Determinants of Carbon Dioxide Emission: The Role of Energy Consumption, Investment, Economic Development, and Environmental Policy in Developed and Developing Countries

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ABSTRACT

Environmental degradation, which significantly affects human survival and the global economy, has intensified efforts to reduce carbon dioxide emissions; however, emissions continue to rise, reflecting persistent and complex challenges. This study examines the effects of Environmental Policy Stringency (EPS), Foreign Direct Investment (FDI), Domestic Investment (DMI), Gross Domestic Product (GDP), and energy consumption including oil, solar, wind, and hydropower on carbon dioxide emissions (CO2E) from 1990 to 2020 in both developed and developing countries, using Ordinary Least Squares (OLS) within a production function framework. The findings show that oil consumption, FDI, and DMI increase emissions in developed countries, while oil consumption and GDP are positively related. In contrast, renewable energy sources such as solar, wind, and hydropower reduce emissions in developing countries. Accordingly, developed countries should focus on clean energy investment for advanced technological infrastructure, whereas developing countries should prioritize the transition to renewable energy.

Keywords: Carbon dioxide Emissions, Energy consumption, Investment, Economic development and Environmental Policy Stringency

INTRODUCTION

Since the Industrial Revolution (Britannica, 2026), national development driven by increased production, infrastructure expansion, and rising energy use in urbanized areas—has relied heavily on fossil fuels, particularly coal, oil, and natural gas (Ali A. Gorji & Martek, 2023). These energy sources currently account for more than 80 percent of global energy consumption due to their relatively low production costs, resulting in substantial carbon dioxide emissions, a major greenhouse gas (Xiaoli Liao et al., 2025). This has become a primary driver of rising global surface temperatures, which have increased from 13.70 degrees Celsius before the 20th century to 15.19 degrees Celsius in 2024, an approximate rise of 1.49 degrees Celsius and has contributed to the intensification of extreme weather events (Rebecca Lindsey & LuAnn Dahlman, 2025). This phenomenon has been described as “global boiling” (United Nations, 2023b).

Global boiling is causing irreversible damage to multiple global systems (Amnuaylojaroen, 2023). Intensifying natural disasters including severe droughts, wildfires, and floods have resulted in more than 2 million deaths and over 4.3 trillion US dollars in damages between 1970 and 2021 (United Nations, 2023a; Rebecca Lindsey & LuAnn Dahlman, 2025). These impacts have adversely affected the global economy, generating average annual losses of approximately 143 billion US dollars (Rebecca Newman & Ilan Noy, 2023). Consequently, environmental issues have become widely discussed, particularly following the Paris Agreement, under which more than 195 countries committed to the Nationally Determined Contributions (NDC) framework to achieve net-zero emissions by 2050 and to strengthen resilience against the impacts of climate change (United Nations, 2025a). Although many countries are actively pursuing reductions in carbon emissions, especially through transitions to clean energy sources such as solar, wind, and hydropower (Huang et al., 2021; Samuel A Sarkodie et al., 2019; Yan Wu et al., 2021) governments have simultaneously sought to establish policy instruments to mitigate environmental impacts. One of the key tools used to assess the strictness of such regulations is Environmental Policy Stringency (EPS), which measures the extent to which environmental policies are designed to reduce emissions and promote cleaner production (Fakhri J Hasanov et al., 2021).

Although countries have committed to reducing carbon dioxide emissions, effective implementation requires comprehensive policy measures. Nevertheless, global carbon dioxide emissions have continued to rise, increasing at an average rate of 0.14 billion tons per year between 2016 and 2024, and reaching a peak of 38.6 billion tons in 2024 (Data, 2024a). At the same time, the impacts of climate change have become increasingly severe, affecting human survival in both social and economic dimensions. Achieving emission reduction targets while simultaneously pursuing rapid economic growth under environmental constraints presents significant challenges, driven by a range of structural factors (Fakhri J Hasanov et al., 2021). Rapid economic development between 2016 and 2024 contributed to an increase in global GDP from 1.80 trillion to 2.19 trillion, representing approximately 21.73% (Bank, 2026c). During the same period, countries became increasingly reliant on fossil fuels, particularly oil, the most widely consumed primary energy source, with consumption rising from 52,315 terawatt-hours (TWh) to 55,292 terawatt-hours (TWh), an increase of over 5.69% (Data, 2024b). In addition, efforts to promote national development and enhance economic potential, while pursuing carbon dioxide reduction targets in both developed and developing countries through Foreign Direct Investment (FDI) and Domestic Investment (DMI), have also contributed to substantial carbon dioxide emissions. Notably, the buildings and construction sector accounts for approximately 37% to 39% of global carbon dioxide emissions (Ecochain, 2025). Examples include large-scale infrastructure and development projects such as the ITER nuclear fusion reactor, which began construction in 2010 in France (EuropeanUnion, 2026), as well as investments in infrastructure connecting tunnels and cross-border transport networks in countries such as Switzerland, China, and India (Agency, 2019b; Huang et al., 2021).

Research by Amnuaylojaroen (2023) indicates that global temperatures could increase by approximately 2.6 degrees Celsius by 2050. Under a worst-case scenario, the global economy could lose up to 10% of its total GDP because of climate change impacts. If key drivers of carbon dioxide emissions such as construction-related investment through Foreign Direct Investment (FDI) and Domestic Investment (DMI), the slow transition toward clean energy, and the insufficient implementation of effective environmental policies by both governments and the private sector are not adequately addressed (SwissRe, 2021), global GDP could decline by more than 18% by the middle of this century. Furthermore, by 2030, the world is projected to lose working hours equivalent to nearly 80 million full-time jobs due to heat stress. At the same time, disaster recovery budgets for floods and wildfires may shift from occasional expenditures to recurring and rapidly increasing financial burdens. Consequently, national budgets that would otherwise support long-term economic development may be repeatedly diverted toward disaster response and recovery efforts (Rebecca Newman & Ilan Noy, 2023).

Therefore, it is essential to examine the factors influencing carbon dioxide emissions by analyzing their relationships across two primary dimensions. The first is the energy structure dimension, which emphasizes the distinction between reliance on fossil fuels particularly oil consumption and the transition toward renewable energy sources such as solar, wind, and hydropower, all of which play a crucial role in determining emission levels. However, changes in the energy structure do not occur in isolation; rather, they are shaped by economic and policy-related factors. These include the size of the economy, as reflected in Gross Domestic Product (GDP), which is often associated with increased energy demand; Foreign Direct Investment (FDI) and Domestic Investment (DMI), which may either facilitate the adoption of clean technologies or contribute to carbon-intensive industries when fossil fuels remain the primary energy source; and Environmental Policy Stringency (EPS), defined as the extent to which environmental policies impose explicit or implicit costs on environmentally harmful activities. Specifically, EPS is measured based on the stringency of 13 policy instruments such as renewable energy certificates, public research and development (R&D) expenditure for low-carbon energy, and emission limit values for particulate matter (PM) aimed at reducing greenhouse gas emissions and promoting sustainable economic development (Organisation for Economic Co-operation and Development, 2024).

These factors are critical in determining whether countries can effectively reduce carbon dioxide emissions in line with international commitments. This study contributes to the existing literature by examining both the greenest developed countries and moderately green emerging economies, as classified by the Global Green Economy Index. A comprehensive understanding of these relationships will enable policymakers to design more effective strategies that simultaneously support carbon dioxide reduction and sustainable economic development.

LITERATURE REVIEW

This section is organized into two subsections. The first provides an overview of carbon dioxide emissions in developed and developing countries. The second examines the role of carbon dioxide emissions in relation to energy consumption, economic development, investment, and government policy.

Overview of CO2 emissions in developed and developing countries

Since the Industrial Revolution, nations have relied heavily on fossil fuels such as oil, coal, and natural gas in industrial processes, transportation, and household consumption to support national development and economic expansion (Ali A. Gorji & Martek, 2023). These energy sources currently account for more than 80 percent of global energy use and are the primary drivers of greenhouse gas emissions, particularly carbon dioxide (Xiaoli Liao et al., 2025), which accounts for approximately 74.5 percent (Commission, 2025). Over time, carbon dioxide emissions have increased dramatically, rising from 2 gigatons in 1900 to 37.6 gigatons in 2024, reaching an all-time high (Brief, 2024). This trend has been a major contributor to the rise in global surface temperatures, from 13.70 degrees Celsius before the 20th century to 15.19 degrees Celsius in 2024, an increase of approximately 1.49 degrees Celsius, and has intensified extreme weather events (Rebecca Lindsey & LuAnn Dahlman, 2025). This phenomenon is referred to as “global boiling” (United Nations, 2023b).

Global boiling has intensified the occurrence of natural disasters worldwide (Amnuaylojaroen, 2023). Events such as severe droughts, wildfires, and floods have resulted in more than 2 million deaths and over 4.3 trillion US dollars in damage between 1970 and 2021 (United Nations, 2023; Rebecca Lindsey & LuAnn Dahlman, 2025). For example, heatwaves displace approximately 23 million people each year, while many others are pushed into poverty. Food security is also adversely affected due to the reduction of grassland areas and water resources essential for agriculture and livestock production (United Nations, 2022). In addition, Ana M Vicedo-Cabrera et al. (2021) found that more than one-third of heat-related deaths out of nearly 30 million people across 43 countries are attributable to anthropogenic climate change. As a result, countries have increasingly recognized the environmental and economic consequences of their development efforts, making this issue widely discussed and leading to the ratification of numerous international conventions, protocols, and agreements particularly following the Paris Agreement. Under this agreement, more than 195 countries committed to the Nationally Determined Contributions (NDC) framework to reduce greenhouse gas emissions by 43 percent by 2030 and to strengthen resilience to climate change impacts (United Nations, 2025a; 2025b). Nevertheless, responses to global warming differ significantly between developed and developing countries, particularly in terms of policy implementation and patterns of energy consumption.

Developed countries are among the largest contributors to global carbon dioxide emissions, accounting for approximately 25 percent of total emissions in 2024, led by the United States and the European Union, with shares of 13 percent and 7 percent, respectively. This is largely driven by their advanced economic development and position as major global economies (Brief, 2024). Nevertheless, these countries have also demonstrated significant efforts to promote environmental sustainability, as reflected in their policy commitments under major international agreements such as the Kyoto Protocol and the Paris Agreement, which are among the few global collaborations to achieve tangible progress in addressing environmental issues (Maxwell Chukwudi Udeagha & Godfrey Muchapondwa, 2023). As highlighted by Aviral Kumar Tiwari et al. (2025), European countries have achieved substantial reductions of more than 32 percent in carbon emissions across sectors such as energy and manufacturing. However, emissions in the transportation sector remain challenging to reduce, accounting for approximately one-quarter of Europe’s greenhouse gas emissions and increasing by over 7 percent between 1990 and 2020. This trend is largely driven by rising demand, with the sector contributing around 5 percent of GDP in 2020. In response, developed countries are implementing comprehensive measures, including the expansion of transportation infrastructure, the promotion of public transit systems, the introduction of transportation-related taxes, enhanced institutional transparency, and the advancement of clean energy usage, all aimed at achieving an ambitious target of reducing emissions by 90 percent by 2050.

Turning to developing countries, they account for more than 65 percent of global carbon dioxide emissions, with China contributing 32 percent and India 8 percent. Like developed countries, these emissions are largely driven by reliance on fossil fuels across transportation, housing, and industrial sectors, reflecting the scale of their economic expansion. For instance, the BRICS countries contributed more than 51.3 percent of the global economy and accounted for over 42 percent of the world's population between 2008 and 2018. This growth has intensified the demand for fossil fuels to sustain development, thereby creating significant challenges in balancing carbon reduction goals with economic stability and improvements in living standards (Fakhri J Hasanov et al., 2021). At the same time, Xuying Zhu et al. (2024) highlight that developing countries are increasingly focusing on improving energy intensity (EI) to enhance energy efficiency, particularly by promoting the use of clean energy sources such as solar, wind, and hydropower. This transition offers dual benefits by reducing dependence on fossil fuels while simultaneously lowering carbon emissions and improving productivity. However, these countries continue to face multiple risks, including challenges related to essential services, food security, and energy availability, all of which directly affect population well-being. Despite ongoing efforts, current policy implementation remains insufficient to effectively mitigate climate change and environmental degradation, as evidenced by the continued rise in carbon emissions to record-high levels in 2024 (Mustafa Tevfik Kartal et al., 2025).

Finally, both developed and developing countries are making serious and urgent efforts to address environmental concerns through the implementation of increasingly stringent policies, particularly by enhancing energy efficiency and expanding reliance on renewable energy sources such as solar, wind, and hydropower to reduce emissions. However, both groups continue to face challenges associated with ongoing economic expansion. For instance, developed regions such as the European Union encounter difficulties in reducing fossil fuel use due to rising demand in the transportation sector, despite achieving emission reductions in other sectors. Similarly, in developing countries, fossil fuels remain a fundamental driver of growth across key sectors, including food security, housing, and energy availability. These conditions underscore the importance of addressing shared structural challenges to sustain economic growth while preserving a high quality of life for populations in both developed and developing countries.

The role of Carbon Dioxide Emissions in Energy consumption, Economic development, Investment and Government policy

Energy consumption

Energy consumption encompassing both fossil fuels and renewable energy plays a crucial role in shaping environmental sustainability and economic development. With respect to fossil fuels, existing literature indicates that since the Industrial Revolution, rapid global economic growth has been heavily dependent on fossil energy sources, which currently account for more than 80 percent of total global energy use and remain the primary driver of carbon dioxide emissions (Ali A. Gorji & Martek, 2023; Lu Chen et al., 2021; Rebecca Lindsey & LuAnn Dahlman, 2025; Xiaoli Liao et al., 2025). Moreover, carbon emissions tend to increase alongside economic development. For example, Lu Chen et al. (2021) found that in rapidly developing regions such as the Upper Yangtze River Economic Zone in China, upstream industries including manufacturing and processing are highly dependent on fossil fuels such as oil and coal, significantly accelerating carbon emissions between 2004 and 2012. Similarly, Fakhri J Hasanov et al. (2021) demonstrate that increased economic activity, reflected in higher consumption of goods and services, leads to rising carbon emissions in BRICS countries. Overall, these findings suggest that fossil fuel consumption has a positive effect on carbon emissions in both developed and developing countries.

In contrast, renewable energy generally exhibits a negative relationship with carbon emissions, as the expansion of renewable energy sources reduces reliance on fossil fuels, particularly in BRICS countries (Narendra N Dalei & Gupta, 2024). Supporting this view, Samuel A Sarkodie et al. (2019) examined the relationship between carbon emissions, modernized agriculture, trade openness, and energy consumption in the top 14 carbon-emitting countries in Africa, finding that renewable energy reduces emissions in low-emitting countries but may increase emissions in high-emitting ones. However, Fakhri J Hasanov et al. (2024) report that renewable energy has no significant impact on carbon emissions in Saudi Arabia, largely because its adoption remains limited compared to the dominant use of fossil fuels.

Economic development

Generally, the outcomes of economic development exert negative impacts on the environment, as increased economic activity leads to higher carbon dioxide emissions driven by factors such as intensive fossil fuel use, non-environmentally friendly production materials, and relatively low levels of technology (Mustafa Tevfik Kartal et al., 2025). Similarly, Fakhri J Hasanov et al. (2021) demonstrate that rising economic activity or income levels are associated with greater consumption of intermediate and final goods and services, which in turn contributes to increased carbon emissions in BRICS countries.

Investment

Investment, in the form of both Foreign Direct Investment (FDI) and Domestic Investment (DMI), exerts a dual impact on carbon dioxide emissions. On the one hand, investment can contribute positively to environmental outcomes through support for clean energy initiatives, such as research and development in renewable energy, which helps reduce carbon emissions while maintaining a high level of welfare (Fakhri J Hasanov, 2021). It also enhances industrial efficiency by improving Energy Intensity, thereby reducing emissions in production processes, particularly in BRICS countries (Xuying Zhu et al., 2024). Furthermore, Yan Wu et al. (2021) find that FDI in the construction sector, under green building regulations, and in the transportation sector through developments such as electric railway networks under Belt and Road Initiative can support carbon reduction efforts. On the other hand, investment may also have adverse environmental effects. For example, Aviral Kumar Tiwari et al. (2025) reveal that, in the long run, transport infrastructure development in several European countries can increase carbon dioxide emissions due to continued reliance on fossil fuels during construction processes and the expansion of road networks, which further stimulates transportation demand.

Government policy

Growing global demand to reduce greenhouse gas emissions and adapt to climate change has strengthened international collaboration, leading to the development of various indicators for measuring environmental sustainability performance. One widely used indicator in both OECD and non-OECD countries is Environmental Policy Stringency (EPS). Maxwell Chukwudi Udeagha and Godfrey Muchapondwa (2023) demonstrate that EPS plays a crucial role in achieving sustainable development by reducing carbon dioxide emissions through strict regulatory enforcement, particularly when policies are effectively implemented in BRICS countries. Moreover, EPS contributes to sustainability in G7 economies by imposing both direct and indirect costs on environmentally harmful activities, thereby encouraging the adoption of green technologies and the use of clean energy (Aamir Javed et al., 2024; Lu Chen et al., 2021; Xuying Zhu et al., 2024). However, if existing policy implementations such as strategies supporting energy transition across short-, medium-, and long-term horizons remains ineffective in reducing fossil fuel dependence, EPS may fail to improve environmental quality or achieve United Nations Sustainable Development Goal 13 (Climate Action). This limitation is particularly evident in major emerging economies, including China, India, Russia, Turkey, and Brazil, as argued by Mustafa Tevfik Kartal et al. (2025).

METHODOLOGY

Data

The dataset consists of annual panel data comprising 270 observations for both developed and developing countries over the period from 1990 to 2020. The sample countries are selected based on the Global Green Economy Index, which evaluates performance across four key dimensions: climate change and social equity, sectoral decarbonization, markets and ESG investment, and environmental health (Dualcitizeninc, 2026).

The developed-country sample comprises Sweden, Switzerland, Norway, France, and Denmark, which consistently rank among the world's leading performers in the Global Green Economy Index (GGEI). The GGEI evaluates countries across four dimensions: climate change and social equity, sectoral decarbonization, markets and sustainable investment, and environmental health (Dual Citizen LLC, 2026). These countries have long implemented stringent environmental regulations, invested heavily in renewable energy technologies, and demonstrated strong commitments to sustainable economic development. Therefore, they provide appropriate case studies for examining the relationship between environmental policy, investment, energy consumption, and carbon dioxide emissions in advanced economies.

The developing-country sample includes Brazil, China, India, and South Africa, which were selected because they are among the largest emerging economies and play a critical role in global climate change mitigation. These countries represent diverse economic structures and energy systems while accounting for a substantial share of global greenhouse gas emissions and energy consumption. They also face common challenges in balancing rapid economic growth, increasing energy demand, and environmental sustainability. Consequently, these countries provide an appropriate basis for investigating the determinants of carbon dioxide emissions in developing economies.

The model in this study incorporates nine variables, consisting of one dependent variable carbon dioxide emissions (CO2E), measured in tons of CO2 and obtained from Our World in Data and several independent variables, including Environmental Policy Stringency (EPS), measured as an index and sourced from the Organization for Economic Co-operation and Development; Foreign Direct Investment (FDI), Domestic Investment (DMI), and Gross Domestic Product (GDP), all measured in US dollars and obtained from the World Bank; as well as energy consumption variables, comprising oil (TWh), solar (TWh), wind (TWh), and hydro (TWh), sourced from Our World in Data.

Theoretical Model

This section describes the theoretical foundation framework that relates the carbon dioxide emission to foreign direct investment, domestic investment, fossil and renewable energy consumption, and environmental policy stringency. Since carbon dioxide emission occurs in parallel with production processes of economy, this research begins with the production function, where links the output (Y) with the production factors including capital stocks (K) and labour (L) through technology (A) (Fakhri J. Hasanov et al., 2021; SOLOW, 1956) as follows:

$$Y=f(A,K,L) \tag{1}$$

To increase the output, countries are heavily dependent on fossil fuel for economic development, especially oil consumption (Xiaoli Liao et al., 2025). Therefore, in this study, the production function was expanded to include oil consumption (Oil) as a production factor to reflect the impact of fossil fuel consumption on economic activities (Ali A. Gorji & Martek, 2023).

$$Y=f(A,K,L,Oil) \tag{2}$$

Moreover, after the worldwide awareness of global warming severe impacts on environment which present serious risks to the long run stability of global economies. Renewable energy consumption that covers solar, wind, and hydropower energy consumption, are direct solutions to overcome these problems with countries increasingly turning to renewable energy (Ali A. Gorji & Martek, 2023). Thus, this study includes this as one of the factors of production as shown in Equation 3.

$$Y=f(A,K,L,Oil,Solar,Wind,Hydro) \tag{3}$$

Technology (A) improves production efficiency and enables the adoption of cleaner energy sources. It is indirectly reflected through renewable energy consumption (Huang et al., 2021), as its production depends

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heavily on technological innovation and efficiency improvements. Therefore, technology is implicitly captured through renewable energy as shown in Equation 4.

$$Y=f(K,L,Oil,Solar,Wind,Hydro) \quad (4)$$

Since production of economy depends on energy consumption both fossil fuel and renewable energy which the expansion of output and energy consumption patterns are directly related to carbon emissions (Ali A. Gorji & Martek, 2023), economies that produce more led to using more energy and if the majority of that comes from fossil fuels, especially oil consumption, main factor affects carbon emission (Xiaoli Liao et al., 2025), its will be higher. In contrast, if the majority of that comes from renewable energy, carbon dioxide emissions will be lower. Therefore, when economic development depends on energy usage which impacts carbon emissions, this study substitutes the output to carbon dioxide emission (CO2E) to reflect a various factor generated carbon dioxide emission. And labor (L) is excluded from the carbon emission model as it is considered a clean factor that does not directly contribute to carbon emissions and it ensures that the model focuses specifically on energy intensive and investment related determinants of emissions (Fakhri J. Hasanov et al., 2021) as shown in Equation 5.

$$CO2E=f(K,Oil,Solar,Wind,Hydro) \quad (5)$$

In context of capital (K) like Domestic Investment (DMI), an increase in domestic capital for economic development will lead to expanded production, which increases carbon emissions. Conversely, investment in green machinery or infrastructure will result in technological advancements and reduced emissions. Similarly, with Foreign Direct Investment (FDI), investing in industries that use clean energy and are managed with environmental considerations will lead to a reduction in carbon emissions (Aviral Kumar Tiwari et al., 2025; Maxwell Chukwudi Udeagha & Muchapondwa, 2023). Therefore, this study included DMI and FDI to reflect the factors that affect carbon dioxide emission as shown in Equation 6.

$$CO2E=f(Oil,Solar,Wind,Hydro,DMI, FDI) \quad (6)$$

In addition, the important variable affecting carbon dioxide emissions is Environmental Policy Stringency (EPS), a stringent policies will result in higher emission costs through stricter regulations, forcing companies to reduce carbon emissions by shifting from fossil fuels to renewable energy. Conversely, weak regulations make emissions easier and there is no incentive for organizations to reduce carbon dioxide emissions (Maxwell Chukwudi Udeagha & Muchapondwa, 2023; Tunahan Degirmenci et al., 2025). Therefore, EPS is included in a study as shown in Equation 7.

$$CO2E=f(Oil,Solar,Wind,Hydro,DMI,FDI,EPS) \quad (7)$$

Although investment and energy variables are included in the model, Gross Domestic Product (GDP) captures the overall scale of economic activities (Huang et al., 2021), including production and consumption, which may not be fully reflected by individual components. Therefore, this study includes this as one of the factors of emission as shown in Equation 8.

$$CO2E=f(Oil,Solar,Wind,Hydro,DMI,FDI,EPS,GDP) \quad (8)$$

Econometric Model

For explanatory the relationship of variables impacting carbon dioxide emission. This study used theory of production function. It describes production factors including labor and capital though technology plays an important role to generate output and modify by linking the production process with carbon dioxide emission and use ordinary least squares (OLS) regression models to explain the relationship between variables (Fakhri J. Hasanov et al., 2021). In the panel data context and econometrically estimable form, it can be written as follows:

$$CO2E_{it} = \beta_0 + \beta_1 Oil_{i,t} + \beta_2 Solar_{i,t} + \beta_3 Wind_{i,t} + \beta_4 Hydro_{i,t} + \beta_5 DMI_{i,t} + \beta_6 FDI_{i,t} + \beta_7 EPS_{i,t} + \beta_8 GDP_{i,t} + \varepsilon_{i,t} \quad (9)$$

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Where CO2E is carbon dioxide emission (Ton of CO2); Oil, Solar, Wind, Hydro, DMI, FDI, EPS and GDP are oil consumption, solar energy consumption, wind energy consumption, hydro energy consumption, Domestic Investment, Foreign Direct Investment, and Environmental Policy Stringency, Gross Domestic Product, respectively. ε is error term, β_0 is a constant term, β_1 to β_7 represent the elasticity of carbon dioxide emissions with respect to variables impacting, t is the number of time series observations and i is the number of cross sections.

To address serial correlation in panel data, this study incorporated an autoregressive term of order one (ε_(i,t-1)) into the model. This helps to correct autocorrelation in the error term and improve estimation efficiency. Therefore, the error term is specified as

$$CO2E_{it} = \beta_0 + \beta_1 Oil_{i,t} + \beta_2 Solar_{i,t} + \beta_3 Wind_{i,t} + \beta_4 Hydro_{i,t} + \beta_5 DMI_{i,t} + \beta_6 FDI_{i,t} + \beta_7 EPS_{i,t} + \beta_8 GDP_{i,t} + \varepsilon_{i,t-1} \quad (10)$$

The effect of oil consumption on CO2E is expected to be positive (Ali A. Gorji & Martek, 2023), it is considered to the main cause of carbon dioxide emission in the country. Solar energy consumption (Solar), wind energy consumption (Wind), and hydro energy consumption (Hydro) is expected to be negative (Huang et al., 2021), one of the key sources to reduce carbon dioxide emission while Gross Domestic Product (GDP) is expected to be positive (Maxwell Chukwudi Udeagha & Muchapondwa, 2023), Investment including Foreign Direct Investment (FDI) and Domestic Investment (DMI) is expected to be positive (Huang et al., 2021), and Environmental Policy Stringency (EPS), one of the key sources to reduce carbon dioxide emission, is expected to be negative (Maxwell Chukwudi Udeagha & Muchapondwa, 2023).

RESULTS AND DISCUSSION

The study employs the Ordinary Least Squares (OLS) regression model to examine the relationships between independent variables and carbon dioxide emissions (CO2E). The R^2 values indicate a high explanatory power, with all independent variables accounting for 99.89% of the variation in carbon emissions in developed countries and 99.99% in developing countries.

For developed countries as shown in Table 1, the results show that Foreign Direct Investment (FDI) is statistically significant at the 5% level, while Domestic Investment (DMI) and oil consumption (Oil) are significant at the 1% level. The estimated coefficients for investment variables are positive, as expected. This suggests that increases in FDI and DMI, aimed at promoting economic development, lead to expanded production activities, thereby increasing carbon emissions, particularly when investments are directed toward infrastructure or industries that depend on fossil fuels. Specifically, a one US dollar increase in FDI is associated with an increase of 0.000022 tons of carbon dioxide emissions, while a one US dollar increase in DMI results in an increase of 25.71 tons of carbon dioxide emissions.

Table 1. The result Ordinary Least Squares (OLS) regression models with carbon dioxide emissions of developed countries

Variable	Coefficient	Std. Error	T-stat	P-value
EPS	-202952.4	1635877	-0.1241	0.9014
FDI	0.0000218	0.0000	1.9849	0.0491**
DMI	25.7120	6.889932	3.7318	0.0003*
GDP	-0.0000	0.0000	-1.0148	0.3120
OIL	263439.8	22447.88	11.7356	0.0000*
SOLAR	-678459.9	619928.3	-1.0944	0.2757
WIND	-157349.2	129457.3	-1.2155	0.2262

HYDRO	8.26.117	16021.99	0.5009	0.6172
C	265000000	2340000000	0.1133	0.9100
AR (1)	0.99	0.009554	104.5646	0.0000*

Notes: Statistical significance is evaluated at 1% level* and 5% level**

In terms of Foreign Direct Investment (FDI) within the countries studied, France was among the largest recipients, attracting approximately 19 billion US dollars in 2020 (Bank, 2026a). Major investment projects include the ITER nuclear fusion reactor, which began construction in 2010 (ITER, 2026), and the establishment of Google's artificial intelligence research center in Paris in 2018 (Phys, 2018). While these initiatives contribute to the advancement of technologies aimed at reducing carbon dioxide emissions and enhancing economic potential, they simultaneously increase energy demand during construction phases, thereby contributing to higher emissions. Similarly, Denmark, Sweden, and Switzerland have experienced rising levels of foreign investment, particularly in large-scale data centers operated by multinational corporations (Bruno Basalisco et al., 2019). Despite the presence of stringent environmental regulations in these countries, the development and operation of data centers and cloud infrastructure require substantial energy consumption. In summary, although FDI plays a critical role in facilitating technology transfer, infrastructure development, and economic growth, these examples illustrate that the expansion of economic activity, especially in high-technology sectors, leads to increased energy demand. Consequently, this contributes to higher carbon dioxide emissions, consistent with Huang et al. (2021). While developed countries maintain strict regulatory frameworks for screening FDI, the positive relationship observed suggests that imported technologies still generate emissions, reflecting the scale effect of FDI on the environment during the early stages of technological and infrastructure development.

The high coefficient of Domestic Investment (DMI) indicates that existing infrastructure remains a major contributor to greenhouse gas emissions. For example, although France has transitioned significantly toward nuclear energy accounting for approximately 70% of electricity generation and 40% of primary energy consumption (Commission, 2025), the construction of new high-speed railways, tunnels, and energy-efficient buildings still requires substantial amounts of concrete. As the second most widely used material in the world after water, cement production involves combustion processes that release significant carbon dioxide emissions (Associations, 2026). Moreover, International Energy Agency (2019) highlights that steel and cement are the primary materials used in infrastructure development in Europe, together accounting for approximately 7% of the region's greenhouse gas emissions. A similar pattern is observed in Switzerland, one of the cleanest countries globally, where investments in tunnel construction and cross-border transport infrastructure continue to generate emissions in both the construction and freight sectors. This is consistent with the findings of Aviral Kumar Tiwari et al. (2025), which show that land transportation in Europe remains heavily dependent on fossil fuels. For instance, Germany continues to expand its road network and land freight transport, while Hungary, as an emerging economy, is increasingly investing in cross-border freight transport by truck.

Oil has a positive impact on carbon dioxide emissions as expected, one Terawatt-hour (TWh) increase of oil consumption leads to increase of over 263,439.80 tons of carbon dioxide. According to previous studies, it is one of main factors emitting carbon dioxide emissions is due to countries heavily relying on oil consumption to developing their countries which currently account for more than 80 percent of all energy use worldwide (Xiaoli Liao et al., 2025). This is consistent with the proportions of oil consumption with total energy consumption in France, Denmark, Norway, Sweden, and Switzerland, with average values since 1990 and 2020 around 34.4% (Data, 2024b).

Table 2. The result Ordinary Least Squares (OLS) regression models with carbon dioxide emissions of developing countries

Variable	Coefficient	Std. Error	T-stat	P-value
EPS	41281756	59474323	0.6941	0.4891
FDI	0.0011	0.000715	1.5330	0.1282

DMI	-0.0006	0.000413	-1.4307	0.1553
GDP	0.0002	0.0000568	3.1521	0.0021*
OIL	272117.8	124830.6	2.1799	0.0314**
SOLAR	-1946809	912197.8	-2.1342	0.0350**
WIND	-2560555	956934.7	-2.6758	0.0086**
HYDRO	-564255.6	173938.1	-3.2440	0.0016**
C	62682615	229000000	0.2738	0.7847
AR (1)	1.0569	0.0081	130.2107	0.0000*

Notes: Statistical significance is evaluated at 1% level* and 5% level**

Turning to developing countries in Table 2, Gross Domestic Product (GDP), wind energy consumption (Wind), and hydropower consumption (Hydro) are found to have a statistically significant impact on carbon dioxide emissions (CO2E) at the 1% level, while solar energy consumption (Solar) and oil consumption (Oil) are significant at the 5% level. The results indicate that GDP and oil consumption remain the primary drivers of carbon dioxide emissions in developing countries. In contrast, greater reliance on renewable energy sources, particularly solar, wind, and hydropower, contributes to a reduction in carbon dioxide emissions.

Oil consumption has a positive impact on carbon dioxide emissions, as expected. Specifically, a one terawatt-hour (TWh) increase in oil consumption leads to an increase of more than 272,117.80 tons of carbon dioxide emissions. Consistent with previous studies, oil remains one of the primary drivers of carbon emissions, like patterns observed in developed countries. However, the key distinction is that most of the developing countries examined including China, India, South Africa, and Brazil are rapidly growing emerging economies that continue to rely heavily on fossil fuels to sustain their development. Collectively, these countries account for more than 40.3% of global carbon emissions (Data, 2024a). China, often referred to as "the world's factory," records the highest level of carbon emissions globally due to its strong dependence on coal and oil consumption. This finding is consistent with Xiaoli Liao et al. (2025), who note that China surpassed the United States in emissions in 2007 and accounted for more than 30.7% of global carbon emissions in 2020.

In India, the world's third-largest importer of crude oil, energy demand continues to rise alongside rapid urbanization. The economy remains highly dependent on road freight, with most transport relying on diesel-powered trucks. In addition, the government's "Make in India" initiative has stimulated manufacturing activities, which require substantial oil inputs for industrial processes, particularly in areas with limited access to electricity (Agency, 2021). Similarly, Brazil exhibits a complex energy structure, functioning both as an oil exporter and a leader in renewable energy. Despite its global recognition for ethanol production, key economic sectors, especially large-scale trucking and agribusiness, which account for more than 26.6% of GDP (Livestock, 2020) remain heavily reliant on diesel, with approximately 60% of transportation dependent on it (Analysis, 2021). This finding aligns with Samuel A Sarkodie et al. (2019), who emphasize that the agricultural sector in developing countries is highly dependent on fossil fuels, thereby contributing significantly to greenhouse gas emissions. In South Africa, the situation reflects a severe energy crisis in 2020, during which diesel was used not only for transportation but also as an emergency fuel for electricity generation due to the declining performance of major coal-fired power plants. Moreover, the load-shedding crisis, amounting to 1,798 gigawatt-hours (GWh) of recorded power cuts forced businesses and households to rely extensively on diesel generators to maintain economic activity (Eskom, 2020).

The study finds a significant positive relationship between Gross Domestic Product (GDP) and carbon dioxide emissions, with a one US dollar increase in GDP leading to an increase of more than 0.000179 tons of carbon dioxide emissions. This result is consistent with the Dirty Growth Hypothesis (Festus Victor Bekun et al., 2024), which suggests that rapidly industrializing and modernizing countries tend to prioritize economic growth over environmental quality. In 2020, China was the only major economy to record positive GDP growth at 2.3%

(Bank, 2026b), reflecting its substantial productive capacity. This economic expansion contributed directly to carbon emissions, accounting for approximately 31% of the global total, driven by industrial activity to meet both domestic and international demand. In contrast, India experienced a GDP contraction of -6.6% (Bank, 2026b) but remained the world's fifth-largest economy. Rising income levels in urban areas contributed to lifestyle-driven emissions, including increased demand for electricity and consumer goods associated with middle-class expansion (Agency, 2021). Similarly, Brazil maintained an economic structure heavily dependent on agribusiness, which accounted for 26.6% of GDP in 2020. Growth in this sector is closely linked to land-use changes and cross-border transportation, both of which contribute significantly to greenhouse gas emissions (Livestock, 2020). Meanwhile, South Africa, despite experiencing a GDP contraction of -6.4% (Bank, 2026b), remained the most industrially concentrated economy in its region. Its relatively higher income levels and level of economic development sustain strong primary energy demand, even during periods of economic slowdown.

Finally, solar, wind, and hydropower energy consumption are found to have a negative impact on carbon dioxide emissions. Specifically, a one terawatt-hour (TWh) increase in solar, wind, and hydropower consumption leads to reductions in carbon emissions of 1,946,809, 2,560,555, and 564,255 tons, respectively. These findings are consistent with existing literature, such as Yan Wu et al. (2021), which demonstrates that clean energy adoption reduces carbon intensity for example, through green construction practices in China's railway network projects and the transition from traditional to technology-based agriculture, thereby reducing diesel consumption in major energy-consuming countries (Huang et al., 2021). In the case of China, the country relied almost entirely on coal in the 1990s but has since become a global leader in renewable energy deployment. A key example is the Three Gorges Dam, the world's largest hydropower project, developed to reduce dependence on coal (Technology, 2020). As a result, renewable energy generation in China has reduced carbon emissions by approximately 2.26 billion tons of carbon dioxide (Xiaoliang Xu et al., 2025). Similarly, India, while initially dependent on coal, has increasingly focused on solar energy, supported by favorable geographic conditions. Initiatives such as the International Solar Alliance and the development of large-scale solar farms in desert regions have enabled India to achieve the fifth-largest solar power capacity globally by 2024 (Energy, 2024). In Brazil, a long-standing leader in clean energy, hydropower has served as the backbone of the energy system, accounting for approximately 60% to 70% of electricity generation in 2024 (Association, 2024). However, severe droughts in 2010 highlighted the risks of overreliance on hydropower (Leeds, 2011), prompting the country to diversify its energy mix by expanding wind, solar, and biofuel usage over the past decade to sustain low-carbon development (Agency, 2024). In contrast, South Africa faces greater challenges in its energy transition, as it remains highly dependent on coal. Although renewable energy initiatives such as the Renewable Energy Independent Power Producer Procurement Programme were introduced after 2011, progress has been relatively slow. Despite significant solar potential, structural challenges—particularly those related to Eskom—have hindered the expansion of clean energy and limited the pace of carbon emission reductions (Agency, 2023; Anton Eberhard & Naude, 2015).

CONCLUSION

Environmental degradation has emerged as one of the most critical global challenges, as carbon dioxide emissions continue to rise alongside economic development. This study examines the effects of Environmental Policy Stringency (EPS), Foreign Direct Investment (FDI), Domestic Investment (DMI), Gross Domestic Product (GDP), and energy consumption: oil, solar, wind, and hydropower on carbon dioxide emissions (CO2E) in both developed and developing countries over the period from 1990 to 2020. The findings reveal clear differences in the determinants of emissions between the two groups. For developed countries, carbon dioxide emissions are primarily driven by fossil fuel consumption and investment-related activities. Oil consumption has a significant positive effect on emissions, indicating that it remains a key energy source for economic activities even in advanced economies, despite stringent environmental policies. Additionally, both FDI and DMI contribute to increased emissions, as large-scale investments in infrastructure and high-technology sectors require substantial energy use and carbon-intensive materials such as steel and cement. In contrast, the results for developing countries show that carbon dioxide emissions are mainly driven by economic growth and continued dependence on fossil fuels. GDP and oil consumption significantly increase emissions, reflecting that rapid industrialization and economic expansion in emerging economies still rely heavily on fossil energy.

However, renewable energy consumption, particularly solar, wind, and hydropower plays a vital role in reducing carbon dioxide emissions. This indicates that transitioning toward renewable energy sources can substantially enhance environmental sustainability while supporting ongoing economic development.

Based on the findings, it is recommended that governments promote green investment frameworks to mitigate the environmental impacts of large-scale capital projects. One key policy approach is Green Infrastructure Investment, which supports the development of low-carbon infrastructure, including electric railway systems, smart energy-efficient buildings, and sustainable urban transportation. Another important initiative is the Sustainable Digital Infrastructure Project, which requires digital facilities and data centers to operate using renewable energy and energy-efficient technologies. For developing countries, where carbon dioxide emissions are primarily driven by economic expansion and dependence on oil, policy efforts should focus on accelerating the transition toward renewable energy. Governments should implement a Renewable Energy Expansion Program that promotes investment in solar, wind, and hydropower projects. Expanding these energy sources can reduce reliance on fossil fuels while simultaneously meeting the increasing energy demands associated with industrialization and urbanization.

Finally, although this study provides important insights into the determinants of carbon dioxide emissions, several areas remain open for further research. Future studies could expand the analysis by incorporating additional energy sources, including coal, to better understand the role of a more diversified energy mix in influencing emissions. Moreover, further research could focus on sector-specific emissions such as those from transportation, industry, and construction to generate more precise and targeted policy recommendations.

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