Environmental Research and Technology
https://dergipark.org.tr/tr/pub/ert
DOI: https://10.35208/ert.1470522

Research Article

The relationship between economic growth, population, FDI, globalization, and CO_2 emissions in OIC member countries

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ARTICLE INFO

Article history
Received: 19 April 2024
Revised: 10 August 2024
Accepted: 20 August 2024

Key words:
CO_2 emissions; OIC countries; Sustainable growth; System GMM

ABSTRACT

The concentration of CO_2 emissions in OIC member countries has decreased over the past decade. The theory of sustainable growth suggests that increased CO_2 emissions can be influenced by various factors such as economic growth, population, FDI, and globalization, and vice versa. However, economic growth, population, FDI, and globalization in OIC member countries have all increased, which contradicts the theory of sustainable growth. Therefore, this study aims to test and analyze the effects of economic growth, population, FDI, and globalization on CO_2 emission concentrations in OIC member countries. This research is quantitative, using data on economic growth, population, FDI, globalization index, economic globalization, political globalization, and social globalization for 53 OIC member countries over the period from 1992 to 2020, obtained from various sources such as the World Bank, UNCTAD, and the KOF Index of Globalization. The data analysis technique used is the System GMM. The results of this study show that economic growth and increased FDI have a significant effect on increasing CO_2 emission concentrations. In contrast, increases in population and globalization have a reducing effect on CO_2 emission concentrations in OIC member countries.

Cite this article as: Zainul Mustofa H. The relationship between economic growth, population, FDI, globalization, and CO_2 emissions in OIC member countries. Environ Res Tec 2025;8(1)161-176.

INTRODUCTION

Over the past 150 years, humans have increased the concentration of carbon dioxide (CO_2) in the atmosphere from about 280 ppm (parts per million) to the current 385 ppm [1]. The increase in CO_2 emissions has caused the global average temperature to rise by about 1 °C since the pre-industrial period, while the oceans have increased in temperature and acidity as they absorb CO_2 and heat [2]. Global resources have depleted since the second half of the twentieth century, and environmental crises have intensified. To address these conditions, a sustainable development strategy was proposed in "Our Common Future" by the World Commission on Environment and Development in 1987. During this period, the concept of the circular economy emerged to reduce the consumption of natural resources and minimize environmental pollution by considering the circulation of resources within social and economic systems [3]. Emissions from burning fossil fuels significantly contribute to today's hotly debated ecological issues. More than half of the contribution to the greenhouse effect is caused by CO_2, primarily released due to the use of fossil fuels, with no economically viable technologies for CO_2 reduction currently available [4]. The continued use of fossil fuels will negatively impact environmental sustainability due to increased CO_2 emissions and may eventually erode the earth's ozone layer.

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The growth of CO_2 emissions in OIC (Organisation of Islamic Cooperation) member countries shows fluctuations from year to year (Fig. 1). From 1992 to 2006, CO_2 emissions produced by OIC member countries continued to increase. However, from 2007 to 2009, they showed a downward trend, which could be attributed to the Subprime Mortgage crisis that negatively impacted the performance of global industries, leading to a reduction in CO_2 emissions. In 2010, CO_2 emissions in OIC countries began to rise again, reaching their peak in 2012. However, from 2013 to 2020, CO_2 emissions generally decreased yearly, indicating growing public awareness in OIC member countries of the importance of sustainability in environmental ecosystems, alongside increased encouragement to adopt renewable technologies over the last decade. The theory of sustainable growth was first coined by Meadows [5] in 1972 in "The Limits to Growth." Meadows revealed that achieving balance in sustainable growth requires consideration of several influencing factors. These factors include population, capital, birth rate, death rate, investment value, depreciation, community values, environmental sustainability, social welfare, and technological progress.

A country's economic growth is one factor that influences the growth of CO_2 emissions. Research on the impact of economic growth on CO_2 emissions has been widely conducted, yielding a variety of findings [6–8]. Anwar's findings show that economic growth significantly increases CO_2 emissions [9]. Meanwhile, Mujtaba's [10] findings show the opposite result, indicating that economic growth significantly reduces CO_2 emissions. By 2022, the total GDP of OIC countries had increased to US$ 8.7 trillion as a result of the ongoing gradual recovery. This economic measure shows that the OIC country group accounted for 8.7% of global GDP that year, up 0.9 percentage points from the previous year. Regarding Purchasing Power Parity (PPP) expressed in international dollars, the total GDP of OIC countries reached 24.4 trillion dollars and accounted for 14.9% of global GDP in 2022, up 0.3 percentage points from 2021 [11]. Based on these data, economic growth may be a factor that plays a role in influencing the increase in CO_2 emissions in OIC member countries. However, some findings suggest that economic growth can also play a role in reducing CO_2 emission levels. Thus, the relationship between economic growth and CO_2 emissions needs further analysis.

Another factor that is thought to influence the growth of CO_2 emissions is the growth of a country's population. As the population increases, new houses, office buildings, malls, and roads are built to accommodate this growth, covering fertile agricultural land and forests that could otherwise absorb CO_2 emissions [12]. By 2021, it is estimated that there will be 1.9 billion Muslims, making up about 25% of the world's population. Over the next decade, the Muslim population is projected to continue growing at twice the rate of the non-Muslim population [13]. Populations in OIC countries are urbanizing more rapidly than the global average. This trend contributes to increased CO_2 emissions

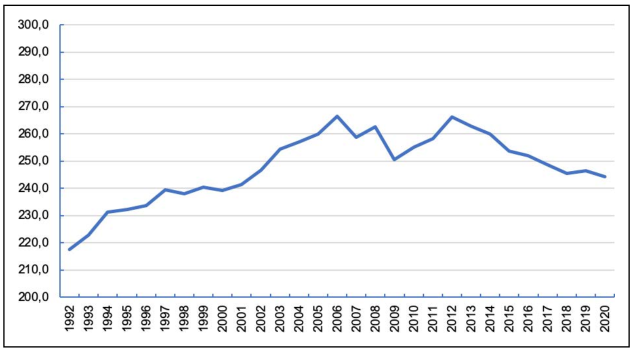

Figure 1. CO_2 emission growth of OIC member countries from 1992–2021.

Source: World Bank Data, 2024.

in OIC countries, as most economic activity, energy consumption, and greenhouse gas emissions occur in urban areas. Therefore, cities need to reduce their energy consumption and switch to renewable energy sources if they are to lower their carbon footprint significantly [14]. Mendonça's [15] findings show that population growth increases CO_2 emissions. However, Yang's [16] findings indicate that population growth contributes to reducing CO_2 emissions. Thus, based on this and the theory of sustainable growth, there is an indication that population growth plays a role in the growth of CO_2 emissions. More in-depth analyses are needed to determine how this influence is realized.

It is also suspected that Foreign Direct Investment (FDI) is one of the factors that can affect the growth of CO_2 emissions. FDI represents investment in productive assets by a parent company in another country [17]. In 2022, FDI flows in OIC countries reached US$ 2.3 trillion, an increase of 18.4% from the value in 2018 [11]. Several studies reveal a relationship between FDI and CO_2 emission intensity [18–20]. Ali pointed out that the increase in FDI inflows to Organization of Islamic Cooperation (OIC) countries has had a detrimental impact on nature and ecological systems, rather than focusing on technology-oriented resource utilization [21]. This indicates that the growth of FDI in OIC member countries has been partially directed towards advancing environmentally friendly technological innovation, but has primarily focused on exploiting natural resources, which negatively impacts the environment and ultimately results in increased CO_2 emissions in these countries. However, Khan's [22] findings show that FDI has a significant positive impact on the ecological footprint and demonstrates an environmentally friendly effect in lower-middle-income OIC member countries. These findings present an opposite result compared to previous studies, making the impact of FDI on CO_2 emissions unclear.

Globalization is now also an essential factor in reducing CO_2 emissions. Several studies show that globalization influences CO_2 emissions [23–25]. Globalization plays a vital role as a means to spread and adopt technology in managing the digital economy market. Through globalization, opportunities for sustainable economic growth are opening up in several sectors, including renewable energy, sustainable transportation, and clean manufacturing, by introducing products and services based on renewable energy resources [26]. Although there is a general opinion that globalization and economic freedom have many benefits for a country's economy [27], the innovations generated by globalization can support the completion of work more efficiently and reduce costs [26]. An overview of globalization development in OIC countries shows that these countries are still having difficulty catching up with more developed nations. OIC countries still face challenges narrowing the economic and developmental gap with developed nations [28]. Therefore, the impact of globalization, such as the introduction of renewable energy technology that can reduce CO_2 emissions, has not been fully explained, and further analysis is needed to determine its impact.

Based on the previously described background, this study aims to analyze and identify the relationship between economic growth, population, FDI, and globalization on CO_2 emissions in OIC member countries. The research also aims to clarify the role of each of these factors in increasing or decreasing CO_2 emissions, considering the specific conditions in OIC countries. This research will provide deeper insights into effective environmental policies and sustainable development strategies for OIC countries. The implications of this research encompass several aspects, including the potential to serve as a foundation for policymakers in OIC member countries when formulating more effective and targeted environmental policies. By capturing the impact of economic growth, population, FDI, and globalization on CO_2 emissions, this research aids policymakers in identifying the key factors that contribute to increasing or decreasing emissions. Additionally, the findings can assist OIC countries in designing sustainable development strategies that balance economic growth with environmental protection, emphasizing green technologies and energy efficiency. The research can also guide international investment and trade decisions by providing insights into how FDI and globalization affect CO_2 emissions and how to direct investments to support greener technologies and practices.

LITERATURE REVIEW

Economic Growth and CO_2 Emissions

Dadkhah explains that national income is an important indicator reflecting a country's economic condition, encompassing the total output of goods and services produced (GDP) as well as its distribution within society, including wages, corporate profits, rental income, interest, and other forms of income [29]. The relationship between economic growth and the environment has long been discussed, notably since the United Nations report "Our Common Future" introduced the concept of "Sustainable Development." Developing countries, including OIC members, often focus more on poverty alleviation than on adopting advanced technologies for environmental protection, unlike high-income developed countries [30]. Meadows [5] explains that increased energy use as part of economic development is often directly related to rising CO_2 emissions. This is because many energy sources used in the economic development come from fossil fuels, which produce carbon emissions. In other words, the more energy consumed to enhance productivity and efficiency, the greater the potential for CO_2 emissions. Adedoyin [31] also supports this statement by asserting that increasing fossil energy production to support economic growth will exacerbate CO_2 emissions and hinder the achievement of sustainable development.

Previous research on the impact of economic growth on CO_2 emissions has produced mixed results. Some studies indicate that economic growth significantly increases CO_2 emissions, as observed in Osobajo's [32] study of 70 countries from 1994 to 2013. Similarly, Li's [33] findings show that economic growth in China, driven by fossil fuel consumption, has significantly increased total CO_2 emissions. These findings are also consistent with Zhang's [34] study of five Asian countries in the short term. However, other studies have shown different findings, such as those of Namahoro et al. [35], which indicate that economic growth has contributed to reducing CO_2 emissions in 50 African countries. Hdom and Fuinhas [36] found that economic growth decreased CO_2 emissions in Brazil and emphasized the need for more significant investment in sustainable infrastructure to support economic growth while reducing emissions. This finding aligns with Rahman's [37] research, which suggests that investment in green technology can promote greener economic growth. This gap in the literature highlights the uncertainty about how economic growth affects CO_2 emissions in different countries. Therefore, more in-depth studies are needed to understand the relationship between economic growth and CO_2 emissions.

Population and CO_2 Emissions

According to Gluns [38], population growth refers to the increase in an area's population over time caused by a higher birth rate than death rate, as well as immigration into the area. The relationship between CO_2 emissions and population is that the more people there are, the greater the need for transportation, electricity, and consumer goods. This can increase CO_2 emissions due to more intense economic activity, even though pollution control technologies have improved [39]. Meadows [5] states that uncontrolled population growth can lead to increased land and resource use, which can cause environmental degradation and higher CO_2 emissions. Additionally, although technology can extend the growth period, more than technological solutions are needed to overcome the limits imposed by population pressure and industrial activities on the environment, including CO_2 emissions. Khan [40] argues that rapid population growth accelerates the depletion of natural resources. As the population increases, the demand for resources such as fossil fuels also rises to meet growing energy needs. This results in increased combustion of fossil fuels, which is one of the primary sources of CO_2 emissions. In other words, the more energy the population requires, the greater the amount of fossil fuels burned, increasing CO_2 emissions.

Studies conducted in different countries provide a varied picture of how population growth affects CO_2 emissions [16, 41–44]. Some findings show that population growth leads to an increase in CO_2 emissions, as found by Mendonça et al. [15] in 50 countries during the period 1990 to 2015. Anser et al. [45] also found that population growth increased CO_2 emissions in member countries of the South Asian Association for Regional Cooperation (SAARC) from 1994-2013. Chandra et al. [46] further points out that population growth significantly increases CO_2 emissions. With more people, the demand for energy for homes, industries, and businesses also rises. This often leads to constructing more power plants that use fossil fuels such as coal and oil, which produce large amounts of CO_2. Additionally, a larger population means a greater need for goods and services, leading to increased production, transport, and packaging, which contributes to CO_2 emissions [46]. However, some findings show that population growth affects reducing CO_2 emissions, as observed by Rehman [47] in Pakistan from 2001 to 2014. Although many studies have explored the relationship between population growth and CO_2 emissions, its influence on CO_2 emissions is still unclear. Therefore, more in-depth analyses are needed to understand the impact of the population on CO_2 emissions.

FDI and CO_2 Emissions

In the relationship between FDI and CO_2 emissions, Meadows states that sustainable growth focuses on various factors that affect development, such as population, capital, technology, investment value, technological progress, and environmental sustainability. Factors like investment value and technological progress are related to how FDI can impact the growth of CO_2 emissions. FDI can bring more efficient technology or capital that increases economic activity. These technologies and capital can, in turn, affect CO_2 emissions by reducing them through clean technologies or increasing them through more excellent energy production and consumption [5]. Veidenheimer [48] explains that FDI can help reduce CO_2 emissions per unit of output by transferring green technology and exploiting economies of scale. By attracting more FDI, countries can improve efficiency and reduce production costs and CO_2 emissions per unit of output. However, to achieve such benefits, significant initial investments in infrastructure and technology are required. Wang [49] explains that FDI is one of the drivers of increased CO_2 emissions. Meanwhile, Marques and Caetano [50] argues that in developed countries, increased FDI can reduce CO_2 emissions, whereas in middle-income countries, increased FDI tends to increase CO_2 emissions.

Previous studies on the relationship between FDI and CO_2 emissions have shown mixed results. Some findings indicate that an increase in FDI leads to a significant rise in CO_2 emissions, as seen in Ullah's [51] study on Vietnam from 1975 to 2017. Similarly, Huang [52] demonstrated that increased FDI contributed to higher CO_2 emissions in G20 member countries from 1996 to 2018. Asongu and Odhiambo [53] also reported similar results for 49 SSA countries between 2000 and 2012. However, other studies present contrasting results, where an increase in FDI significantly reduces CO_2 emissions, such as Rafique's [54] findings for BRICS countries from 1990 to 2017. Wang's [55] research also revealed that an increase in FDI lowers CO_2 emissions in 28 provinces in China during the period 2000 to 2018. Several other studies align with this view [56, 57]. While theory suggests that FDI should reduce CO_2 emissions through the adoption of clean technology and improved efficiency, empirical evidence indicates that the impact of FDI is highly dependent on country-specific factors, such as environmental regulations, the level of economic development, and the type of technology adopted. Therefore, further research is needed to understand the conditions under which FDI will reduce or increase CO_2 emissions.

Globalization and CO_2 Emissions

Globalization is a key driver, including global price competitiveness and future automation. Communication technology enables companies to expand their reach globally [58]. In the relationship between globalization and CO_2 emissions, Meadows revealed that globalization increases interconnections between countries, accelerating technological progress and investment by transferring knowledge and capital. This fuels economic growth and infrastructure development and pressures the environment and social welfare [5]. Shahbaz [59] states that globalization is vital in reducing CO_2 emissions because it helps developing countries acquire the necessary technology and management experience to reduce pollution earlier in their economic development. Jahanger et al. [60] also mentions that globalization benefits developing countries by improving technology, production, and consumption efficiency, thus allocating more funds to environmentally friendly projects. This suggests that globalization can significantly help reduce environmental pollution. Ting Ma [61] provides evidence that participation in globalization can improve developing countries' performance in protecting the environment by implementing stricter regulations in response to pressure from international norms.

Studies on the effect of globalization on CO_2 emissions have been widely conducted by researchers, with mixed results. Some researchers state that an increase in globalization significantly impacts reducing CO_2 emissions. For example, Xiaoman's [25] study on Middle East and North Africa (MENA) countries from 1980 to 2018 found this effect. Tsimisaraka [62] also reported that an increase in globalization will decrease CO_2 emissions in OBOR countries. Umar's findings show that globalization played a vital role in reducing CO_2 emissions in China in the long run from 1980 to 2017 [23]. Similarly, Muhammad's [63] findings for 170 countries from 1990 to 2018 indicate increased globalization will increase CO_2 emissions. Conversely, Anser's [64] study shows increased CO_2 emissions are influenced by increased globalization in South Asian countries from 1985 to 2019. Other findings are consistent with this view [24, 65]. These studies highlight a gap between theory and reality regarding the impact of globalization on CO_2 emissions. While some studies suggest that

Table 1. Summary of literature review

Author	Year	Region	Period	Variable	Method	Results
Namahoro et al. [35]	2021	Afrika regions	1980–2018	GDP → CO_2	PMG, CCEMG, CS-DL	Negative
Hdom et al. [36]	2020	Brazil	1975–2016	GDP → CO_2	FMOLS, DOLS	Negative
Osobajo et al. [32]	2020	70 countries	1994–2013	GDP → CO_2	POLS, fixed effect	Positive
Li et al. [33]	2021	China	1990–2020	GDP → CO_2	ARDL	Positive
Adedoyin et al. [31]	2020	BRICS	1990–2014	GDP → CO_2	PMG-ARDL	Positive
Zhang et al. [34]	2023	6 Asian countries	1975–2020	GDP → CO_2	AMG	Positive
Rahman et al. [37]	2021	10 countries	1979–2017	GDP → CO_2	DOLS, FMOLS, PMG	Negative
Yang et al. [16]	2021	OCED	1971–2016	POP → CO_2	FMOLS, DOLS, AMG	Negative
Wang and Li [41]	2021	154 countries	1992–2016	POP → CO_2	Panel threshold model	Negative
Mendonça et al. [15]	2020	50 countries	1990–2015	POP → CO_2	Hierarchial regression	Positive
Anser et al. [45]	2020	SAARC countries	1994–2013	POP → CO_2	Fixed effect	Positive
Khan et al. [40]	2021	United States	1971–2016	POP → CO_2	GMM, GLM	Positive
Rahman et al. [43]	2021	Bangladesh	1973–2014	POP → CO_2	ARDL	Positive
Yu et al. [42]	2023	30 Provinces in China	2000–2019	POP → CO_2	Systematic GMM	Negative
Xiaoman et al. [25]	2021	MENA countries	1980–2018	GLB → CO_2	Cup-FM, Cup-BC	Negative
Umar et al.	2020	China	1980–2017	GLB → CO_2	ARDL	Negative
Muhammad and Khan [63]	2021	170 countries	1990–2018	GLB → CO_2	GMM, fixed effect	Negative
Anser et al. [64]	2021	South Asian	1985–2017	GLB → CO_2	FMOLS	Positive
Mehmood et al. [65]	2020	South Asian	1972–2013	GLB → CO_2	ARDL	Positive
Ma et al. [61]	2021	179 countries	1995–2014	GLB → CO_2	Fixed effect	Negative
Ullah et al. [51]	2021	Vietnam	1975–2019	FDI → CO_2	ARDL	Positive
Huang et al. [52]	2022	G20 countries	1996–2018	FDI → CO_2	FGLS	Positive
Rafique et al. [54]	2020	BRICS	1990–2017	FDI → CO_2	AMG	Negative
Asongu et al. [53]	2020	49 countries in SSA	2000–2012	FDI → CO_2	GMM	Negative
Wang and Li [41]	2021	30 provinces in China	2004–2016	FDI → CO_2	VECM	Positive
Lin et al. [56]	2022	China	2004–2015	FDI → CO_2	Two-way fixed effect	Negative
Khan et al. [57]	2023	108 countries	2000–2016	FDI → CO_2	VECM	Negative
Wang and Li [41]	2021	28 provinces in China	2000–2018	FDI → CO_2	Quantile regression	Negative

Source: Author processed, 2024.

globalization can reduce emissions through technology and efficiency, others indicate that it increases emissions due to economic activity and energy consumption. This suggests further research to understand the relationship between globalization and CO_2 emissions.

Gap Research

This study identifies a gap in the literature regarding the relationship between economic growth, population, FDI, and globalization with CO_2 emissions in OIC member countries. Meadows' sustainable growth theory states that increases in CO_2 emissions usually go hand in hand with economic growth, population, globalization and FDI. However, empirical data from OIC countries over the past decade show the opposite trend, where an increase in these variables is accompanied by a decrease in CO_2 emissions. This phenomenon suggests an anomaly that warrants further research to understand other factors that may have contributed to the decline in emissions in OIC countries, which have not been fully explained by existing theories. In addition, most previous studies have focused on developed or developing countries in general, without considering the unique characteristics of OIC countries. This study aims to test the relevance of Meadows' theory in the context of OIC countries, while exploring other factors that may play a role in reducing CO_2 emissions. As such, this study is expected to make a significant contribution to understanding the complexity of the relationship between economic and environmental variables in OIC countries, as well as assist policy makers in formulating more sustainable development strategies.

MATERIALS AND METHODS

Research Approach and Data

This research is a quantitative study utilizing secondary data within the category of dynamic panel data. Quantitative research is an approach that involves the collection, analysis, and interpretation of data in numerical or statistical form to investigate relationships, patterns, or trends within a phenomenon [66]. The data analyzed include annual data on CO_2 emissions, GDP, population, Globalization Index, Economic Globalization, Political Globalization, Social Globalization, and FDI for OIC member countries (Table 3) covering the period from 1992 to 2020. The data sources representing the sample in this study are presented in Table 2. The collected data were processed and analyzed using Stata 17 and Eviews 12 software.

Table 2. Variables and data sources

Variable	Description	Unit	Period	Source
CO_2	CO_2 per capita	Metric tons	1992–2020	World Bank data
Y	GDP per capita	US dollar	1992–2020	World Bank data
P	Population	Million person	1992–2020	World Bank data
FDI	Foreign direct investment	Million USD	1992–2020	UNCTAD
IG	Index of globalization	Scale (1–100)	1992–2020	KOF globalization
EG	Economic globalization	Scale (1–100)	1992–2020	KOF globalization
PG	Political globalization	Scale (1–100)	1992–2020	KOF globalization
SG	Social globalization	Scale (1–100)	1992–2020	KOF globalization

Source: Author processed, 2024.

Table 3. Country list

Country	Period	Country	Period	Country	Period	Country	Period
Afghanistan	1993–2020	Gabon	1992–2020	Malaysia	1992–2020	Sudan	1992–2020
Albania	1992–2020	Gambia	1992–2020	Maldives	1992–2020	Suriname	1992–2020
Algeria	1996–2020	Guinea	1992–2020	Mali	1992–2020	Tajikistan	1995–2020
Azerbaijan	1994–2020	Guinea–Bissau	1992–2020	Mauritania	1992–2020	Togo	1992–2020
Bahrain	1999–2020	Guyana	1992–2020	Morocco	1992–2020	Tunisia	1992–2020
Bangladesh	1992–2020	Indonesia	1992–2020	Mozambique	1992–2020	Türkiye	1992–2020
Benin	1992–2020	Iran	1992–2020	Niger	1992–2020	Turkmenistan	2000–2020
Brunei	1992–2020	Iraq	2000–2020	Nigeria	1992–2020	Uganda	1992–2020
Burkina Faso	1992–2020	Jordan	1992–2020	Oman	1992–2020	UAE	1992–2020
Cameroon	1992–2020	Kazakhstan	1997–2020	Pakistan	1997–2020	Uzbekistan	1995–2020
Chad	1992–2020	Kuwait	1999–2020	Qatar	1995–2020	Yemen	1992–2016
Comoros	1992–2020	Kyrgyzstan	1994–2020	Saudi Arabia	1994–2020		
Cote d'Ivoire	1992–2020	Lebanon	1992–2020	Senegal	1993–2020		
Egypt	1992–2020	Libya	1992–2020	Sierra Leone	1992–2020		

Source: Author processed, 2024.

Model Specifications

In creating the econometric model, we based it on Meadows' [5] statement that the factors affecting pollution are economic growth, population, investment, and globalization. Additionally, we used previous studies to select the variables for the model. The first variable selected regarding its influence on CO_2 emissions is economic growth [32, 33, 35, 36]. This variable was chosen because economic growth is often directly related to the level of energy use and CO_2 emissions. Economic growth is usually accompanied by increased energy consumption, much of which comes from fossil fuels that produce CO_2 emissions. Some studies also mention the effect of population on CO_2 emissions [15, 16, 41, 45]. An increase in population is generally associated with higher energy consumption and transport, increasing CO_2 emissions. Other studies show that FDI influences CO_2 emissions [49, 56, 57]. FDI can impact CO_2 emissions by introducing new technologies and practices that may increase or reduce emissions, so the FDI variable is included in the model. The following variable included in the model is globalization. In this study, the globalization variable consists of the globalization index, economic globalization, political globalization, and social globalization. Globalization can affect CO_2 emissions through increased trade, investment, and cultural exchange, which can lead to higher energy consumption and transportation [23, 25, 63, 64]. We transformed all variables into natural logarithms to obtain elasticity and simplify data processing. Logarithmic transformation also helps reduce heteroscedasticity and address scale issues between variables. Thus, the econometric model can be written as follows:

$$lnco_2=\beta_1\ lnco_{2i,t-1}+\beta_2\ lny+\beta_2\ lnp+\beta_3\ lnfdi+\beta_4\ lnig+\beta_5\ lneg+\beta_6\ lnpg+\beta_7\ lnsg+\varepsilon_{it} \quad (1)$$

Where $lnco_2$ is the natural logarithm of carbon dioxide, *lny* is the natural logarithm of GDP, *lnp* is the natural logarithm of population, *lnfdi* is the natural logarithm of FDI, *lnig* is the natural logarithm of globalization index, *lneg* is the natural logarithm of economic globalization, *lnpg* is the natural logarithm of political globalization, and *lnsg* is the natural logarithm of social globalization. The use of $lnco_{2\,i,t-1}$ indicates the dependence of current CO_2 emissions on CO_2 emissions in the previous period, reflecting the dynamic nature of the CO_2 emission phenomenon. Then the interaction between economic growth, population, and FDI variables with globalization is included in the model to measure the combined effect of these variables on CO_2 emissions, as the effect of one variable may differ when influenced by another variable. Furthermore, globalization drives economic growth by increasing trade, investment, and market efficiency. Increased economic activity often results in higher energy production and consumption, leading to increased CO_2 emissions if the energy comes from non-renewable sources [67]. Some OIC countries still depend on fossil fuels to support their economic growth, and as industrial activity and energy consumption increase, they experience a rise in CO_2 emissions. Therefore, in the model (2), we include the interaction between economic growth and globalization to measure the combined impact of economic growth and globalization on CO_2 emission growth.

$$lnco_2=\beta_1\ lnco_{2i,t-1}+\beta_2\ lny+\beta_2\ lnp+\beta_3\ lnig+\beta_4\ lneg+\beta_5\ lnpg+\beta_6\ lnsg+\beta_7\ lnfdi+\beta_8\ (lny\times lnig)+\varepsilon_{it} \quad (2)$$

Where *lny×lnig* represents the interaction between the economic growth and globalization variables. Furthermore, population growth is usually accompanied by an increase in energy consumption. Globalization, which often drives industrialization and urbanization, also increases energy consumption. If the primary energy source is fossil fuels, this will lead to increased CO_2 emissions [68]. Therefore, model (3) includes the interaction between population and globalization to measure their combined effect on CO_2 emission growth.

$$lnco_2=\beta_1\ lnco_{2i,t-1}+\beta_2\ lny+\beta_2\ lnp+\beta_3\ lnig+\beta_4\ lneg+\beta_5\ lnpg+\beta_6\ lnsg+\beta_7\ lnfdi+\beta_8\ (lnp\times lnig)+\varepsilon_{it} \quad (3)$$

Where *lnp×lnig* represents the interaction between population and globalization variables. Furthermore, developed countries may shift the production of polluting goods to developing countries. Globalization, through foreign investment flows, may accelerate this phenomenon [57]. OIC member countries, mainly developing countries, often have more lax environmental regulations than developed countries. As a result, FDI from developed countries may lead to increased CO_2 emissions in these developing countries. Thus, in the model (4), we also include the interaction between FDI and globalization to measure the combined impact of FDI and globalization on CO_2 emission growth.

$$lnco_2=\beta_1\ lnco_{2i,t-1}+\beta_2\ lny+\beta_2\ lnp+\beta_3\ lnig+\beta_4\ lneg+\beta_5\ lnpg+\beta_6\ lnsg+\beta_7\ lnfdi+\beta_8\ (lnfdi\times lnig)+\varepsilon_{it} \quad (4)$$

Where *lnfdi×lnig* represents the interaction between FDI and globalization variables. So that the interaction effect of FDI and globalization can be seen on the growth of CO_2 emissions.

Data Analysis Method

The method used in this study is the Generalized Method of Moments (GMM). GMM is a statistical method used in econometric analysis to evaluate and estimate parameters in statistical models introduced by Arellano and Bond [69]. In the difference GMM estimator, the instrument uses lagged values of the differences and levels of the endogenous variables to overcome the endogeneity problem under the assumption that the first differences of the instrument variables are uncorrelated with the fixed effects. However, the difference GMM has the limitation of lacking efficiency in estimating parameters, especially when the model considers long-run relationships between variables. In addition, using only the first difference of the endogenous variable as an instrument may ignore important information from the level of the endogenous variable and cause bias in parameter estimation. Therefore, the GMM system was introduced by Arellano-Bover [70] and Blundell-Bond [71] as a development of difference GMM. System GMM is used to deal with endogeneity by extending the difference GMM approach to consider the second difference of the endogenous variables as well as incorporating the exogenous variables as instruments. In the GMM system, lagged values of the levels of endogenous variables are used. It also allows the model to capture the long-run effects of exogenous variables and is more efficient in estimating parameters.

Although the GMM method offers many advantages, some limitations must be considered. Complex endogeneity problems can still occur even though GMM is designed to address endogeneity. Therefore, better instrument selection and rigorous instrument validation are required. Estimation efficiency is also a concern, as Difference GMM may be less efficient at estimating parameters, especially when the model considers long-run relationships between variables. The use of System GMM can improve estimation efficiency by considering second differences of endogenous variables as well as exogenous variables as instruments. In addition, dynamic panel data requires certain assumptions that may not always hold in every case. Alternative techniques such as System GMM can help overcome some limitations. Instrument validity is also fundamental, as invalid instruments may result in biased estimates. The Sargan and Arellano-Bond autocorrelation tests are used to ensure instrument validity and consistency of estimation results.

RESULTS AND DISCUSSION

Descriptive Statistics and Correlation Matrix

Descriptive statistics of the variables in this study are presented in Table 4. The average CO_2 emissions per capita of OIC member countries is 4.50 metric tons, with a standard deviation of 7.72. The minimum value of CO_2 emissions is 0.04 metric tons, indicating that some countries have low CO_2 emissions, while the maximum value is 47.66 metric tons, suggesting that some OIC countries have very high CO_2 emissions. The average value for the GDP per capita variable is 5,584.94$, with a minimum of 137.18$ and a maximum of 98,041.41$, indicating positive economic development in OIC member countries. The average population is 27.80 million, with a minimum of 0.24 million and a maximum of 271.86 million, indicating a medium population size on

Table 4. Descriptive statistics

Variable	Mean	Std. dev	Min	Max
CO_2	4.50	7.72	0.04	47.66
Y	5583.94	10949.78	137.18	98041.40
P	27.80	47.77	0.24	271.86
FDI	1436.18	3219.54	-10176.40	25120.70
IG	49.49	12.14	22.10	81.10
EG	47.73	14.76	7.90	87.70
PG	57.13	17.76	11.90	92.70
SG	43.59	16.61	10.50	83.00

Source: STATA Output, 2024.

Table 5. Correlation matrix of variables from 53 OIC member countries

	$LNCO_2$	LNY	LNP	LNFDI	LNIG	LNEG	LNPG	LNSG
$LNCO_2$	1.0000							
LNY	0.8857	1.0000						
LNP	-0.1933	-0.2358	1.0000					
LNFDI	0.4692	0.5060	0.4246	1.0000				
LNIG	0.6460	0.6948	0.1296	0.7075	1.0000			
LNEG	0.6514	0.6238	-0.2079	0.4770	0.7589	1.0000		
LNPG	0.0420	0.0999	0.6853	0.5428	0.6003	0.0918	1.0000	
LNSG	0.7451	0.7970	-0.2808	0.4995	0.8182	0.6929	0.1456	1.0000

Source: STATA Output, 2024.

average across OIC countries. The Globalization Index variable has an average of 49.49, suggesting that globalization in OIC countries is classified as developing. The average values for Economic Globalization, Political Globalization, and Social Globalization are 47.73, 57.13, and 43.59, respectively. The FDI variable has an average value of 1,436.18$ thousand, with a minimum value of -10,176.40$ thousand and a maximum of 25,120.70$ thousand. This range reflects the inadequate infrastructure in some OIC member countries, which can lead to lower foreign investor interest.

The correlation matrix in Table 5 shows the relationship between the variables studied. GDP per capita shows a robust positive correlation with CO_2 emissions at 88.57%, indicating a significant contribution of economic growth to the increase in CO_2 emissions in OIC member countries. Social Globalization also exhibits a positive correlation, at 74.51%, followed by Economic Globalization at 65.14%. Additionally, the Globalization Index shows a correlation of 64.60%, indicating that the growth of globalization substantially influences the growth of CO_2 emissions in OIC member countries. FDI shows a correlation of 46.92%. In contrast, Political Globalization contributes very little to the growth of CO_2 emissions, with a correlation of 4.20%. Notably, the relationship between Population and CO_2 emission growth is negative, with a correlation of -19.33%, suggesting that population growth contributes very little to CO_2 emissions in OIC member countries.

Unit Root Tests

The stationarity test refers to checking whether the statistical properties of a time series remain consistent over time. In this context, the stationarity test aims to determine whether some trends or patterns may affect the behavior of the time series. In this study, the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests are used to test the stationarity of the data. The null hypothesis for these tests is that the data is stationary. If the data turns out to be non-stationary, the next step is to transform it to achieve stationarity before further modeling [72]. The results of the unit root or stationarity test are presented in Table 6. The unit root test results using the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) methods show that most variables in this study are not stationary at the level but become stationary after first differencing. The variables $LNCO_2$, LNY, LNP, LNSG, and LNIG are not significant at the level but become significant at the 1% level after first differencing. Meanwhile, the variables LNFDI, LNEG, and LNPG are significant at the level and become even more significant after first differencing.

Empirical Results

The System GMM (One-Step) results in Model (1) show that an increase in GDP per capita has a statistically significant positive effect on CO_2 emissions at the 5% level. This indicates that increasing GDP per capita will increase

Table 6. Unit root test results

Variable	Augmented dickey fuller		Phillips-perron	
	Level	First difference	Level	First difference
$LNCO_2$	-0.01328	-15.9269***	-0.32705	-24.3342***
LNY	1.44983	-14.7592***	1.42439	-19.8488***
LNP	6.76055	-7.63735***	6.76320	-5.99558***
LNFDI	-2.95539***	-21.6938***	-7.88638***	-31.0757***
LNIG	-1.31639*	-16.2449***	-2.92135***	-22.5276***
LNEG	-2.87490***	-17.3072***	-5.75709***	-27.5009***
LNPG	-4.52863***	-19.0307***	-8.41432***	-26.5086***
LNSG	0.43378	-11.5910***	0.65713	-20.4595***

Source: Eviews Output, 2024. Significant at 10% (*), 5% (**), 1% (***).

CO_2 emissions in OIC member countries. This finding is consistent with Meadows' sustainable growth theory, which states that economic growth positively and significantly affects CO_2 emissions. It also aligns with the research by Osobajo et al. [32] and Li and Haneklaus [33]. Meanwhile, population has a statistically significant negative effect on CO_2 emissions at the 10% level, suggesting that an increase in population will reduce CO_2 emissions in OIC member countries. This finding is consistent with the research by Yang et al. [16] and Wang and Li [41], though it contradicts the sustainable growth theory, which posits that an increase in population will increase CO_2 emissions. The interaction between FDI and CO_2 emissions shows that FDI has a statistically significant positive effect on CO_2 emissions at the 5% level, indicating that an increase in FDI will lead to higher CO_2 emissions in OIC member countries. This finding aligns with the research by Ullah et al. [51] and Huang [52]. The Globalization Index has a statistically significant negative effect on CO_2 emissions at the 1% level, indicating that an increase in the Globalization Index will decrease CO_2 emissions in OIC member countries. This finding is consistent with the research by Xiaoman et al. [25], Umar et al. [23], and Muhammad and Khan [63]. Furthermore, Economic Globalization, Political Globalization, and Social Globalization have a positive and statistically significant effect on the increase in CO_2 emissions, indicating that an increase in these three variables can contribute to the growth of CO_2 emissions in OIC member countries.

Model (2) shows the interaction between GDP per capita and the Globalization Index on CO_2 emissions. The interaction between these two variables has a statistically significant negative effect on CO_2 emissions at the 5% level, suggesting that their combined effect will reduce CO_2 emissions in OIC member countries, including the interaction between GDP per capita and the Globalization Index results in the Globalization Index having a positive impact on CO_2 emissions, which is statistically significant at the 5% level. This finding aligns with the research by Anser et al. [64] and Mehmood and Tariq [65], which states that an increase in globalization will lead to higher CO_2 emissions. Model (3) shows that the interaction between the Population Index and Globalization has a statistically significant negative effect on CO_2 emissions at the 10% level, indicating that their combined effect will reduce CO_2 emissions in OIC member countries. Including the interaction between Population and the Globalization Index causes the Population variable to have a positive and statistically significant effect on CO_2 emissions at the 10% level. This suggests that increased population will increase CO_2 emissions in OIC member countries. This finding is consistent with the research by Mendonça et al. [15] and Anser et al. [45]. Then, in Model (4), the interaction between FDI and the Globalization Index shows a negative but statistically insignificant effect on CO_2 emissions. The interaction causes the Population variable and the Globalization Index variable to negatively and statistically significantly affect CO_2 emissions in OIC member countries. Meanwhile, Models (1) through (4) constants show negative values.

The System GMM (Two-Step) results in Table 8 show that the variable interactions in Model (1) are the same as in the One-Step GMM, but the constant in Model (1) shows a positive value. Meanwhile, Model (2) shows a different interaction with the Population variable, where Population has a positive but statistically insignificant effect on CO_2 emissions. In Model (3), changes occur in the Population, Globalization Index variables, and the interaction between Population and Globalization Index. Population and Globalization Index shows a positive but statistically insignificant effect on CO_2 emissions. Meanwhile, the combined effect of the Population and Globalization Index shows a negative but statistically insignificant impact on CO_2 emissions. In Model (4), the difference lies in the combined impact of FDI and Globalization Index, where the effect becomes negative and statistically significant on CO_2 emissions in the Two-Step GMM. This suggests that the combined impact of FDI and the Globalization Index will reduce CO_2 emissions in OIC member countries.

Model criteria tests, such as instrument tests and autocorrelation tests, are needed to ensure the model's validity. We use the Sargan [73] test to determine the validity of the instruments in the model, with the null hypothesis stating

Table 7. GMM test results (one-step)

Variable	(1)	(2)	(3)	(4)
$LNCO_{2\,i,t-1}$	0.9296***	0.9291***	0.9282***	0.9294***
	(0.0133)	(0.0133)	(0.0133)	(0.0133)
LNY	0.0234**	8.7011**	0.0238**	0.0237**
	(0.0118)	(3.7450)	(0.0117)	(0.0118)
LNP	-0.0297*	-0.0299*	2.2032*	-0.0294*
	(0.0157)	(0.0157)	(1.2328)	(0.0158)
LNFDI	0.0065**	0.0063**	0.0063*	0.0921
	(0.0032)	(0.0032)	(0.0032)	(0.2535)
LNIG	-1.2248***	7.4779**	1.0255	-1.1405***
	(0.3440)	(3.7696)	(1.2955)	(0.4234)
LNEG	0.4496***	0.4481***	0.4452***	0.4504***
	(0.1114)	(0.1112)	(0.1111)	(0.1115)
LNPG	0.4450***	0.4364***	0.4321***	0.4443***
	(0.1258)	(0.1256)	(0.1258)	(0.1259)
LNSG	0.3472***	0.3391***	0.3456***	0.3475***
	(0.0974)	(0.0974)	(0.0972)	(0.0975)
LN(Y*IG)		-8.6768**		
		(3.7445)		
LN(P*IG)			-2.2322*	
			(1.2323)	
LN(FDI*IG)				-0.0857
				(0.2536)
Constant	-0.1529	-0.1879	-0.1515	-0.1511
	(0.2180)	(0.2183)	(0.2174)	(0.2183)
Obs	1419	1419	1419	1419
Sargan (Prob.)	0.1656	0.1821	0.1496	0.1652
Abond (Prob.)	0.7355	0.6702	0.7474	0.7266
FEM	0.8582206	0.8599803	0.8586164	0.8574561
PLS	0.9812088	0.9812486	0.9811302	0.9810241

Source: STATA Output, 2024. Notes: Significant at 10% (*), 5% (**), 1% (***).

that no overidentifying instruments are used. Therefore, the p-value must be more significant than alpha to accept the null hypothesis. The results of the Sargan test on all models in both the One-Step and Two-Step GMM systems show that the instruments used are valid, with all p-values greater than alpha. For the autocorrelation test, we use the Arellano-Bond [69] test to detect the presence of autocorrelation in model errors in GMM estimation, with the null hypothesis stating that there is no autocorrelation in the model used. The p-value must be more significant than alpha to accept the null hypothesis. The results of the autocorrelation test on all models also show no autocorrelation, indicating that all models are consistent and suitable for use. Additionally, to demonstrate the unbiasedness of the model, the estimation results must lie between the upwardly biased Pooled Least Squares (PLS) and the downwardly biased Fixed Effects. The test results show that all GMM model estimates fall between the PLS and Fixed Effects estimation results, indicating that all models used are unbiased.

In the aftermath of the COVID-19 pandemic, all countries, including OIC member states, are working to recover their declining economies. In 2022, OIC member countries experienced an increase in GDP per capita to US$12,851, a 10.8% increase from the previous year [11]. Economic growth in OIC member countries indicates an increase in economic activity. The analysis shows that economic growth can lead to increased CO_2 emissions. Meadows revealed that massive industrial expansion often drives a country's economic growth [5]. However, industrial growth that relies on fossil fuels can result in higher CO_2 emissions, which have severe environmental impacts. Using fossil fuels tends to be more desirable due to their low cost [74]. To mitigate these impacts, OIC

Table 8. GMM test results (two-step)

Variable	(1)	(2)	(3)	(4)
LNCO2 i,t-1	0.9051***	0.9162***	0.9083***	0.9093***
	(0.0186)	(0.0197)	(0.0233)	(0.0178)
LNY	0.0332***	7.1327**	0.0263***	0.0308***
	(0.0094)	(2.3748)	(0.0068)	(0.0103)
LNP	-0.0766***	-0.0138	2.1523	-0.0579**
	(0.0293)	(0.0466)	(1.5300)	(0.0286)
LNFDI	0.0079***	0.0083***	0.0075***	0.7623**
	(0.0013)	(0.0014)	(0.0012)	(0.3609)
LNIG	-2.2470***	5.0532*	0.5060	-1.7691**
	(0.5272)	(2.6992)	(1.6409)	(0.8987)
LNEG	0.6727***	0.7002***	0.5237***	0.7401***
	(0.1489)	(0.1969)	(0.1618)	(0.2390)
LNPG	0.8404***	0.7472***	0.5886***	0.9397***
	(0.2003)	(0.2515)	(0.2181)	(0.3126)
LNSG	0.6820***	0.5830***	0.5215***	0.7326***
	(0.1640)	(0.1826)	(0.1425)	(0.2345)
LN(Y*IG)		-7.1100***		
		(2.3718)		
LN(P*IG)			-2.1945	
			(1.5265)	
LN(FDI*IG)				-0.7530**
				(0.3605)
Constant	0.1745	0.0023	0.1535	0.3618
	(0.2278)	(0.2014)	(0.2362)	(0.3623)
Obs	1419	1419	1419	1419
Sargan (Prob.)	1.0000	1.0000	1.0000	1.0000
Abond (Prob.)	0.8193	0.6737	0.8871	0.7065

Source: STATA Output, 2024. Notes: Significant at 10% (*), 5% (**), 1% (***).

member states need to intensify the shift to renewable energy by diversifying energy sources, developing green policies, raising awareness and education, and fostering regional and international cooperation. Strategies that can be implemented include investment in renewable energy infrastructure, public-private partnerships, research and development of clean energy technologies, and supportive regulations.

The population of OIC member countries has increased significantly over the past 33 years, reaching more than 1.9 billion in 2020, which accounts for 29.2% of the developing world's population and 24.5% of the global population. According to United Nations projections, this figure is expected to continue increasing [30]. This population increase can have both positive and negative impacts on environmental sustainability. The analysis shows that an increase in population can reduce CO_2 emissions. Ahlburg et al. [75] revealed that population growth drives increased efficiency, economies of scale, and technological innovation. However, population growth can also positively impact environmental sustainability, including a decrease in CO_2 emissions, provided that it is controlled. Therefore, population control policies that lead to sustainable growth must be strengthened to manage CO_2 emissions. OIC member countries should implement effective population control policies to ensure that population growth does not put excessive pressure on natural resources and the environment. Additionally, increasing public awareness through educational campaigns and training programs on the benefits of using renewable energy is necessary to maintain environmental sustainability.

The SESRIC report shows that the value of Foreign Direct Investment (FDI) inflows in OIC member countries was recorded at US$ 98 billion in 2020, increased to US$ 138 billion in 2021, but decreased by 1.7% in 2022 to US$ 135 billion. This value accounts for about 5.3% of total global FDI, down from a contribution of about 6.1% in 2018 [11]. The data shows that while FDI flows in OIC countries are stable, their contribution to global FDI is declining. The analysis shows that increased FDI can lead to higher CO_2 emissions. Mitchell [76] explained that a market-based approach to investment regulation can increase FDI, potentially boosting industrial activity and CO_2 emissions. An increase in FDI can drive industrial growth, including environmentally unfriendly FDI, potentially leading to higher CO_2 emissions. Although FDI flows in OIC countries are relatively stable, CO_2 emissions may also remain stable. Mitchell also emphasizes the need for regulations to reduce investment incentives that could lead to higher CO_2 emissions [76]. To effectively reduce CO_2 emissions, OIC member countries need to develop regulations that decrease investment incentives that increase emissions while providing incentives for green technologies.

Finally, the COVID-19 pandemic and changes in trade policies caused uncertainty in global supply chains, resulting in a decline in globalization within OIC member countries [77]. Post-COVID-19, OIC member countries reached a consensus to discuss policies, foster cooperation, and engage in joint problem-solving. This consensus encouraged OIC countries to plan strategies to harness globalization and capitalize on new opportunities for sustainable development [78]. The consensus highlights that globalization is vital in industrial development within OIC countries. Today, globalization drives market expansion, increased trade, and more excellent production, increasing energy consumption [79]. Increased globalization, especially within OIC member countries, can catalyze innovation in green technologies, contributing to reducing CO_2 emissions. Therefore, OIC member countries need to enhance international cooperation by leveraging globalization by transferring green technologies and sharing knowledge on sustainable industrial practices. OIC member countries should also devise appropriate strategies to exploit globalization's opportunities, including integrating environmental sustainability considerations into development planning.

CONCLUSION

The results of this study show that economic growth can increase the concentration of CO_2 emissions in OIC member countries. However, the combined effect of economic growth and globalization shows a statistically negative effect, indicating that an increase in both economic growth and globalization results in a decrease in CO_2 emission concentrations. Therefore, there is a need for policies that support global economic integration in favor of sustainable development. Population growth shows a statistically negative influence on CO_2 emission concentration. The combined effect of population growth and globalization also shows a statistically negative effect on CO_2 emission concentrations. This suggests that population growth can reduce CO_2 emission concentrations in OIC member countries, which may be due to effective population control measures. This highlights the importance of policies that support sustainable development. Furthermore, FDI has a statistically positive effect on CO_2 emissions, meaning that an increase in FDI can raise the concentration of CO_2 emissions in OIC member countries. An increase in FDI can lead to the expansion of industries that are not environmentally friendly, thereby increasing CO_2 emissions. Therefore, strict FDI regulations are needed to control CO_2 emissions while supporting sustainable development. The interaction between FDI and globalization shows a statistically negative effect on CO_2 emissions. Meanwhile, the globalization index shows a statistically negative effect on CO_2 emissions, indicating that an increase in globalization will reduce CO_2 emissions in OIC countries. Conversely, economic, political, and social globalization each show a statistically positive effect on CO_2 emission concentrations.

Based on the findings of this study, it is suggested that future research should focus more specifically on analyzing the economic sectors that contribute most to increased CO_2 emissions in OIC member countries. Future research should also consider the impact of different types of FDI, such as investments in the energy sector versus manufacturing, to understand better how each sector affects CO_2 emissions. Additionally, it is vital to explore the role of government policies and existing environmental regulations in moderating the relationship between economic growth, globalization, and CO_2 emissions. Further research could also examine the role of green technologies introduced through globalization and FDI and how these technologies can be optimized to reduce emissions. This study has limitations, mainly related to the data covering only 1992 to 2020 due to limited data sources. As a result, the data may only partially reflect the long-term dynamics within OIC member countries. Furthermore, this study has yet to fully isolate other factors that may affect changes in CO_2 emissions, such as climate change, energy policy, and changes in consumer behavior. Therefore, future research should adopt a more comprehensive approach by considering additional relevant variables and utilizing more up-to-date and detailed data to provide a more accurate picture.

DATA AVAILABILITY STATEMENT

The author confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

USE OF AI FOR WRITING ASSISTANCE

Not declared.

ETHICS

There are no ethical issues with the publication of this manuscript.

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