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RESEARCHARTICLE

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The Interplay of CO2 Emissions, Health Expenditure, and Economic Growth: Evidence from Pakistan

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Abstract
There is a wide recognition of the detrimental effects of greenhouse gases (GHGs) and their connection to increased levels that impact public health. Carbon dioxide (CO2) is recognized as the most significant GHG, plays a major role in the environmental degradation process, and affects human health in adverse ways. Economic growth plays a vital role in addressing this arena. This research explores the interplay of CO2 emissions (CO2E), health expenditures (HEP), and economic growth in Pakistan from 2000 to 2023. The study examines the interrelationship between CO2E, health expenditure per capita (HEPC), and economic growth, with a focus on key economic indicators, including Gross Domestic Product (GDP) and trade openness (TRO). This study uses gross capital formation (GCF), Gross domestic product per capita (GDP per capita), population (POP), and energy use (ENU) as control variables. Utilizing the ARDL model, this study uses logarithmic transformations on all variables to account for non-linearity and reduce variance. The results demonstrate a complex interaction between the variables, with CO2 emissions showing a significant positive relationship with GDP, HEPC, POP, and GCF. This suggests that higher economic activity, increased health spending, and population growth are generally associated with a greater environmental impact. A key finding is that energy use (ENU) exhibits a strong causal link with GDP, highlighting that economic growth is a major driver of energy consumption. The study concludes with policy recommendations aimed at reducing CO2 emissions and managing health expenditures to ensure that economic growth is achieved without compromising environmental and health outcomes.

KEYWORDS
Gross Domestic Product, Economic Growth, Carbon Emissions, Health Expenditure, Trade Openness

1 |INTRODUCTION

The modern era is developing and consistently focusing on environmental issues, also highlighting the fact that economic growth is the most crucial area of research concerning carbon emissions and health expenditure, particularly in developing countries such as Pakistan (Ullah et al., 2020). Carbon emission is believed to be the byproduct of industrial and economic activities (Rotty, 1983). The quality of life is facing a significant threat in the shape of environmental degradation, global warming and other climate changes are challenging the weather system only because of increase in GHG emissions, carbon emissions is one of the main participants in this manner (Ahmed et al., 2018). Moreover, these elevated GHG emissions always pose a significant threat to human health and are also known as an environmental risk. The most recognized GHG is the gas emitted from different activities is carbon emission (Kiehbadroudinezhad et al., 2024; Wang et al., 2019; Zafarullah & Mehnaz, 2025). The emissions of CO2 not only contributed to global warming but also impacted human health, resulting in negative consequences related to economic growth. (Zhang & Zhang, 2024). This study aims to examine the link between carbon emissions, economic growth and health expenditures in Pakistan's perspective.

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Moreover, some researchers have successfully established a link between carbon emissions and health expenditures as an essential perspective in the investigation of related economic growth. Carbon emissions increase the concentration of harmful matter and substances being a primary contributor to air pollution and leading to higher ozone level (Richard et al., 2024). There is also an established viewpoint by (Hamzah et al.) These emissions have a negative impact on human health, resulting in increased mortality and hospitalization rates among employees across various industries. The link between economic growth and health expenditure cannot be ignored as several researcher (Abdulqadir et al., 2024; Çobanoğulları, 2024; Hu & Wang, 2024; Slathia et al., 2024; Wang et al., 2019; Zhang & Zhang, 2024) agreed upon and identified a significant relationship between economic growth and health expenditures. (Zaman et al., 2016) argued that the threat to human health due to these carbon emissions inspired researchers to dig deeply into the concerns and connections in this nexus between the variables of economic growth and human health expenditure. In Pakistan, past studies and research data show that the degradation of the environment, specifically in CO2 emissions, is a significant reason for several skin allergies, cardiovascular conditions, and asthma in people, regardless of whether they are working in any industry or not (Aqeel et al., 2025; Lin et al., 2024; Sannoh et al., 2024). Moreover, some recent researchers found that there is a very significant role of carbon emissions in increasing air pollution, resulting a severe increase in hospital admissions rates, specifically in cardiology and skin departments, which put an impact and results in increased health expenditures (Azimi & Rahman, 2024; Dong et al., 2025; Kumar et al., 2025).

To achieve productive outcomes in different aspects of life, a healthy and strong environment and lifestyle is vital, which can only lead to the welfare of the society and development of human health and thus result in an efficient workforce (Zhang & Qian, 2024). The economic strength of a nation is dependent on its people's health care system and its healthcare sector as well (Folland et al., 2024; Gul et al., 2024). Since many researchers established a positive relationship between health expenditure and economic growth from Pakistan's perspective, especially it is also noted that environmental factors are not considered adequately, resulting in an ordinary healthcare situation in Pakistan (Abbas & Talib, 2024).

Furthermore, an escalating rise in environmental concerns and the burden of growing healthcare issues in parallel time is causing problems for economies. Pakistan is a developing country, facing parallel and dual challenges, on the one hand dealing with the rise in pollution-related diseases, on the other hand trying to manage the health expenditures within its limited available resources (Shaheen & Konain, 2024). In order to read this situation as it is raising questions on the effectiveness of public health expenditure, it is essential to know if these expenditures are responsive to the leading causes of environmental degradation caused by elevated carbon emissions (Islam et al., 2024). For national development and growth, economic growth remains a priority and goal for countries. However, this pursuit of economic expansion may conflict with public health objectives and environmental situations. To achieve higher growth, countries tend to move forward with industrial expansion and increasing industrial activities, which lead to more energy consumption and thus more carbon emission (Hunjra et al., 2024). Therefore, policymakers must investigate whether economic growth is contributing to or hindering environmental and human health factors.

This study arises from the need for a comprehensive investigation in the context of Pakistan, utilizing a large dataset spanning 23 years from 2000 to 2023, as data availability allows. The ARDL model is employed, and Granger causality is also investigated from a wide angle. This nexus of CO2E, health expenditure and economic growth is undoubtedly studied by various researchers investigating these variables in isolation or pairs. There is limited evidence examining these interactions in a time series. Most of the studies may overlook the specific institutional economic and environmental conditions of Pakistan as existing literature has focused chiefly on cross-country analysis in this regard.

Objectives of the Study:

1. To investigate the short-run and long-run relationships among carbon emissions, health expenditure, and economic growth.
2. To identify the direction of causality
3. To evaluate whether CO2E impacts healthcare spending or not
4. To provide policy recommendations.

Literature Review

Theoretical Evidence

Several economic and environmental theories can support the nexus among CO2 emissions, economic growth, and health expenditure. To understand this nexus, it is important to understand environmental degradation (Amer et al., 2024). Environmental degradation is defined as the deterioration of the environment, including the depletion of natural resources such as water, air, forests, soil, and minerals, as well as the destruction of ecosystems (Duraiappah, 1996; Lonergan, 1998). Additionally, environmental degradation is linked to human capital theory in the context of human health, as noted by Reder (1967), who suggests that a good and healthy production function is dependent on a healthy population. This theory focuses on three aspects: first, an increase in pollution leads to

a rise in cardiovascular diseases and respiratory problems. Secondly, they have an impact on mortality rates, and thirdly, they cause reduced labor productivity. Furthermore, another theory that supports this nexus is endogenous growth theory presented by (Romer, 1994). They proposed that an increase in health expenditure results in lower absenteeism and improved productivity. Additionally, the effectiveness and efficiency of health expenditure are crucial in mitigating the impacts of CO2E on employee performance (Hourcade & Robinson, 1996).

Carbon Emissions and Economic Growth

The connection between CO2 emissions and economic growth has been well investigated and studied by several researchers in recent times. The main focus is not only on one country, but on different countries in various regions, each with its unique environmental and economic conditions, which have been studied over the last two decades. Using a time series from 1990 to 2022 (Rasheed & Liu, 2024) studied a complex nexus among CO2E, energy consumption, and economic growth employing the environmental Kuznets curve (EKC). They shared this view with Javaid et al. (2024) also, if targeted measures are set, then environmental degradation can be reduced in a big economy like China. Raghutla et al. (2024) Using data from six global investment countries, this study investigated the impact of public-private partnerships on foreign direct investment and energy in the context of environmental quality. They found that the usage of clean energy plays a significant role in the economy and causes reduced emissions by improving the quality of the environment. Apergis et al. (2018) Conducted a study using data from 50 states and found that states with higher spending on health expenditure have higher levels of carbon emissions, so they found a positive relationship between them. A recent study conducted by Islam (2024) found a bidirectional causality between economic growth and CO2E, and they studied the data of SAARC member countries. Furthermore, a very recent study regarding the investigation of the relationship of CO2E and economic growth conducted by (Hussain et al., 2025)They found an inverted U-shaped relationship between economic growth and CO2 emissions in 59 Belt and Road Initiative countries from 2002 to 2020.

Carbon Emission and Health Expenditure

A panel co-integration analysis was performed by (Yacour et al., 2024) to investigate the linkage of healthcare expenditures and environmental quality by utilizing a dataset of five North American countries from 1990 to 2019, and found that a higher level of CO2E is a continuous potential threat to the cost of health expenditures for these countries. Another article investigated by Islam et al. (2024) by using time series data from 2004 to 2023, by employing the modified least squares method and dynamic least squares, they found a significant correlation between urbanization, natural resources, CO2E, and economic growth on healthcare expenditures. Another recent study by (Beşer et al., 2025) utilized the Generalized method of moments (GMM) estimator and found that CO2E and urbanization have a negative impact on life quality; secondly, elevating healthcare expenses and GDP result in higher air quality. They also found that higher spending in the healthcare sector led to better quality, indicating a causal relationship. This view is also shared by (Akinwale, 2021; Alwago, 2023; Ansari & Ansari, 2023; Halicioglu, 2009). Moreover, Usman et al. (2019) employing ARDL, using the data of 13 emerging countries with a time frame of 1994-2007, found that CO2E and the environment index have a significant positive relationship with government health expenditures, and both factors negatively affect the private health expenditures. Additionally, using the FMOLS technique in Ghana from 1970 to 2008, it was investigated and found that GDP as an indicator of economic growth has a positive relationship with health expenditure, while CO2 emissions negatively impact health expenditures (Boachie et al., 2014). Despite limited literature on CO2 emissions and health expenditures, previous studies have confirmed a positive and causal relationship between these variables (Beşer et al., 2025; Fosu et al., 2025; Karaaslan & Çamkaya, 2022; Li et al., 2023; Mar et al., 2022; Zafarullah & Mehnaz, 2025; Zhang & Zhang, 2024).

Economic Growth and Health Expenditure

The importance of economic growth cannot be neglected in developing countries, especially in Pakistan. In the moderate economy of Pakistan, which is struggling, maintaining full health expenditure capacity to address health issues is challenging. Barro (1996) conducted research and stated that there may be a positive impact of health expenditures on economic growth, but there is also a slight chance in the long run to have a negative relationship built upon time. Another study conducted by (Slathia et al., 2024) applying the ARDL model, found that carbon emissions and GDP have a positive relationship because high economic activities lead to high industrial activities, resulting in high carbon emissions. Additionally, a recent study by (Ibukun & Omisore, 2025) applying Granger causality, we investigated a long-run dynamic causal relationship between health expenditure, economic growth, and air pollution in four countries. They found a bidirectional causal link between CO2E and economic development in Mexico, Indonesia, and Turkey, except Nigeria, where they reported a bidirectional relationship between air pollution and health expenditure. Some other studies found a positive relationship between economic growth and health expenditure such as (Kocakoc, 2024; Silva et al., 2024; Yacour et al., 2024).

Table 1: Variables with their impact

Dependent Variable	Description	Expected Impact
CO2E	CO2 Emissions (Dependent Variable)	Negative: More industrial output (possible negative effects in long term)
Independent Variables	Description	Expected Impact on CO2E
HEP	Health Expenditure Per Capita (Independent Variable)	Negative: Healthier populations may reduce environmental degradation
GDP (USD)	Gross Domestic Product (Independent Variable)	Measure of economic output
TRO	Trade Openness (Independent Variable)	Positive: Access to global markets and resources
GCF	Gross Capital Formation (Control Variable)	Positive: Investment leads to future growth
GDPC	Gross Domestic Product per capita (control variable)	Measure of economic output
POP	Population (control variable)	Positive: More people mean more labor and consumption
ENU	Energy Use (control variable)	Positive

2 METERIAL AND METHOD

In this study, the autoregressive distributed lag (ARDL) model is employed, whose purpose is to capture both long-run and short-run dynamics between variables (Wang et al., 2019). The data is secondary, this research is quantitative, and the data is taken from the World Bank database for different variables in the article. The period analyzed spans from 2000 to 2023, enabling us to examine the relationships between key variables during this time. The variables included in this study are carefully selected to understand their impact on the dependent outcomes. The ARDL model provides a comprehensive framework for assessing the interdependencies and causal relationships among these variables.

VAR Model Equation

$$\ln(CO2E_t) = \alpha + \lambda_1 \ln(GDP_t) + \lambda_2 \ln(CHEP_t) + \lambda 3 \ln(POPt) + \lambda 4 \ln(GCFt) + \lambda 5 \ln(TROt) + \epsilon t$$

Where;

- $CO2E_t$ represents the value of the dependent variable at time t
- The summation operator $\sum^{p}_{i=1}$ indicates that the model includes multiple lags of each independent variable
- C represents the constant term or intercept,
- *t*=1 represents the value of the corresponding variable from the *i period.*
- ϵt represents the error term

Further values of alpha, beta, gamma, theta, and so on are coefficient parameters used to examine causal relationships within the system.

3 RESULTS

The results from the Augmented Dickey-Fuller (ADF) test show that most of the variables in the level form are non-stationary**,** as indicated by the high p-values (greater than 0.05) (Harris, 1992). ln_co2**,** ln_enu**,** ln_gdp**,** and ln_chep all have p-values greater than 0.05, implying that they are not stationary at the level. However, after taking the first difference, all variables, except ln_pop, become **s**tationary with significant p-values less than 0.05. The first difference was used to make the series stationary. All variables, except ln_pop**,** became stationary after the first differencing. Significant results (p-value < 0.05) were observed for ln_co2e (-3.155), ln_enu (-3.121), ln_gdp (-4.563), ln_chep (-5.046), ln_tro (-5.046), and ln_gcf (-3.615). However, ln_pop remained non-stationary at both the level and first difference.

Table 02: Dickey Fuller Unit Root Test

Variable	*Level Test Statistic*	*Level p-value*	*First Diff Test Statistic*	*First Diff p-value*
ln_co2	-1.222	0.664	-3.155	0.023
ln_enu	-1.222	0.664	-3.121	0.025
ln_gdp	-1.222	0.664	-4.563	0.000
ln_chep	-1.222	0.664	-5.046	0.000
ln_pop	-0.959	0.768	-0.959	0.768
ln_tro	-1.222	0.664	-5.046	0.000
ln_gcf	-1.222	0.664	-3.615	0.006

Note: To achieve stationary and stable variance, a first difference is applied. First difference also used to reduce autocorrelation.

Table 03: Correlation Matrix

	ln_co2e	ln_enu	ln_gdp	ln_hepc	ln_pop	ln_tro	ln_gcf
ln_co2e	1						
ln_enu	0.7899	1					
ln_gdp	0.9687	0.7051	1				
ln_hepc	0.979	0.7616	0.9762	1			
ln_pop	0.9669	0.6572	0.9792	0.9554	1		
ln_tro	0.8695	0.7322	0.8954	0.8941	0.8429	1	
ln_gcf	0.959	0.7604	0.9848	0.9725	0.9409	0.9306	1

The correlation matrix reveals that the variables in the study are strongly interconnected. CO2 emissions (ln_co2e) exhibit high positive correlations with economic output (ln_gdp), health expenditures (ln_hepc), population size (ln_pop), trade openness (ln_tro), and gross capital formation (ln_gcf), indicating that as these factors increase, CO2 emissions tend to rise as well. Energy use (ln_enu) exhibits moderate to strong correlations with all other variables, reflecting its positive association with economic and environmental

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factors, albeit slightly weaker than CO2 emissions; this finding is consistent with a previous study (Zhang & Zhang, 2024). The indicator of economic growth is GDP, which seems to be correlated with the health expenditures indicator HEPC, POP, and GCF. This means that GDP has a strong influence on these variables. Health expenditure has a significant positive relationship with economic growth. CO2E and POP are dependent on economic conditions (Dritsaki & Dritsaki, 2024). Overall, this analysis shows that the variables are highly interdependent: population, economic growth, and health expenditure.

Table 4: Granger Casualty Test:

Equation	Excluded	chi2	df	Prob > chi2
ln_co2e	ln_enu	5.7285	2	0.057
ln_co2e	ln_gdp	5.0539	2	0.080
ln_co2e	ln_hepc	2.5115	2	0.285
ln_co2e	ln_pop	4.7794	2	0.092
ln_co2e	ln_tro	1.918	2	0.383
ln_co2e	ALL	31.164	10	0.001
ln_enu	ln_co2e	10.775	2	0.005
ln_enu	ln_gdp	19.785	2	0.000
ln_enu	ln_hepc	14.855	2	0.001
ln_enu	ln_pop	9.3312	2	0.009
ln_enu	ln_tro	13.981	2	0.001
ln_enu	ALL	51.38	10	0.000
ln_gdp	ln_co2e	0.7452	2	0.689
ln_gdp	ln_enu	14.857	2	0.001
ln_gdp	ln_hepc	11.907	2	0.003
ln_gdp	ln_pop	2.2492	2	0.325
ln_gdp	ln_tro	3.3177	2	0.190
ln_gdp	ALL	91.749	10	0.000
ln_hepc	ln_co2e	0.84603	2	0.655
ln_hepc	ln_gdp	6.8532	2	0.032
ln_hepc	ln_pop	7.0189	2	0.030
ln_hepc	ln_tro	6.6901	2	0.035
ln_hepc	ALL	89.167	10	0.000
ln_pop	ln_co2e	2.0979	2	0.350
ln_pop	ln_enu	2.1963	2	0.333
ln_pop	ln_gdp	18.749	2	0.000
ln_pop	ln_hepc	16.66	2	0.000
ln_pop	ln_tro	16.904	2	0.000
ln_pop	ALL	70.474	10	0.000
ln_tro	ln_co2e	5.2552	2	0.072
ln_tro	ln_enu	7.9922	2	0.018
ln_tro	ln_gdp	30.972	2	0.000
ln_tro	ln_hepc	14.896	2	0.001
ln_tro	ln_pop	21.137	2	0.000
ln_tro	ALL	71.985	10	0.000

The study employed the Granger causality test to determine whether there is any causality between variables that can aid in predicting the relative information for other time series. The results of the Granger causality test show a significant link among certain variables in the model. The past values can help forecast the future values of another time series (Detthamrong et al., 2024). Moreover, the findings show that the log of GDP ln_gdp has a strong causal relationship with the log of ENU ln-enu and the log of TRO ln_tro, with their p-values of 0.001 and 0.000 showing strong causality. Furthermore, the relationships of the log of CO2E ln_co2e, ln-enu, ln_gdp, and ln_pop is showing as weak as their p-values are higher than the cutout of 0.05. These results also show that GDP and ENU are closely affecting each other while POP and TRO are less closely linked, similar to (Barkat et al., 2025).

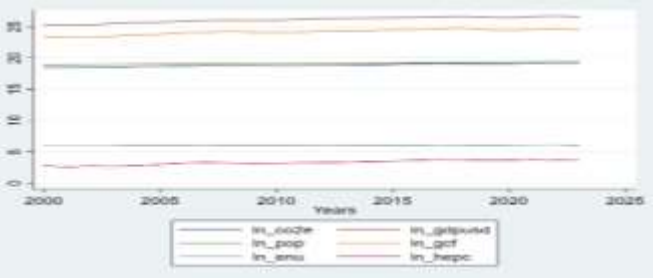

Fig. 1: Time Series Graph

Fig. 2 shows the graphical representation of logged values for lnCO2e, lnGDP, lnHEPC, lnGCF, and lnENU from 2000 to 2023. All the variables exhibit a general upward trend, indicating consistent economic development, industrial activity, and population growth over time. LnCO2e and lnENU are closely linked and move much closer, obviously highlighting the link between consumption and emissions. On the other hand, the HEPC shows a nominal increase, indicating that elevated healthcare costs are related to economic activities. Overall, all the variables are showing an interlinked connection as more economic activities will bring more emissions and more attention towards public healthcare investments, this view is supported by (Gershon et al., 2025).

Table 5: ARDL Model Short-Run Coefficients;

ln_co2e	Coef.	Std. Err.	P>t	t P>t	[95% Conf.	Interval]
ln_co2e						
L1.	-.3933668	.4264951	-0.92	0.083	-1.376866	.5901327
ln_gdpusd						
.	-.4148234	.4463849	-0.93	0.038	-1.444189	.614542
L1.	-1.065681	.6332099	-1.68	0.031	-2.525865	.394504
ln_pop						
.	13.21259	17.1859	0.77	0.064	-26.41817	52.84335
L1.	-15.32714	34.24415	-0.45	0.066	-94.2943	63.64001
L2.	-5.40837	30.51564	-0.18	0.064	-75.77756	64.96082
L3.	11.45591	12.31568	0.93	0.079	-16.9441	39.85591
ln_hepc						
.	.6119668	.3257825	1.88	0.097	-.139289	1.363223
L1.	.5813196	.3610219	1.61	0.046	-.2511983	1.413838
L2.	-.1645738	.1727735	-0.95	0.069	-.5629901	.2338425
L3.	-.0325056	.1609666	-0.2	0.045	-.4036952	.3386839
_cons	-34.27737	12.89449	-2.66	0.029	-68.554736	

Table 5 presents the ARDL short-run coefficients, indicating how changes in other variables affect carbon

emissions over a short period. The results show that the lag of CO2 is showing a negative coefficient along with a slightly insignificant value. The results show that GDP at current and after taking lagged value is showing a negative impact on emissions. Still, a significant one showing (p= 0.031), this shows that economic growth may reflect a reduction in carbon emission to some period which may be possible due to shifting towards green environment and green energies (Sannoh et al., 2024). The population has an insignificant role across all variables (Beşer et al., 2025). HEPC with logged value ln_hepc shows a mixed approach towards the variables, but a short-term link is produced with carbon emission. A strong lag effect of economic growth is also reported, indicating a short-term link with carbon emissions (Zhang & Qian, 2024).

Furthermore, upon checking the Breusch-Godfrey LM test as suggested by (Idowu et al., 2024)The study reports a p-value of 0.2871, indicating that the value is greater than 0.05; therefore, there is no evidence of serial correlation in the model residuals.

Conclusion

This study examines the relationship between carbon emissions, health expenditure, and economic growth. For economic development, GDP was studied as the key indicator, and health expenditure per capita was sourced from the World Bank database to examine Pakistan's health expenditure from 2000 to 2023. This study uses POP, GCF, and TRO as control variables to model. This study finds that as the economy grows, environmental degradation also occurs at exactly the same rate, which is justified for economic growth. This study finds a negative impact of trade openness and economic development on public health in Pakistan.

Furthermore, by employing the ARDL approach, this study discovered long-term relationships among these variables. The results indicate a dynamic interplay among economic growth, health expenditure, and carbon emissions. Carbon emissions adversely affect health outcomes. (Guo et al., 2024). Moreover, our findings align with previous research by (Stevens et al., 2013) and (Cornia et al., 2007) which emphasize that while trade openness and economic growth improve living standards, they also contribute to environmental degradation, which negatively impacts public health in. Pakistan, like other Belt and Road countries, has immense potential for energy production and conservation if it effectively utilizes its natural resources (Zhang et al., 2017).

Additionally, this study contributes to improving living standards by focusing on economic growth. The findings also indicate that Pakistan's economic growth is linked to environmental degradation, both negatively and positively, which affects public health and leads to rising healthcare expenditures. This linkage underscores the need for a balanced policy that fosters sustainable and manageable growth while also prioritizing environmental protection and advancements in public health.

Future Implications and Limitations

A comprehensive policy is needed in resolving these issues and inviting all the stakeholders, governments, businesses, and consumers to reduce carbon emissions. The renewable energy should be the primary focus of the government; this could happen by imposing high carbon taxes in order to discourage heavy industrial emission activities near public areas and cities. Public health policies should be implemented and initiated to encourage healthy practices by reducing emissions nationwide and by raising awareness. Future development is not achievable if environmental concerns are not addressed. The role of society and the community needs to be reassessed.

Furthermore, this study provided valuable insights into the dynamic relationship between carbon emissions, health expenditure, and economic growth; however, it is still subject to some limitations. At first, the relatively small sample size of 23 years of annual observations may limit the statistical power and generalizability of the findings. Secondly, there is a limited set of explanatory and control variables that are tested. This study suggests that variables such as industrial progress and environmental policy can be further explored in this domain.

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Author Contributions

Dr. Basit Raza was involved in conceptual development and also contributed to the methodology, software implementation, data analysis, and writing. Aimen participated in reviewing and editing the manuscript. Fajar was responsible for preparing the initial draft and handling the data collection and validation**.**

Disclosure of Potential Conflict

The authors confirm that they have no conflict of interest regarding the study, authorship, and publication of this work.

Data Availability Statement

As this study did not involve the generation or analysis of any datasets, data sharing is not relevant to this study.

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