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Exploring the Environmental Kuznets Curve in Pakistan: Economic Growth and Sustainability

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Abstract
This study employs the Kuznets Curve framework to explore the intricate relationship between economic growth and environmental impact in Pakistan. The framework, rooted in the Environmental Kuznets Curve hypothesis, postulates that environmental degradation initially increases with economic growth but eventually decreases as economies mature and adopt cleaner technologies. By applying this theoretical model, the research aims to assess whether Pakistan's economic development aligns with the inverted U-shaped trajectory suggested by the EKC. This approach provides insights into the critical turning points where economic policies could transition from fostering growth at the expense of the environment to promoting sustainable development practices. The study utilizes descriptive statistics, pairwise correlations, and regression analysis to investigate the complex interactions among key variables, including pollution, environmental performance, GDP, income, and taxation, over the period from 1980 to 2021. Descriptive statistics provide an overview of the data's central tendencies and variability, offering foundational insights. Pairwise correlations identify the strength and direction of relationships between variables, highlighting potential associations. Regression analysis, the core methodological approach, delves deeper to quantify the influence of independent variables such as income and taxation on dependent variables like pollution and environmental performance. This comprehensive analytical framework aims to uncover nuanced patterns that inform policy and theoretical implications regarding economic growth and environmental sustainability. The results highlight the intricate trade-offs and non-linear dynamics underlying the relationships among pollution, environmental performance, GDP, income, and taxation. These findings emphasize the critical need for informed and context-sensitive policy decisions to achieve sustainable development. In the case of Pakistan, this involves striking a delicate balance between economic growth and environmental preservation. By acknowledging and addressing these complexities, policymakers can craft strategies that foster economic advancement while mitigating environmental degradation, ensuring long-term sustainability.
Keywords: Environmental Kuznets Curve, Economic Growth, Environmental Sustainability, Pakistan
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1. INTRODUCTION

Recent research has extensively explored the relationship between environmental quality and economic development (Kayani et al., 2022; Petrakis, 2021; Khan & Hassan, 2019). Empirical studies frequently suggest a curvilinear association, most notably an inverted-U relationship, between economic growth—commonly measured as per capita income—and environmental conditions. This pattern aligns with the Environmental Kuznets Curve hypothesis, which postulates that environmental degradation increases in the early stages of economic development but declines as income levels rise, reflecting shifts toward sustainable practices and improved technologies at higher levels of economic prosperity. Conversely, in the initial stages of economic development, there is a direct relationship between environmental degradation and per capita income (Ali et al., 2021; Porro & Gia, 2021). However, as economies transition to higher income levels, this relationship becomes inverse, with environmental contamination declining as per capita income rises. This phenomenon is widely recognized as the Environmental Kuznets Curve, as demonstrated in the studies of Bradford et al. (2005) and Cole (2004). The EKC hypothesis underscores the dynamic interplay between economic growth and environmental quality, reflecting the shift toward cleaner technologies and more sustainable practices at advanced stages of development (Ahmad & Ali, 2019; Durbin & Filer, 2021).

The Environmental Kuznets Curve theory posits that economic development can eventually serve as a solution to environmental challenges, suggesting that the relationship between economic growth and environmental degradation follows a distinct trajectory. At the initial stages of development, increased industrial activity and resource utilization lead to heightened environmental harm, such as greater pollution and deforestation (William & Adam, 2018; Diaz & Weber, 2020). However, as economies transition to higher levels of income and technological advancement, they often adopt cleaner technologies, implement stricter environmental regulations, and shift toward more sustainable practices, thereby reducing environmental degradation. Despite its theoretical appeal,

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the clarity of reported experimental results and research objectives on the EKC often remains limited, raising questions about the generalizability and applicability of the framework across different contexts. A particular focus of the literature has been on validating the presence of an EKC for various indicators of environmental degradation, such as carbon dioxide emissions, water pollution, and deforestation rates. For instance, many empirical studies have confirmed that environmental harm increases with economic growth up to a certain income threshold, after which it begins to decline, forming an inverted-U curve. This pattern emphasizes that while economic development may initially contribute to environmental problems, it can also pave the way for solutions through improved policies, innovations, and global cooperation aimed at achieving sustainability (Allen, 2021; Zhang, 2021). Nevertheless, certain academics argue that the Environmental Kuznets Curve hypothesis does not have sufficient empirical support to validate its claim of a consistent and universal association between pollution levels and per capita income. Day and Grafton (2003) and Lindmark (2002) highlight that the EKC framework often oversimplifies the complexities of environmental and economic interactions, ignoring the influence of region-specific factors, policy differences, and varying levels of technological advancement. Critics contend that the EKC hypothesis assumes a natural progression toward reduced environmental degradation as economies grow, but this trajectory is neither automatic nor guaranteed. For instance, in some developing countries, environmental damage may persist or even worsen despite rising incomes due to inadequate governance, weak enforcement of regulations, or dependency on resource-intensive industries. Additionally, the EKC may fail to capture the global dimensions of environmental problems, such as the outsourcing of pollution-intensive activities to low-income countries, which could distort the apparent relationship between income levels and environmental quality in high-income nations (Ali & Audi, 2016; Lin, 2021).

These challenges underline the need for more nuanced models that account for socio-political contexts, institutional capacities, and international trade dynamics to better understand the intricate connections between economic growth and environmental sustainability (Audi & Ali, 2017). Consequently, while the EKC hypothesis provides a valuable starting point for examining these relationships, its limitations call for further empirical investigation and refinement. A significant body of empirical research investigating the Environmental Kuznets Curve hypothesis employs cross-national panel data to evaluate the relationship between economic growth and environmental indicators. This approach allows researchers to identify broader trends and variations across different countries and regions, offering valuable insights into the potential generalizability of the EKC phenomenon.

Increasingly, scholars are adopting the practice of juxtaposing findings from single-nation studies with those derived from cross-country analyses. This comparative approach provides a dual advantage: it not only addresses the inherent challenges of cross-national data—such as varying institutional frameworks, environmental policies, and levels of technological advancement—but also enables a more focused and detailed exploration within the context of an individual country (Ansari et al., 2020; Saboori and Sulaiman, 2013).

The methodology of confining analyses to a single nation's data offers several benefits. It allows for a deeper understanding of country-specific factors that influence the EKC relationship, such as unique economic structures, cultural attitudes towards environmental issues, and policy interventions. Furthermore, it avoids potential biases and inconsistencies that arise from aggregating data across nations with disparate socio-economic and political conditions. By narrowing the focus, single-nation studies can provide policymakers with targeted recommendations tailored to the unique circumstances of their country, which may not emerge from broader cross-national comparisons. In this way, the integration of both cross-national and single-nation approaches enriches the empirical literature on the EKC, offering a more comprehensive understanding of the complex interplay between economic growth and environmental sustainability. Focusing on specific countries for investigating the Environmental Kuznets Curve offers several advantages over cross-sectional approaches, particularly in capturing the dynamic nature of the relationship between economic development and environmental degradation. The EKC theory suggests that as a country’s income rises, environmental quality initially worsens but improves at higher income levels. However, to truly understand this complex interaction, it is essential to study the kinetics of economic and environmental development in a particular context, which is often not fully captured in cross-country studies (Jalil et al., 2009; Zambrano-Monserrate et al., 2019).

By concentrating on individual countries, researchers can better address the specific factors influencing the EKC, which vary significantly across national contexts. Each country has unique economic structures, policy frameworks, and developmental histories that affect how economic growth impacts environmental quality. For example, countries with more robust environmental policies might experience a different relationship between income growth and pollution compared to nations where rapid industrialization takes precedence. Therefore, examining a single country allows for a more detailed analysis of how local conditions shape the environment-economy dynamic. Moreover, focusing on one country enables a deeper exploration of the socio-economic, political, and institutional factors that contribute to environmental outcomes. These factors—such as governance, institutional strength, political will, and public awareness—can significantly alter the trajectory of pollution and its eventual reduction. As such, a country's specific regulatory and policy environment can either exacerbate or alleviate the environmental consequences of economic growth. For instance, a nation that enforces stringent environmental regulations may experience an earlier turning point in the EKC curve compared to one where environmental protection is not prioritized. Additionally, country-specific studies offer the opportunity to identify specific turning points or thresholds in the

EKC where the relationship between economic growth and environmental degradation shifts. This detailed, longitudinal analysis can reveal how various factors—such as energy consumption patterns, technological advancements, and urbanization—interact with economic growth and influence the progression of pollution levels over time. By tracing these trends within the same national context, scholars can better understand the causal relationships at play and develop more targeted and effective policy recommendations.

A nation-specific approach also helps to overcome the limitations of cross-country studies, which often fail to account for the diverse economic, social, and political landscapes in which countries operate. Cross-country comparisons may mask significant differences in development stages, cultural contexts, and policy effectiveness, leading to broad generalizations that may not be applicable to all countries. Therefore, focusing on a specific nation allows researchers to refine their models and provide more contextually relevant insights for policymakers, ultimately leading to more informed and targeted solutions for achieving sustainable economic growth while minimizing environmental harm. Investigating the EKC within a specific national context enhances the understanding of the complex interactions between economic development and environmental quality. By delving deeper into the unique circumstances of each country, researchers can offer more nuanced insights into how economic growth affects environmental outcomes and identify tailored policy solutions that are better suited to the specific needs and challenges of individual nations. This approach provides a more holistic and actionable understanding of the environmental impacts of economic development. The environmental conditions in Pakistan have played a significant role in its classification as one of the most vulnerable countries in terms of climate change. Ahmed and Long (2012) suggest that the rise in temperature in Pakistan is expected to exceed the global average, exacerbating the nation's environmental challenges. Pakistan's economy heavily relies on agriculture, a sector that is highly sensitive to climatic shifts. According to projections by Nasir and Rehman (2011), temperatures in Pakistan may rise by as much as 4°C by the year 2100, a significant increase that could further strain agricultural productivity and food security.

The atmospheric composition in Pakistan is increasingly being affected by harmful gas emissions, including carbon dioxide (CO_2), carbon monoxide (CO), nitrogen oxides (NO_x), particulate matter (PM_{10}), and sulfur dioxide (SO_2), all of which contribute to the growing problem of anthropogenic climate change. The emission of these pollutants plays a key role in altering atmospheric conditions and intensifying climate change. Greenhouse gases (GHGs), in particular, have a notable impact on trapping solar radiation within the Earth's atmosphere, preventing it from dissipating into the higher layers, thus contributing to global warming (Antweiler et al., 2001; Dinda & Coondoo, 2006). As these gases accumulate, they intensify the greenhouse effect, leading to long-term environmental damage. The increase in the concentration of GHGs is largely attributed to human activities, particularly deforestation, which significantly reduces the Earth's capacity to absorb carbon dioxide. Several studies have highlighted this connection, including those by Managi and Jena (2008), Nasir and Rehman (2011), Shahbaz et al. (2011), and Song et al. (2013), which emphasize the role of land use changes, particularly the loss of forests, in exacerbating the climate crisis in Pakistan. Additionally, the public health impact of these environmental factors is profound. Exposure to pollutants, especially SO_2 and PM_{10}, has been linked to an increase in respiratory ailments such as asthma. This is particularly concerning for children, who are more vulnerable to the harmful effects of poor air quality (Aqeel & Butt, 2001). The growing burden of these health issues places additional pressure on the healthcare system and the overall economy. To address these challenges and reduce the negative impacts of emissions, Pakistan needs to implement more effective energy and industrial policies. Proper management of the country's energy sector, including the transition to cleaner and renewable sources, as well as industrial reforms, could help mitigate emissions. Strengthening these areas will not only improve environmental quality but also contribute to building a more resilient and sustainable economic framework (Lotfalipour et al., 2010). By investing in cleaner technologies and enforcing stronger environmental regulations, Pakistan can reduce its vulnerability to climate change and its associated health and economic consequences.

Energy consumption (EC) plays a crucial role in fostering economic development, as it is deeply intertwined with all manufacturing and consumption activities. Fossil fuels, which serve as the primary energy sources, undergo various conversion processes to facilitate gradual industrial and economic transformation. The efficient use of these energy sources to promote development has led to a significant increase in global emissions, stemming from numerous potentially harmful activities. The release of pollutants into the Earth's atmosphere, particularly from industrial and transportation activities, has a profound impact on the health of the human population and the overall environment. Air pollutants, including particulate matter, sulfur dioxide, and nitrogen oxides, present significant risks to both human health and the natural environment. Among these pollutants, carbon dioxide (CO_2) stands out due to its critical role in global warming, as it is responsible for over 60% of greenhouse gas emissions (Birdsall & Wheeler, 1993). This greenhouse gas traps heat in the Earth's atmosphere, contributing to the intensification of the greenhouse effect and resulting in rising global temperatures. As CO_2 levels continue to increase, the potential for more severe climate impacts grows, threatening ecosystems, biodiversity, and human communities worldwide.

In Pakistan, the industrial sector poses a major environmental challenge, contributing significantly to pollution in the form of emissions from factories, power plants, and other industrial activities. While vehicular emissions are a major source of air pollution, industrial pollutants also play a crucial role in environmental degradation. The drive for economic growth through industrialization has led to environmental deterioration, a trend observed globally. Saboori and Sulaiman (2013) highlight that industrialization's impact on the natural environment is a pressing concern, affecting both developing and developed countries. In Pakistan, key industries contributing to pollution include agriculture, textiles, oil, and gas production. These sectors release harmful substances into the air, water, and soil, leading to widespread contamination and public health issues. Usman et al. (2022) emphasize that adopting cleaner technologies and implementing stringent government policies can significantly reduce pollution from industrial operations. The transition to cleaner production methods, coupled with regulatory reforms, can help mitigate the environmental impacts of industrialization while ensuring sustainable economic growth. By investing in cleaner energy sources and enforcing robust environmental protection measures, Pakistan can reduce the adverse effects of industrial pollution and improve the well-being of its citizens and the environment. Over the past two decades, Pakistan's economy has witnessed significant growth. However, this economic expansion has been accompanied by an increase in energy consumption (EC), particularly within the industrial sector, which has contributed to rising levels of environmental pollution (Farrukh & Sadiq, 2022). Natural gas, in particular, is responsible for the majority of carbon dioxide (CO2) emissions, accounting for approximately 50% of total emissions in the country (Farrukh & Sadiq, 2022). Carbon monoxide (CO) is typically produced as a result of incomplete combustion processes, while nitrogen oxides (NOx) are often generated under high-temperature conditions in heavy vehicles and industrial operations. Particulate matter (PM10), composed of dust particles and other pollutants, originates from a variety of sources including construction sites, landfills, agricultural activities, and industrial emissions (Coondoo & Dinda, 2008). The expansion of the transportation sector, driven by the growing number of personal and commercial vehicles, has further exacerbated the problem of air pollution. As urban areas become more congested and industrial activities continue to increase, the natural environment is experiencing heightened stress, contributing to a decline in air quality. While environmental pollution is a global issue, the role of individual countries in addressing these concerns remains critical. In Pakistan, the government has made notable efforts to pursue sustainable development and address the environmental challenges caused by rapid industrialization and energy consumption. One of the key steps in this direction was the enactment of a national environmental policy (NEP) in 2005. The primary objective of this policy is to protect the nation's natural ecosystem and improve air quality for the benefit of its residents.

Despite these efforts, the rapid growth of various economic sectors, particularly in recent years, has led to increased energy consumption, further exacerbating environmental challenges. As energy use continues to rise, the demand for cleaner technologies and sustainable practices becomes more urgent. Coondoo and Dinda (2002) emphasize that the growth in energy consumption must be carefully managed to minimize its adverse effects on the environment, particularly in the industrial sector. For Pakistan to achieve sustainable development, it must prioritize the transition to cleaner energy sources, enforce stricter environmental regulations, and invest in innovative technologies that reduce emissions and enhance environmental quality. There is currently a lack of scholarly research that specifically focuses on Pakistan and analyzes carbon dioxide (CO2) emissions. This study seeks to build upon prior research that has examined various environmental pollutants, aiming to provide additional insights into the relationship between environmental quality and economic growth. The research also explores the Environmental Kuznets Curve (EKC) hypothesis in the context of Pakistan, focusing on the connection between economic development and environmental degradation. This approach is similar to previous studies that have investigated the EKC model across different countries.

The primary objective of this study is to conduct a time-series analysis of prominent pollutants in Pakistan, particularly CO2, carbon monoxide (CO), particulate matter with a diameter of 10 micrometers or less (PM10), nitrogen dioxide (NO2), and sulfur dioxide (SO2). The study covers the period from 1979 to 2018, providing a comprehensive examination of the trends and correlations between these pollutants and economic variables over time. The motivation behind this research is driven by intellectual curiosity and the desire to understand the dynamics between industrialization, economic growth, and environmental quality in Pakistan. Economic growth per capita, energy consumption (EC), and industrialization are used as the independent variables in this study. By analyzing these factors, the study aims to identify patterns and trends that can inform policy decisions and contribute to the ongoing discourse on sustainable development. The subsequent sections of the paper are organized as follows: Section 2 reviews the existing literature on the EKC, with particular emphasis on the benefits of conducting single-country studies as opposed to cross-country analyses. Section 3 outlines the data used in the study, along with the specifications of the econometric model employed. The empirical findings are presented in Section 4, while the concluding section summarizes the key results and offers recommendations for further research and policy action.

2. LITERATURE REVIEW

In 1991, Grossman and Krueger introduced the idea that the relationship between per capita income and pollutants, specifically sulfur dioxide (SO2) and soot, follows an "inverted U-shaped" pattern rather than a linear one. This concept, later termed the Environmental Kuznets Curve (EKC), was formalized by Panayotou in 1993. The EKC describes the observed relationship between pollution and income, wherein pollution levels initially increase with economic growth but eventually decrease after a certain level of income is reached. Grossman and Krueger further explored this relationship in 1995, reaffirming that the early stages of economic development are marked by rising pollution levels. However, as income continues to grow and the economy undergoes structural changes, pollution levels begin to decrease, following the downward slope of the inverted U-shaped curve. However, over the medium to long term, pollution levels tend to decrease gradually as a result of both structural and technological changes in economic activities, coupled with the enforcement of environmental regulations by governments (Badeeb et al., 2020). This concept has generated considerable discussion in academic circles, with scholars offering different interpretations regarding its validity and the circumstances under which it may occur. Some researchers argue that technological progress, including the adoption of cleaner production methods and more efficient energy use, plays a key role in reducing pollution. Others emphasize the importance of stringent environmental policies that encourage industries to adopt more sustainable practices. While opinions differ on the specific mechanisms, most scholars agree that the relationship between economic growth and environmental degradation is multifaceted, influenced by various factors such as the level of technological innovation, institutional frameworks, and the stage of development within a given economy. Nevertheless, a consensus on the existence and applicability of the Environmental Kuznets Curve (EKC) remains elusive, as scholars continue to debate its universal validity and the various factors that influence its manifestation. The body of literature examining the relationship between economic growth and carbon emissions is extensive, yet it reveals significant discrepancies in findings. Studies by Ahmed and Long (2021), Apergis and Ozturk (2015), Alam et al. (2016), Alola et al. (2021), Ahmad et al. (2022), and Churchill (2020) have all delved into this relationship, each contributing unique perspectives on how economic development correlates with environmental degradation, particularly carbon emissions. Some studies, such as those by Apergis and Ozturk (2015) and Alola et al. (2021), provide evidence in support of the EKC hypothesis, suggesting that economic growth may initially lead to higher pollution levels, which eventually decrease as nations industrialize and adopt cleaner technologies and more stringent environmental regulations. These findings align with the classic interpretation of the EKC, where pollution increases during the early stages of economic development but begins to decline after reaching a certain threshold of income per capita. On the other hand, other research, including that by Alam et al. (2016) and Ahmed et al. (2022), offers a more nuanced view, highlighting the role of additional factors such as technological advancements, government policies, and energy consumption patterns in shaping the relationship between economic growth and environmental quality. For example, Alam et al. (2016) argue that while economic growth may lead to increased carbon emissions in some contexts, the adoption of renewable energy sources and the implementation of environmental regulations can mitigate the negative environmental impacts, even in the early stages of development.

Furthermore, studies like Churchill (2020) emphasize the importance of contextual factors, such as the stage of industrialization and the nature of the economic structure, in determining whether the EKC pattern holds. Churchill's analysis suggests that the EKC may not be universally applicable to all countries, particularly in regions where industrialization is heavily reliant on fossil fuels or where there are significant gaps in regulatory frameworks. The diversity in findings highlights the complexity of the relationship between economic development and environmental degradation. It underscores the need for more localized and context-specific studies, which consider not only the direct effects of economic growth on carbon emissions but also the moderating influence of policy interventions, technological innovation, and international cooperation. Additionally, scholars have pointed out that while the EKC offers a useful framework for understanding the potential trajectory of pollution levels as economies grow, it should not be viewed as a definitive or one-size-fits-all model. Instead, the relationship between economic development and environmental quality is likely to be influenced by a range of dynamic factors that vary across different countries and regions.

Academic researchers have increasingly focused on investigating the Environmental Kuznets Curve (EKC), a theoretical framework that explores the relationship between CO2 emissions and economic growth across various sectors. A substantial body of scholarly literature has been dedicated to using Gross Domestic Product (GDP) as a primary measure of economic growth, alongside CO2 emissions as a key indicator of environmental impact. These studies aim to evaluate the validity of the EKC hypothesis in different national and regional contexts. For instance, Shi et al. (2019) employed a variety of econometric methodologies to assess the EKC hypothesis in China. Their study uncovered interesting insights, though they noted some minor discrepancies at the point of inflection where the relationship between economic growth and CO2 emissions changes direction. Despite these discrepancies, their research confirmed that the general trend in China aligns with the EKC theory, where economic growth leads to increased emissions in the early stages, but this relationship eventually reverses as the country advances economically and adopts cleaner technologies. One of the key findings of Shi et al. (2019) was the observed variability in the dynamics of this relationship across different provinces within China. This suggests that the correlation between economic growth and CO2 emissions is not uniform across the country. Provincial-level differences in industrial composition, energy sources, and environmental policies contribute to the divergence in the manifestation of the EKC. For example, more industrialized provinces with higher reliance on coal may exhibit a stronger positive correlation between economic growth and emissions, while provinces that have diversified their energy sources or implemented more stringent environmental regulations may experience a decline in emissions as economic growth continues.

This provincial variation in the EKC relationship highlights the importance of considering regional differences when examining the impact of economic growth on the environment. It underscores that the EKC may not operate in the same way across all regions, even within a single country. Thus, the findings of Shi et al. (2019) emphasize the need for more localized studies to capture the specific mechanisms at play in different areas, considering factors such as industrial structure, policy interventions, and technological advancements. The study by Shi et al. (2019) contributes to the growing body of literature on the EKC by demonstrating the temporal and spatial variability of the relationship between economic growth and CO2 emissions. This research serves as a reminder that while the EKC theory offers valuable insights into the potential trajectory of pollution and economic development, it must be adapted to local contexts to fully understand the underlying dynamics. Further studies are needed to explore the causal mechanisms that drive the observed variability and to assess the effectiveness of environmental policies in shaping the trajectory of CO_2 emissions in the context of sustained economic growth.

Dong et al (2019) observed that developed nations typically exhibit a more pronounced and consistent decoupling of their Gross Domestic Product (GDP) from Carbon Dioxide (CO_2) emissions, as compared to their developing counterparts. This decoupling trend indicates that these countries are able to achieve economic growth without corresponding increases in CO_2 emissions. According to Dong's findings, the primary drivers of this decoupling process in developed nations include factors such as trade openness and advancements in research and development (R&D). These elements, as noted in studies conducted in 2020 and 2021, play a significant role in fostering cleaner and more efficient economic practices, enabling these nations to grow economically while minimizing their environmental impact. In contrast, developing nations face greater challenges in achieving a similar decoupling pattern. This disparity is largely attributed to structural factors such as reliance on energy-intensive industries, limited access to advanced technologies, and slower adoption of cleaner energy sources. Consequently, the economic growth in these countries is often accompanied by an increase in CO_2 emissions, thus hindering progress toward decarbonization. Neves and Marques (2020) extended this discussion by focusing specifically on the transportation sector in the United States. Their study investigated the effects of adopting both conventional and unconventional energy sources on the decarbonization process within this critical sector. Their findings emphasize that simply improving energy efficiency is insufficient to achieve full decarbonization. While energy efficiency improvements can reduce emissions to some extent, they argue that a more comprehensive approach is necessary, involving the simultaneous adoption of cleaner energy sources and the implementation of policies that promote sustainable practices across various sectors of the economy. These findings resonate with recent studies that highlight carbon emissions as the most accurate and widely accepted metric for assessing environmental pollution. Carbon emissions serve as a direct indicator of the amount of greenhouse gases being released into the atmosphere, which is a primary driver of climate change. However, researchers have also pointed out the need to consider additional indicators of environmental health, such as particulate matter (PM_{10}), nitrogen oxide (NO_x) levels, and sulfur dioxide (SO_2) emissions. These additional metrics can provide a more comprehensive picture of the environmental challenges faced by different countries and regions.

Recent scholarly investigations, particularly those conducted in 2021, have underscored the importance of utilizing a range of environmental indicators to better assess the impact of economic activities on the planet. By incorporating multiple measures of pollution, researchers can gain deeper insights into the effectiveness of decarbonization efforts and the broader implications of economic growth on environmental sustainability. This approach reflects a growing recognition of the complexity of the relationship between economic development and environmental degradation, and the need for nuanced, multi-dimensional strategies to address the challenges of climate change. Mengual et al. (2021) conducted a study to assess the sustainability of economic growth by utilizing the environmental footprint (EF2017) metric. Their findings indicate that evaluating the environmental footprint provides a more comprehensive and reliable measure of the potential environmental consequences associated with economic activities compared to traditional metrics like carbon emissions. The environmental footprint encompasses a broader range of environmental impacts, including land use, water consumption, and pollution, thereby offering a more holistic view of the sustainability of economic growth.

Similarly, Ji et al. (2021) adopted pollutant discharge fees as a metric for assessing environmental degradation. Their research aimed to explore the decoupling relationship between economic growth and environmental impact. They identified a shift from a state of strong coupling, where economic growth and environmental degradation are closely linked, to a state of weak coupling, where economic growth continues without a corresponding increase in pollution. This transition is a key indicator of decoupling, suggesting that economic growth can be pursued while minimizing environmental harm. The findings of Ji et al. (2021) are supported by the research conducted by Zhang et al. (2021) on the Yangtze River Economic Belt, which also highlighted a similar trend of decoupling between economic growth and environmental degradation. This reinforces the notion that, over time, it is possible to achieve a decoupling effect, especially when effective environmental policies are implemented alongside economic development strategies.

In a related study, Wu et al, (2019) observed a phenomenon of absolute decoupling between air pollution and economic growth. By examining specific air pollution indicators such as sulfur dioxide (SO_2), particulate matter (PM_{10}), wastewater, and solid waste emissions, Wu et al found that economic growth could occur independently of an increase in these pollutants. This suggests that with the right technological and policy interventions, it is possible to reduce the environmental strain caused by industrialization while fostering economic development. Furthermore, particulate matter with a diameter of 2.5 micrometers or less ($PM_{2.5}$) has become a widely used indicator for measuring environmental strain. $PM_{2.5}$ is particularly concerning due to its potential health risks, as these fine particles can penetrate deep into the respiratory system and cause a variety of health issues. As a result, the monitoring and reduction of $PM_{2.5}$ levels are critical components of environmental policies aimed at ensuring sustainable economic growth without compromising public health. These studies emphasize the importance of adopting a range of environmental indicators to assess the relationship between economic growth and environmental sustainability. By using comprehensive metrics such as the environmental footprint, pollutant discharge fees, and specific air pollution indicators, researchers and policymakers can gain a more nuanced understanding of how economic development impacts the environment and identify strategies for achieving a sustainable balance between growth and environmental preservation.

3. METHODOLOGY

This study investigates the relationship between economic growth, energy consumption (EC), and the industrial sector in Pakistan, with a primary focus on the Environmental Kuznets Curve (EKC) hypothesis. The aim is to assess whether the EKC phenomenon is observable within the context of Pakistan, exploring how economic growth and industrialization relate to environmental degradation. By identifying the model for these variables, the study seeks to contribute to the broader discourse on environmental economics and the potential for sustainable development in emerging economies. Begum's empirical study, which examines the Cobb-Douglas production function as outlined by Copeland and Taylor (1994), provides a foundational basis for understanding the dynamics between economic growth, industrial output, and environmental quality. The Cobb-Douglas function is commonly used to model production processes where output is a function of capital, labor, and technology, with environmental considerations integrated into this framework to analyze pollution outcomes associated with growth. This model allows for a more detailed understanding of how increases in industrial output and EC can affect environmental quality. Additionally, it is crucial to recognize that human activities, particularly in industrial manufacturing and energy consumption, are significant contributors to atmospheric pollution. This study, therefore, extends previous research by incorporating additional variables such as industrial production, energy consumption, and specific pollutants, to capture a more comprehensive picture of environmental degradation. By focusing on both the economic and environmental dimensions, this research aims to refine the EKC hypothesis in the context of Pakistan, taking into account the complex interactions between these factors. As highlighted by Zafar et al. (2020), the expansion of manufacturing activities is closely linked to both economic growth and environmental degradation. The increasing industrial output often results in higher levels of energy consumption, which, in turn, contributes to pollution and other negative environmental impacts. In Pakistan, the industrial sector has been a major driver of economic growth, but this growth has been accompanied by challenges such as air and water pollution, resource depletion, and the emission of greenhouse gases. Therefore, it is essential to examine the trade-offs between industrial expansion and environmental sustainability, and whether the EKC pattern holds true as the economy progresses.

Incorporating these additional variables into the analysis of the EKC allows for a more nuanced understanding of how industrial activities and energy consumption influence the environment in Pakistan. It also provides valuable insights into the policy measures that could facilitate sustainable economic growth without exacerbating environmental degradation. By addressing these issues, the study contributes to ongoing discussions about the role of industrialization and energy consumption in shaping a nation's environmental trajectory and its long-term sustainability goals.

The model of our study become as:

$CO2=f(EP, GDP, IN, TAX)$

CO2 represent the level of environmental pollution in metrictonnes per capita, while the EC is denoted by ECt in kilograms of oil equivalent per capita. The variable GDPt represents the real GDPper capita, and (GDP)2 t is utilised to examine the presence of theEKC. The datautilised in this study was derived from the World Development Indicators (WDI) and the Statistics Department of Pakistan (SDP).The data is collected from 1980 to 2021.

4. RESULTS AND DISCUSSIONS

This table 1 presents the descriptive statistics for the variables under analysis, providing a snapshot of their central tendencies, dispersion, and range. These statistics offer essential insights into the variability and distribution of each variable across the dataset, which is critical for understanding the dynamics of the study and guiding subsequent analyses. The CO2 variable, representing carbon dioxide emissions, has a mean value of 19.67, indicating the average level of emissions across observations. However, the substantial standard deviation of 16.749 reflects high variability in emissions, with some observations having very low values (as small as 0.002) and others reaching as high as 70. This wide range suggests a significant disparity in emission levels, likely influenced by factors such as economic activity, energy sources, and industrial practices across different regions or entities. Energy production (EP) has a mean value of 117.418, with a standard deviation of 36.742, highlighting a moderate level of variability. The values range from 30 to 290, showing that while some entities have relatively low energy production, others have significantly higher levels. This variation could be attributed to differences in energy infrastructure, resource availability, and consumption demands across the dataset.

Domestic production (DP) shows a mean of 6.392 with a high standard deviation of 12.532, suggesting a skewed distribution. The minimum value is 0, indicating that some observations have no domestic production, while the maximum value of 92.62 reflects exceptionally high production in certain cases. This disparity points to structural differences in domestic production capacity and economic focus among the entities being studied. The squared GDP variable (GDP2) has a mean value of 2.749 and a standard deviation of 4.24, with values ranging from 0 to 23.763. The wide range indicates substantial differences in economic output and its non-linear effects, which might be relevant for understanding relationships such as environmental impact or industrial development. Industrialization (IN) exhibits a mean of 63.833 and a relatively low standard deviation of

5.724, suggesting less variability compared to other variables. The range of 49.354 to 76.058 indicates that industrialization levels are somewhat consistent across observations, reflecting similar levels of industrial capacity and development within the dataset.

Taxation (TAX) shows a mean value of 55.377 and a large standard deviation of 38.35, with values ranging from as low as 1 to as high as 125. This substantial variation underscores significant differences in taxation policies or revenue collection capabilities, which could reflect economic, political, or structural disparities among the entities in the study. These descriptive statistics reveal considerable diversity within the dataset. Variables such as CO2, DP, and TAX show high variability, indicating heterogeneous conditions or policies, while others like IN are relatively stable. Understanding these distributions and ranges is critical for interpreting the relationships between variables and assessing their potential impact in further econometric or statistical analyses. This variability also underscores the need for robust modeling approaches to capture the nuances of the data effectively.

Table 1: Descriptive Statistics

Variables	Mean	Standard deviation	Min	Max
CO2	19.67	16.749	0.002	70
EP	117.418	36.742	30	290
DP	6.392	12.532	0	92.62
GDP^2	2.749	4.24	0	23.763
IN	63.833	5.724	49.354	76.058
TAX	55.377	38.35	1	125

This table presents the correlation matrix for the variables under study, including carbon dioxide emissions (CO2), energy production (EP), gross domestic product (GDP), squared GDP (GDP2), industrialization (IN), and taxation (TAX). The correlation coefficients range from −1 to 1, where positive values indicate a direct relationship, negative values indicate an inverse relationship, and values close to zero suggest no correlation. The correlation between CO2 and EP is 0.320, indicating a moderate positive relationship. This suggests that higher levels of energy production are associated with increased carbon dioxide emissions, likely due to reliance on energy sources that contribute to greenhouse gas emissions. The correlation between CO2 and GDP is 0.011, indicating a negligible relationship. This suggests that variations in GDP are not strongly associated with changes in carbon dioxide emissions across the observations in this dataset. CO2 and GDP2 exhibit a correlation of −0.042, suggesting a very weak negative relationship. This may imply that as economic activity reaches higher levels (as reflected in the squared term of GDP), the marginal impact on carbon dioxide emissions diminishes slightly.

The relationship between CO2 and IN is very weak, with a correlation coefficient of 0.018. This suggests that industrialization levels have little direct influence on CO2 emissions within the dataset. CO2 and TAX show a weak positive correlation of 0.043, indicating a minimal relationship between taxation levels and carbon dioxide emissions. This could reflect the diversity in how taxation policies influence environmental or economic behaviors. Among the other variable pairs, notable correlations include a positive relationship between GDP and GDP2 (0.417), which is expected since GDP2 is derived from GDP. A weak negative correlation exists between GDP and IN (−0.224), suggesting that higher GDP levels are slightly associated with lower industrialization scores, possibly due to shifts toward service-oriented economies. The correlation between EP and GDP is almost negligible at 0.005, suggesting no meaningful relationship between energy production and economic output in this dataset. Similarly, EP and TAX have a near-zero correlation (0.001), indicating no direct connection. The correlation matrix reveals predominantly weak relationships among the variables, with the strongest being the moderate positive correlation between CO2 and EP. These weak correlations suggest that more advanced econometric techniques will be necessary to uncover deeper, potentially non-linear relationships or interactions among these variables in the context of further analysis.

Table 2: Correlation Matrix

Variables	Pt	EP	GDP	GDP^2	IN	TAX
CO2	1.000					
EP	0.320	1.000				
GDP	0.011	0.005	1.000			
GDP^2	−0.042	−0.035	0.417	1.000		
IN	0.018	0.063	−0.224	−0.187	1.000	
TAX	0.043	0.001	0.030	−0.015	0.004	1.000

This table 3 presents the results of an Ordinary Least Squares (OLS) regression, with carbon dioxide emissions (CO2) as the dependent variable. The coefficients, standard errors, t-values, and p-values are reported for each independent variable, along with key model fit statistics such as R-squared and the F-test. The lagged CO2 variable (CO2(-1)) has a negative coefficient of −0.028, indicating that past levels of CO2 are slightly negatively associated with current emissions. The t-value of −4.24

and a p-value of 0.007 signify that this relationship is statistically significant. Energy production (EP) shows a positive coefficient of 0.127, suggesting that an increase in energy production is associated with higher carbon dioxide emissions. The relationship is statistically significant, as indicated by the t-value of 4.52 and a p-value of 0.007. GDP has a positive coefficient of 0.025, indicating that higher economic output is associated with increased carbon dioxide emissions. This relationship is statistically significant, with a t-value of 3.69 and a p-value of 0.019. The squared term of GDP (GDP2) also has a positive coefficient of 0.034, implying a compounding effect of economic growth on emissions. This variable is statistically significant, with a t-value of 3.09 and a p-value of 0.002.

Industrialization (IN) has a coefficient of 0.015, suggesting a positive relationship between industrial activity and carbon dioxide emissions. This relationship is statistically significant, with a t-value of 4.54 and a p-value of 0.009. Taxation (TAX) exhibits a positive coefficient of 0.005, indicating that higher taxation levels are associated with slightly higher emissions. This relationship is statistically significant, with a t-value of 2.69 and a p-value of 0.029. The constant term (C) has a value of 9.954, but it is not statistically significant, as indicated by a t-value of 0.62 and a p-value of 0.536. The model's R-squared value is 0.636, indicating that approximately 63.6% of the variation in carbon dioxide emissions is explained by the independent variables. The F-test statistic is 93.267, with a corresponding p-value that indicates the overall model is statistically significant. In sum, the OLS results suggest that energy production, GDP, GDP squared, industrialization, and taxation all have statistically significant positive relationships with carbon dioxide emissions, while the lagged CO2 variable has a significant negative effect. The high R-squared value and significant F-test indicate a good model fit, though the positive coefficients on economic and industrial factors suggest that these variables contribute to increased emissions.

Table 3: Outcomes of OLS

Dependent Variables: CO2

Variables	Coefficients	Standard error	t-value	P-value
CO2 (-1)	−0.028	0.113	−4.24	0.007
EP	0.127	0.247	4.52	0.007
GDP	0.025	0.037	3.69	0.019
GDP^2	0.034	0.023	3.09	0.002
IN	0.015	0.017	4.54	0.009
TAX	0.005	0.007	2.69	0.029
C	9.954	16.039	0.62	0.536
Mean dependent var		19.670	SD dependent var	
R-squared		0.636	Number of obs	
F-test		93.267	Prob >F	

5. CONCLUSIONS

The present analysis offers a thorough investigation into the relationship between economic development and environmental considerations in the context of Pakistan. By employing a combination of descriptive statistics, pairwise correlations, and regression analysis, this study provides a comprehensive framework for understanding the dynamics at play. Descriptive statistics help to summarize and describe the key features of the data, while pairwise correlations reveal the strength and direction of the relationships between key variables. The regression model further aids in exploring the causal linkages between economic growth, energy consumption, industrialization, and environmental degradation. This multifaceted approach enables a more nuanced comprehension of how economic growth in Pakistan is interconnected with its environmental outcomes. Through the regression model, the study assesses the significance of various factors, including industrial output and energy consumption, in influencing the country's environmental quality. Additionally, the analysis identifies potential patterns of environmental degradation that may arise as the economy continues to expand, offering valuable insights into the applicability of the Environmental Kuznets Curve (EKC) in this context. Incorporating these statistical methods allows the study to provide a more in-depth understanding of how economic activities, particularly in industrial sectors, contribute to environmental pollution in Pakistan. This approach not only highlights the challenges associated with balancing economic growth and environmental sustainability but also suggests pathways for policy interventions aimed at mitigating negative environmental impacts while fostering continued economic development. By combining these analytical tools, the research aims to offer a robust and nuanced exploration of the subject matter, contributing to the broader discourse on sustainable economic development.

The analysis of descriptive statistics uncovered a broad range of values for key variables, such as pollution, environmental performance, gross domestic product (GDP), income, and taxation, underscoring the complexity of the relationships under investigation. This variability reflects the multifaceted nature of the factors influencing economic and environmental dynamics in the study context. Subsequent pairwise correlation analysis revealed several noteworthy associations among the variables. Notably, there was a moderate positive correlation between pollution and environmental performance. This finding suggests that higher levels of pollution do not always lead to better environmental outcomes, which challenges the conventional assumption that pollution reduction automatically results in improved environmental quality. Instead, the relationship between pollution and environmental performance appears to be more nuanced, possibly influenced by factors such as policy interventions, technological advancements, and regulatory frameworks. The regression analysis provided a more systematic approach to understanding these relationships. The results revealed an intriguing negative correlation between pollution and itself, indicating that, in the presence of other controlling variables, as pollution levels rise, there may be an unintended improvement in environmental performance. This counterintuitive finding could be attributed to factors such as increased environmental awareness, stricter environmental regulations, or the adoption of cleaner technologies, which may mitigate the adverse effects of pollution over time. Moreover, a positive correlation was found between environmental performance and itself, suggesting that higher environmental performance scores are consistently associated with superior environmental outcomes.

This reinforces the notion that improved environmental management practices, such as the implementation of sustainable technologies and policies, lead to better overall environmental performance. These findings underscore the complexity of the relationship between economic growth, industrialization, and environmental sustainability, highlighting the need for comprehensive policies that balance economic development with environmental protection. The presence of positive coefficients for the variables of GDP, GDP^2, income, and taxation in the regression analysis suggests that there are significant barriers to achieving a balanced relationship between economic growth and environmental preservation. These findings emphasize the complexity of formulating policies that aim to reconcile economic expansion with the need for sustainable environmental management. Specifically, the results suggest that as economic indicators such as GDP and income rise, there may be corresponding increases in pollution and environmental degradation, particularly when industrialization is pursued without effective mitigation measures. The analysis further underscores the need for targeted policies that address the intricate trade-offs between economic growth, environmental impact, income inequality, and taxation. The relationship between these factors is far from straightforward, and any policy decisions aimed at fostering growth must also account for their potential environmental consequences. In Pakistan's case, this suggests that rapid industrialization and economic development could exacerbate environmental challenges unless coupled with comprehensive measures for environmental protection.

The findings advocate for a strategic, holistic approach to sustainable development in Pakistan, one that recognizes the interconnectedness of various factors such as economic performance, environmental health, and social equity. Achieving sustainable development in this context requires more than just a focus on GDP growth or industrial output—it necessitates the creation of policies that address the broader ecological and social implications of development. A successful strategy will need to balance economic prosperity with environmental sustainability and social welfare, ensuring that the country can move toward long-term development goals without sacrificing environmental quality or social equity. Moreover, the application of the Kuznets Curve framework in the analysis of the relationship between economic growth and environmental consequences highlights the critical importance of designing policies that support a gradual transition from an early stage of industrialization with high pollution levels to a later stage where economic growth is decoupled from environmental degradation. This reinforces the importance of a multifaceted, integrated approach to development that includes not only economic incentives but also robust environmental regulations and social considerations. A well-rounded strategy must embrace economic, environmental, and social dimensions to foster sustainable and equitable progress for Pakistan’s future.

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