Environmental Science and Pollution Research (2023) 30:74441–74451
https://doi.org/10.1007/s11356-023-27727-2

RESEARCH ARTICLE

The environmental cost of FDI and spatial implications of CO2 emissions in Sub-Saharan Africa

Syed Jaffar Abbas[1,2] · **Asim Iqbal**[3] · **Muhammad Munawar Hussain**[2,4] · **Aftab Anwar**[3]

Received: 8 March 2023 / Accepted: 14 May 2023 / Published online: 20 May 2023

Abstract

This study endeavors to investigate the environmental cost of FDI inflows in the Sub-Saharan African (SSA) region over the period of 2006 to 2020. There are two opposing theories about how FDI impacts the environment, namely, the pollution halo hypothesis (PHH) and the pollution haven hypothesis (PH). Given the SSA region's poor environmental performance and potential spatial spillover effects on neighboring nations, the study underlines the necessity to look into the pollution hypotheses in the region. The examination is carried out through non-spatial and spatial panel data econometric approaches. The empirical findings provide evidence that an increase in FDI inflow by 1% in SSA is positively associated with increasing levels of CO2 emissions by 0.03% on average, thus validating the notion of a *pollution haven* in the region. Furthermore, the study reveals that the environmental spillovers of CO2 emissions are not confined to the host country alone, but also extend to neighboring nations. Other key determinants of CO2 emissions, including GDP, population, and urbanization, were also found to be positively linked to CO2 emissions, whereas the use of renewable energy resources was found to have a mitigating effect. The empirical findings offer valuable insights for policymakers and stakeholders in the SSA region. These insights highlight the importance of the adoption of renewable energy sources and enacting regulatory measures to monitor the environmental cost of FDI, with the aim of mitigating the deleterious consequences of CO2 emissions, not only in the host nation but also in the neighboring nations.

Keywords Foreign direct investment · CO2 emissions · Spatial autoregressive model · Pollution haven · Pollution halo

Introduction

FDI is a major source of capital and technology for developing countries, which helps raise living standards and create employment opportunities. However, it may also cause environmental damage. FDI's impact on the environment is contingent upon several factors, such as the host nation's economic situation, degree of development, and environmental regulatory framework. These factors play a crucial role in shaping the magnitude and nature of the environmental cost of FDI in the host nation. There are two contrasting hypotheses in the literature: the pollution halo hypothesis (PHH) and the pollution haven hypothesis (PH).

The PHH posits that environmental quality in the host country can improve due to FDI. This hypothesis states that multinational corporations that invest in developing nations bring with them advanced technology, efficient processes, and better environmental practices, leading to a reduction in environmental pollution (Sapkota and Bastola 2017; Saqib et al. 2023; Shahbaz et al. 2019b; Wang and Luo 2020). However, studies on FDI's effects on the environment in underdeveloped and developed nations have produced contrasting results, with the PHH being true in developed nations and not in underdeveloped nations due to poor environmental governance (Cole et al. 2006; Nguyen 2021).

Responsible Editor: Arshian Sharif

✉ Syed Jaffar Abbas
jaffar.abbas1@yahoo.com

1 Government Shalimar Graduate College, Baghbanpura, Lahore, Pakistan

2 Division of Management and Administrative Science, University of Education, Lahore, Pakistan

3 Department of Economics, Division of Management and Administrative Science, University of Education, Lahore, Pakistan

4 Higher Education Department, Govt. of the Punjab, Lahore, Pakistan

The PH suggests that FDI can lead to increased environmental degradation in countries with weak environmental regulations, as multinational corporations seek to take advantage of lower labor and production costs and avoid environmental regulations (Adeel-Farooq et al. 2021; Apergis et al. 2023; Cil 2023; Mahmood 2023). This notion has been validated by prior studies, which have shown that FDI can negatively affect the environmental values of lower-income countries (Cole et al. 2006; Yin et al. 2021). It is established that the phenomenon of PH can result in a rise in child and infant mortality in developing economies due to the proliferation of industrial water pollution (Jorgenson 2009).

Environmental degradation in one country can have a spillover effect on neighboring countries, creating interdependence between the environmental conditions of different nations. This interdependence occurs through several mechanisms, including air and water pollution, the spread of harmful chemicals, and the displacement of environmental problems from one area to another (Cheng 2016; Ning and Wang 2018; Zhang et al. 2019). For example, air pollution generated by industries in one country can travel across national borders and contribute to the deterioration of air quality in neighboring nations.

Similarly, the discharge of pollutants from industries or agricultural practices in one country can pollute rivers and other water sources, leading to environmental degradation in neighboring countries that rely on these resources for drinking water, irrigation, and other uses (Swain 1996). In addition, the displacement of environmental problems from one area to another can result in transboundary environmental degradation. This often occurs when countries export hazardous waste or toxic chemicals to other nations or when they engage in resource extraction practices that have negative environmental impacts in other countries (Swain 1996).

Research on the intricate connection between FDI and environmental degradation assumes paramount importance, particularly in the context of SSA countries (Mahmood et al. 2020), given the potential spatial linkages between environmental degradation in one country and its impact on neighboring countries. The region is known for its high levels of biodiversity, fragile ecosystems, and limited natural resources, making the preservation of the environment a pressing issue. Understanding the consequences of FDI on the environment is crucial to ensure that economic progress does not come at the cost of environmental degradation (Mahmood 2020), which may have severe consequences for both the host nation and its neighbors.

The idea of PH/PHH in SSA has been highlighted by some earlier studies; it was discovered that production capacity has a substantial impact and directly influences PM2.5 emissions (Malik et al. 2021). In some of the SSA nations, FDI seems to increase CO2 emissions, while the reverse effect is found in other nations (Kivyiro and Arminen 2014). Some studies discovered that FDI was mitigating CO2 emissions (Acheampong et al. 2019), while others found that FDI improved the environment (Ojewumi and Akinlo 2017). A reduction in carbon emissions via the use of renewable energy sources improved air quality (Hanif 2018). This demonstrates a debate among researchers on whether PH or PHH is present in SSA.

The SSA region is characterized by subpar environmental performance (Table 1), as evidenced by the low scores of most nations in the Environmental Performance Index (EPI). The EPI analyzes a country's environmental quality and sustainability; stronger environmental performance is indicated by higher EPI values. A majority of countries in the SSA region rank at the lower end of the 180 countries list. This presents a significant environmental concern and highlights the need to examine the pollution hypotheses in the region.

This paper conducts a thorough assessment of the linkage between FDI and environmental damage in SSA, with a particular emphasis on exploring any potential spatial linkages of environmental degradation in the region. A substantial contribution to the extant literature is made by this study by presenting a multifaceted understanding of the environmental cost of FDI in SSA. Through a systematic examination of this relationship, the study sheds light on the various factors that impact this association and whether it is a positive or negative one. The insights generated from this research hold significant implications for policymakers in the region, providing them with valuable information to inform decisions that are critical to environmental sustainability. The study provides a roadmap for harnessing FDI as a tool to support environmental sustainability and to help prevent or reduce environmental degradation in the region.

The literature on FDI's environmental cost in SSA is limited and does not adequately address the issue of spatial spillover effects. Previous studies have rather ignored to examine the externalities of CO2 emissions that result from the presence of PH in SSA. There is also conflicting evidence in the prior studies regarding the existence of both the PHH and PH in different regions (Nguyen 2021; Xu et al. 2021). This research endeavors to address the lacunae in the prior studies by analyzing the effect of FDI on CO2, spatial spillover effects of CO2, and verifying the phenomenon of PH in SSA. The findings have significant implications, as they impart an understanding of the ecological influence of FDI inflows and the requirement for boosting the use of renewable energy and regulating the environmental impact of FDI. This research also provides an invaluable contribution to a more comprehensive understanding of the potential CO2 emissions spillover effects on neighboring countries.

Table 1 EPI (2020) of 45 SSA countries investigated in this study

Sr	Country	EPI	EPI World Rank	Sr	Country	EPI	EPI World Rank	Sr	Country	EPI	EPI World Rank
1	Seychelles	58.2	38	16	Zambia	34.7	132	31	Angola	29.7	158
2	Gabon	45.8	76	17	Ethiopia	34.4	134	32	Togo	29.5	159
3	Mauritius	45.1	82	18	Mozambique	33.9	136	33	Mali	29.4	160
4	South Africa	43.1	95	19	Eswatini	33.8	137	34	Guinea-Bissau	29.1	161
5	Botswana	40.4	103	20	Rwanda	33.8	137	35	Lesotho	28.0	165
6	Namibia	40.2	104	21	Cameroon	33.6	139	36	Gambia	27.9	166
7	Burkina Faso	38.3	112	22	Cabo Verde	32.8	144	37	Mauritania	27.7	167
8	Malawi	38.3	112	23	Comoros	32.1	148	38	Ghana	27.6	168
9	Equatorial Guinea	38.1	115	24	Tanzania	31.1	150	39	Burundi	27.0	170
10	Sao Tome and Principe	37.6	119	25	Nigeria	31.0	151	40	Chad	26.7	172
11	Zimbabwe	37.0	123	26	Niger	30.8	152	41	Madagascar	26.5	174
12	Central African Republic	36.9	124	27	Republic of Congo	30.8	152	42	Guinea	26.4	175
13	Dem. Republic Congo	36.4	125	28	Senegal	30.7	155	43	Cote d'Ivoire	25.8	176
14	Uganda	35.6	127	29	Eritrea	30.4	156	44	Sierra Leone	25.7	177
15	Kenya	34.7	132	30	Benin	30.0	157	45	Liberia	22.6	180

Source: Wendling et al. (2020)

Literature review

The nexus between FDI and CO2 emissions is a multifaceted issue that has been the subject of many studies. Several researchers have attempted to investigate the different factors that contribute to environmental degradation including the industries and sectors involved, the technologies and methods used, and the environmental policies in place. In this literature review, several studies are highlighted that provide insight into the linkage between FDI and CO2 emissions.

Marques and Caetano (2022) investigated 15 OECD nations for CO2 emissions and FDI linkage and found the existence of PH. They recommended that policymakers concentrate on improving the national environmental legislation in the host countries. Yin et al. (2021) analyzed the linkage among CO2 emissions, FDI, and economic growth for a panel of 101 countries which were divided into 4 income groups. They used simultaneous equations framework for the period 1990 to 2014. Except for high-income countries, they discovered proof of bidirectional causal linkage between CO2 emissions and FDI. Xu et al. (2021) examined how the energy transition affects the linkage between SO2 emissions and FDI. Their study used a semi-parametric method for the period 2002 to 2006 on China's provincial panel data. Their study's results showed that due to an increase in coal consumption as a result of technological advancement, SO2 emissions are not reduced. Overall their study found a mix of both PHH and PH.

Wang and Luo (2020) employed panel data from thirty Chinese provinces spanning from 2006 to 2016 to assess the impact of FDI quality and quantity as threshold variables. Their study revealed that enhancing the quality of FDI can aid in the improvement of the environment, thereby recommending the incorporation of scientific and technological innovations. Meanwhile, Singhania and Saini (2021) probed the interrelationship among FDI, sustainability, and financial development by analyzing panel data from 21 developed and developing economies for the period 1990–2016. Results from their GMM and system-GMM models showed that FDI has a negative impact on the environment, supporting the existence of PH. Bildirici and Gokmenoglu (2020) examined the linkage between FDI and environmental pollution in selected developing economies through panel cointegration and causality tests covering the period 1975–2017. Their findings established a long-term bidirectional causal connection between FDI and CO2 emissions.

Wang et al. (2022) utilized a spatial econometrics approach by employing panel data from 276 Chinese cities, to examine the effect of FDI on urban haze pollution from 2004 to 2018. Their findings revealed that the relationship between FDI and urban haze pollution is positive. Nejati and Taleghani (2022) explored FDI's effect on the environment using environmental CGE models. These findings support the existence of PH and show that FDI harms the environment. Adeel-Farooq et al. (2021) analyzed the effect of FDI from developing and developed nations on the environment for 76 countries between 2002 and 2012. Their research revealed that PHH occurred when FDI came from rich nations and PH occurred when FDI came from underdeveloped countries.

Shahbaz et al. (2018) analyzed the linkage among CO2 emissions, FDI, energy use, financial development, energy research innovations, and economic growth in France. Their study used bootstrapping bounds testing approach to check cointegration for the period 1955–2016. They discovered that FDI has increased CO_2 emissions. Their study concluded the presence of PH in France. Shahbaz et al. (2019b) examined the linkage between energy use, trade openness, CO_2 emissions, and FDI in the USA for the period from 1965 to 2016. Their study found that FDI increased CO_2 emissions. It was recommended by the study to transform the energy consumption structure in order to protect the environment. Bakhsh et al. (2017) checked the impact of FDI on environmental pollution and economic growth in Pakistan from 1980 to 2014. They employed a simultaneous equation model to check the linkage. Results revealed a positive linkage between FDI and pollution in Pakistan.

In their recent study, Liu et al. (2022) examined the environmental cost of FDI in Pakistan spanning from 1980 to 2017 by utilizing ARDL bounds and the Bayer and Hancks test. Their findings provide compelling evidence that FDI inflows have inflicted severe environmental harm in Pakistan. Hitam and Borhan (2012) investigated the linkage among FDI, GDP growth, and environmental degradation. They analyzed the cost and benefit of FDI in the case of Malaysia from 1965 until 2010. Results of the non-linear model indicated that FDI increased environmental damage in Malaysia. Balsalobre-Lorente et al. (2022) examined the link among economic complexity, renewable energy, urbanization, FDI, and CO_2 emissions in PIIGS countries from 1990 until 2019 and confirmed the presence of PH in these countries.

Sapkota and Bastola (2017) analyzed how pollution emissions are effected by income and FDI in 14 countries of Latin America for the period from 1980 to 2010. They used fixed effect and random effect panel models to investigate the relation. Results of their estimated models indicated the presence of PH. It was recommended to adopt policies attracting clean and effective industries as FDI to improve the environment. Cole et al. (2006) studied the linkage between environmental policies and FDI using panel data from 33 countries for the time period from 1982 to 1992. The results of their study using fixed effect estimates showed that depending upon the degree of the corruptibility of the government, FDI affected environmental policies. PH was found in countries with high corruptibility. Nguyen (2021) examined how FDI affected the environment in developing and developed nations. This study used GMM for the time period from 2005 to 2018. The results supported PHH in 31 developed countries with good governance for environmental protection and supported a PH for 55 developing countries with bad environmental governance. They recommended better environmental policies are required in the case of developing countries.

Jorgenson (2009) investigated the link between FDI and industrial organic water pollution intensity. He estimated panel regression analysis for 33 developing economies from 1980 to 2000. The results of his study indicated the presence of positive relation between FDI and industrial water pollution. This analysis found that industrial water pollution increased infant and child mortality in developing counties. Raza and Hussain (2016) analyzed the linkage between FDI inflow, transport, storage and communication sector, and GDP growth utilizing the ARDL model for the period 1972–2011 in the case of Pakistan. The findings showed that Pakistan's carbon emissions rose as a result of FDI inflow. Hakimi and Hamdi (2016) investigated the relation between environmental quality and trade liberalization in Tunisia and Morocco. Their study used VECM and panel VECM for analysis. The findings revealed that the environment degraded because of FDI in both Tunisia and Morocco. There are several studies validating PH in different regions/countries (Table 2).

Ren et al. (2014) employed input–output analysis to check the linkage between CO_2 emissions and FDI in China for period 2000–2010. It was revealed that FDI inflow increases carbon emissions. It was recommended to adjust the FDI structure to lessen CO_2 emissions in China. Marques and Caetano (2020) explored how FDI and the environment are related. They used a Panel ARDL model for 21 countries grouped by income level. Their study checked FDI's impact on CO_2 emissions from 2001 to 2017. Their results showed that FDI reduced carbon emissions in high-income countries. Conversely, FDI increased carbon emissions in middle-income countries which reflects PH. Shahbaz et al. (2019a) examined how FDI and CO_2 emissions were related from 1990 until 2015. They used data of the MENA region to apply GMM technique. Results of their study revealed that FDI increased CO_2 emissions. A focus on cleaner production practices was recommended by designing enhanced trade and energy policies.

It is represented in the above-discussed review of the literature that FDI has caused environmental degradation in various countries. FDI and CO_2 emissions are linked, although the exact extent of the link depends on the particular situation. The building and operation of new industries, power plants, and other infrastructure projects that may be necessary to support the investment can generally result in higher CO_2 emissions. This may be especially true in developing nations, as FDI accelerates urbanization and industrialization both of which may have an adverse effect on the environment. The pollution haven hypothesis (PH) is a representation of the concept that FDI damages the host country's environmental conditions.

Data sources and methodology

Data sources

This study investigated how FDI affected CO_2 emissions in 45 SSA countries. The impact of additional control variables like GDP, population growth, renewable energy usage, and urbanization on CO_2 emissions was also estimated. The data

Table 2 Summary of existing studies validating PH

Authors	Countries	Time Period	Method and Techniques
Cole et al. (2006)	33 countries	1982–1992	Fixed effect estimates
Jorgenson (2009)	33 developing countries	1980–2000	Panel regression analysis
Hitam & Borhan (2012)	Malaysia	1965–2010	Non-linear model
Ren et al. (2014)	China	2000–2010	Input–output analysis
Raza & Hussain (2016)	Pakistan	1972–2011	ARDL
Hakimi & Hamdi (2016)	Morocco and Tunisia	1971–2013	VECM and panel VECM
Sapkota & Bastola (2017)	14 Latin American countries	1980–2010	Fixed effect and random effect models
Bakhsh et al. (2017)	Pakistan	1980–2014	Simultaneous equation model
Shahbaz et al. (2018)	France	1955–2016	Bootstrapping bounds testing approach
Shahbaz et al. (2019b)	United States	1965–2016	VECM Granger causality
Bildirici & Gokmenoglu (2020)	9 countries	1975–2017	Panel cointegration
Yin et al. (2021)	101 countries	1990–2014	Simultaneous equations framework
Singhania & Saini (2021)	21 countries	1990–2016	GMM
Adeel-Farooq et al. (2021)	76 countries	2002–2012	GMM
Wang et al. (2022)	276 Chinese cities	2004–2018	Generalized spatial 2SLS
Liu et al. (2022)	Pakistan	1980–2017	ARDL
Balsalobre-Lorente et al. (2022)	PIIGS countries	1990–2019	Dynamic ordinary least square (DOLS)

Source: Author's creation by doing literature review

was collected from WDI, World Bank. The missing data of CO2 emissions, FDI, GDP, renewable energy usage, and population growth were obtained by using ipolate method. This study examined the linkage among variables for the period from 2006 to 2020 (Table 3).

FDI sometimes entails building new facilities to manufacture goods or offer services in the host nation. These facilities, like factories or power plants, may use a lot of energy and produce a lot of CO2 during operation. The overall amount of CO2 emissions in the host nation may rise as a result of this activity. It is crucial to remember that FDI may also offer new technology and management techniques that can aid in lowering CO2 emissions. Nevertheless, it is crucial for host nations to carefully assess the potential CO2 emissions of FDI and put policies in place to prevent any negative effects.

The firms may target countries with laxer environmental restrictions in order to lower their compliance costs and boost their profitability. The theory suggests that businesses may opt to move their operations to countries with laxer environmental regulations in order to avoid the expenses related to adhering to stricter regulations, such as the expense of installing pollution control equipment or the expense of paying fines for exceeding emission limits (Adeel-Farooq et al. 2021; Nguyen 2021) As per PH, nations with lax environmental rules may draw more FDI from businesses eager to cut their compliance costs. This might result in increased pollution in these nations and decreased pollution in those with better environmental controls. Earlier studies have revealed a relation between greater levels of pollution and FDI from foreign firms in nations with laxer environmental restrictions, which lends some support to the PH (Bildirici and Gokmenoglu 2020; Jorgenson 2009).

This study utilized data from 45 SSA nations and discovered empirical evidence indicating the presence of PH in the region. Weak administration and a lack of resources in SSA have resulted in minimal enforcement of environmental laws, making the region a desirable location for environment-degrading FDI. As a result, FDI has contaminated

Table 3 Definition of variables

Variable	Description	Measurement
lnCO2	CO2 emissions	(kt)
lnGDP	GDP	Constant 2015 US$
lnFDI	Foreign direct investment	Net inflows (BoP, current US$)
lnEN	Renewable energy consumption	(% of total final energy consumption)
POP	Population growth	(Annual %)
UP	Urban population growth	(Annual %)

Source: WDI, World Bank

the environment. The ability to monitor and control CO2 emissions and their impact on the environment is severely constrained in many SSA countries.

It is evident from Fig. 1 that during the period from 2006 and 2019, the FDI has increased in SSA. The darker green color shade/legend shows a higher level of FDI inflow in 45 SSA countries which the present study investigated.

Figure 2 depicts the status of CO2 emissions in SSA during 2006 and 2019. The darker brown color shade/legend represents a higher level of CO2 emissions in 45 SSA countries. It is noted that CO2 emissions have increased in SSA during the abovementioned period. Increasing CO2 emissions may harm the environment in a variety of ways. As a greenhouse gas that traps heat in the atmosphere, CO2 has a negative impact on global warming. This may result in a variety of climatic changes, including more frequent and severe weather incidents, increasing sea levels, and changing precipitation patterns. In seawater, CO2 dissolves and produces carbonic acid. As a result, the seas' acidity rises, endangering sea life and upsetting entire ecosystems. Biodiversity can decrease as a result of climate change, which can impact plants, animals, and humans. Fossil fuel combustion produces air pollution that can be harmful to human health, especially for those who already have respiratory issues.

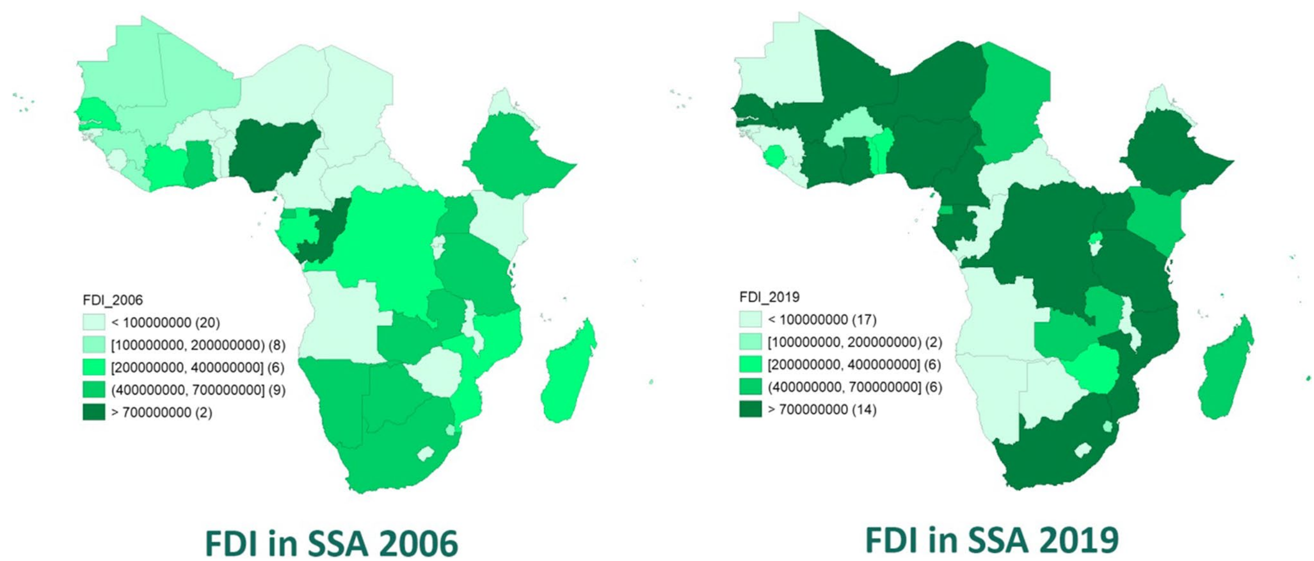

Fig. 1 FDI in SSA (2006 & 2019). Source: Author's creation by using WDI data

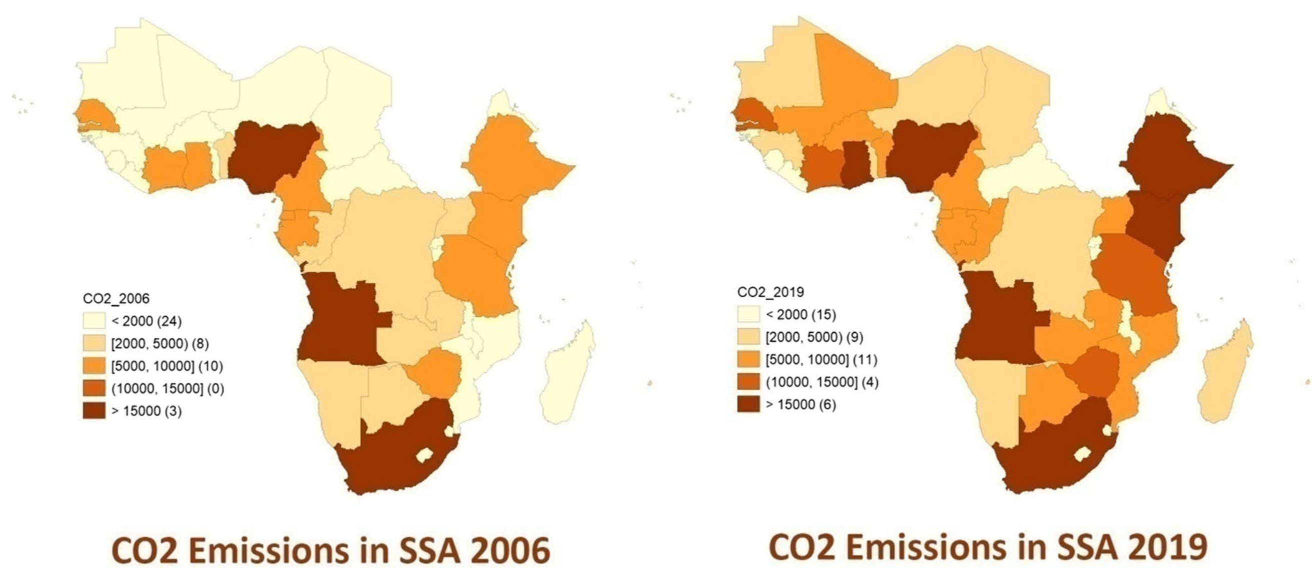

Fig. 2 CO2 emissions in SSA (2006 & 2019). Source: Author's creation by using WDI data

Methodology

There are some earlier studies done in the past to test the PH in different regions. In the case of SSA, a thorough investigation is still lacking, particularly the one that checks the spatial spillover effects of CO2 emissions due to FDI inflow. Therefore, by investigating the impact of FDI, GDP, renewable energy, population growth, and urbanization on CO2 emissions in 45 SSA countries, the present study covers a gap in the existing literature. For the purpose of rigor, this study estimated non-spatial model specifications and spatial autoregressive (SAR) model specifications to investigate the PH in 45 SSA countries. The purpose of performing both non-spatial and spatial analysis is to investigate the PH in both local and spatial aspects.

Initially, the present study estimates the effect of FDI on CO2 emissions in presence of controlled variables by using the cross-section fixed effect and random effect model. When there are more cross-sections than time periods in panel data, it is more appropriate to utilize GMM (Khan et al. 2020). To avoid the endogeneity problem, this study also applied system GMM.

$$\ln CO2_{it} = \gamma_1 \ln GDP_{it} + \gamma_2 \ln FDI_{it} + \gamma_3 \ln EN_{it} + \gamma_4 POP_{it} + \gamma_5 UP_{it} + \delta_{1i} + \theta_{1t} + \varepsilon_{1it} \quad (1)$$

where Eq. 1 represents the specification form of non-spatial models estimated by the present study. It is evident that γ's are the slope coefficients of the regressors, and δ_{1i} and θ_{1t} are the cross-section fixed effect and time fixed effect, respectively. Here, ε_{1it} is an error term which is identically independently distributed from independent variables. After performing the non-spatial analysis, this study applied the following spatial autoregressive (SAR) model to check the spatial spillover effects of CO2 emissions in SSA.

$$\ln CO2_{it} = \rho W.\ln CO2_{it} + \beta_1 \ln GDP_{it} + \beta_2 \ln FDI_{it} + \beta_3 \ln EN_{it} + \beta_4 POP_{it} + \beta_5 UP_{it} + \delta_{2i} + \theta_{2t} + \varepsilon_{2it} \quad (2)$$

where Eq. 2 represents the specification of SAR models estimated to check PH in SSA by this study. Here, ρ captures the spatial interdependence of CO2 emissions in SSA countries; δ_{2i} and θ_{2t} are the cross-section fixed effect and time fixed effect, respectively, in our SAR model; and ε_{2it} is the error term. It is evident from Eq. 2 that β's are the slope coefficients of the regressors.

Here, it is explained that W is a 45×45 matrix that represents the geographical distance in kilometers between the 45 SSA countries. Additionally, W is normalized, as Elhorst (2001) suggested. The spatial impacts in neighboring nations are estimated by the parameter of the variable multiplied by W. The Hausman test is used to determine which model is more suitable for analysis among fixed effect and random effect models. As this model may have the problem of endogeneity, to resolve this issue, the present study has utilized system GMM. It is an estimation method that efficiently estimates parameters by using moment conditions. The GMM estimator may find the parameters that best suit the data by resolving the moment conditions. Flexible moment conditions that can be specified to match the properties of the underlying data-generating process are possible to employ with GMM. As a result, GMM can be a helpful technique for modeling estimation when the method used to generate the data is not well known. Additionally, GMM permits the application of a variety of moment conditions, including orthogonality conditions, instrumental variables conditions, and control function conditions. GMM can still generate reliable estimates even if the underlying assumptions regarding the data-generating process are not fully met since it is relatively robust to model misspecification because GMM estimates the parameters based on the moment conditions rather than relying on the assumptions about the distribution of the data.

Results and interpretation

Table 4 displays the descriptive statistics of the variables analyzed in the present study. The descriptive statistics show an overall summary of the data which has been used in the current study to check PH in SSA.

The descriptive statics presented in Table 4 shows the overall picture of the data used in this study. Table 5 represents the non-spatial model results which were investigated to check PH in SSA. This study utilized fixed effect model, random effect model, and GMM to reach a rigorous non-spatial conclusion.

In Table 5, It is evident from the results of Hausman specification test that probability values of Hausman tests are less than 5%; this finding guides this study that random effect model is appropriate for estimating the impact of FDI inflow on CO2 emissions in SSA. It is indicated in all non-spatial models that FDI inflow is responsible for increasing CO2 emissions in SSA. This finding provides evidence for PH in SSA. The idea of FDI degrading the environment has been proved by earlier studies (Adeel-Farooq et al. 2021). GDP and population growth are found to be increasing CO2 emissions in SSA. This result is similar to some earlier investigations (Amin et al. 2021; Bakhsh et al. 2017; Chaabouni and Saidi 2017; Malik et al. 2021). Existing literature also indicates that an increase in GDP also causes the FDI to rise (Siddiqui and Iqbal 2018). The use of renewable energy and urbanization are causing a reduction in CO2 emissions. This finding is similar to earlier investigations (Li and Haneklaus 2022). Population growth is positively related to CO2 emissions, similar to earlier investigations (Ahmad et al. 2013).

Table 4 Descriptive statistics of variables used by present study

Variables	Observations	Mean	Std. Dev	Skewness	Kurtosis
lnCO2	675	7.885	1.625	0.487	3.854
lnGDP	675	22.972	1.475	0.225	3.341
lnFDI	675	22.808	0.265	−9.287	142.474
lnEN	675	3.970	0.855	−2.756	11.427
POP	675	2.441	0.931	−1.030	4.745
UP	675	3.704	1.334	−0.534	4.096
wCO2	675	7.860	0.232	−0.148	1.998

Source: Author's estimations

Table 5 Determination of CO2 emissions through non-spatial models to investigate PH in SSA

Variables	Specification 1 Country Fixed Effect	Specification 2 Random Effect	Specification3 System GMM
Lag.lnCO2			0.871*** (0.008)
lnGDP	1.131*** (0.035)	1.107*** (0.027)	0.130*** (0.010)
lnFDI	0.021 (0.029)	0.022 (0.029)	0.021*** (0.003)
lnEN	−0.382*** (0.075)	−0.374*** (0.055)	−0.015 (0.013)
POP	0.035 (0.025)	0.034 (0.024)	−0.001 (0.013)
UP	−0.004 (0.017)	−0.007 (0.016)	−0.012 (0.008)
Constant	−17.135*** (1.172)	−16.629*** (0.964)	−**2**.308*** (0.168)
R-squared	0.696	0.696	
F-test	286.748***		27,794,493.361
Chi-square		1917.631***	
Hausman test	2.98		

Source: Author's estimations, *** prob. < 0.01, ** prob. < 0.05, * prob. < 0.1 (standard error values are in parentheses)

Table 6 represents the spatial models which were investigated to check PH in SSA. This study applied Hausman test to check whether SAR fixed effect or random effect model is appropriate for estimation purpose. The Hausman test's probability value is greater than 10%; therefore, this study accepts the null hypothesis of using random effect model. This study used different specifications of the SAR models including SAR-GMM model to reach a rigorous spatial conclusion regarding the existence of PH in SSA.

In SAR model specification 5, the value of rho is significant at 5% and has a positive sign. It indicates that the CO2 in the FDI receiving nation has positive spillover effects in its neighboring countries. This finding supports the idea that rising CO2 levels in one nation may extend their impacts to nearby ones. In order to design an adequate environmental policy, regulations in one nation should be planned with adjacent nations in mind. It is observed that all SAR models show FDI inflow and CO2 emissions are positively related in SSA. These SAR models represent that FDI inflow has an environment degrading impact. It proves the existence of evidence for the PH. This result is comparable to several earlier studies (Apergis et al. 2023; Cil 2023; Nejati and Taleghani 2022). It occurs when FDI from developed nations flows toward developing nations at the cost of environmental damage, turning the recipient nations into a pollution haven for the FDI supplying country. It is observed that GDP is causing CO2 emissions to rise in SSA. This finding is similar to earlier research (Chaabouni and Saidi 2017). It happens because manufacturing and production usually cause CO2 emissions to rise. The use of renewable energy is reducing CO2 emissions; this idea has also been proven by other studies (Saidi and Omri 2020; Saqib et al. 2023). It has been discovered that population and urbanization are increasing CO2 emissions in SSA. This finding is similar to earlier investigations (Abbas et al. 2022; Firoj et al. 2023; Wang et al. 2019).

This study also estimated the spatial spillover effect of CO2 emissions with SAR-GMM. It is evident from SAR model specification 6 that distance-weighted CO2 emissions (*W*.lnCO2) in the case of 45 SSA countries are significantly related to CO2 emissions. This finding reveals the presence of cross-border spillover effects of CO2 emissions in SSA. It highlights the concern that FDI inflow in SSA is not only harmful for the recipient nation but also for the neighboring countries. The estimated SAR-GMM model demonstrates that the environment is being seriously damaged by FDI inflow in the region by increasing CO2 emissions. This finding is similar to some previous investigations (Mahmood 2023; Marques and Caetano 2022; Shahbaz et al. 2018). This result indicates that FDI inflow is a cause of the poor environmental performance of SSA countries as compared to the world. FDI inflow is the significant reason why CO2 emissions are increasing in SSA.

The estimation shows that CO2 emissions in SSA are rising as GDP rises. This is due to the fact that growth in GDP often results in a country's manufacturing capacity, which emits CO2 (Chaabouni and Saidi 2017). The results also show that the utilization of renewable energy sources reduces CO2 emissions in SSA. An important factor in reducing CO2 emissions in a country is the use of renewable energy sources (Saidi and Omri 2020). Population growth and CO2 emissions are proven to be positively related, similar to earlier findings (Mendonca et al. 2020). Urbanization is significantly related to CO2 emissions in SAR-GMM model.

By comparing the model specifications, it is observed that FDI inflow is increasing CO2 emissions in SSA in both

Table 6 Determinants of CO2 emissions through spatial models to investigate PH in SSA

Variables	Specification 4 SAR with Country Fixed Effects	Specification5 SAR with Random Effects	Specification 6 SAR System GMM
Lag.lnCO2			0.868*** (0.007)
lnGDP	0.865*** (0.137)	0.990*** (0.061)	0.135*** (0.009)
lnFDI	0.035** (0.015)	0.032** (0.015)	0.013*** (0.002)
lnEN	−0.345* (0.193)	−0.326*** (0.123)	−0.044*** (0.010)
POP	0.031 (0.050)	0.036 (0.050)	0.003 (0.011)
UP	0.018 (0.051)	0.008 (0.052)	−0.010 (0.007)
Intercept		−15.898*** (1.701)	−2.903*** (0.196)
rho (*W*.lnCO2)	0.290** (0.122)	0.190** (0.088)	0.099*** (0.006)
lgt_theta		−2.315*** (0.143)	
sigma2_e	0.024*** (0.004)	0.025*** (0.005)	
R-sq:	0.7102	0.7077	
Log-pseudo likelihood	307.1490	173.3606	
Hausman test	5.08		
F-test			14,530,565.264

Source: Author's estimations, *** prob. < 0.01, ** prob. < 0.05, * prob. < 0.1 (standard error in parentheses)

spatial and non-spatial analysis. This finding indicates that FDI in SSA is responsible for an increase in CO2 emissions and its spillover to neighboring countries as well. It reflects the existence of PH in the region. GDP is also increasing CO2 emissions in both spatial and non-spatial model specifications. Renewable energy consumption is decreasing CO2 emissions. Population and urbanization are showing distinct nature of relationship with CO2 emissions in different model specifications; however, they are statistically insignificant.

Conclusion

The examination of the spatial spillover impact of CO2 emissions in SSA is of paramount importance given the region's subpar environmental performance. This study sought to address the literature gap on the topic by investigating the spatial spillover effect of CO2 emissions in SSA, which is caused by FDI inflow. The study employed a combination of non-spatial and spatial autoregressive (SAR) models to determine the major contributors to CO2 emissions in SSA from 2006 to 2020 and evaluate the spatial implications of these emissions. The findings revealed several key conclusions. *Firstly*, CO2 emissions were shown to be increasing as a result of FDI, elucidating that an increase in FDI leads to a corresponding increase in CO2 emissions in the recipient country. *Secondly*, the spatial spillover effect of CO2 emissions was also found to be positive, indicating that CO2 emissions have a detrimental effect on the environment of neighboring nations. *Additionally*, the study supported the presence of the phenomenon of PH in SSA. As multinational enterprises from developed nations opt to establish their polluting industries or production in SSA, CO2 emissions in the FDI recipient country increase. This leads to a transfer of technology that is environmentally harmful and a cause of environmental deterioration in both the FDI recipient country and neighboring countries through the spillover of CO2 emissions.

Given these findings, policymakers in SSA should take into consideration the environmental sustainability not only of the FDI recipient country but also of peripheral nations, as CO2 emissions have significant geographical spillover effects. This study validates the existence of PH in SSA and highlights that (1) adopting strict environmental policies that protect the environments of both the host nation and its neighbors, is crucial to preventing environmental deterioration and ensuring compliance with environmental standards;

(2) the use of renewable energy sources in SSA nations through incentives like tax breaks, subsidies, and grants can mitigate CO2 emissions; (3) authorities in SSA should encourage green FDI by offering incentives to large corporations to invest in environmentally friendly businesses; and (4) promotion of green spaces, eco-friendly building techniques, and public transportation as green urbanization strategies can reduce CO2 emissions. This study places a strong emphasis on mitigating CO2 emissions in SSA with suggested policy recommendations for sustainable development through collaboration with international organizations and neighboring countries. It is pertinent to note that the current study was constrained by issues with data availability, which precluded the inclusion of certain countries in SSA. The evaluation of other pollutants that could have an influence on the environment was also constrained by the concentration on CO2 emissions alone. Government policies and socioeconomic variables, among others, that can have an impact on CO2 emissions and their regional spillover effects, were not taken into consideration. Furthermore, research is needed to investigate PH using other spatial methods and to provide a more comprehensive understanding of the issue.

Author contribution Syed Jaffar Abbas: Conceptualization, writing (original draft preparation), data curation, methodology, formal analysis, investigation. Asim Iqbal: Methodology, formal analysis, reviewing and editing, supervision. Muhammad Munawar Hussain: Visualization, resources. Aftab Anwar: Validation, supervision.

Data availability The data used in the present study will be available on a reasonable request.

Declarations

Ethical approval Not applicable.

Consent to participate Not applicable.

Consent for publication The authors give permission for this paper to be published.

Competing interest The authors declare no competing interests.

References

Abbas SJ, Hussain MM, Salman M, Shahid S, Iqbal A (2022) Economic growth, energy consumption and environment relationship: a panel data analysis of South Asian Countries. J Policy Res 8(4):143–151

Acheampong AO, Adams S, Boateng E (2019) Do globalization and renewable energy contribute to carbon emissions mitigation in Sub-Saharan Africa? Sci Total Environ 677:436–446

Adeel-Farooq RM, Riaz MF, Ali T (2021) Improving the environment begins at home: revisiting the links between FDI and environment. Energy 215:119150

Ahmad N, Iqbal A, Mahmood H (2013) CO2 Emission, population and industrial growth linkages in selected South Asian countries: a co-integration analysis. World Appl Sci J 21(4):615–622

Amin S, Ahmad N, Iqbal A, Mustafa G (2021) Asymmetric analysis of environment, ethnic diversity, and international trade nexus: empirical evidence from Pakistan. Environ Dev Sustain 23(8):12527–12549

Apergis N, Pinar M, Unlu E (2023) How do foreign direct investment flows affect carbon emissions in BRICS countries? Revisiting the pollution haven hypothesis using bilateral FDI flows from OECD to BRICS countries. Environ Sci Pollut Res 30(6):14680–14692

Bakhsh K, Rose S, Ali MF, Ahmad N, Shahbaz M (2017) Economic growth, CO2 emissions, renewable waste and FDI relation in Pakistan: new evidences from 3SLS. J Environ Manage 196:627–632

Balsalobre-Lorente D, Ibáñez-Luzón L, Usman M, Shahbaz M (2022) The environmental Kuznets curve, based on the economic complexity, and the pollution haven hypothesis in PIIGS countries. Renew Energy 185:1441–1455

Bildirici M, Gokmenoglu SM (2020) The impact of terrorism and FDI on environmental pollution: evidence from Afghanistan, Iraq, Nigeria, Pakistan, Philippines, Syria, Somalia, Thailand and Yemen. Environ Impact Assess Rev 81:106340

Chaabouni S, Saidi K (2017) The dynamic links between carbon dioxide (CO2) emissions, health spending and GDP growth: A case study for 51 countries. Environ Res 158:137–144

Cheng Z (2016) The spatial correlation and interaction between manufacturing agglomeration and environmental pollution. Ecol Ind 61:1024–1032

Cil N (2023) Re-examination of pollution haven hypothesis for Turkey with Fourier approach. Environ Sci Pollut Res 30(4):10024–10036

Cole MA, Elliott RJ, Fredriksson PG (2006) Endogenous pollution havens: Does FDI influence environmental regulations? Scand J Econ 108(1):157–178

de Souza Mendonca AK, Barni GDAC, Moro MF, Bornia AC, Kupek E, Fernandes L (2020) Hierarchical modeling of the 50 largest economies to verify the impact of GDP, population and renewable energy generation in CO2 emissions. Sustain Prod Consum 22:58–67

Elhorst JP (2001) Dynamic models in space and time. Geogr Anal 33(2):119–140

Firoj M, Sultana N, Khanom S, Rashid MHU, Sultana A (2023) Pollution haven hypothesis and the environmental Kuznets curve of Bangladesh: an empirical investigation. Asia Pac J Reg Sci 7(1):197–227

Hakimi A, Hamdi H (2016) Trade liberalization, FDI inflows, environmental quality and economic growth: a comparative analysis between Tunisia and Morocco. Renew Sustain Energy Rev 58:1445–1456

Hanif I (2018) Impact of economic growth, nonrenewable and renewable energy consumption, and urbanization on carbon emissions in Sub-Saharan Africa. Environ Sci Pollut Res 25(15):15057–15067

Hitam MB, Borhan HB (2012) FDI, growth and the environment: impact on quality of life in Malaysia. Procedia Soc Behav Sci 50:333–342

Jorgenson AK (2009) Foreign direct investment and the environment, the mitigating influence of institutional and civil society factors, and relationships between industrial pollution and human health: A panel study of less-developed countries. Organ Environ 22(2):135–157

Khan A, Chenggang Y, Hussain J, Bano S, Nawaz A (2020) Natural resources, tourism development, and energy-growth-CO2 emission nexus: a simultaneity modeling analysis of BRI countries. Resour Policy 68:101751

Kivyiro P, Arminen H (2014) Carbon dioxide emissions, energy consumption, economic growth, and foreign direct investment: Causality analysis for Sub-Saharan Africa. Energy 74:595–606

Li B, Haneklaus N (2022) Reducing CO2 emissions in G7 countries: The role of clean energy consumption, trade openness and urbanization. Energy Rep 8:704–713

Liu Y, Sadiq F, Ali W, Kumail T (2022) Does tourism development, energy consumption, trade openness and economic growth matters for ecological footprint: Testing the Environmental Kuznets Curve and pollution haven hypothesis for Pakistan. Energy 245:123208

Mahmood H (2020) CO2 emissions, financial development, trade, and income in North America: a spatial panel data approach. SAGE Open 10(4):2158244020968085

Mahmood H (2023) Trade, FDI, and CO2 emissions nexus in Latin America: the spatial analysis in testing the pollution haven and the EKC hypotheses. Environ Sci Pollut Res 30(6):14439–14454

Mahmood H, Alkhateeb TTY, Furqan M (2020) Exports, imports, foreign direct investment and CO2 emissions in North Africa: Spatial analysis. Energy Rep 6:2403–2409

Malik S, Iqbal A, Imran A, Usman M, Nadeem M, Asif S, Bokhari A (2021) Impact of economic capabilities and population agglomeration on PM2. 5 emission: empirical evidence from sub-Saharan African countries. Environ Sci Pollut Res 28(26):34017–34026

Marques AC, Caetano R (2020) The impact of foreign direct investment on emission reduction targets: Evidence from high-and middle-income countries. Struct Chang Econ Dyn 55:107–118

Marques AC, Caetano RV (2022) Do greater amounts of FDI cause higher pollution levels? Evidence from OECD countries. J Policy Model 44(1):147–162

Nejati M, Taleghani F (2022) Pollution halo or pollution haven? A CGE appraisal for Iran. J Clean Prod 344:131092

Nguyen VB (2021) THE difference in the fdi-co$_2$ emissions relationship between developed and developing countries. Hitotsubashi J Econ 62(2):124–140

Ning L, Wang F (2018) Does FDI bring environmental knowledge spillovers to developing countries? The role of the local industrial structure. Environ Resource Econ 71(2):381–405

Ojewumi SJ, Akinlo AE (2017) Foreign direct investment, economic growth and environmental quality in sub-Saharan Africa: a dynamic model analysis. Afr J Econ Rev 5(1):48–68

Raza SS, Hussain A (2016) The nexus of foreign direct investment, economic growth and environment in Pakistan. Pakistan Dev Rev 55(2):95–111. http://www.jstor.org/stable/44986032

Ren S, Yuan B, Ma X, Chen X (2014) International trade, FDI (foreign direct investment) and embodied CO2 emissions: a case study of Chinas industrial sectors. China Econ Rev 28:123–134

Saidi K, Omri A (2020) Reducing CO2 emissions in OECD countries: Do renewable and nuclear energy matter? Prog Nucl Energy 126:103425

Sapkota P, Bastola U (2017) Foreign direct investment, income, and environmental pollution in developing countries: Panel data analysis of Latin America. Energy Econ 64:206–212

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 Res 116:136–148. https://doi.org/10.1016/j.gr.2022.12.018

Shahbaz M, Balsalobre-Lorente D, Sinha A (2019a) Foreign direct Investment–CO2 emissions nexus in Middle East and North African countries: Importance of biomass energy consumption. J Clean Prod 217:603–614

Shahbaz M, Gozgor G, Adom PK, Hammoudeh S (2019b) The technical decomposition of carbon emissions and the concerns about FDI and trade openness effects in the United States. Int Econ 159:56–73

Shahbaz M, Nasir MA, Roubaud D (2018) Environmental degradation in France: the effects of FDI, financial development, and energy innovations. Energy Econ 74:843–857

Siddiqui A, Iqbal A (2018) In search of spatial interdependence of US outbound FDI in the MENA region. World Econ 41(5):1415–1436

Singhania M, Saini N (2021) Demystifying pollution haven hypothesis: Role of FDI. J Bus Res 123:516–528

Swain A (1996) Environmental migration and conflict dynamics: focus on developing regions. Third World Q 17(5):959–974

Wang F, He J, Niu Y (2022) Role of foreign direct investment and fiscal decentralization on urban haze pollution in China. J Environ Manage 305:114287

Wang X, Luo Y (2020) Has technological innovation capability addressed environmental pollution from the dual perspective of FDI quantity and quality? Evidence from China. J Clean Prod 258:120941

Wang Y, Luo X, Chen W, Zhao M, Wang B (2019) Exploring the spatial effect of urbanization on multi-sectoral CO2 emissions in China. Atmos Pollut Res 10(5):1610–1620

Wendling Z, Emerson JW, de Sherbinin A, Esty DC (2020) Environmental Performance Index 2020. Yale Center for Environmental Law & Policy, New Haven. https://doi.org/10.13140/RG.2.2.21182.51529

Xu C, Zhao W, Zhang M, Cheng B (2021) Pollution haven or halo? The role of the energy transition in the impact of FDI on SO2 emissions. Sci Total Environ 763:143002

Yin Y, Xiong X, Hussain J (2021) The role of physical and human capital in FDI-pollution-growth nexus in countries with different income groups: a simultaneity modeling analysis. Environ Impact Assess Rev 91:106664

Zhang WW, Sharp B, Xu SC (2019) Does economic growth and energy consumption drive environmental degradation in China's 31 provinces? New evidence from a spatial econometric perspective. Appl Econ 51(42):4658–4671