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*Original Research*

# Fostering a Green Tomorrow: Exploring the Impact of Economic Fitness on $CO_2$ Reduction Along the Environmental Kuznets Curve with Capital and Renewable Energy

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## Abstract

To pursue sustainable development, it is crucial to explore and prioritize economic growth and environmental protection. Global competitiveness is central to sustainable development in the complex relationship between economic growth and environmental protection. Analyzing the data of 121 countries, both developed (37) and developing (84), from 1995 to 2019, this study examines how economic fitness impacts environmental sustainability. The findings revealed that nations with higher economic fitness (0.038; -0.054) tend to have lower emissions, which is consistent with the EKC pattern, whereas increased capital investments (β = 0.137) and low consumption of renewable energy (β = -0.049) are linked with higher CO2 emissions. Similarly, the study findings highlighted the crucial role of economic fitness and the complexities of its relationship with environmental outcomes across different country groups. Moreover, the turning point for the overall sample of countries where the EKC starts to decline occurs at $63211.89 GDP per capita for high economic fitness, and for low economic fitness, it is $66070.98. Similarly, the turning points in the relationship between GDP per capita and environmental quality vary significantly between developed and developing countries. Therefore, nations with higher economic fitness experienced environmental improvements at lower GDP per capita levels in both groups of countries. This trend is particularly pronounced in developing countries, where nations with high economic fitness have demonstrated earlier improvements. In conclusion, this study contributes significantly to the understanding of the complex interplay between economic fitness and ecological sustainability.

**Keywords:** economic fitness, environmental Kuznets curve, $CO_2$ emission, economic growth, renewable energy, capital formation

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## Introduction

In the pursuit of sustainable development, the intricate interplay between economic growth, environmental conservation, and global competitiveness has taken center stage. In today's world, the main focus is on achieving sustainable economic development rather than solely prioritizing economic growth [1]. It is widely accepted that economic activities are a major cause of environmental degradation [2], and extensive research shows a robust correlation between economic activities and their adverse effects on the environment [3]. Consequentially, reducing CO2 emissions is the top priority of governments in many developing and developed countries [4]. In the midst of ongoing discussions on global and domestic policies, the pressing issue of global warming has become a significant topic of debate in recent years [5]. Therefore, the rising temperature is of significant concern not only to the general public but also in the context of economic and political decision-making [6]. Thus, the primary objective of worldwide efforts has been to reduce the impact of environmental degradation. The urgency of addressing climate change has emerged as a foremost concern [7] because it has detrimental impacts on human health, causes drought and environmental destruction, and disrupts food production [8]. Therefore, long-term sustainable development has intensified [9].

Consequently, the research work has been shifted towards exploring the factors that affect $CO_2$ emissions. For example, the impact of foreign direct investment [10], economic growth [11], urbanization [12], human capital [13], energy consumption [14], industry structure [15], ICT [16], and biomass consumption [17]. Among these factors, trade is an empirically verified and highly influential determinant of CO2 emissions. An increase in trade stimulates macroeconomic activities, and it directly influences CO2 emissions through multiple channels, including scale, technique, and composition [18]. Therefore, these channels play a significant role in determining whether trade leads to a rise or fall in $CO_2$ emissions [19].

Recently, the primary concern has been analyzing the connection between trade and $CO_2$ emissions. They have done this by using trade openness as a proxy variable, which is measured in terms of "volume" as a stand-in for trade and its impact on emissions (known as the scale effect) [20]. For the purpose of analyzing the impact of trade, some researchers have used "export product diversification," a strategy that is considered to affect the environment. Product diversification is now seen as a far better alternative to export product diversification when it comes to reducing environmental deterioration [21]. Only a few empirical studies have analyzed the relationship between product diversification and $CO_2$ emissions [22]. However, it is important to note that product diversification is just one aspect of economic fitness (EF) [23]. Consequently, this study used the EF, which is considered a more comprehensive metric, to better encompass the full impact of economic activities on the degradation of the environment along the environmental Kuznets curve (EKC) in both developed and developing countries.

The ability of a country to produce globally competitive and diversified products is more than just an economic indicator; it encapsulates a multifaceted concept known as "economic fitness" [24, 25]. Economic fitness represents a nation's capacity to navigate the intricate dynamics of economic growth and environmental sustainability, transcending the conventional paradigm of growth at the expense of ecological well-being. Economic fitness plays a pivotal role in shaping not only its economic growth [26, 27] but also its contribution to the reduction of $CO_2$ emissions. This symbiotic relationship underscores the interconnectedness of economic development and environmental sustainability, highlighting the potential for a win-win scenario where economic prosperity aligns with carbon footprint reduction. This intricate interplay is rooted in several key mechanisms:

The pursuit of global competitiveness necessitates continuous innovation and technological advancement [28]. As countries invest in research and development to remain competitive in the global market [29], they often adopt cleaner and more efficient technologies. These advancements lead to the adoption of environmentally friendly production processes, reducing energy consumption, resource use, and emissions per unit of output. Diversification of products often requires a country to leverage its resources efficiently and effectively [30]. This prompts a shift towards sustainable resource management practices, which are essential for long-term economic viability. By utilizing resources more responsibly, countries can curtail excessive resource extraction, minimize waste, and reduce emissions associated with resource-intensive industries. The global market is increasingly favoring sustainable and eco-friendly products [31]. Countries that produce globally competitive and diversified products aligned with these market trends are better positioned to capitalize on growing consumer demand for environmentally friendly options. This shift towards sustainable goods translates into reduced emissions, as these products are often designed with lower carbon footprints.

The study acknowledges the heterogeneity of the global terrain, which is marked by the contrast between developing and developed countries. Developing nations frequently have the dual task of seeking economic advancement and upholding environmental sustainability amidst constraints in resources and conflicting objectives. On the other hand, developed countries exhibit superior technological capacities, resources, and institutional structures that enable them to pursue sustainable trajectories. Therefore, a comprehensive analysis of the influence of economic viability on the mitigation of $CO_2$ emissions within these many contexts offers a multifaceted viewpoint on the intricacies of sustainable development. The importance of the two primary factors, namely gross fixed capital formation (GCFC) and renewable energy consumption, should not be underestimated within this particular context. GRFC denotes the allocation of resources towards the acquisition of tangible assets and infrastructure, which play a pivotal role in fostering economic expansion. On the other hand, renewable energy consumption shows the shift towards utilizing cleaner and more sustainable sources of energy. The intricate interaction between these factors and economic viability introduces intricate dimensions to the correlation between economic expansion, carbon dioxide emissions, and ecological integrity. The primary objective of this study is to comprehensively examine the relationship between economic fitness and the decrease of $CO_2$ emissions. By doing so, this research will provide significant contributions to the current global dialogue surrounding environmental sustainability. Through an analysis of the underlying mechanisms that govern the relationships among economic fitness, GCFC, renewable energy consumption, and the EKC, this study aims to establish a comprehensive framework that can guide policymakers, researchers, and stakeholders in their efforts to navigate a path towards a more environmentally friendly and sustainable future.

This study contributes to existing research in many ways: First, it explores the impact of EF on $CO_2$ emissions in the context of the EKC hypothesis in both developed and developing countries. Second, it contains the EKC trajectories in developed and developing countries separately. Third, integrating various factors like GRFC and REC into the analysis further provides an understanding of how economic fitness shapes the balance between economic development and environmental well-being. Fourth, how economic fitness demonstrates the improvements in or turning points of EKC in both developing and developed countries.

Ultimately, this research endeavors to provide insights into how nations can leverage their economic fitness to foster a greener tomorrow. It seeks to unravel the synergies between economic prosperity and environmental sustainability, offering a nuanced understanding of the role of globally competitive and diversified production in $CO_2$ emission reduction. In doing so, the study contributes to the broader discourse on sustainable development and offers policymakers valuable insights to inform strategic decisions that align economic progress with the imperative of a healthier planet. Therefore, the following research objectives have been specified;

To explore how economic fitness influences $CO_2$ emissions along the EKC in both developed and developing countries.

To analyze how increased GFCF impacts $CO_2$ emissions in developing and developed nations.

To investigate renewable energy consumption's (REC) role in curbing $CO_2$ emissions within the EKC framework.

To contrast EKC trajectories in developed and developing nations, focusing on economic fitness, GFCF, and REC.

## Review of Literature

The EKC theory has been a focal point of research in environmental economics, aiming to decipher the intricate relationship between economic development and environmental degradation. This literature review provides an overview of studies that have investigated EKC patterns while utilizing various economic variables, shedding light on the multifaceted nature of this relationship. Moreover, studies have engaged in comparisons of EKC trajectories between developing and developed nations. Grossman and Krueger [32] have scrutinized emissions across different industries in various countries, revealing considerable variations in the turning points on EKC paths. Developing countries often grapple with challenges such as technology transfer and institutional capacity, influencing the shape and timing of their EKC curves. Contemporary research has also embraced factors such as income inequality, trade openness, and institutional frameworks as modifiers of EKC dynamics. Lindmark [33] has investigated the impact of trade openness on $CO_2$ emissions, highlighting that the relationship hinges on the level of development. Such studies emphasize the necessity of considering comprehensive socio-economic contexts among developed and developing nations while analyzing EKC patterns.

### Economic Growth and Environmental Degradation

Numerous scholars including [34-43] have explored the linkage between economic growth and carbon emissions along the trajectory of the EKC. Pioneering works by [44, 45] have delved into the proposition that initial economic growth contributes to escalating pollution levels until a turning point is reached, beyond which further development results in diminished pollution. These studies frequently employ GDP per capita as a surrogate for economic growth. The findings have been heterogeneous, with some studies supporting the existence of an EKC pattern, while others unveil intricate relationships shaped by technological advancements and policy interventions [46, 47]. Stern [48] assessed Sweden's $CO_2$ emissions trend from 1870, utilizing a structural time series approach involving GDP growth, and fuel and cement price changes. Notably, periods of high growth (1920-1960) displayed fewer CO2-related changes compared to lower growth eras, hinting at the potential influence of time-specific technological clusters on EKC patterns. Olubusove and Musa [49] utilized ARDL, Mean Group (MG), and Pooled Mean Group (PMG) models to study the EKC in 43 African countries (1980-2016), finding CO2 emissions rise with economic growth in 79% of countries. Weimin et al. [50] examined EKC in globalized economies (1990-2019), noting economic growth increases CO2 emissions while squared growth and globalization lower emissions. Liu [51] analyzed CO2 emissions and economic expansion, identifying EKC patterns using mean value decomposition and Kuznets curve modeling. Ganda [52] assessed EKC in South Africa (1980-2014), revealing varied long-run relationships for energy consumption sources. Cheikh et al. [53] introduced a nonlinear PSTR approach to analyze MENA region emissions, highlighting nonlinear energy-CO2 dynamics and GDP growth's influence. Kong and Khan [54] explored EKC for 29 countries, confirming it for various emissions. Wang et al. [55] found an inverted U-shaped EKC for China's grain production. Genc et al. [56] analyzed Turkey's $CO_2$ emissions under output volatility–augmented EKC, highlighting economic-environmental balance.

Therefore, economic growth has a substantial impact on the environment in the context of $CO_2$ emissions, based on the EKC hypothesis. This hypothesis describes that in the early stages of economic growth, pollution, and income levels increase simultaneously, but after reaching a certain level of income, the environmental level begins to improve. Maroufi and Hajilary [57] have described the contribution of economic growth to the reduction of pollutants and $CO_2$ emissions in both the short and long run. While Yunita et al. [58] have found a significant positive impact of GDP per capita on $CO_2$ emissions. Jóźwik et al. [59] have confirmed the existence of the EKC hypothesis in Central European countries. The imperative to achieve sustainable development has grown exponentially in recent decades, fueled by the recognition of the alarming environmental challenges confronting the world. Among these challenges, the heightened levels of carbon dioxide ($CO_2$) emissions have emerged as a formidable threat [40] to the delicate balance between economic progress and environmental preservation. The intricate relationship between economic growth, environmental degradation, and sustainability has given rise to a host of research inquiries, resulting in the formulation of theoretical frameworks to decipher these intricate dynamics. One such conceptual framework is the Environmental Kuznet Curve (EKC), which postulates an inverted U-shaped relationship between economic development and environmental quality [41]. Thus, the following hypothesis has been developed:

H1: Economic growth has a substantial impact on $CO_2$ emissions in both developing and developed countries, based on the EKC hypothesis.

## Gross Fixed Capital Formation and Environment

Incorporating GRFC as an economic variable, several researchers have enriched the comprehension of the EKC concept. Shafik and Bandyopadhyay [60] have scrutinized the impact of investment in infrastructure, concluding that augmented GFCF could induce initial environmental degradation, followed by eventual amelioration as economies mature. Nonetheless, divergences emerge due to disparities in sectoral compositions and the nature of infrastructure investments across countries [60]. GRFC supports growth and sustainability. Thus, one major factor, GRFC, has a profound impact on $CO_2$ emissions in the environment. Various studies have described the role of GRFC in determining the carbon intensity of capital assets. For example, developing nations tend to invest in resource-intensive assets, including infrastructure and machinery, while developed countries prefer to invest in less resource-intensive assets like software, computers, and services [61]. Moreover, there is an asymmetry in the relationship between GRFC and $CO_2$ emissions. In fact, shocks to GRFC have an uneven impact on emissions in both the short and long run [62]. Thus, the following hypothesis has been developed:

H2: GRFC is expected to have an asymmetric impact on $CO_2$ emissions in both developing and developed countries.

## Renewable Energy Consumption and Environmental Degradation

REC has emerged as a pivotal economic variable in EKC investigations. Akbostanici et al. [63] have probed the nexus between REC and $CO_2$ emissions, proposing that heightened utilization of renewable energy resources might facilitate an earlier downturn in emissions. This insight underscores the potential for policy-driven transitions toward cleaner energy sources to expedite the EKC process [63]. Lee [24] investigates the economic and energy impacts of the Belt and Road Initiative on selected countries. The analysis confirms the presence of the EKC, highlighting fossil fuels' negative impact and renewable energy's positive role. A call to support green energy and clean tech is recommended. Mitic et al. [64] examine Balkan countries, finding cointegration between $CO_2$ emissions, industry, services, and capital formation. Bidirectional causality exists among industry, services, and capital, with unidirectional causality from industry and capital to emissions. Policymaking should prioritize modernization and renewables. Bekht et al. [65] explore Malaysia's dynamic connections among financial development, growth, energy, $CO_2$ emissions, and capital formation. Cointegration and Granger causality confirm relationships, advocating for combined financial development, growth, and effective energy policies. Jalil et al. [66] address Malaysia's carbon emission challenge, focusing on various factors' impacts. Technological development is key to sustainable goals. Capital formation and renewable energy investments are vital for manufacturing and GDP sustainability. Prakash et al. [67] assess India's liberalization, finding GFCF's positive impact on emissions post-reforms. Investment in cleaner technologies is suggested for sustainable development. Zafar et al. [68] explore financial development and renewable energy effects on emissions for G-7 and N-11 countries, finding varied impacts on environmental quality. Human capital's role is underscored, while renewables alone are insufficient. Akalpler and Hoves [69] examine China's renewable energy and $CO_2$ emissions asymmetric relationship, highlighting the impact of negative shocks. Human capital and technology play roles, supporting the EKC theory. Investments in renewable energy infrastructure are encouraged. Pata and Caglar [70] address China's pollution challenges, identifying factors influencing pollution. Income, human capital, globalization, and trade drive pollution, with human capital's importance in curbing degradation emphasized. Renewable energy's limited impact is noted. Pata [71] investigates Turkey's GDP, emissions, and sustainable growth relationship. Economic growth, financial development, and urbanization contribute to environmental degradation. Renewable energy isn't effectively reducing emissions. Turning points for emissions reduction are suggested. Jiang et al. [72] analyze China's asymmetric relationship between renewable energy and emissions, finding negative shocks' stronger effects. The importance of legislative support for clean energy and low-carbon projects is highlighted. Riti et al. [73] examined SSA's link between renewable energy, GDP, GHG emissions, and capital using PARDL (1990-2018), finding positive long-term connections. Renewable energy and capital enhance growth while reducing emissions, countered by GDP and capital. Feedback exists between GDP, renewable energy, and capital, with renewable energy affecting $CO_2$ emissions unidirectionally. Zhang et al. [74] focused on Pakistan, confirming EKC for renewable and non-renewable energy (1970-2012), highlighting renewable energy's emission reduction role and bidirectional energy-$CO_2$ causality. Sensitivity analysis underscores policy importance, urging more government investment in renewable energy for climate mitigation. Thus, the following hypothesis has been developed:

H3: Renewable energy consumption will have a significant negative influence on $CO_2$ emissions in both developed and developing countries.

## Economic Fitness and Environmental Degradation

The pursuit of economic fitness spurs the growth of industries and sectors which leads to economic development [25] that generates employment opportunities and increases income levels. This economic empowerment can contribute to social stability, enhanced well-being, and poverty reduction [34]. Importantly, when economic growth is decoupled from high carbon intensity, these positive socio-economic outcomes can be achieved without exacerbating $CO_2$ emissions. Nurturing globally competitive and diversified industries often requires collaboration between governments, industries, and other stakeholders [35]. Such collaborations can lead to the formulation and implementation of policies that promote sustainable practices, invest in clean technologies, and incentivize low-carbon production processes [36-38]. By producing innovative, sustainable, and diversified products, countries can distinguish themselves in the global market. This differentiation not only enhances their economic prospects but also positions them as leaders in environmental stewardship. This reputation can attract investments, partnerships, and international cooperation, leading to the exchange of best practices and shared goals for $CO_2$ reduction.

In this particular environment, the capacity of a nation to manufacture goods that are globally competitive and diverse (referred to as economic fitness) assumes great importance. The scope of this issue stretches well beyond just economic considerations and is inextricably connected to the urgent need to decrease $CO_2$ emissions and address environmental damage. By employing a blend of technical advancements, optimizing resource utilization, adhering to sustainable market trends, and fostering collaboration, countries may effectively navigate the complex landscape of economic growth while concurrently mitigating their carbon emissions. The aforementioned complex approach to development serves to strengthen the concept that economic fitness is not exclusively concerned with financial profits, but also involves the integration of economic advancement with the welfare of the environment and its inhabitants. Therefore, the economic viability of a society plays a pivotal role in determining the path towards achieving environmental sustainability.

The EKC posits that the relationship between economic growth and environmental quality is complicated and subject to the effect of diverse causes. The implementation of cleaner technology, advancements in resource management, and transitions towards sustainable consumption behaviors have the potential to modify the course of environmental impact during periods of economic growth. Nevertheless, the literature has not extensively explored the impact of economic fitness on the formation of this association. The objective of this study is to address the existing disparity by examining the complex relationship between economic competitiveness, the decrease of $CO_2$ emissions, and the EKC hypothesis in both developed and developing countries. Thus, the following hypothesis has been developed.

Industrialization improves a country's economic fitness [75, 76] allowing it to compete in increasingly complex industries. Increases in GDP per person may emerge as a result of this development [77]. Early on, most energy is expended on agriculture since biomass is such a vital resource [78]. While agriculture's contribution to the economy and the labor force declines as a result of sector diversification and mechanization, biomass extraction and utilization remain largely consistent throughout industrialization. There is also significant expansion in the use of technical energy (such as fossil fuels) and minerals (which include building materials and metals) [79], which acts as a structural barrier to development [80] and may lead to environmental disputes [81]. After a country reaches a high level of economic fitness and industrial development, a combination of forces may cause absolute dematerialization and decarbonization of the system. These elements typically include (i) structural shifts in production and consumption patterns; (ii) advanced technical capabilities leading to more efficient resource use; and (iii) surplus resources allocated to environmental protection. These trends may eventually coalesce into what is being called an "Environmental Kuznets Curve" (EKC). Thus, initially, in early economic development, industries focus on resource-intensive activities, leading to high $CO_2$ emissions due to energy-intensive processes. As economies progress and enhance their fitness, they diversify production towards less carbon-intensive, technologically advanced industries. This shift mirrors reduced carbon intensity. In later stages of development and increased economic fitness, nations adopt cleaner technologies, produce low-carbon goods, and enact sustainable policies, resulting in declining or stabilizing $CO_2$ emissions.

The continuous increase in carbon dioxide (CO2) emissions and the growing risks associated with climate change have generated a critical imperative to harmonize economic progress with the principles of environmental sustainability. The impact of economic fitness on successfully negotiating the complex link between economic growth and environmental deterioration remains a relatively understudied issue. The purpose of this research is to examine how developing and developed countries differ in their patterns of economic fitness, carbon dioxide (CO2) emissions, and the EKC. This research intends to shed light on strategies that can foster a more ecologically friendly and sustainable future by exploring deeply into the complex systems that govern these interactions. The EKC is a theoretical model that can be used to make sense of the correlation between economic growth and environmental degradation. However, the importance of economic fitness must be explored as a central factor here. The concept of economic fitness pertains to the capacity of an economy to effectively adapt and withstand environmental conditions. As countries strive to achieve a harmonious equilibrium between economic advancement and environmental conservation, the extent to which economic viability impacts the decrease of carbon dioxide emissions emerges as a crucial inquiry. The primary objective of this study is to address the existing disparity by examining the impact of economic fitness on the structure and progression of the EKC.

H4: EF is expected to correlate with earlier turning points on EKC in both developing and developed countries.

The research gap highlighted above is directly linked with the concept of economic fitness, which is a fundamental gap that has not been extensively studied. While scholars have explored the relationship between economic growth and carbon emissions within the context of the EKC, there remains a critical need to delve deeper into the role of economic variables such as GRFC and REC. These factors including economic fitness are essential components of a nation, as they contribute to both growth and sustainability. Furthermore, the comparison of EKC trajectories between developing and developed nations underscores the necessity of considering socio-economic contexts and structural differences to understand how economic fitness evolves across diverse regions influences the EKC trajectories. Integrating factors like GRFC and REC into the analysis further enriches the understanding of how economic fitness shapes the balance between economic development and environmental well-being. In essence, this research gap directly addresses the core question of how nations' economic fitness plays a role in the relationship between economic growth and environmental impacts, making it a central and foundational aspect of the study of economic sustainability.

## Materials and Methods

In order to find the relationship between economic fitness (Eco. fit) and $CO_2$ emissions along the EKC, we analyzed data from a panel of 121 countries, encompassing both developing and developed nations, including different variables over the period of 1995-2019. These variables include $CO_2$ emissions, GDP per capita, economic fitness, GCFC, and REC.

The measurement of $CO_2$ emissions per capita is an important environmental metric that signifies the quantity of carbon dioxide that is discharged into the atmosphere by each individual. The utilization of the metric tons per capita measurement enables the standardization of emissions among countries characterized by diverse population sizes, hence facilitating the establishment of valid comparisons.

Gross domestic product (GDP) per capita is a significant economic metric that quantifies the economic output per individual within a given nation. The economic performance of a nation at a specific moment in time is represented in current US dollars.

The concept of economic fitness (Eco. fit) is a comprehensive measure that evaluates a nation's ability to withstand economic shocks, its capacity for innovation, and its competitiveness in the international arena. It depicts the ability of an economy to produce diversified and globally competitive goods. A greater economic fitness score indicates a stronger and more flexible economy.

GFCF pertains to the aggregate monetary worth of investments directed toward the acquisition and enhancement of a nation's tangible assets, encompassing infrastructure, machinery, and equipment. The aforementioned factor has a pivotal role in facilitating and promoting economic growth and development.

The measurement of renewable energy consumption (ENCO) as a proportion of overall energy consumption is a crucial environmental indicator. The aforementioned statement underscores a nation's dedication to the utilization of sustainable energy resources, thereby facilitating a decrease in carbon dioxide emissions and the preservation of the environment.

The data included in this analysis is obtained from the World Development Indicators (WDI), a comprehensive dataset that offers important insights into the economic and environmental attributes of countries worldwide. The dataset used in this study consists of a panel of countries, encompassing a wide range of nations. Specifically, there are 84 countries classified as developing nations and 37 countries classified as developed nations. This categorization facilitates a comparative examination of these two groups, elucidating potential discrepancies in environmental and economic metrics. Therefore, the general form of the model is presented below.

$$CO_2 = f(GDP, Eco.Fit, GFCF, ENCO)$$

Where, GDP indicates gross domestic output per capita, Eco.Fit indicates economic fitness, GFCF indicates gross fixed capital formation, and ENCO indicates REC. The study further modified Equation (1) to the reduced form of EKC, in which different variables entered the domain of $CO_2$ emissions per capita and GDP per capita.

$$\ln CO_2 = \zeta_o + \zeta_1 lnGDP_{i,t} + \zeta_2 \ln GDP_{i,t}^2 + \zeta_3 \ln GFCF_{i,t} + \zeta_4 ENCO_{i,t} + \mu_{i,t}$$

Where I indicate the cross-section identifier, t describes the time period from 1995 to 2019, and shows the error term. The values of ζ1 and ζ2 in the model help determine the nature and significance of the relationship between per capita carbon emissions and per capita GDP, ranging from no relationship to linear, monotonically increasing or decreasing, and U-shaped or inverted U-shaped relationships. Therefore, if both ζ1 and ζ2 possess a value of 0, it indicates that there is no observable relationship between carbon emissions and GDP, and the relationship is basically flat. When ζ1 is higher than 0 and ζ2 is equal to 0, it indicates that GDP has a statistically significant positive impact on emissions; however, the square of per capita GDP does not have a statistically significant effect. This observation implies that there is a consistently increasing relationship between emissions and economic growth. If ζ1 is negative and ζ2 is zero, it infers that per capita GDP has a statistically significant negative impact, whereas the square of per capita GDP does not have a statistically significant impact on emissions. This suggests a consistent decline in the relationship between emissions and economic growth. The existence of an inverted U-shaped relationship between emissions and economic growth requires that the coefficient of GDP per capita (ζ1) is positive (>0) and the coefficient of squared value of per capita GDP (ζ2) is negative (<0). However, if the coefficient of GDP per capita (ζ1) is negative (<0) and the coefficient of squared value of per capita GDP (ζ2) is positive (<0), it confirms the existence of a U-shaped relationship between economic growth and emissions. The current study has adopted the robust econometric technique called panel two-stage least squares (2SLS). It assists in assessing the country-specific effect (2SLS fixed effect) and time-varying shocks (2SLS random effect). The panel two-stage least squares (2SLS) approach integrates the complementary analytic method. The instrumental variable method, also known as two-stage least squares (2SLS), offers notable benefits in addressing endogeneity concerns, specifically when there is a correlation between the error term and certain independent variables. The proposed methodology offers a concise and direct strategy for mitigating endogeneity issues through the utilization of instrumental factors in the initial stage to estimate potentially endogenous variables. These estimates are subsequently integrated into the second stage of regression analysis. This two-step process helps mitigate bias and improve the reliability of parameter estimates. In contrast, GMM can be computationally intensive and requires specifying moment conditions, while ARDL is designed specifically for time series data and may not be as effective in situations with strictly exogenous instruments. Therefore, 2SLS can be a more accessible and effective method for handling endogeneity in cross-sectional data, offering a simpler and more interpretable solution.

## Results

Table 1 provides a comprehensive descriptive analysis of several key variables of the study including economic and environmental indicators. The dataset contains a wide range of countries allowing us to observe the variation and disparities in the variables at the global level. The overall statistics of the countries show that the mean $CO_2$ emission is equal to 4.345 metric tons per capita with a standard deviation of 4.340 metric tons per capita. The higher standard deviation implies greater variability among the countries considering their environmental impacts in terms of GHG emissions. The range spans from a minimum of 0.022 metric tons per capita to a maximum of 20.575 metric tons per capita. This shows the spread of emission values in the dataset. It implies that there are countries with significantly higher emissions and other relatively low emissions.

The average GDP per capita of 121 countries is approximately $11717.91 per capita with a standard deviation of $16554.19 per capita. It shows the total monetary value of goods and services produced within a country's boundary. The standard deviation implies

Table 1. Descriptive analysis of the key variables.

| Variable | Mean | Std. Dev. | Min | Max | Obs. |
|---|---|---|---|---|---|
| $CO_2$ | 4.345 | 4.340 | 0.022 | 20.575 | 3025 |
| GDP | 11717.910 | 16554.190 | 99.757 | 1.04e+05 | 3025 |
| Economic fitness | 1.239 | 2.892 | 0.000 | 33.259 | 3025 |
| Gross fixed capital formation | 1.08e+11 | 4.12e+11 | 0.9307183 | 6.12e+12 | 3025 |
| Renewable energy consumption | 34.604 | 31.067 | 0.000 | 98.340 | 3025 |
| Developing Countries | | | | | |
| $CO_2$ | 2.742 | 3.475 | 0.022 | 20.575 | 2100 |
| GDP | 3688.246 | 4852.650 | 99.757 | 46844.200 | 2100 |
| Economic fitness | 0.599 | 2.508 | 0.000 | 33.259 | 2100 |
| Gross fixed capital formation | 5.76e+10 | 3.35e+11 | .9307183 | 6.12e+12 | 2100 |
| Renewable energy consumption | 19.297 | 18.243 | 0.000 | 81.570 | 2100 |
| Developed Countries | | | | | |
| $CO_2$ | 7.985 | 3.887 | 0.235 | 20.470 | 925 |
| GDP | 29947.430 | 19082.930 | 629.782 | 1.04e+05 | 925 |
| Economic fitness | 2.692 | 3.168 | 0.000 | 18.585 | 925 |
| Gross fixed capital formation | 2.24e+11 | 5.30e+11 | 5.41e+08 | 4.49e+12 | 925 |
| Renewable energy consumption | 41.346 | 33.095 | 0.000 | 98.340 | 925 |

that there is a significant difference in the size of the economies of the countries. It means some countries have higher GDP and others have lower GDP. The range of GDP from a low GDP value of $99.76 per capita to a higher value of $104000 per capita highlights the large variation in the dataset. Therefore, some countries have very large economies, while others have very small size economies.

Economic fitness describes the ability of the country to produce diversified and globally competitive goods. The average score of the 121 countries of 1.239 highlights that the countries have moderate levels of economic fitness. The standard deviation of 2.892 indicates considerable variability among the ability of countries to produce diversified and globally competitive goods. It implies greater differences in the economic fitness of the countries. The minimum value of economic fitness (equal to 0.00) suggests that some countries have potential challenges in their ability to produce competitive and diversified goods.

GRFC indicates the amount of investment made by an economy in the acquisition and production of goods and services including equipment, infrastructure, and machinery. The average value of GRFC of 121 countries is $108 trillion, which describes the productive capacity of an economy. A larger standard deviation highlights the larger disparities in the national investment level. Similarly, the range of the GRFC describes the diverse investment magnitude in the dataset. It implies that some countries are making relatively little investment in their production capacity, while others are investing significantly larger.

On average, 34.60% of the energy of the countries is from renewable energy sources such as solar, wind, and hydro. The higher standard deviation implies that there are substantial differences in the prevalence of renewable energy adoption across the countries.

Similarly, developed countries ($29947.430 per capita) have significantly higher GDP per capita as compared to developing countries ($ 3688.24 per capita). Therefore, the GDP per capita of countries categorized as developed is much higher than the nations that fall into the developing category. Thus, this implies that advanced and industrialized economies tend to produce more economic output overall. Similarly, the developed countries have higher economic fitness compared to the developing countries, which implies that the developed countries have a greater ability to produce diversified and globally competitive goods. Moreover, developed countries tend to have typically more extensive investment in the acquisition and production of capital goods, which reflects the higher level of economic development and industrial infrastructure. The developed countries use more energy generated by renewable energy sources including solar, wind, and hydro than developing countries do. It implies that developed countries extensively practice and use cleaner energy sources.

When correlation scores between the variables are large, especially above the 0.7 critical value,

Table 2. Correlation analysis and VIF scores.

| Overall | | | | | | |
|---|---|---|---|---|---|---|
| Variables | $CO_2$ | GDP | Economic fitness | Gross fixed capital formation | Renewable energy consumption | VIF |
| | 1.000 | | | | | |
| GDP | 0.623 | 1.000 | | | | 1.45 |
| Economic fitness | 0.351 | 0.379 | 1.000 | | | 4.44 |
| Gross fixed capital formation | 0.319 | 0.278 | 0.548 | 1.000 | | 3.79 |
| Renewable energy consumption | -0.648 | -0.330 | -0.273 | -0.182 | 1 | 1.06 |
| Developing countries | | | | | | |
| Variables | $CO_2$ | GDP | Economic fitness | Gross fixed capital formation | Renewable energy consumption | |
| | 1.000 | | | | | |
| GDP | 0.652 | 1.000 | | | | 1.094 |
| Economic fitness | 0.132 | 0.069 | 1.000 | | | 5.13 |
| Gross fixed capital formation | 0.135 | 0.111 | 0.587 | 1.000 | | 5.10 |
| Renewable energy consumption | -0.671 | -0.478 | -0.145 | -0.116 | 1 | 1.07 |
| Developed countries | | | | | | |
| Variables | $CO_2$ | GDP | Economic fitness | Gross fixed capital formation | Renewable energy consumption | |
| Co2 | 1 | | | | | |
| GDP | 0.297 | 1 | | | | 3.08 |
| Economic fitness | 0.340 | 0.318 | 1 | | | 3.96 |
| Gross fixed capital formation | 0.439 | 0.272 | 0.661 | 1 | | 2.68 |
| Renewable energy consumption | -0.426 | 0.062 | -0.362 | -0.224 | 1 | 1.80 |

the possibility of multicollinearity is a concern. The finding across all categories in Table 2 regarding the assessment of multicollinearity is presented. We used both correlation coefficient and VIF to evaluate the multicollinearity within the three groups, overall, developing and developed countries. The results across all the categories, collectively indicate that there is no correlation score between the variables surpassing the 0.70 threshold value, or VIF score above 10. They suggest that the risk of multicollinearity is quite minimal across the overall dataset, as well as its distinct datasets of developed and developing countries. The findings provide the pathways for further analysis with the confidence that the interdependence of the variables is not a major challenge.

All three-panel two-stage least-square models provide robust evidence in favor of the presence of EKC in the chosen panel of 121 countries. The current study reveals a discernible pattern between GDP per capita and environmental quality in terms of $CO_2$ emission. Initially, the rise in GDP per capita escalated the carbon emission per capita, indicating the degradation of the environment. However, a notable turning point arises during the progression of economic development. The inclusion of the squared GDP per capita variable alters the nature of this relationship. As GDP per capita continues to rise, the inclusion of squared GDP per capita becomes crucial in the context of diminishing carbon emission per capita. The EKC phenomenon has been consistently validated using several analytical methodologies, such as the panel 2SLS (cross-sectional fixed effect) and 2S-EGLS (two-way random effect) approaches. This observed consistency provides empirical support for the robustness of the relationship between economic development, as measured by GDP per capita, and complex dynamics of environmental degradation, as measured by carbon emission per capita.

Concerning the impact of economic fitness on $CO_2$ emission along the EKC, the findings of all three models (Table 3) demonstrate the statistically significant coefficient of economic fitness. The panel 2SLS with cross-sectional fixed effect reveals a statistically significant and negative coefficient at a 1% level of significance. It implies that there is a negative relationship between $CO_2$ emission and economic fitness along the EKC. Similarly, in the context of panel

Table 3. 2SLS outcomes based on a panel of 121 countries.

| | Panel 2SLS (cross-sectional fixed) | Panel 2S-EGLS (period random effect) | Panel 2S-EGLS (two-way random effects) |
|---|---|---|---|
| Constant | -5.79* | -5.769* | -18.36* |
| GDP | 0.792* | 0.669* | 3.878* |
| $GDP^2$ | -0.046* | -0.028* | -0.191* |
| Eco. Fit | -0.038* | -0.054* | 0.05*** |
| GFCF | 0.137* | 0.138 | 0.044 |
| ENCO | -0.049* | -0.116* | -0.154* |
| R2 | 0.23 | 0.356 | 0.73 |
| F-statistics | 59.81* | 73.29* | 154.91* |

two stage-EGLS (period random effect) model, and two stage EGLS (two-way random effect) model, it is observed that the coefficient of economic fitness holds a significant negative relationship with $CO_2$ emission, suggesting a consistent pattern.

In the panel 2SLS model, the GRFC's coefficient exhibits a statistically significant and positive relationship with $CO_2$ emission. It implies that an increase in GRFC leads to higher $CO_2$ emissions. On the other hand, the other two models exhibit a comparable positive coefficient for GRFC. However, it does not attain statistical significance. All three models reveal the significant negative coefficient of REC. It suggests a strong relationship between the adoption of renewable energy sources and a decrease in $CO_2$ emissions.

Fig. 1 therefore supports the existence of an EKC among the sample of countries, so long as the economic fitness of these nations is allowed to fluctuate, taking into account the impact of gross fixed capital formation and consumption of renewable energy.

The coefficients for GDP per capita (0.229, 0.244, and 6.469) in all models suggest that as GDP per capita increases, carbon emission initially rises, which aligns with the patterns observed in economic expansion. The coefficient associated with GDP square (-0.007, -0.001, and -0.372) indicates the turning point of EKC in developing countries, where further economic growth leads to a decline in per capita $CO_2$ emission. The findings in developing countries indicate that the relationship between GDP per capita and environmental quality partially aligns with the EKC hypothesis, which highlights the turning point where environmental deterioration initially rises and subsequently declines with economic development.

The negative coefficients (-0.042, and -0.058) in both models for economic fitness show that higher economic fitness leads to low carbon emission per capita (Table 4). It highlights that the countries engaged in the production of diversified and globally competitive products tend to have low carbon emissions. However, these results are not consistent across all the models.

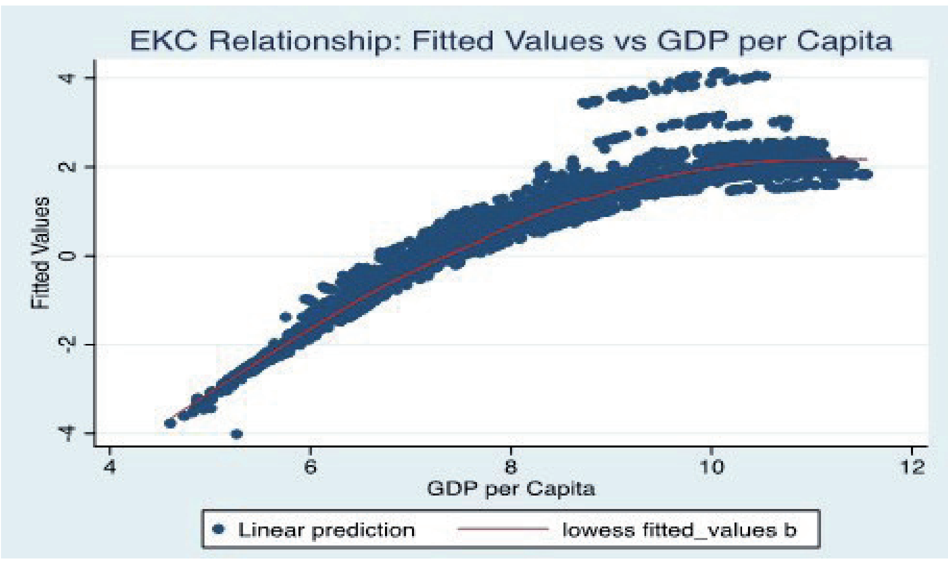


Fig. 1. EKC.

Table 4. 2SLS outcomes based on a panel of 84 developing countries.

| | Panel 2SLS (cross-sectional fixed) | Panel G2SLS (period random effect) | Panel 2S-EGLS (two-way random effects) |
|---|---|---|---|
| Constant | -5.79* | -5.169* | -18.36* |
| GDP | 0.229*** | .244 | 6.469* |
| GDP2 | -0.007*** | -0.001 | -0.372* |
| Eco.fit | -0.042* | -0.058* | 0.038 |
| GFCF | 0.151* | 0.166* | 0.041 |
| ENCO | -0.04 | -0.164* | -0.23* |
| R2 | 0.205 | 0.312 | 0.68 |
| F-statistics | 33.81* | 52.19* | 103.02* |

Similarly, the observed coefficient for GRFC at 0.151, and 0.166 implies a positive relationship with the emission of $CO_2$, which may suggest a potential link to heightened industrialization. These findings regarding GFCF contradict the EKC hypothesis. The negative coefficient (-0.04, -0.164, and -0.23) for the REC across all the models depicts a diverse relationship with emissions. The negativity of the coefficient of energy consumption signifies that the higher consumption of renewable resources leads to low carbon emissions. The findings are consistent with the objective of investigating the impact of renewable energy on reducing emissions.

Fig. 2 therefore supports the existence of an EKC among the sample of developing countries, so long as the economic fitness of these nations is allowed to fluctuate, taking into account the impact of gross fixed capital formation and consumption of renewable energy.

The GDP per capita coefficient (0.951, 1.181, and 5.887) in all models suggests that there is a positive relationship between GDP and carbon emission per capita (Table 5). The negative and significant coefficient of GDP square (-0.069, -0.077, and -0.286) indicates the turning point at which more growth results in the decline in carbon emission per capita. The findings regarding the developed countries also provide support for the EKC hypothesis, which suggests the presence of a turning point between GDP per capita and environmental quality. The positive coefficient for GDP and the negative coefficient for squared GDP term indicates a comparable turning point pattern observed in developing nations, although the relationship is more pronounced.

The negative and significant coefficients (-0.087 and -0.073) in the context of economic fitness imply an inverse relationship between economic fitness and carbon emission per capita. The relationship between GFCF and carbon emission is positive which potentially contributes to the development of industrial activities. The coefficient of REC (-0.038 and -0.042) suggests

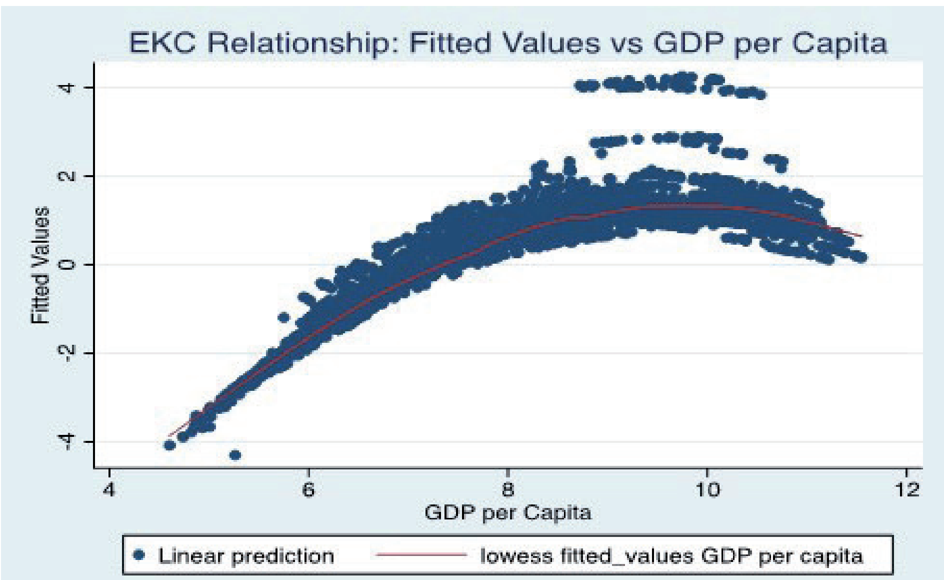


Fig. 1. EKC in the case of developing countries.

Table 5. 2SLS outcomes based on a panel of 37 developed countries.

| | Panel 2SLS (cross-sectional fixed) | Panel G2SLS (period random effect) | Panel 2S-EGLS (two-way random effects) |
|---|---|---|---|
| Constant | -6.743* | -7.184* | -29.68* |
| GDP | 0.951* | 1.181* | 5.887* |
| $GDP^2$ | -0.069* | -0.077* | -0.286* |
| Eco. Fit | -0.087** | -0.073** | -0.025 |
| GFCF | 0.254* | 0.211* | 0.064 |
| ENCO | -0.038* | -0.042* | -0.018 |
| $R^2$ | 0.27 | 0.29 | 0.69 |
| F-statistics | 74.502 | 71.51* | 26.59* |

that the increase in consumption of renewable energy sources leads to a decline in carbon emission.

Fig. 3 therefore supports the existence of an EKC among the sample of developed countries, so long as the economic fitness of these nations is allowed to fluctuate, taking into account the impact of gross fixed capital formation and consumption of renewable energy.

## EKC Trajectories and Economic Fitness

The turning point for the overall sample of countries where the EKC starts to decline occurs at $63211.89 GDP per capita for high economic fitness, and for low economic fitness, it is $66070.98 (Table 6). It is seen that nations characterized by high economic fitness exhibit a lower turning point compared to countries characterized by low economic fitness. This observation indicates that nations exhibiting more economic prowess, or economic fitness, tend to experience a decline in environmental degradation at a relatively lower threshold of GDP per capita as compared to those with poorer economic fitness.

When examining developing nations in particular, a turning point is observed at a GDP per capita of $8,019.55 for countries with a high level of economic fitness and $26,704.79 for countries with a low level of economic fitness. This suggests that the inverted U-shaped correlation remains valid in the context of emerging nations, and the impact of GDP per capita on environmental results is significant. In developing nations, the contrast between individuals with great and low economic fitness is particularly noticeable. Nations with high economic fitness in the developing world experience a turning point at a somewhat lower GDP per capita in comparison to nations with low economic fitness. This implies that the environmental quality in developing countries with high economic fitness is more immediately improved by economic development.

In the case of developed nations, the inflection point is identified at a GDP per capita of $15,155.02 for countries with strong economic fitness and $37,100.95 for countries with low economic fitness. In developed nations, there are distinct disparities in the inflection points for both high and low economic well-being.

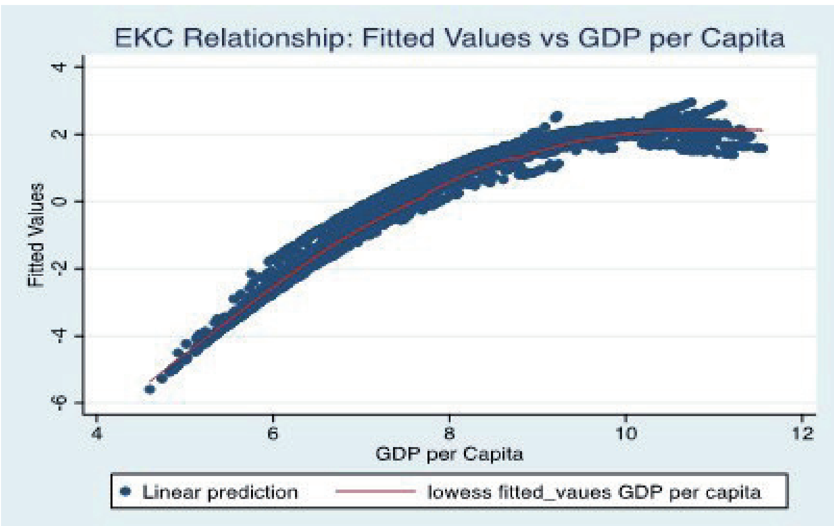


Fig. 3. EKC in the case of developed countries.

Table 6. EKC Trajectories (turning points) with different levels of economic fitness.

| | EKC shape | Currency | High Economic Fitness | Low Economic fitness |
|---|---|---|---|---|
| Overall Sample | Inverted U-shaped | Current US$ | 63211.89 | 66070.98 |
| | Joint F test for GDP per Capita | | 1152.88* | 1685.83* |
| Developing countries | Inverted U-shaped | Current US$ | 8019.55 | 26704.79 |
| | Joint F test for GDP per Capita | | 1272.42* | 931.67* |
| Developed countries | Inverted U-shaped | Current US$ | 15155.02 | 37100.95 |
| | Joint F test for GDP per Capita | | 23.58* | 380.15* |

*, **, *** describe the significance at 1%, 5% and 10% level of significance.

However, in this particular scenario, it is noteworthy that the two categories of developed countries exhibit turning points that are considerably higher in comparison to those observed in the developing world. This implies that in industrialized nations, the positive environmental outcomes resulting from economic progress become apparent at higher income thresholds, irrespective of economic fitness.

## Discussion

In a world where the undeniable implications of climate change have become more and more apparent, the endeavor to achieve a sustainable future has surpassed the boundaries of basic environmental preoccupation. Navigating the intricate equilibrium between development and environmental preservation has emerged as a crucial economic and social necessity. The EKC is a fascinating perspective for examining the complex interplay between several factors. In the exploration of the concept of "fostering a green tomorrow," we undertake an analysis of the complex relationship between economic fitness, the mitigation of carbon dioxide ($CO_2$) emissions, and the EKC trajectory. The investigation of this topic becomes particularly interesting when examining its application to both developing and developed nations, each characterized by unique socio-economic landscapes, varying levels of access to capital, and diverse initiatives related to renewable energy. We invite you to join us in exploring the complex terrain of sustainable development, looking into the ways in which countries might strategically place themselves on the EKC to attain a harmonious equilibrium of prosperity and environmental well-being.

The primary objective of the current study was to explore the relationship between economic fitness, gross fixed capital formation (GFCF), and REC in the context of $CO_2$ emissions along the EKC in both developed and developing countries. Our analysis will compare the EKC trajectories, with a specific emphasis on important variables such as economic fitness, to reveal distinct elements influencing $CO_2$ emissions and provide insights into the complex relationship between economic development and environmental sustainability. The three-panel, two-stage least squares models robustly support the presence of an EKC in the panel of 121, including 37 developed and 84 developing nations studied overall and separately. The findings uncover a clear inverted U-shaped pattern between GDP per capita and environmental quality (measured by $CO_2$ emissions) in the overall sample of countries as well as in both developed and developing countries. Initially, as GDP per capita rises, $CO_2$ emissions also increase, indicating environmental degradation. This implies that, beyond a certain point, the rise in GDP per capita reduces carbon emissions. Our findings are consistent with those of [82] who examined the EKC hypothesis among a panel of 14 European Union nations while taking into account their levels of knowledge. Additionally, [83] in their panel-based study encompassing 109 countries, corroborated the presence of the EKC hypothesis. So, [84-87] have all supported the EKC hypothesis by showing that there is an inverted U-shaped relationship between income per capita and emissions. Similarly, the EKC hypothesis exists in both developing and developed countries. Recently, Baba [88] confirmed the existence of EKC in developing countries when $CO_2$ emissions were dependent variables. On the other hand, Moosa and Burns [89] have found a monotonic relationship between economic growth and $CO_2$ emissions, while they confirmed the existence of the EKC hypothesis in developed countries.

The results revealed a significant negative impact of EF on $CO_2$ emissions and a low-income level turning point for EKC for nations experiencing high EF. Our findings are in line with Çınar et al. [23] in the case of the negative and significant impact of EF on $CO_2$ emissions. Boleti et al. [90] explore the impact of economic complexity on the environmental performance of 88 countries by using the economic complexity index, which is equivalent to the EF algorithm. They concluded that economic complexity negatively influences air pollution. The findings of the current study also revealed that the higher EF tends to experience environmental degradation at a lower level of economic growth, or GDP per capita. This emphasizes the influence of sustainable economic growth on immediate environmental improvements, especially when coupled with a diverse and sustainable economic framework.

The Gross Fixed Capital Formation (GRFC) is statistically significant and positively related to $CO_2$ emissions, signifying that an increase in GRFC results in higher $CO_2$ emissions. Gross fixed capital formation (GRFC) boosts GDP and technology, but it may also increase $CO_2$ emissions. Many scholars, like [91] and [77] have examined the link between GDP growth and environmental quality, which suggests that gross capital formation is an important factor in a country's economic development. Moreover, the connection between GCF and the environment is conditional on a country's stage of development. For example, investments in new or emerging industries require factories, manufacturing plants, and other infrastructure. Energy and fossil fuel-based industrial operations can increase emissions for these companies. Power plants, manufacturing facilities, and transportation networks require a lot of energy to build and maintain. If they employ fossil fuels, these operations can emit plenty of $CO_2$. Infrastructure developments in roads, bridges, and airports may boost traffic. More cars, especially gasoline and diesel, may pollute. Cement, steel, and concrete are needed to develop fixed assets, yet they produce loads of $CO_2$. Carbon footprints are high in cement. Infrastructure construction may deforest or urbanize. Changes in land use may release carbon from forests and soils, boosting emissions. Maintaining fixed assets takes time and resources. These actions increase pollution if left unchecked. Technology and equipment decisions made during investment may affect emissions. Renewable electricity and energy-efficient technologies reduce new investment emissions. Our results can be evidenced by the study conducted by Muradian et al. [92] which critically examined the effects of investing in infrastructure. Their findings suggest that an increase in gross fixed capital formation (GFCF) may initially lead to environmental degradation, but as economies develop and mature, there is a potential for improvement in environmental conditions. Moreover, Sapkota and Bastola [93] also found the positive and significant impact of GFCF on GHG emissions. According to the same study, there is a positive relationship between GDP and gross capital fixed formation, and between trade per capita and the level of $CO_2$ emissions in a given country. The augmentation in gross fixed capital formation is also seen as a pivotal catalyst for both economic growth and carbon emissions.

There is a significant negative coefficient for REC, indicating a strong relationship between the adoption of renewable energy sources and a decrease in $CO_2$ emissions. It is evident that renewable energy sources are extremely important in reducing emissions of greenhouse gases, especially carbon dioxide ($CO_2$), which makes up more than 60% of greenhouse gases [94]. Riti et al. [73] discovered that in low-income nations, the consumption of renewable energy is positively associated with emissions and negatively associated with output, but in high-income countries, the associations are negatively associated with emissions and positively associated with production. Wang et al. [95] found that the same is true of renewable energy in terms of reducing emissions. Additionally, our research is in line with those of [96-103] both in the case of emerging and developed nations.

The above findings for both developing and developed countries show that economic fitness exerts a significant role in influencing $CO_2$ emission per capita. The presence of a negative coefficient of economic fitness for both types of countries implies that as economic fitness improves, there is a tendency for $CO_2$ emissions to decline. This suggests that nations having a greater capacity to manufacture a wide range of diversified and globally competitive goods are more inclined to exhibit reduced levels of carbon emissions. The findings are aligned with the framework of the EKC hypothesis. The observed negative relationship indicates that as economic progress, they are more likely to adopt environment-friendly technologies resulting in low emissions.

The results regarding the impact of GFCF on carbon emissions describe the positive relationship across developing and developed countries. This may imply that the higher GFCF leads to high carbon emissions. The coefficients of REC are consistently negative across developed and developing countries. In the context of EKC, this is consistent with the objective of the current study of analyzing the role of REC in controlling carbon emissions. The findings may support the transition to greener and sustainable energy sources contributing to slowing down environmental degradation.

## Conclusions

Economic health is essential in the quest for sustainable development because it encourages a symbiotic relationship between economic expansion and environmental protection. The mutual benefits of this partnership include decreased energy use and fewer pollutants. Sustainable resource management is promoted by diversification, which reduces the need for excessive resource exploitation and waste. Eco-friendly goods are on the upswing in the global market, which encourages nations to boost their productivity while cutting their carbon impact. This interaction highlights the possibilities for ecologically sound economic growth. Therefore, the current study has addressed the crucial concept of economic fitness, examining its role in the complex relationship between economic growth and environmental impacts through the EKC. By considering key variables such as gross fixed capital formation and REC, we have gained a more nuanced understanding of how economic fitness shapes the delicate balance between economic development and environmental sustainability. This research underscores the fundamental importance of economic fitness in the study of environmental and economic sustainability based on a panel of 121 countries, including 84 developing and 37 developed nations, from the time period of 1995 to 2019.

Overall, the findings support the idea that economic fitness, gross fixed capital formation, and the use of renewable energy sources all play significant roles in shaping $CO_2$ emissions as economies grow. The goals and the EKC hypothesis can be used to explain some interactions. Considering the findings of the regression analysis: The analysis reveals a noteworthy inverse correlation between economic fitness and $CO_2$ emissions, suggesting that nations with greater economic fitness tend to exhibit lower levels of $CO_2$ emissions, following the EKC pattern. There exists a positive correlation between the augmentation of Gross Fixed Capital Formation (GFCF) and the subsequent rise in $CO_2$ emissions, indicating that heightened capital investments are associated with increased emissions. The analysis of Renewable Energy Consumption (ENCO) reveals a noteworthy inverse correlation with $CO_2$ emissions, suggesting that nations that embrace a greater proportion of renewable energy sources tend to exhibit reduced emissions.

In the comparative analysis of developed and developing countries, distinct patterns emerge regarding the relationship between economic factors and carbon emissions. In developing countries, GDP per capita initially rises with carbon emissions, in line with early-stage economic expansion, but the negative coefficient for GDP square indicates a turning point, supporting the EKC hypothesis. Negative coefficients for economic fitness suggest that globally competitive product producers have lower carbon emissions, though not consistently. Positive coefficients for gross fixed capital formation (GFCF) contradict the EKC, while negative coefficients for REC align with emission reduction goals. In developed countries, positive GDP per capita coefficients indicate growth-related emissions, with significant negative GDP square coefficients confirming the EKC hypothesis. Negative economic fitness coefficients imply inverse relationships; positive GFCF coefficients suggest industrial activity impacts; and negative REC coefficients support emission reduction efforts. These findings emphasize the nuanced relationships between economic variables and emissions, guiding environmental policy considerations for both types of economies.

In summary, our analysis underscores the critical role of economic fitness and the interplay between economic growth and environmental outcomes in different categories of countries. The turning points in the relationship between GDP per capita and environmental quality vary significantly. In the overall sample of countries, nations with higher economic fitness tend to experience a decline in environmental degradation at lower GDP per capita thresholds, indicating a more immediate environmental improvement as economic development progresses. This trend is particularly pronounced in developing countries, where nations with high economic fitness demonstrate earlier improvements, confirming the inverted U-shaped correlation. In contrast, developed nations exhibit turning points at considerably higher income levels, suggesting that the positive environmental effects of economic progress become apparent at more advanced stages of development. These findings emphasize the complexity of the relationship between economic factors and environmental sustainability, highlighting the need for tailored policies and strategies in different contexts.

## Policy Recommendations

### Developing Countries

In developing nations, prioritizing education and skill development is fundamental to equipping the workforce with the knowledge and expertise required for diverse industries. Simultaneously, fostering a culture of innovation and research and development (R&D) is crucial to creating cutting-edge products and technologies. Supporting entrepreneurship and start-ups through mentorship programs and financial incentives can stimulate economic dynamism. Moreover, ensuring access to affordable and stable financing for businesses, especially small and medium-sized enterprises (SMEs), is essential for their growth and diversification efforts. Investment in modern infrastructure, encompassing transportation, logistics, and digital connectivity, facilitates the seamless movement of goods and information, aiding competitiveness. Simplifying trade procedures, reducing trade barriers, and forging favorable trade agreements expand market access and bolster exports. Sustainable resource management practices should be implemented to ensure a reliable supply of raw materials while mitigating environmental impacts. Enforcing environmental regulations and promoting eco-friendly production processes help meet international sustainability standards. Finally, fostering global market research and access, along with public-private partnerships (PPPs) to fund infrastructure and industrial projects, can further enhance economic fitness in developing countries.

### Developed Countries

For developed nations, maintaining leadership in innovation and technological advancements remains paramount. Diversifying industries to reduce reliance on a single sector promotes resilience in changing market conditions. Supporting start-ups and SMEs through access to capital, mentorship programs, and streamlined regulations encourages a vibrant entrepreneurial ecosystem. Investment in modern infrastructure and digitalization enhances production efficiency and connectivity. Expanding access to global markets through trade agreements and reducing trade barriers can spur export growth. Promoting sustainable and eco-friendly production practices aligns with the increasing demand for environmentally responsible products. Continued investment in education and workforce development ensures a skilled and adaptable labor force. Encouraging financial innovation and expanding access to financing for businesses support diversification efforts. Engaging in international collaborations and partnerships facilitates access to global supply chains and fosters innovation. Implementing responsible resource management practices helps maintain a stable supply of raw materials while minimizing environmental impact. These strategic policy recommendations, tailored to each country's unique circumstances, can empower both developing and developed nations to bolster their economic fitness and excel in producing globally competitive and diversified products, fostering economic growth and sustainability.

## Conflicts of Interest

The authors declare no conflict of interest

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