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Effects of Inflation, Foreign Direct Investment, Energy Consumption, and Trade Openness on CO2 Emissions: Panel Data Analysis for Developing Countries

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Abstract This study investigates the drivers of CO2 emissions in developing countries, with emphasis on the nexus role exerted by key economic variables such as inflation, FDI, energy use, and trade openness. This is a panel study covering 1990-2020 for nine developing countries: Brazil, India, Türkiye, South Africa, Indonesia, Mexico, Malaysia, Nigeria, and Pakistan. Due to heteroscedasticity detection, the method Huber-Eicker-White is used for estimation to estimate the coefficients correctly. The results indicate that FDI, energy use, and openness to trade significantly positively influence CO2 emissions. In contrast, inflation significantly influences CO2 emissions negatively. Considering that FDI, investment, energy use, and trade openness have a positive effect on CO2 emissions, governments are always encouraged to focus on energy efficiency and renewable energy transitions by offering incentives. Inversely, the negative relationship between inflation and carbon dioxide emissions indicates that using inflationary periods as an opportunity to adopt green technology.

Keywords CO2 emissions · inflation · FDI · energy consumption · trade openness

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Effects of Inflation, Foreign Direct Investment, Energy Consumption, and Trade Openness on CO2 Emissions: Panel Data Analysis for Developing Countries

Fossil fuel combustion is the major source of CO2 emissions, followed by deforestation, industrial processes, and specific agricultural practices, which altogether contribute to the atmospheric CO2 concentration (Paraschiv & Paraschiv 2020). CO2 plays a fundamental role in the greenhouse effect. However, its anthropogenic increase and that of other greenhouse gases have enhanced the effect, leading to an accelerated rate of global warming (Bayraktar et al., 2023). Elevated CO2 levels in the atmosphere are associated with considerable changes in climate patterns. This includes an increase in average global temperatures (Rehan & Nehdi, 2005). Moreover, a key feature of CO2 is its persistence in the atmosphere. Certain fractions of released CO2 can endure for thousands of years, indicating that present-day emissions have lasting effects on the climate system (Archer et al., 2009). In contrast, the significant increase in the levels of CO2 in the atmosphere during modern times is primarily due to human activities, which contrasts sharply with the natural changes that occurred in atmospheric CO2 levels in the past. This rate of increase has been especially rapid since the start of the industrial revolution (Salam & Noguchi, 2005). Additionally, CO2 emissions are measured by mass. Monitoring such emissions is integral to understanding and managing the anthropogenic impact of climate dynamics (Dixon & Romanak, 2015). Reducing CO2 emissions is crucial to combating climate change, as highlighted by international agreements such as the Paris Agreement. Key mitigation strategies include shifting to renewable energy sources, improving energy efficiency, and adopting policies that promote sustainable development (Dong et al., 2018). In essence, CO2 emissions are a focal concern in the realm of environmental and climatological sciences, primarily because of their significant role in intensifying the greenhouse effect and driving anthropogenic climate change. Addressing these emissions is imperative for mitigating the adverse impacts of global warming.

The factors influencing carbon dioxide emissions are multiple and varied, but each comprises one or more of many other factors interlaced together in a complex way to shape total emissions. Understanding these elements is crucial for devising effective climate change mitigation strategies. The identified major determinants are: Fossil fuel-based energy use, economic growth and industrialization, population size and urbanization, technology and energy efficiency, energy mix composition, regulatory policies and environment governance, and foreign trade and global production chains (Sharma, 2011). The leading cause of CO2 emissions is energy use, particularly the burning of fossil fuels. These fuels are mainly used for electricity generation, transportation, and industrial processes (Apergis & Payne, 2010). Similarly, economic activities, particularly industrial production and CO2 emissions, are also closely related. Greater economic development and industrialization generally go hand in hand with more energy consumption and higher emissions. The type and efficiency of the economy can also make an important difference in this regard (Asumadu-Sarkodie & Owusu, 2016). Besides, demographic processes contribute to the emissions of CO2. For instance, a large population implies high energy and resource use, resulting in higher emissions. Further, urbanization affects emissions because urban areas are viewed as illustrating higher energy use than rural areas (O'Neill et al., 2012). Moreover, technological change plays a dual role in influencing the rate of CO2 emissions. While some technological changes have indeed brought about energy efficiency and reduced emissions, other technological changes, especially those involving fossil fuel-based technologies, could raise the level of emissions (Khan et al., 2023). Some technological changes tend to increase emissions. The mix of energy types used by a nation again determines its CO2-related emissions. The use of renewable energy sources correlates with diminished emissions, whereas reliance on fossil fuels is linked to increased emissions (Long et al., 2015). Similarly, governmental policies and regulations aimed at the reduction of emissions, which encompass strategies such as carbon pricing, energy efficiency standards, and controls on industrial emissions, play a crucial role in determining the trajectories of national CO2 emissions (Dehdar et al., 2022). The dynamics of international trade also influence CO2 emissions through the manufacturing and transportation of goods. Global supply chain configurations can lead to the geographical redistribution of production and associated emissions (Fan et al., 2021).

This study investigates how inflation, FDI, energy consumption, and trade openness affect CO2 emissions in developing countries. To achieve this purpose, Panel Data Analysis is conducted using data from the economies of Brazil, India, Türkiye, South Africa, Indonesia, Mexico, Malaysia, Nigeria, and Pakistan from 1990 to 2020. The study is organized into the following sections: Introduction, theoretical framework, literature review, methodology and dataset, findings, and conclusion.

Theoretical Framework

The macroeconomic factors influencing carbon dioxide emissions include various factors at both national and international levels that significantly impact the quantity of CO2 emitted into the atmosphere (Ozyilmaz et al., 2023). These factors should be considered when assessing the environmental impacts of macroeconomic activities. The primary macroeconomic determinants include gross domestic product, investment, inflation, foreign direct investment, energy consumption, degree of industrialization, energy intensity of the economy, energy portfolio composition, trade openness and global economic integration, urbanization processes, fiscal and regulatory policies and technological innovation (Tsaurai, 2020). Gross Domestic Product (GDP) represents the aggregate economic output of an economy. A significant relationship can be observed between gross domestic product (GDP) and carbon dioxide (CO2) emissions, as increased GDP frequently aligns with augmented energy usage and heightened emissions. Nevertheless, this relationship is influenced by fluctuations that depend on the energy efficiency and the structure of the energy mix within the economy (Myszczyszyn & Suproń, 2021). The degree of an economy's industrialization serves as a critical factor influencing CO2 emissions. Industrial sectors are major contributors to CO2 emissions and are highly reliant on fossil fuels. In general, the transition from an agrarian economy to an industrially structured system is positively related to increasing CO2 emissions (Dong et al. 2019). Economies that consume energy intensively emit high levels of CO2. Reductions in energy intensity, which can be achieved through technological changes and efficiency improvements, are crucial for the abatement of emissions. The composition of energy sources employed by an economy significantly affects its carbon dioxide emissions. Economies that predominantly use fossil fuels are correlated with elevated levels of CO2 emissions, in contrast to those that exhibit a greater dependence on renewable or nuclear energy (Danish et al., 2020). The pace and nature of urbanization have meaningful repercussions on CO2 emissions. Metropolitan regions generally demonstrate greater per capita energy usage than rural regions; however, they also offer potential for enhanced energy efficiency and advanced public transportation networks (Zhang et al., 2017). Governmental initiatives, such as carbon pricing strategies, subsidies for renewable energy, and environmental regulations, significantly affect CO2 emissions. Policies that encourage energy efficiency and the adoption of renewable energy sources play a crucial role in the mitigation of carbon emissions (Halkos & Tzeremes, 2013). The pace and scale of technological change and diffusion across various industries are crucial parameters. Technologically efficient improvements or the facilitation of cleaner alternatives could significantly lower the amount of

CO2 emitted (Du et al., 2019). This study investigates the effects of inflation, investment, foreign direct investment, energy use, and trade openness on CO2 emissions.

The relationship between inflationary trends and CO2 emissions includes a diverse set of economic and environmental factors, including macroeconomic slowdown, inflation-related effects on energy and raw material prices, consumer spending behaviors in inflationary circumstances, budgetary investments in green technology during periods of inflation and corresponding policy actions (Ahmad et al., 2021). Inflationary pressures frequently signal impending macroeconomic slowdowns or recessions. With the contraction in economic cycles, energy demand in industries and other sectors often falls simultaneously. This will reduce the levels of CO2 emissions in the atmosphere. Practical examples of such events are available during the 2008 financial crisis and in the initial stages of the COVID-19 pandemic (González-Álvarez & Montañés, 2023). Inflation is one of the driving factors that increases the cost of energy and its raw materials. This inflationary impact can split into two distinct pathways. On the one hand, it may serve as a catalyst for enhanced energy efficiency and the adoption of cleaner technological paradigms as entities seek cost optimization. On the other hand, if the inflationary surge extends to renewable energy domains, it could delay the transition to greener energy modalities (Khan et al., 2022). Inflation is generally associated with a squeeze on consumer expenditure, which could be positively linked to a reduction in CO2 emissions. However, if inflation significantly raises the relative costs of green products and technologies, it could dampen consumer demand for these environmental alternatives (Munksgaard et al., 2000). High inflation levels can negatively affect green technology investment in the public and private sector. Investment in green technology generally contributes to a substantial decrease in carbon dioxide emissions by encouraging the utilization of renewable energy sources, enhancing energy efficiency, and supporting sustainable industrial and economic methodologies (Kuang et al., 2022). Financial constraints may lead to reduced investment in R&D in sectors essential for mitigating CO2 emissions. The measures implemented by governments to combat inflation have considerable repercussions on carbon dioxide (CO2) emissions. For instance, policies favoring fossil fuel subsidies as a counterinflationary measure can result in an increase in CO2 emissions. Subsidies can also discourage investment in clean and renewable energy technologies (Arzaghi & Squalli, 2023).

The relationship between Foreign Direct Investment (FDI) and carbon dioxide emissions implicates a complex interaction among transnational capital flows, economic development pathways, and environmental outputs. This relationship is manifested in several dimensions: Technological transference and environmental norms, industrialization acceleration directly linked with economic expansion, the pollution haven hypothesis that talks about how markets relocate within countries due to changing policies for polluting firms between rich-poor nations (Blanco et al.,2013). FDI acts as a vehicle for transferring more advanced technologies and stricter environmental standards carried out by economies that are developed to those which remain developing. FDI can bring more advanced, cleaner, and efficient technology paradigms to the recipient countries, contributing positively to reduce CO2 emissions (Khan et al.) FDI often serves as a stimulant for industrialization and economic proliferation in host economies. This process has often been associated with higher CO2 emissions because it leads to increased energy requirements and industrial activity. However, the exact nature of the investment determines this factor since investment into renewable energy and green technologies promises growth in economic activities while lessening environmental degradation (Haug & Ucal, 2019). FDI may trigger structural shifts in the host country's economy. Capital invested in industries like services or high-tech manufacturing, which are generally characterized by lower CO2 emissions than old manufacturing industries, may lead to a shift toward an economic structure with low carbon reliance (Zhou et al., 2013). Another possibility is that FDI may influence environmental policy-making and capacity building in host countries. Multinational corporations are likely to encourage stringent environmental regulations and practices and make various constructive contributions toward improving local abilities in managing environmental impact, perhaps reducing CO2 emissions (Neves et al., 2020).

The relationship between energy consumption and carbon dioxide emissions is a critical facet in the discourse on environmental impact and has a statistically significant and strong relationship. It is explicable from various standpoints: Dependence on fossil fuels, shift to renewable and alternative low-carbon fuels, enhancement of energy efficiency, variations in economic structural and energy intensity, and demographic trends and urbanization burdens (Chen et al., 2016). The most influential factor catalyzing CO2 emissions is the global dependence, mostly on fossil fuel-based sources, for the fulfillment of energy needs. The combustion of these fuels releases enormous quantities of CO2, a major contributor to the greenhouse effect. Thus, the degree and type of energy consumption dependence on fossil fuels is a direct cause of CO2 emission rates (Hanif, 2018). Renewable energy sources and low-carbon alternatives, including nuclear energy, have relatively lower CO2 emissions than fossil fuels. A higher percentage of the energy supply from such resources is directly associated with a reduction in overall CO2 emissions (Jaforullah & King, 2015). The improvement in energy efficiency is associated with a reduction in the overall CO2 emissions. This includes technological changes, consumer behavior changes, and efficiency gains in industry, buildings, and transport systems (Tajudeen et al., 2018). The structure of an economy is strongly linked to a country's energy use and therefore its CO2 emissions. Highly industrialized economies or economies with heavy manufacturing dependence are also known to be highly energy-consuming and thus have high CO2 emissions, whereas purely service-based economies have lower consumption and therefore lower associated emissions. Energy intensity is an important measure because low energy intensity means low environmental impact (Namahoro et al., 2021). High population growth and high urbanization are associated with increased energy consumption and CO2 emissions. Urban centers, defined by their densely populated areas and robust economic activities, generally require increased energy consumption; however, they simultaneously offer prospects for enhancements in efficiency (Adusah-Poku, 2016).

The relationship between trade liberalization and carbon dioxide emissions is complex and multidimensional, with many economic, technological, and policy angles. From an analytical perspective, these may be approached through arguments related to industry specialization and comparative advantage mechanisms, international technology transfers and their diffusion, the effects of income and consumption behaviors, transportation and logistics factors, and global supply chains and production influences (Zhang et al., 2017). Openness to trade allows a nation to specialize in sectors with which it has a comparative advantage. If such specialization occurs on carbon-intensive sectors, the result would be increased CO2 emissions. However, when the specialization has low-carbon-intensive industries, it leads to decreased emissions (Andersson & Karpestam, 2013). Openness to trade creates pathways for the diffusion of clean technologies and practices. Countries with strict environmental rules and new green technologies may export these technologies and thus reduce global CO2 emissions (Afesorgbor & Demena, 2022). Trade liberalization can stimulate growth and boost incomes; a bigger pay will mean a greater demand for a greener environment and therefore for the severity of environmental policy (Karedla et al., 2021). Greater trade is likely to require more transportation; the latter reduces emissions, and the longer the transport distance, the more so. The ecological consequences are contingent on the types of transportation and the associated efficiency metrics (Timilsina & Shrestha, 2009). The worldwide interconnection of supply chains can enhance production techniques, which may reduce emissions per unit produced. Nevertheless, this improvement in efficiency might be offset by a rise in total emissions if the scale of global production expands and if these supply chains are fundamentally energy-demanding (Fan et al., 2017).

Literature Review

Shpak et al. (2022) focused on the dependence of CO2 emissions on some macroeconomic indicators in the US and the Asia-Pacific region using data from 1970 to 2020. In this paper, using econometric approaches like correlation-regression analysis, the authors point out the multi-directional relationships among CO2 emissions and economic indicators, including GDP, export, import, inflation rate, and unemployment rate. The results indicate that carbon dioxide emissions in the United States have experienced a downward trend since 2009, whereas gross domestic product, exports, and imports have shown an upward trajectory. Furthermore, this research highlights a direct relationship between carbon dioxide emissions and the aforementioned economic indicators. It also assumes that inflation and unemployment significantly influence CO2 emissions, for which different regional and global evidence is also provided. All the relation measurements performed by several multiple regression models point to the coefficient of determination and Fisher's criteria as crucial indicators for the quality assessment of the models. Grolleau and Weber (2024) studied the interaction between inflation and CO2 emissions using data from 189 countries covering the period 1970-2020. They found that core inflation depresses CO2, but the effect remains so small that monetary policy cannot be a main measure to significantly reduce emissions. The authors' contribution was to the understanding of the economic-environmental relationship-that there is some complexity in those types of relationships, and depending on inflationary indications is not sufficient to bring improvements in environmental quality. This indicates the demand for a more holistic policy approach that would consider the weight of economic and environmental aspects. Musarat et al. (2021) investigated the relationship between inflation and CO2 emissions for Malaysia. This paper relies on data provided by the Malaysian government and focuses on the correlations between inflation rates, construction activities, and CO2 emissions. From the results, a drop in the inflation rate decreases the price of building materials, hence increasing construction activities and inadvertently increasing CO2 emissions, thus becoming a major hindrance to achieving environmental sustainability. This inverse relation between inflation and CO2 emissions underscores the need for great caution when formulating economic policy to adequately consider environmental aspects. The paper concludes by putting forward one special proposal about a CO2 emission calculator related to the construction industry in view of the absence of methods for calculating the emission due to construction activity and also about the need to introduce environmental considerations into economic and industrial policy-making. Mbassi et al. (2023) investigated the effect of inflation targeting on environmental pollution in developed and emerging market economies during the period 1980-2017. This study finds that conducting inflation targeting significantly reduces CO2, N2O, CH4, and total greenhouse gas emissions using a double-track econometric approach that combines parametric and non-parametric methods. Indeed, the estimate shows that this is the main channel of financial instability, as well as the level and stability of financial development. To the best of our knowledge, this paper represents the first attempt to investigate the ecological consequences of inflation targeting; therefore, it extends previous studies by incorporating both parametric and non-parametric approaches. This study analyzes different channels that may affect how inflation targeting impacts environmental degradation and develops a wide set of pollution indicators for developed and developing economies.

Xie et al. (2020) used high-order panel regression analysis to analyze the effects of FDI on CO2 emissions in developing countries. They note that this interaction between FDI and CO2 emission is dynamic, with a threshold effect-increasing CO2 emissions at first, hence supporting the hypothesis of a pollution haven; when the FDI surpasses its critical threshold value, this effect then reverses to support the hypothesis of a pollution halo. This, therefore, implies that at the initial stages of FDI inflow, there may be environmental degradation due to poor environmental regulation and the presence of high-polluting industries; however, with increased FDI, cleaner production and good environmental practices are promoted because economies will focus on qualitative investment. This study further explains the positive relation of CO2 emission with variables such as population growth, energy consumption, and trade openness, all of which contribute to environmental degradation. In conclusion, the findings provide insights into emerging markets toward sustainable development paths that balance economic growth with environmental protection. Essandoh et al. (2020) presented a detailed analysis of how international trade and FDI affect CO2 emissions, underlining the difference that exists between developed and developing countries. The results indicate that, regarding CO2 emissions, the autoregressive distributive lag model for 52 countries across 1991-2014 showed a negative long-run relationship with trade in developed countries and, correspondingly, a positive relationship with FDI inflows in developing countries. This study then examines the interrelationship that exists between international trade and the emissions transfer argument, considering individual effects of the pollution haven and pollution halo hypothesis induced through FDI, energy use, and renewable energy toward attaining environmental sustainability. Panel cointegration tests are used here along with the Dumitrescu-Hurlin panel causality test to see how the mentioned variables are related, pointing out that the developmental stages of a nation have been imperative in taking decisions over environmental and trade policies toward the effective control of global emissions. Sung et al. (2018) investigated whether FDI caused an increase in CO2 emissions in the Chinese manufacturing industry during the period 2002-2015. Estimating GMM for 28 manufacturing subsectors, they find that FDI positively influences the environmental quality of China, thus supporting the halo effect hypothesis. The panel framework analysis of various data properties and stationarity tests indicates that economic activities cannot be separated from environmental changes.

Wang et al. (2016) explored the relationship between economic growth and energy use with regard to CO2 emissions in China using data from 1990 to 2012. Using different types of econometric analysis, the authors find evidence of a co-integration relationship among the variables under consideration eventually. Thus, this paper indicates the need for sustainable development policies that balance economic growth with environmental concerns. The study also contributes to the literature by demonstrating how developing economies balance economic growth and environmental sustainability. Shafiei and Salim (2014) investigated, for the OECD countries and for the period 1980-2011, the impact of different types of energy-renewable versus non-renewable-on the emissions of gases related to CO2 using the STIRPAT model. Their analysis reveals the diverging roles of these types of energy, increasing and decreasing,, respectively, in emissions. The second part of the study goes ahead to explain the Environmental Kuznets Curve in the context of urbanization and emission; it, therefore, hypothesizes that increasing levels of urbanization reduce the levels of emission. This paper also calls for the implementation of renewable energy and sustainable urban development policies, mainly targeting developed countries. The present study provides important inferences related to energy use dynamics and environmental impact, thus underlining the need for strategic policy changes toward sustainability in the OECD countries. Chen et al. (2016) explored the interrelationship between economic growth, energy consumption, and CO2 emissions based on data from 188 countries, ranging from 1993 to 2010. Based on the Vector Error Correction Model, the results show that energy consumption has a negative effect on the GDP of the whole world and developing countries but not in developed nations. It also represents one-way causality from energy use to CO2 emission; hence, CO2 emissions may decrease with increasing urbanization and development. The present work underscores the fact that although environmental regulations are required to mitigate the adverse effect of economic growth on the environment, in the tune of the global climate change and sustainable development, both developed and developing economies require a different policy angle. Al-Mulali et al. (2013) explore interrelations of urbanization, energy consumption, and CO2 emission in the MENA region within the period of 1980-2009. Employing the techniques of Pedroni co-integration tests and dynamic OLS tools, their study provides evidence for the presence of a bi-directional long-run relationship among these variables. It was indicated that urbanization significantly enhances energy consumption and CO2 emission; this was mentioned to be due to the dependence on fossil fuel resources. This research underscores the fact that, within the MENA region, the regulation of the rate of urbanization by urban planners and policymakers is essential, along with increasing energy efficiency and undertaking energy-saving measures that are an important perspective for balancing the strategy of urban growth and environmental sustainability within the MENA area.

Using data from nine African countries between 1990 and 2016, Dauda et al. (2021) empirically investigated the nexus of innovation, trade openness, and CO2 emissions. The results are presented in the form of an inverted U-curve. The rich methodological framework of the research, underlined by tests for cross-sectional dependence, positioned the positive contribution of renewable energy use and human capital to the decrease of emissions, recognized differential effects of trade openness, and accepted the hypothesis of the Environmental Kuznets Curve. The study results in a critical identification of how innovation relates to environmental policy and human capital development in the attainment of sustainable environmental goals in Africa, even though the study at the same time indicates its own limitations regarding country focus and reliance on patent laws as an innovation proxy, pointing toward avenues of future research. Mahmood et al. (2019) investigated the asymmetrical effects of trade liberalization on the CO2 emission of Tunisia during the period 1971-2014 and confirm the Environmental Kuznets Curve hypothesis. In fact, the results show that although an increase in trade openness positively influences CO2 emissions but insignificantly, its decline does insignificantly influence such emissions, hence supporting the Pollution Haven Hypothesis. By using a non-linear ARDL, the authors have once again asserted that the relationship is indeed complex and interwoven, and hence, long-term environmental policy is crucial in Tunisia, one that effectively balances economic development with sustainability. The study is, therefore, significant in the analyses of how trade policy affects the differential quality of the environment, especially within the context of a developing economy like Tunisia. Mutascu (2018) examined the nexus between trade openness and CO2 emissions in France using wavelet tools throughout the period 1960-2013. This is a very important contribution as far as the methods used are concerned because the effects of this relation were analyzed in the time-frequency domain. This proves that the medium-run effects of CO2 emissions tend to influence trade openness, thereby showing that lenient environmental regulations may affect international trade. In return, long-term estimates indicate that trade openness affects gas emissions, implying a business cycle-driven interaction. This paper enhances the already rich literature in the area of reviewing a broad set of hypotheses on the relationship between trade and CO2 emissions with new theoretical dimensions and presents evidence that shows the time dimension and also economic conditions of the various periods. Dou et al. (2021) conducted an analytical review on the influence of openness to trade on CO2 emissions in relation to free trade agreements. The general evidence of the increase in CO2 emissions due to trade openness, although at a dampened rate since the FTA, underscores once more the fact that such agreements may be designed in ways to minimize their environmental impact. Further, their analysis segregates the import and export effects of emissions and finds evidence of increasing CO2 emissions by imports, whereas exports reduce CO2 emissions. This paper has contributed to filling the literature gap by analyzing the separate effects of both and by examining underlined mechanisms such as scale, technical, and structural effects. This underscores the complexity of the trade-environment relationship due to factors such as economic growth, technological change, and the details of trade policy that provide useful insight into policymakers and researchers concerned with the reconciliation of trade policies with environmental objectives.

This review of the related literature provides a wide-ranging overview of how CO_2 emissions relate to inflation, FDI, energy consumption, trade liberalization, and economic growth. The relationships derived from the literature are complex and indicate that while the use of energy and processes for industrialization always lead to increased CO_2 emissions, the effects of inflation and trade openness vary with different economic and regulatory environments. This method applies various methodical approaches, such as panel data analysis, autoregressive distributed lag models, and co-integration tests, to explain the time-series behavior of emissions. Further, it efficiently embeds the results regarding the Environmental Kuznets Curve, pollution haven, and pollution halo hypotheses, hence illustrating the possibilities of how FDI and trade could worsen or improve the environment. This literature review notes the key differences in CO_2 emissions drivers between developed and developing countries. In developed countries, economic growth ties to energy efficiency and cleaner technologies, with trade openness and FDI generally lowering emissions, whereas inflation has little effect because of stable policies. Economic growth, industrialization, and energy use in developing countries lead to higher emissions, often because of trade and FDI, in a way that operationalized the pollution haven hypothesis. Inflation cuts emissions by slowing economic activity but attracts lower clean technology investment because of stringent financial resources. Obstacles to the transition toward renewable energy include the relevance of policy solutions at the local level. This study tries to add to the growing body of literature on the determinants of the level of CO_2 emissions, considering inflation, FDI, energy consumption, and trade liberalization in developing countries. It considers panel data for nine countries—Brazil, India, Türkiye, South Africa, Indonesia, Mexico, Malaysia, Nigeria, and Pakistan—for the period 1990-2020, something larger than most of the studies so far considered, which majorly have focused on either economic growth or energy consumption.

Methodology and Dataset

Panel data analysis is an elaborated econometric method that includes data for a great number of entities over several time periods and provides the possibility of controlling entity and temporal effects. Checking can be performed for variations in the entities over time and between entities, thus enriching and making the results more accurate. The methodology has great significance in that it tends to resolve the problem of the unobserved variables for which variation across entities may exist but is invariant over time, thereby reducing the chances of biased results. Inflation of the number of data points due to panel data increases the statistical efficiency of the research study, facilitating better estimates of the associations among the variables. Another wider application of methodology falls within economics, finance, and social sciences to model dynamics at every level, from the change in behavior up to economic policy and trends. It usually encompasses in the analysis of panel data the fixed effects model, focusing on the changes that take place within the entities by means of controlling unobserved heterogeneity; the random effects model, assuming no correlation of the unobserved variable with the explanatory ones and thus allowing an analysis across entities; and the pooled OLS model, pooling all the observations without distinction across entities or periods (Yerdelen Tatoğlu, 2013). Panel data analysis offers a broad framework through which the complicated interactions among variables across different time periods and contexts can be examined.

This tool becomes a tool that researchers cannot use without understanding the intricacies associated with longitudinal data.

In the application part of this study; Panel Data Analysis is performed to determine the effects of inflation, FDI, energy consumption, and trade openness on CO2 emissions in developing countries. In this analysis, all data were obtained from the World Bank database. The variables are explained in Table 1.

Table 1

Variables

Variable	Explanation	Source of Data
CO2	CO2 Emissions	World Bank
GDP	Gross Domestic Product (constant prices)	World Bank
INV	Gross Fixed Capital Formation (constant prices)	World Bank
INF	Inflation (consumer prices, annual %)	World Bank
FDI	Foreign Direct Investment (constant prices)	World Bank
ENG	Energy consumption (kg of oil equivalent per capita)	World Bank
OPN	Trade Openness (the ratio of total trade to GDP)	World Bank

The panel data application part of this study continues with the Im-Pesaran-Shin Unit Root Test, F Test, Breusch-Pagan Lagrange Multiplier Test, White's Test, and Wooldridge Test.

Findings

Table 2

Im-Pesaran-Shin Unit Root Test

	Level		First Difference	
Variables	**Statistic**	**P-Value**	**Statistic**	**P-Value**
CO2	−1.8647	0.0311	−7.6641	0.0000
GDP	1.7444	0.9595	−5.0384	0.0000
INV	0.7146	0.7626	−7.5361	0.0000
INF	−3.9186	0.0000	−9.9051	0.0000
FDI	−3.1425	0.0008	−9.6021	0.0000
ENG	1.9894	0.9767	−8.7098	0.0000
OPN	−3.5366	0.0002	−8.4501	0.0000

To prevent spurious regression in Panel Data Analysis, it is essential that the series used are stationary, meaning that they should not contain unit roots. As shown in the Im-Pesaran-Shin Unit Root Test results in Table 2, some series initially exhibited unit roots at a 1% significance level. However, these series became stationary after the first differences. Consequently, using the first difference values of the series eliminates the risk of spurious regression.

Table 3

F Test and Breusch-Pagan LM Test

Test	Statistic	P-Value
F Test	1.06	0.3907
Breusch-Pagan LM Test,	0.05	0.8190

Based on the F Test results presented in Table 3, the null hypothesis (H0) that unit effects are zero is accepted. Similarly, the Breusch-Pagan Lagrange Multiplier Test results indicate that the null hypothesis (H0) that the variance of the unit effects is zero is also accepted. These findings indicate that the pooled ordinary least squares model is appropriate for use in the Panel Data Analysis. Additionally, since the Pooled OLS Model was employed, it is necessary to test for heteroscedasticity and serial correlation although testing for cross-sectional correlation is not required.

Table 4

White and Wooldridge tests

Test	Statistic	P-Value
White Test	90.56	0.0000
Wooldridge Test	1.768	0.2203

The white-test results (Table 4) reject the null hypothesis (H0) of homoscedasticity, indicating heteroscedasticity. Similarly, the Wooldridge Test results accept the null hypothesis (H0) that there is no first-degree autocorrelation, revealing that there is no autocorrelation problem in the model.

To perform the Panel Data Analysis in this study using the dataset that became stationary after first differencing and is appropriate for the pooled ordinary least squares model, which encounters heteroscedasticity issue, a suitable estimation method must be employed. The method recommended in the literature for such conditions is the Huber-Eicker-White Estimation model.

Table 5

Results of the Huber-Eicker-White Estimation

Number of obs: 270				
Wald chi2: 1946.39			Prob > chi2: 0.0000	
R^2: 0.7039				
Variable	**Coefficient**	**z**	**P > |z|**	**Robust Std. Err.**
GDP	0.704698	4.03	0.000	0.1748098
INV	0.4359625	8.34	0.000	0.0523021
INF	−0.0000138	−16.99	0.000	8.12e-07
FDI	0.0069957	2.28	0.023	0.0030705
EGN	0.6587467	3.51	0.000	0.1875357
OPN	0.0666464	2.85	0.004	0.0233441

The Huber-Eicker-White Estimation results shown in Table 5 indicate that the Wald chi2 Test is significant; therefore, the independent variables collectively have a significant impact on explaining the dependent variable. The coefficient of determination, R^2, reveals that the model accounted for 70.39% of the variance in CO2 emissions. The z-test results indicate that all coefficients have a significant effect on the dependent variable. As a result, in developing countries, GDP, FDI, investment, energy consumption, and trade openness have positive effects on CO2 emissions, whereas inflation has a negative effect on CO2 emissions.

Conclusion

CO2 mainly originates from burning fossil fuels, deforestation, and industrial processes. Human activities have significantly increased CO2 levels, leading to climate changes such as rising temperatures and extreme weather. CO2 remains in the atmosphere for thousands of years, meaning current emissions have long-term effects. Efforts to reduce CO2, like the Paris Agreement, focus on renewable energy, energy efficiency, and sustainable practices. Some of the important determining elements of CO2 emissions identified in this study include energy use, economic progress, demographic factors, technology, energy sources, regulatory policies, and international trade. The consumption of fossil fuels—especially electricity, transportation, and industry—is the most dominant source of CO2 emissions. Economic growth and industrialization result in high energy consumption and therefore high emissions, while the size and rate of urbanization of the population contribute significantly. It can be either increasing or decreasing, depending on how the technology is applied. The proportionality of renewable energy sources used in a nation's mix of energy is very vital for reducing emissions. Emission reduction through government policies is very important, and international trade affects CO2 levels through the resultant global movement and production of goods.

This study investigates the influence of inflation, FDI, energy consumption, and trade openness on CO2 emissions in developing countries, focusing on Brazil, India, Türkiye, South Africa, Indonesia, Mexico, Malaysia, Nigeria, and Pakistan, using panel data analysis for the period from 1990 to 2020. Several tests were conducted for the study variables: Im-Pesahan-Shin Unit Root Test, F Test, Breusch-Pagan Lagrange Multiplier Test, White's Test, and the Wooldridge Test. It can be observed from the result of these analyses that the dataset, upon first-order differencing, has become stationary and thus, suitable for application in the pooled OLS model, although at the cost of prevailing heteroscedasticity. Therefore, an appropriate estimation technique for panel data analysis is required. Under these conditions, the Huber-Eicker-White Estimation model. The results of Huber-Eicker-White estimation provide the inference that all the independent variables contribute significantly to explaining the dependent variable, and each of the coefficient contributors has a significant impact on the dependent variable. The findings reveal that in developing countries, GDP, FDI, investment, energy consumption, and trade openness positively impact CO2 emissions, whereas inflation negatively impacts CO2 emissions. The analysis strengthens previous studies that showed that economic growth, industrial development, and energy use are major driving forces for CO2 emissions. Other related papers also found evidence of the contribution of economic activities and trade liberalization to increased emissions. However, the negative effect of inflation on CO2 emission was discovered by this research runoff, which contradicts previous studies, as its impact was shown to differ depending on economic conditions. The overall results of the study are congruent with general findings in the literature, which again emphasize the role of economic and energy policy in handling environmental degradation in developing countries. This study has some limitations like that a generalization of findings for any other region, apart from those studied, is not possible because the scope covers only nine developing countries. In addition, panel data across 1990-2020 can fail to capture all shifting economic and environmental circumstances and concentrating on only macroeconomic variables such as inflation, FDI, energy use, and trade openness. This study can miss other important variables like technological innovation.

Since the variables like GDP, FDI, investment, energy use, and trade openness contribute positively to explaining variations in CO2 emissions, governments should focus on policies related to energy efficiency and the transition toward renewable energy resources. The application of financial incentives, subsidies, and regulatory frameworks may be used in the diffusion of clean energy technological innovations in industries, transport, and urban development. In general, policies should be directed at attracting sustainable economic growth through green investment, especially in sectors that are developing low-carbon technologies and infrastructure. This can also involve greening trade policies to support the environmental course by promoting green goods and services, imposition of carbon tariffs, and assurance of environmental protection within trade agreements. Improved environmental regulations and governance are crucial for emission control, especially for highly energy-consuming industries and urban areas. This includes stringent emission standards, compelling companies to provide energy efficiency, and forcing businesses to be more transparent in disclosing their carbon emissions. Furthermore, the finding that inflation is detrimental to CO2 emissions indicates that inflationary periods offer an opportunity for green technologies and energy-efficient approaches to be developed with support for the right subsidies and fiscal policy. The fostering of international cooperation is crucial for acquiring advanced technologies and sharing best practices that are vital in reducing global emissions. With such a policy framework, developing countries can reduce the environmental impact of economic activities, thus realizing the twin goals of sustainable development and long-term economic growth.

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