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The Impact of Carbon Emission and Renewable Energy on Health Expenditure in Pakistan

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Abstract

Climate change and air pollution are global challenges with substantial threats to public health. Extended exposure to CO2 can result in a range of negative health effects and illnesses leading to increased health expenditures. This study explores how carbon emissions and the usage of renewable energy affect Pakistan's per capita health expenditures from 2000 to 2021. The 2SLS-ARDL method is deemed suitable to address potential endogeneity and due to existence of severe multicollinearity. The findings indicate significant positive association between carbon emissions and health spending both in short and long-run. Conversely, renewable energy consumption instrumented by its first lag) shows a negative association with health expenditures per capita both in short & long run. Therefore, promoting environment friendly and sustainable energy-favorable policies, along with limiting CO2 emissions are recommended steps in terms of reducing health costs.

Key words: *Carbon emissions, Renewable energy consumption, Health expenditures, Pakistan,*

1. Introduction

The largest health risk to humanity is climate change, which is mostly caused by burning fossil fuels, which exposes 99% of the world population to unhealthy air pollution levels. The World Health Organization has set air quality limitations, yet nearly all people on the earth (99%) breathe air that is dangerous to their health. Examining the data on air quality, from more than 6000 cities across 117 nations, for fine particulate matter and nitrogen dioxide, which are mostly abundant in the air of developing nations, are observed to be inhaled by the residents of these places at a rate that is hazardous to their health (World Health Organization, 2022). According to the World Bank, health risks driven by climate change might kill at least 21 million more people by 2050. These risks include heat stress, diarrhea, dengue, malaria, and malnutrition. The major part of the deaths are anticipated to crop up in least and underdeveloped nations in South Asia and Sub-Saharan Africa. This estimate does not account for deaths caused by other climate change-related hazards, such as wildfires, floods, and extreme weather events (World Bank, 2024).

One of the main factors in assessing life quality is health and public healthcare, which is impacted by CO_2 emissions. Extended exposure to CO_2 can source a range of negative effects, the most dangerous conditions caused by CO_2 emissions are lung infections, allergic rhinitis, pulmonary diseases, and bronchitis. Consequently, residents' healthcare expenses can rise if their health declines (Raihan et al., 2022). Same is true in case of Pakistan, the health of people has been negatively impacted by CO_2 emissions. Environmental deterioration, specifically CO_2 emissions in Pakistan, is the primary cause of a number of illnesses, including asthma, cardiovascular disorders, and skin allergies. Although the number of paramedic personnel (nurses and doctors) is rising, their use is not up to par. Because of air pollution, hospital admission rates are high, especially in the cardiology department, thereby raising the total health expenses (Wang et al. 2019).

The use of renewable energy (RE) adds to a cleaner environment by preventing the emission of harmful gases, such as CO2, SO2, and NO2. Countries that rely heavily on technologies with high CO2 emissions negatively impact their environmental quality and the health of their populations. Transitioning from polluted technologies and greenhouse gas leaks to sustainable energy such as wind, solar, and geothermal energy, can substantially enhance environmental quality and address climate change by reducing CO2 emissions. In conclusion, CO2 emissions directly affect public health, but this can be mitigated by increasing RE use, particularly in industrial areas (Ullah et al., 2020). Since excessive fossil fuel consumption exacerbates global warming, renewable energy is regarded as a clean and environmentally sustainable option. The utilization of renewable energy lowers emissions of greenhouse gases from fossil fuel, which in turn reduces carbon pollution and lessens its detrimental effects on environment and thereby public health (Sasmaz et al., 2021). Also, Renewable energy consumption instead of fossil fuels reduces health care costs (Aydin & Bozatli, 2023; Ferhi & Helali, 2024).

The prime objective of this study is to examine the impacts of carbon emission and sustainable energy consumption on health expenditures per capita in Pakistan. A nation facing critical challenges of climate change and energy shortfalls. Thereby, filling a critical gap in the prevailing

literature on the environmental determinants of health costs in developing economies like Pakistan. This study tests the following hypothesis:

H1: Carbon emission hava a significant positive effect on health expenditure per capita in Pakistan.

H2: Renewable energy have an inverse impact on health expenditures per capita in Pakistan.

The current research is of importance because it is aligned with Sustainable Development Goals (SDGs), in particular with good health and wellbeing (SDG 3), affordable and clean energy (SDG 7) and climate action (SDG 13). These SDGs emphasize the importance of ensuring healthy lives for all, promoting sustainable energy sources and combating climate change. The study adds to the current frame of research in several course of action: first, it provides a focused empirical investigation of the link between carbon outflow, sustainable energy utilization, and health spending per capita in Pakistan, a topic that is analyzed mostly in regional context and for developed nations and not particularly focused in terms of developing nations like Pakistan. Hence, it adopts an interdisciplinary approach to examine and highlights the critical interconnections between these critical societal challenges. Secondly, the study employed recent time-series data from 2000 to 2021. Thirdly, it take on the 2SLS-ARDL method to address potential bias from a small sample size, severe multicollinearity and endogeneity providing more authentic and precise results. Lastly, the findings are expected to offer insights into the connections between carbons pollution and health spending, as well as between use of sustainable energy and health expenses. The empirical results will inform policy recommendations on improving environmental quality, promoting clean technologies usage, and optimizing the allotment of health care resources to achieve better health outcomes nationally. The formation of study is as: Section 1 introduces the study theme and objectives. Section 2 furnishes the review of literature. Part 3 comes up with research methodology. Part 4 illustrates the outcomes using tables and figures. Lastly, Section 5 reports the key conclusions and proposes policy recommendations.

2. Literature review

This section provides a systematic and critical review of literature on the association between per capita health expenditure, Co2 outflow and utilization of renewable energy. Fundamental and important studies are presented here to discuss these linkages across different countries and contexts, along with their methodologies, key findings and limitations. The review is organized by discussing the role of carbon emission on health spending and of renewable energy in reducing environmental pollution and health costs. Eventually, the section concludes by identifying and reporting the existing gaps in the literature that this study aims to address.

The effect of environmental pollution usually measured by carbon outflow and health expenditure are explored by several studies. Jerrett et al. (2003) conducted an initial research in this regard and established that counties with higher pollution levels devote more resources to healthcare. The cross-sectional data of 49 states in Canada from 1991–1992 and a two-stage regression was used. After Jerrett et al.'s (2003) investigations, the link between healthcare expenditure and the environment has not gotten much attention from scholars for a specific amount of time. Subsequently, Yahaya et al. (2016) explored the connection among quality of environment and health outlay per capita again in 125 developing nations between 1995 and

2012. The outcome showed that CO2 had the strongest ability to explain changes in health spending per capita. In the long run, as opposed to the short run, the variables' explanatory power has a higher impact. Focusing on Pakistan, Wang et al. (2019) analyzed the vital relation between CO_2 outflow, economic growth and health expenses in the context of gross fixed capital formation and trade per capita for Pakistan utilizing the ARDL model and data from 1995 to 2017. The results show a substantial long-term as well as the immediate causative link between Pakistan's economic growth, health spending and CO2 emissions. Granger causation in a bidirectional link has been observed in health outlay and CO_2 outflows as well as of health outlay and economic growth. A short-run, unidirectional causal relationship is found between carbon outflows and spending related to health. Chen et al. (2019) used longitudinal data from thirty provinces of china from 2005 to 2016 to present Bayesian quantile regression for discussing the relationship of Carbon pollution and spending of healthcare. It shows that emissions of CO_2 in fact having a notable influence on healthcare payout in China is rather greater than that of the income variable. Additionally, it is shown that impact of carbon dioxide outflow on health-care expenses at a upper quantile was significantly tinny, suggesting that majority of individuals aren't giving enough thought to the link between health issues and air pollution. Raihan et al. (2022) examined the relation among CO_2 emission, use of energy, and health spending in Bangladesh. DOLS was applied by using data for years 2000 to 2020. The results showed that health care costs will rise by 0.95% and 2.67%, respectively, for every 1% escalation in carbon outflows and the use of fossil fuels for power. A few studies, however, indicate different conclusions. As an example Li et al. (2022) studied the link of carbon outflow, expenditures of health and economic growth in BRICS states. It is established that long term association is not found between carbon outflows, health expenses and economic growth. Despite these results, there is a fair amount of evidence suggesting that healthcare expenditures are correlated with economic growth and environmental quality. ***While the studies discussed above provide convincing confirmation of a positive link between carbon outflow and health care expenditure, some limitations still exist. The cross-sectional studies do not establish causality and panel data have the limitation of fully considering the country specific variations. Although Wang et al.(2019) focuses on time series data for Pakistan but the focus was on carbon outflow, growth and health expenditure rather than inclusion of renewable energy.***

On the contrary, the impact of Renewable energy use on health expenditure is relatively less discussed in empirical literature, but the findings are clear. Ullah et al.(2020) suggested that sustainable energy serves a considerable role in augmenting quality of environment and lowering expenses of health, which are affected harmfully by carbon emission. The study employed time series for years 1998 to 2017 in Pakistan and simultaneous equation method. However there focus was on the link of trade, sustainable energy, CO2 emissions, and health expenses. Similarly, Shahzad et al. (2020), also focusing on Pakistan, indicated that the use of sustainable energy negatively impacted health spending. The study investigated the relationship amidst expenses of health, information & communication technologies (ICT), economic growth, consumption of sustainable energy, and CO2 outflow by utilizing data from 1995-2017 in Pakistan and employing ARDL model. Majeed et al. (2021) studied the link between sustainable energy and health outcomes for 155 nations. Although the study establishes the significance of clean energy in

improving health outcomes like death rate and life expectancy but it differs from the current study that focuses on health expenditures instead of health outcomes. Mehmood et al. (2022) based on panel of five South Asian nations established that sustainable energy lowers health spending. FMOLS and DOLS techniques were applied utilizing data for years 1990 to 2018. Ferhi and Helali (2024) based on empirical analysis of 24 OECD countries concluded that renewable energy might mitigate the adverse impacts of carbon dioxide outflow on economic growth and development of humans. The generalized method of moments and annual data from 1990 to 2015. Aydin and Bozatli (2023) analyzed the consumption effect of sustainable energy, carbon pollution, growth of economy and population of refuges on Turkey's spending of health during 1975-2019. The Fourier-based integration technique was utilized to check the variables' long-term impacts on health expenses. The findings indicate a long-run relationship between the predictor variables and health expenditures. But the usage of sustainable energy declined. The findings of the causality analysis show a unidirectional, permanent causal relationship among expenditures on health and the consumption of sustainable energy. Moreover, Raihan et al. (2022) in Bangladesh reported that a 1% increase in the usage of renewable energy might eventually provide a route to 1.44% decrease in health care costs. ***While the aforementioned studies offer encouraging evidence for the beneficial role of renewable energy in relation to health and healthcare expenditure, it is important to note a significant potential limitation in their analyses. Despite employing different methodologies, the studies overlooked the probable severe multicollinearity between carbon outflow and renewable energy and thereby errors of estimation.***

Summing up the literature, it's evident that carbon emission, renewable energy usage and expenses of health are interrelated. While, the association between carbon pollution, consumption of renewable energy and health outlays are investigated, a notable gap exist specially in case of Pakistan to investigate this issue further and thoroughly with updated data and advanced techniques. The development of comprehensive policy solutions to lessen the adverse impacts of environmental factors on health is hindered by this knowledge gap. Furthermore, a critical limitation also lies in use of econometric methodology for tackling the potential severe multicollinearity and endogeneity issues. To fill this gap, the current study aims to analyze the combined effects of carbon outflows and the usage of sustainable energy on health spending in Pakistan, utilizing recent time-series data from 2000 to 2021 and employing the 2SLS-ARDL methodology. The findings of this research are expected to add significantly to the understanding of these complex relationships in a developing economy.

3. Data and Methodology

3.1 Theoretical framework

The study aimed to evaluate the impact of carbon pollution and utilization of sustainable power on health spending using the following model, which was established inside the structure of the conventional Marshallian demand function (Friedman, 1949).

$$HE_t = F(CO_{2t};\ RNE_t) \quad (1)$$

Where HE_t is the expenses of health for time t, CO_{2t} is the CO_2 emissions of time t, and RNE_t is the renewable energy use of time t.

3.2 Data and Econometric model

The analysis is based on time series for the years 2000 to 2021 for Pakistan. The data source is World Development Indicators (WDI). Health spending is measured as current health expenditure per capita, It captures the burden of health care cost per capita in the economy. Carbon emissions measured in the Million metric tons (Mt Co2eq) is an important indicator of environmental degradation and a key factor of climate change. Consumption of sustainable energy is taken as a percentage of total final energy use. This variable captures the extent to which Pakistan utilizes renewable energy sources, which are essential for combating climate change and phasing out fossil fuels. It provides an indicator of progress towards sustainable energy goals. The variables employed are summarized in table 1.

Table 1: Variables Description & the Data Source

Variables	Description	Units	Sources
HE_Pc	Health expenditure per capita	Dollars	WDI
CO_2	CO_2 emissions	Million Metric tons (Mt CO2eq)	WDI
RNE	Renewable energy use	Percentage of total final energy use	WDI

To investigate the effect of carbon emission and renewable energy consumption on health spending, 2SLS auto-regressive distributed lag model (2SLS_ARDL) is utilized in the work to apprehend short and long term dynamics. The reason to employ 2SLS-ARDL was the potential endogeneity and the severe and model distorting multicollinearity. In order to tackle the problem in first stage of estimation lag value of renewable variable is used to estimate the instrumental variable for renewable energy. The following equation is used to develop the instrumental variable series.

$$RNE_t = \beta_0 + \beta_1 RNE_{t-1} + e_t \quad (2)$$

After estimating the coefficients, instrumental variable for renewable energy (RNE_IV) is generated.

In the second stage following equation represents the ARDL approach:

$$\Delta HE_t = \beta_0 + \beta_1 HE_{t-1} + \beta_2 CO_{2t-1} + \beta_3 RNE\_IV_{t-1} + \sum_{i=1}^{\rho-1} \varphi_i' \Delta HE_{t-i} + \sum_{i=1}^{\rho-1} \delta_i' \Delta CO_{2t-i} + \sum_{i=1}^{\rho-1} \emptyset_i' \Delta RNE\_IV_{t-i} + e_t \quad (3)$$

ARDL is introduced by Pesaran et al. (2001) and helps in estimating coefficients of short & long run. The bounds test is employed to decide about existence of co-integration among variables. Although various econometric techniques like VECM can be used to analyze time series data, the ARDL is preferable because of its multiple advantages. For example, it is helpful when all variables are I(1) or mix of I(1) and I(0) and qualify the test of cointegration (Pesaran et al., 2001; Nkoro & Uko, 2016; Shrestha & Bhatta, 2018). It yields reliable results regardless of sample size, it's helpful for balancing the lags and producing reliable t-statistics for long-term model estimations. For time series data, this modeling strategy is appropriate in the presence of endogeneity and serial correlation (Pesaran et al. 2001). Furthermore, employing 2SLS strategy further enhances its capability.

4. Results and Discussion

4.1 Unit Root Test

The order of integration is necessary to be checked in the first stage of data analysis. It is done through the ADF test suggested by Dickey and Fuller (1979). Each series is checked for unit root and the findings are presented in table 2. All variables are found integrated of order one. The hypothesis that series have unit root at level could not be rejected for all series and it is found that they are stationary at their first difference. The ADF test results support to label them as I(1) variables.

Table 1: Unit Root Test Results

Variable/P-values	Level	First difference	Conclusion
HE_Pc	0.9785	0.0348	I(1)
CO_2	0.8370	0.0007	I(1)
RNE_IV	0.7288	0.0098	I(1)

4.2 Cointegration Test

Bounds test is used for confirmation of cointegration. Table 3 provide the results of bound testing and confirms existence of the long-run association among variables. The hypothesis that no co-integration occurs is rejected because the F-statistic have greater values when compared to critical values for upper bounds at 10% and 5% level of significance.

Table 2: Co-integration Results of Bounds Test

F-statistics	K	1%	5%	10%
6.322232	2	7.873	5.473	4.47

4.3 Long-Run and Short-Run Results

The 2SLS-ARDL technique is utilized to explore the short & long run dynamics. Table 4 of the study reports the results of the long & short run dynamics between carbon emissions, renewable energy consumption and health spending. The results establish that in the long-run carbon emission and health spending are positively related and is statistically significant. The coefficient value is 0.815561 and p-value is 0.0001. The result indicates that one unit change in carbon emission brings 0.815561 unit changes in health expenditure in same direction. The result is in line with previous empirical work of Yahaya et al. (2016), Wang et al. (2019) and Raihan et al. (2022) implying that increase in carbon pollution leads to higher health spending in the long-run. Our finding is in contrast with Li et al. (2022) that reported no long-term correlation between CO2 emissions and health spending.

Furthermore, the long run estimate of renewable energy consumption (RNE) is found to be inversely related with health spending. The coefficient -4.263829 with a p-value of 0.0784 suggests that one percentage point change in use of renewable energy brings changes of 4.26389 units in an opposite direction. This confirms the hypothesis that increased use of renewable energy reduces health spending in the long run. If we dig deeper into the units of measurement then the results shows that if the use of renewable energy in total energy use is increased by one percent then the health spending will decline by more than four dollar per capita which is a very

huge and significant decline in health spending. This finding is consistent with the previous empirical result of Shahzad et al. (2020), Mehmood et al. (2022) and Aydin and Bozatli (2023) and Ullah et al. (2020) implying that the renewable energy have a substantial importance in improving quality of environment and lowering expenses of health.

Table 3: ARDL Results

Long-run Estimates				
Variables	Coefficient	S.E	t-statistics	Prob.
CO_2	0.815561	0.153679	5.306905	0.0001
RNE_IV	-4.263829	2.245762	-1.898612	0.0784
Short-run coefficients				
CO2**	0.330566	0.099887	3.309419	0.0052
RNE_IV**	-1.728232	0.950569	-1.818103	0.0905
C	68.72529	13.89147	4.947302	0.0002
D(HE_PP(-1))	0.609771	0.150964	4.039170	0.0012
D(HE_PP(-2))	-0.452661	0.158233	-2.860726	0.0126
CointEq(-1)*	-0.405324	0.087058	-4.655773	0.0004
Diagnostic test				
R^2	0.703627	Adjusted R^2		0.648057
F-Stat	12.66201	S.E of regression		4.285208
Prob(F-statistic)	0.000171	DW Test		1.571930
**** Variable interpreted as Z = Z(-1) + D(Z).**				

In the short run, the error correction term (CointEq (-1)*) is negative (-0.405324) and significant with the probability value 0.0004 indicating a significant adjustment towards long-run equilibrium. The deviations seem to adjust relatively quickly. In line with long run pattern, the relationship of CO2 emission appear to be positive and significant in short run as well, it is as expected, implying that increase in carbon pollution increases health expenditures both in short and long run. Likewise, the instrumental variable for renewable energy showed the same negative pattern as in the long run. The RNE_IV variable is significant and have negative sign in the short run as well. The results are in confirmation with the previous studies like Shahzad et al. (2020).

4.4 Diagnostic Tests

To verify the accuracy of the results, diagnostic testing looks for any possible problems in the data or the model. This section contains the results of several statistical tests.

4.4.1 Variance Inflation Factor

Variance inflation factor (VIF) is utilized to test multicollinearity and to decide along with other tests about the appropriate model selection. VIF values above 5 or 10 are generally considered as threshold for determining severity of multicollinearity. Multicollinearity, the presence of high correlation among independent variables, causes serious problems in the estimation and interpretation of the model. When the problem is too severe, the model reports important determinants insignificant due to large variances and the resultant low t-values. Also, there is possibility of wrong signs of coefficient estimates. The same issue occurred in the estimation of the prior models in estimation process, when the variable RNE was not instrumented, the VIF values were too high in some models in hundreds and the model specification tests, coefficients signs and magnitudes and their significance were all distorted. However, model specification was improved by testing different model specifications and using VIF and other tests like Ramsey Reset test, heteroscedasticity and others. Finally the model that contains the instrument of RNE and estimated through 2SLS ARDL qualified all the tests with VIF results indicating a statistically manageable level of multicollinearity.

Table 5: Variance Inflation Test

Variable	Coefficient Variance	Centered VIF
CO2	0.009977	10.00824
RNE_IV	0.903581	4.058167

The VIF results are shown in table 5, the VIF for RNE_IV is less than 5 and well acceptable, in contrast the CO2 variable is on exact threshold of 10. Although value 10 is on border and is indicative of multicollinearity, however despite of multicollinearity problem all other tests of model are clear, the individual coefficient estimates show significance, implying that even with probable large variance (due to multicollinearity) the variables still show significance; reinforcing their importance. Also, the coefficient signs are in conformity with the theoretical understanding of the relationship.

4.4.2 Serial correlation LM test

Table 6 confirms that that the problem of auto correlation does not exist in the defined model.

Table 6: Breusch-Godfrey Serial Correlation Test

F-stat	**0.548946**	**Probability F(2,12)**	**0.5914**
Obs*R-squared.	1.676441	Probability Chi Square	0.4325

4.4.3 Heteroscedasticity Test

The defined model also qualifies the test of heteroscedasticity. The results are reported in table 7.

Table 7: Breusch-Pagan-Godfrey Test

F-stat	**1.095227**	**Probability F(5,14)**	**0.4056**
Obs*R-squared.	5.623429	Probability Chi-square(1)	0.3446

4.4.4 Ramsey's RESET Test

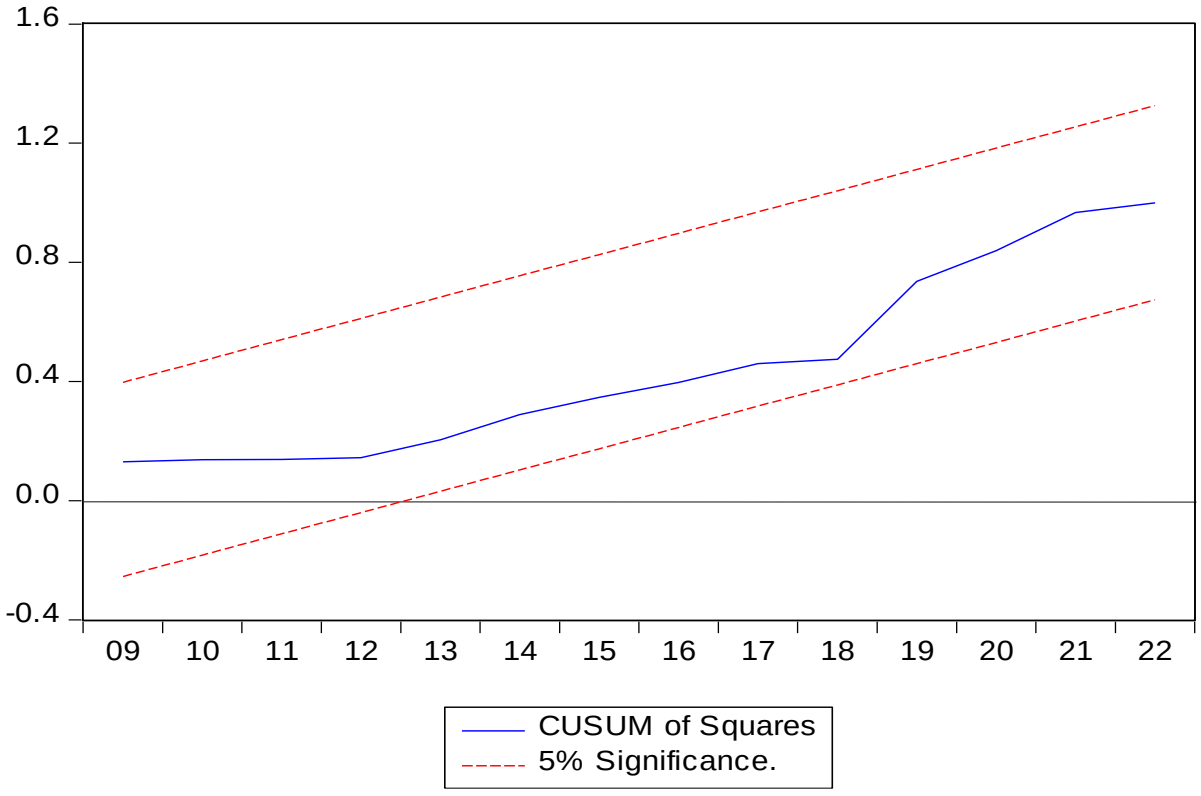
This test is used to find out whether or not the regression's functional form is appropriate. The Ramsey RESET test confirms that there is no functional form bias in the defined model.

Table 8: Ramsey's RESET

	Value	Df	Probability
F-stat	1.860099	(2, 12)	0.1979

4.4.5 CUSUM and CUSUM of Squares

The stability is checked by obtaining the cumulative sum and cumulative sum of squares recursive residual plots. Fig. 1 shows the results. The values of CUSUM and CUSUMSQ fall within the lower and upper critical boundaries and signifies the model's stability (at the significance level of 5%).



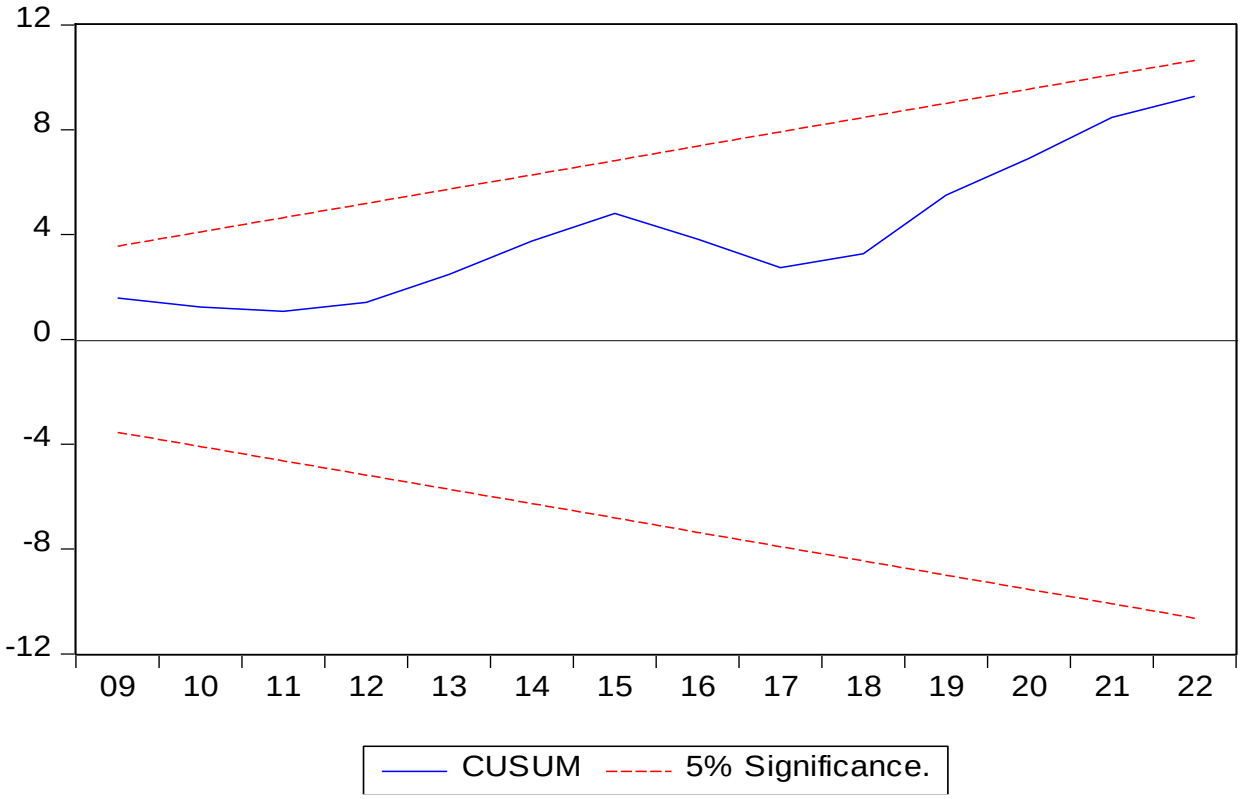


Figure 1: CUSUM & CUSUMSQ

5. Conclusion and Policy Recommendations

5.1 Conclusions

This study examines the possible impacts of sustainable energy use and CO2 outflows on expenses of health in Pakistan. First, the stationarity of the variables are assessed using ADF test. Then the long-run & short-run dynamics among variables are estimated using the 2SLS- ARDL.

The 2SLS-ARDL results confirm the short & long run association between per capita expenditures on healthcare, Carbon pollution, and use of sustainable energy in Pakistan. In the long run the coefficients are found significant. The sign of the carbon emission coefficient implies that increase in carbon pollution increases health spending. While the negative sign of coefficient of clean energy usage signifies its role in reducing health spending.

Whereas, in the short run, both coefficients are found significant carrying positive sign for carbon emission variable and negative sign for instrumental variable of renewable energy. The results show that in the short run both carbon pollution and use of renewable energy are associated with health spending per capita. The positive and significant coefficient of carbon pollution in the short run signifies the immediate impact of carbon pollution on health and health expenditures per capita. While the negative and significant coefficient of renewable energy variable explains that the benefits of use of clean energy in reducing health expenditures per capita are evident in the short-run as well.

5.2 Policy Recommendations

This study suggests the need for integrated policies to address the carbon emissions and adoption of renewable energy in Pakistan. A comprehensive strategy is crucial to address environmental pollution and mitigating negative health outcomes and expenditures. For reduction of carbon emission several measures can be taken. First, all relevant stakeholders including the government, corporations and consumers must share of the responsibility. It is essential to integrate environmental concerns in all development and commercial plans and enforce policies that directly mitigate CO2 emission. Public awareness campaigns can also be useful in promoting healthy life styles and protecting the public from harms of air pollution. Carbon taxes and emission penalties to discourage emission-causing activities are also recommended but with caution of its impact on economic growth. Simultaneously, the renewable energy projects should be incentivized to reduce air pollution and health care expenditures. This can be done by providing tax breaks and introducing subsidies for green technologies and expansion of the sector.

The key limitation of this study is that it does not focus on the effect of specific sources of renewable energy on health spending (e.g. solar, wind, hydro). This may overlook the unique health impacts associated with different renewable energy sources. Furthermore, the analysis does not consider the potential impacts of industrial energy consumption on health expenditures, which could provide valuable insights into the complex interplay between industrial activity, environmental pollution, and healthcare costs. Forthcoming researches could be aimed to find the multiplier effect and overspill effects of specific sources of renewable energy in Pakistan.

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