra Leone
12 Benin	41 Eswatini	70 Malta	99 Slovak Republic
13 Bhutan	42 Finland	71 Mauritania	100 Slovenia
14 Bolivia	43 France	72 Mexico	101 South Africa
15 Bosnia and Herzegovina	44 Gabon	73 Moldova	102 Spain
16 Botswana	45 Germany	74 Morocco	103 Sudan
17 Brazil	46 Greece	75 Mozambique	104 Sweden
18 Brunei Darussalam	47 Guatemala	76 Namibia	105 Switzerland
19 Bulgaria	48 Guinea-Bissau	77 Nepal	106 Tanzania
20 Burkina Faso	49 Haiti	78 Netherlands	107 Togo
21 Burundi	50 Honduras	79 New Zealand	108 Tunisia
22 Cambodia	51 Hungary	80 Nicaragua	109 Uganda
23 Cameroon	52 Iceland	81 Niger	110 Ukraine
24 Canada	53 India	82 Nigeria	111 United Arab Emirates
25 Chile	54 Iran, Islamic Rep.	83 North Macedonia	112 United Kingdom
26 China	55 Ireland	84 Norway	113 United States
27 Colombia	56 Israel	85 Oman	114 Uruguay
28 Comoros	57 Italy	86 Pakistan	115 Vietnam
29 Congo, Dem. Rep.	58 Japan	87 Panama	