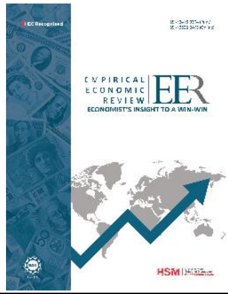
Empirical Economic Review (EER)
Volume7 Issue 1, Spring 2024
ISSN$_{(P)}$: 2415-0304, ISSN$_{(E)}$: 2522-2465
Homepage: https://ojs.umt.edu.pk/index.php/eer



Article QR

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DOI: https://doi.org/10.29145/eer.71.06

History: Received: March 15, 2024, Revised: March 30, 2024, Accepted: June 20, 2024, Published: June 30, 2024

Citation: Atif, R. M., Pervaiz, B., Fatima, M., Manzoor, M. Q., Javed, A., & Gull, R. H. (2024). Impact of financial development, energy consumption, trade openness, and population on CO^2 emissions in Pakistan: Application of STIRPAT model. *Empirical Economic Review*, *7*(1), 139-155 https://doi.org/10.29145/eer.71.06

Conflict of Interest: Author(s) declared no conflict of interest

A publication of
Department of Economics and Statistics, Dr. Hasan Murad School of Management
University of Management and Technology, Lahore, Pakistan

Impact of Financial Development, Energy Consumption, Trade Openness, and Population on CO_2 Emissions in Pakistan: Application of STIRPAT Model

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Abstract

Environmental degradation is one of the contemporary issues faced by people across the globe. Carbon dioxide (CO_2) emissions resulting from increased economic activities have been observed as the major contributor towards current environmental deterioration. Efforts have been made to reduce CO_2 emissions through various mitigations and adaptations at various levels. Financial sector interventions are considered as one of the effective ways to reduce this menace. Therefore, the current study applied modified version of the STIRPAT model to examine the nexus between financial sector expansion and CO_2 emissions in Pakistan using yearly data from 1980-2023. The Augmented Autoregressive Distributed Lag (ARDL) bounds testing corroborated the long-run co-integration with CO_2 emissions when variables of energy consumption, trade openness, Gross Domestic Product (GDP), and population were included as control variables in the analysis. The empirical results showed that the financial sector development, energy consumption, and GDP had a positive and significant association with CO_2 emissions. However, trade openness was observed to be inversely associated with CO_2 emissions in the country. Moreover, the population had a negligible and inverse association by CO_2 emissions. The study concluded that financial sector reforms were instrumental to lower the CO_2 emissions in Pakistan. Therefore, economic policy with embedded environmental approach should be implemented to encourage clean production and diminish CO_2 emissions in the country.

***Keywords*:** Augmented Autoregressive Distributed Lag (ARDL) bounds testing, carbon footprint, clean production, economic policy, environmental degradation

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Introduction

The use of energy has increased with the passage of time due to human activities, such as deforestation, massive industrialization, construction, and increased means of transportation. The energy acquired through fossil fuels discharges a considerable amount of toxic gases in the environment, such as carbon dioxide (CO_2), sulphur hexafluoride, methane, and nitrous oxide (Balat et al., 2014). The temperature in Pakistan has also increased to 0.6 degrees Celsius during the last century (Iqbal & Arif, 2010). The CO_2 emissions significantly contribute towards environmental degradation. Therefore, controlling this menace has always been a matter of great interest for researchers and policymakers. All economic activities involve monetary transactions; hence, the significance of financial institutions cannot be overstated. According to Bloomberg, Pakistan's financial industry is showing signs of supporting economic development (Usman et al., 2022).

An advanced and well-developed financial sector may alleviate the difficulty of information asymmetries. Financial development may improve domestic credit services and lessen the environmental hazards. Furthermore, it may also encourage clean investment and lower the cost of borrowing (Muhammad et al., 2011). Due to financial tools, such as derivatives and loans, the firms' obtaining economies of scale have been promoted because it reduces environmental pollution (Cole & Elliot 2003). Hossain (2012) indicated that excessive energy consumption leads towards more pollution. Higher economic prosperity leads to more use of energy and CO_2 emissions, however, the progress of financial sector and trade openness lowers the environmental pollution (Shahbaz et al. 2013). Nevertheless, once the economy achieves financial stability, it must be able to achieve green advancement. This is because at this point, the country controls CO_2 emissions while experiencing continuous growth.

Pakistan is a developing country and is facing the problem of air pollution due to the increasing rate of CO_2 and nitrogen emissions (Khan & Majeed, 2019). The contribution of Pakistan to global greenhouse gases is 0.8% (Khan et al., 2019). Recently, Pakistan has increased its industrial output by 36.8% in May 2021 (Mettis Global, 2021). This increasing rate of industrial output demands a high rate of energy consumption, and to fulfil this requirement, this high usage of energy releases CO_2 emissions and deteriorates the environmental quality (Koondhar et al., 2021). Financial sector development impacts energy use since it has the potential to fuel economic expansion in emerging nations (Sadorsky, 2014). The main cause of environmental degradation is CO_2 emissions (Zaman et al., 2016) which is an important challenge faced by the economy of Pakistan.

CO_2 emissions have various effects on human health and activities, causing different diseases, such as heart diseases and lung cancer, and also affect the economic growth inversely (Piaggio & Padilla, 2012). In order to lessen these effects, CO_2 emissions need to be reduced. For instance, the effective role of factors must be examined which determine CO_2 emissions. Factors, such as the financial sector development, population, Gross Domestic Product (GDP), and international trade are the main contributors to CO_2 emissions. Financial sector development might be a favourable tool for lowering the energy usage and reducing CO_2 emissions (Grossman & Krueger, 1995).

A few studies in Pakistan have explored the relationship between CO_2 emissions and the development of financial industry. The instant study aimed to examine the linkage between financial sector expansion and CO_2 emissions using an enhanced version of Stochastic Impacts by Regression on Population, Affluence, and Technology (STIRPAT) model. Moreover, the study also focused on how financial development effected the CO_2 emissions both in the long-run and short-run. Additionally, the impact of trade openness, energy consumption, population, and economic growth was also examined on environment degradation in Pakistan.

Research Background

The development of financial sector has been acknowledged as a significant and influencing contributor to CO_2 emissions (Feridun, 2014). For instance, Tamazian and Rao (2010) examined the effect of a country's financial development and institutional quality on the environment. The estimates from GMM indicate that financial development cannot improve environment unless it is accompanied by a strong institutional quality measure. Shahbaz et al. (2013) examined the interrelationship between coal consumption, trade, and financial development for South Africa. The estimates from Augmented Autoregressive Distributed Lag (ARDL) bounds testing approach indicated that a well-developed financial sector reduced CO_2 emissions in South Africa. Omri et al. (2015) analysed environment, financial liberalization, and trade nexus in Middle East and North African (MENA) countries. The estimates from panel ARDL exhibited a bi-directional causality between GDP growth and CO_2 emissions. Nonetheless, no statistically significant relationship was observed between financial liberalization and CO_2 emissions. However, Nasreen and Anwar (2015) examined the impact of CO_2 emissions and financial development both in developed and developing counties. The estimates indicated that financial sector liberalization improved environment and reduced CO_2 emissions. On the other hand, reverse was established in middle income and lower income economies.

The interconnection between globalization, financial liberalization, and CO_2 emissions for Pakistan was studied by Khan et al. (2019). Findings indicated that both Foreign Direct Investment (FDI) and financial development were positively associated with CO_2 emissions. Solarin, Al-Mulali and Ozturk (2017) also observed the same positive association between financial liberalization and CO_2 emissions for Ghana. However, the impact of institutional quality was found negative on CO_2 emissions. Balli et al. (2024) examined the relationship between economic growth, population size, and CO_2 emissions in Asia-Pacific Economic Cooperation (APEC) countries. The results confirmed that both economic growth and population size positively contributed towards CO_2 emissions. However, the magnitude of these interrelationships varied from country to country, indicating that specific factors of some countries e.g. urban population, labour force and technology also contributed towards environmental pollution. On the contrary, Sulaiman and Abdul-Rahim (2018) did not find any long-run causal relationship between population size and CO_2 emissions. Although, the impact was found significant in short-run estimates.

Similarly, Lu (2018) examined the association between CO_2 emissions and the financial sector expansion of 12 Asian economies. The results established that the expansion of financial sector was the major contributor to CO_2 emissions in these economies. Similarly, Paramati et al. (2018) also verified the relationship between CO_2 emissions and stock market in 20 developing markets of 23 advanced economies from the time frame 1992-2011. Their analysis found that CO_2 emissions had an adverse effect on rich countries, whereas a positive effect on developing countries due to their financial policies. Later on, Godil et al. (2020) investigated the relationship between information and communication technologies, financial development, and CO_2 emissions in Pakistan. The estimates from Quantile

ARDL technique indicated that technological development and financial development reduced CO_2 emissions in Pakistan. Aydin and Turan (2020) examined how trade openness and financial development affected CO_2 emissions in BRICS countries. Findings indicated that both trade liberalization and financial development reduced CO_2 emissions in the member countries. Additionally, Wei et al. (2024) used the ARDL estimation technique to scrutinize the period from 1985-2021 and established that financial sector development negatively affected CO_2 emissions in Pakistan. However, the impact of FDI was found positive on CO_2 emissions. These mixed findings regarding the impact of financial development on CO_2 emissions provided a good justification to access this relationship.

Materials and Methods

The STIRPAT model incorporates economic, social, and technical elements to address the environmental concerns. In the current study, '*I*' represents CO_2 emissions, '*P*' represents sociological factors represented by population, and '*A*' represents the economic parameter represented by GDP. The technical parameter '*T*' represents the utilisation of fossil fuel energy. Several empirical researches have been conducted on the link between environment deprivation and various indicators using the STIRPAT model. The econometric form of model is given as following:

$$lnCO_{2\,t} = \beta_o + \beta_1 lnFD_t + \beta_2 lnFFC_t + \beta_3 lnTO_t + \beta_4 lnGDP_t + \beta_5 lnPO_t + u_t$$

where,

CO_2 is carbon emissions, FD is financial development, FFC is fossil fuel energy consumption, TO is trade openness, GDP is gross domestic product, PO is population, ln = log, β_o = constant, $\beta_{1\text{-}5}$ = slopes, t = time, and u_t = error term. Data was collected from World Development Indicators (WDI) published by the World Bank for the period of 1981-2023.

Table 1

Description of Variables

Variables	Description
$lnCO_2$	CO_2 Emissions
$lnFD_t$	Financial Development -monetary sector credit to private sector (% GDP)

Variables	Description
lnFFC	Fossil Fuel Energy Consumption (kg of oil equivalent per capita)
lnTO	Trade Openness (% of GDP)
lnGDP	GDP (Constant 2015 US$))
lnPO	Population

Results and Discussion

Table 2 shows the results of time series properties of the indicators incorporated in the model, that is, mean values of the financial development (FD), fossil fuel energy consumption per capita (FFC), GDP, population (PO), and trade openness (TO). The probability value of Jarque-Bera statistics shows their allocation point at mean zero and stable discrepancy. It can be observed that the values have been normally distributed among all the indicators of interest and have accepted the null hypothesis that the residuals are normal. Jarque-Bera test of probability is greater than 5% for all variables expect the fossil fuel energy consumption per capita. Therefore, the null hypothesis of the normal distribution is acceptable.

Table 2

Descriptive Statistics

Variables	$lnCO_2$	lnFD	lnFFC	lnGDP	lnPO	lnTO
Mean	-	3.09119	5.72666	6.92677	0.92646	3.45999
Median	-	3.16375	5.87636	6.92801	1.05598	3.49246
Maximum	0.09531	3.39404	6.15631	7.31794	1.48684	3.65064
Minimum	-	2.68663	4.68130	6.41694	0.18569	3.20686
Std. Dev.	0.36458	0.20358	0.45387	0.25341	0.33453	0.11702
Skewness	-	-	-	-	-	-
Kurtosis	2.27903	2.22216	2.66972	2.24042	2.36962	2.22672
Jarque-	4.89365	5.03265	7.69117	1.98941	3.07535	2.73168
Probabilit	0.08656	0.08075	0.02137	0.36983	0.21488	0.25516
Sum	-	142.194	263.426	318.631	42.6171	159.159
Sum Sq.	5.98157	1.86517	9.26999	2.88993	5.03606	0.61624
Observati	43	43	43	43	43	43

The current study employed Augmented Dickey and Fuller (1979) (ADF) test to determine the stationarity of variables. Table 3 demonstrates the results of unit root test at level and first difference. The t-values indicated that fossil fuel energy use and population were stationary at level. Whereas, the rest of variables, such as CO_2 emissions, financial development, and GDP were found stationary at first difference. The variables were integrated both at level and first difference which provides a good justification to apply ARDL model in order to gauge short-run and long-run relationship among the variables.

Table 3

ADF Unit Root Test Statistics

Variables	Level	First Difference	Integrated order
$lnCO_2$	-1.05 (0.925)	-5.761 (0.000)	I(1)
lnFD	-2.297 (0.426)	-5.780 (0.000)	I(1)
lnFFC	-4.38 (0.001)	-4.928 (0.000)	I(0)
lnGDP	-2.244 (0.353)	-5.272 (0.000)	I(1)
lnTO	-2.45 (0.132)	-6.799 (0.000)	I(1)
ln PO	-3.792 (0.026)	-3.043 (0.040)	I(0)

Table 4 provides the Bounds test estimate from ARDL model. It exhibits the critical value for lower bounds and upper bounds at 10%, 5%, 2.5%, and 1% significance levels. The F-test value i.e. 11.024 of Bounds testing was much higher as compared to its highest acceptable value of 4.250 at all levels. Therefore, the null hypothesis that there was no co-integration among variables was rejected which confirmed the existence of a co-integration among variables.

Table 4

ARDL Bounds Test and Critical Bound Values

Description	Value	Significance	I(0)	I(1)
F-statistic	11.024	10%	2.75	3.79
k	5	5%	3.12	4.25
		2.5%	3.49	4.67
		1%	3.93	5.23

Table 4 shows the *F*-test value (11.024) of Bounds test which is high as compared to its higher bound value (4.25) at all levels. It shows the subsistence of a co-integration among indicators. Therefore, the null hypothesis of no co-integration association among indicators is discarded.

Table 5

Short-run Results of ARDL Model

Variables	Coefficients	Std. Error	t-Statistic	Prob.
C	-6.013117	0.685381	-8.773391	0.0000
@TREND	-0.006900	0.000832	-8.291432	0.0000
D(lnFD)	0.169016	0.041760	4.047278	0.0004
D(lnFFC)	0.067187	0.088426	0.759804	0.4535
D(lnFFC(-1))	-0.221500	0.100353	-2.207211	0.0354
D(lnPO)	0.039708	0.046386	0.856028	0.3990
D(lnPO(-1))	0.021089	0.052173	0.404214	0.6890
D(lnPO(-2))	0.200669	0.054772	3.663740	0.0010
ECM_{t-1}	-0.805518	0.091471	-8.806232	0.0000
R-sq	0.791610	Mean dep var		0.0260
Adjusted *R*-sq	0.742577	*S.D.* dept var		0.0414
S.E. of reg	0.021019	Akaike info criterion		-4.7029
Sum sq resid	0.015021	Schwarz criterion		-4.334
Log likelihood	110.1144	Hannan-Quinn criter.		-4.5671
F-statistic	16.14448	Durbin-Watson stat		2.46633

Table 5 shows that the result of ECM is inverse and significant which depicts a long-run connection between indicators in Pakistan. The speed correction of short-run deviation from the long-run stability is -0.805% every year in Pakistan. ECM indicates the speed of adjustment to restore stability in the model. The value is inverse and significant at 1%. This means that 80.1% of the short-run distortion is rectified in the first year of achieving equilibrium or CO_2 emissions in Pakistan, based on changes in the financial expansion, energy use, GDP, population, and international trade.

In case of first lag, the linkage between financial progress and CO_2 emissions is positive. Energy use is inversely interrelated to CO_2 emissions in case of second lag. Population is also positively related to CO_2 emissions in case of first, second, and third lags.

Table 6

Estimated Long-run Coefficients using ARDL Approach

Variables	Coefficient.	Std. Error	*t*-Statistic	Prob.
lnFD	0.134493	0.046049	2.920637	0.0067
lnFFC	0.601590	0.053386	11.26860	0.0000

Variables	Coefficient.	Std. Error	*t*-Statistic	Prob.
lnGDP	0.678952	0.190079	3.571938	0.0013
lnPO	-0.099327	0.067606	-1.469201	0.1525
lnTO	-0.333790	0.064148	-5.203400	0.0000

The long-run estimates suggest that the financial sector expansion has a positive and significant impact on Pakistan's CO_2 emissions, and 1% financial expansion results in boosting CO_2 emissions to the tune of 0.13%. Resultantly, financial development is associated with negative environmental repercussions since it increases CO_2 emissions. Credit facilities for increased industrial production are ascribed to good influence of financial development. The financial sector provides loans to customers for the purchase of more commodities, vehicles, and other home equipment, which increases CO_2 emissions. The relaxation of capital lending constraints for consumption and production is attributed to the environment-degrading influence of financial development. Increased financial expansion promotes information regularity as well as extends and strengthens the financial links through improved credit services. The stock market frequently signals the economy's rapid development which considerably enhances the assurance of enterprises and customers as well as drives spending and production activities resulting in enlarged energy consumption and CO_2 emissions. This is consistent with the studies conducted by Zhang (2011) and Majeed and Mazhar (2019).

Findings indicated that the financial industry in Pakistan is not concerned about environment-friendly investment and does not direct investors or set any restrictions on loan utilisation for environment-friendly technology. The probabilities also exist that financial institutions lend more money to the oil industry as compared to any other industry. Additionally, it is also expected that the equipment utilised in financial industry is obsolete and inefficient, contributing to CO_2 emissions in the country. Financial growth also stimulates infrastructure development initiatives, reduces credit limits, and enhances income levels. All these variables may boost energy consumption leading towards CO_2 emissions in Pakistan. Due to the availability of credit, financial expansion stimulates economic action and raises energy consumption.

The availability of low-cost financing encourages the acquisition of durable items, automobiles, and houses, hence increasing the energy usage and ensuing in increased CO_2 emissions (Bui, 2020). Financial sectors give loans without considering how these loans would be used; as a result, they favour activities that reduce costs by transferring the load to the environment, leading towards greater CO_2 emissions (Majeed & Mazhar, 2019). Increased loan availability promotes the expansion of polluting companies and contributes to environmental damage (Hafeez et al., 2019). Furthermore, the financial sector provides liquidity to the country's real economy which contributes to pollution (Solarin, Al-Mulali, Musah, & Ozturk, 2017). Moreover, the operations of an effective financial intermediary create encouragement for enterprises to secure credit facilities in order to purchase vehicles utilised in manufacturing. Additionally, when sufficient funding is made accessible and new machinery is purchased, energy consumption and contamination levels rise. Resultantly, despite attempts being made to enhance Pakistan's financial sector, the nation has not been able to assign credits to initiatives that should cut CO_2 emissions or considerably reduce environmental pollution.

Table 6 also shows that the overall energy usage and CO_2 emissions in Pakistan have a positive and substantial long-run connection. It has been shown that excessive energy usage is closely related to greenhouse gas emissions. The positive and substantial link suggests that increasing the overall energy consumption in the form of fossil fuel or biomass and manufacturing waste would increase CO_2 emissions in the country. Therefore, a 1% raise in CO_2 emissions is attributed to 0.60% increase in energy consumption in Pakistan.

The linkage between CO_2 emissions and GDP is substantial and positive, implying that a 1% increase in GDP raises CO_2 emissions by 0.67%. The conclusion shows that economic activities in emerging countries are harmful to the environment. Economic activities in Pakistan consume more energy and increase CO_2 emissions. GDP is the key determinant of environment deterrence. According to Ang (2007), GDP has a positive effect on CO_2 emissions since CO_2 emissions are caused by economic growth and industrial improvement. This results in conformity with Chen et al. (2016).

Trade has an inverse impact on CO_2 emissions and is statistically significant. This demonstrates that trade openness provides emerging economies with access to modern technology that emits fewer CO_2 emissions. Trade increases the worth of environment through the method effect. Therefore, it means that trade openness allows organizations to import environment favourable technology from developed countries, resulting in lower CO_2 emissions and enhanced environment eminence (Karedla et al., 2021). Furthermore, by importing energy-intensive items that consume less energy and reduce CO_2 emissions, a 0.33% rise in CO_2 emissions may be offset by a 1% increase in trade openness. This fact is supported by rivalry among local producers which drives them to adopt sophisticated technology in order to reduce per unit cost. Resultantly, less energy pollutants are released during production.

The connection between population and CO_2 emissions is similarly inverse, however, it is not significant and implying that increase in economic scale requires greater sanitation and environmental protection facilities, lowering CO_2 emissions (Zhang et al., 2020). As a result, 0.09% increase in CO_2 emissions may be offset by a 1% increase in population.

Table 7

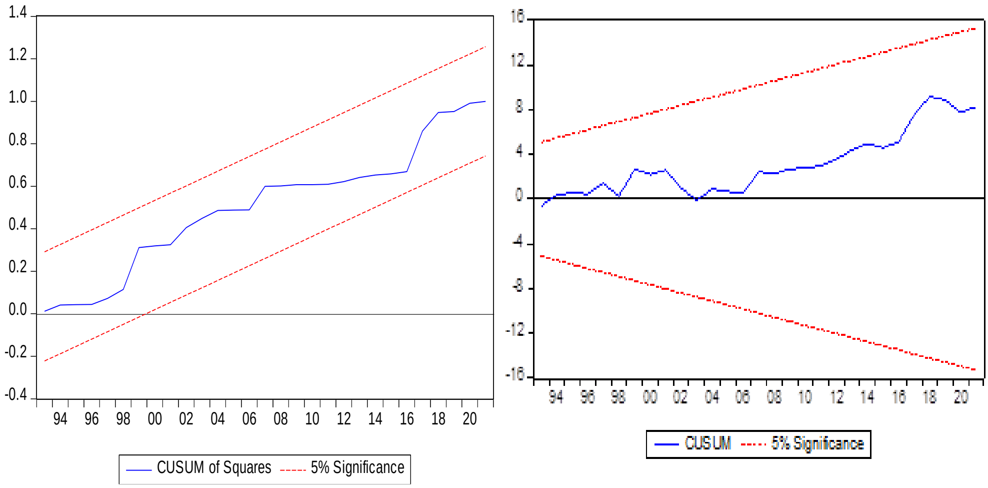
Diagnostic Check-ups

Diagnostic Tests	Problem	*p*	Decision
LM Test	Serial Correlation	0.531	There is no serial correlation
Jarque-Bera	Normality	0.304	Residuals are normally distributed
Breusch-Pagan-Godfrey	Heteroskedasticity	0.881	There is no Heteroskedasticity
Ramsey RESET Test	Specification of the Model	0.353	Model is correctly specified
CUSUM	Stability	-	Yes, the Model is stable
CUSUMSQ	Stability	-	Yes, the Model is stable

Table 7 displays the post-estimation diagnostic check-ups of the estimates. The *p*-value of 0.531 from LM test refers that there is no serial correlation in the model which means that the model does have the issues related to auto-correlation. Similarly, the p-value of 0.304 from Jarque-Bera test indicates that residuals of estimates are normally distributed. The *p*-value of 0.881 from Breusch-Pagan-Godfrey test exhibits that there is no heteroskedasticity in the model and the variance of the errors is constant. The Ramsey RESET test for model specification returns *p*-value of 0.353, suggesting that the model is correctly specified and does not omit any significant variables or include unnecessary ones. Additionally, the stability of the model is confirmed by the CUSUM and CUSUMSQ test which indicate that the model's coefficients remain stable over the sample period. The stability of the model through CUSUM and CUSUMSQ test is graphically presented in Figure 1. The results from these diagnostic tests collectively affirm that the ARDL model is well-specified with reliable residual properties, making it a robust framework to analyse the relationship between exports, regulatory quality, and unemployment in Pakistan.

Figure 1

CUSUM and CUSUMSQ Test



Conclusion

The current study attempted to examine the linkage between financial sector expansion and CO_2 emissions using an enhanced version of STIRPAT model. The ARDL model was applied to calculate the long-run link between CO_2 emissions and explanatory indicators. The findings indicated that,

1. GDP had a positive and substantial association with CO_2 emissions;
2. financial development had a considerable and favorable association with the country's CO_2 emissions;
3. the overall energy consumption in the country had a positive and substantial association with CO_2 emissions;
4. in Pakistan, the population had an inverse and negligible association by CO_2 emissions; and

5. trade had a long-term inverse association with the country's CO_2 emissions.

The results suggest that Pakistani Government should implement an environmental approach that stimulate sectors to expand investment in advanced and clean technologies as well as implement strict laws and restrictions for the reduction of pollution. Therefore, economic policy encouraging clean production is required to diminish CO_2 emissions caused by an increase in GDP per capita.

Conflict of Interest

The authors of the manuscript have no financial or non-financial conflict of interest in the subject matter or materials discussed in this manuscript.

Data Availability Statement

Data associated with this study will be provided by corresponding author upon reasonable request.

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