



RESEARCH PAPER

Catalysts of Change: Assessing the Multifaceted Impact of Technological Innovation on Pakistan's Economic Evolution

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ABSTRACT

This study examines the impact of technological innovation on Pakistan's economic growth and identify the socio-economic factors affecting the adoption of innovative technologies. Technological advancement plays a significant role in enhancing productivity, exports, and overall economic performance. However, developing countries like Pakistan face several social and economic barriers in achieving sustainable technological progress. This study employed a quantitative research approach using statistical techniques to analyze the relationship between innovation and economic growth. Secondary data related to productivity, labor force, health, education, exports, and GDP were examined. The study focused on Pakistan's economic indicators to evaluate the contribution of technological improvements to national development. The findings reveal that productivity, skilled labor, improved health and education systems, and export growth positively influence GDP. Innovation was identified as a major driver of economic and productivity growth in Pakistan. The study recommends increasing investment in research and development, strengthening education and health sectors, and promoting innovation-oriented policies to achieve sustainable economic growth.

Keywords: Labor Force, Health, Education, Exports, Gross Domestic Product

Introduction

The country of Pakistan is located in the region of South Asia, with revolution of new technologies and innovation that changing the growth performance of the economy. In preceding years, the innovative solution of cross sectors and provision of digital technologies increase the performance growth of that country. And that revolution of technologies reveals the best transformation of the different employment sectors that not only increase the growth performance but also increase the ratio of capabilities in research and development centers. The ripple effects of these innovative technologies bring long run and positive effects on different sectors of urban and rural community centers that also increase the performance and growth of the economy and improve the living status of citizens (Bilal et al., 2021; Haq, 2018; Huang et al., 2021; Nizamet a., 2020).

The main goal of this paper is to release different social and economic factors that are responsible for facing many problems in achieving that type of innovative technology. The positive contributions of policymakers and entrepreneurs and governmental and non-governmental sectors are very important to this revolutionary path to explore the interests of different sectors to adopt that technology changes and raise the performance of economic growth (Ortega-Argilés et al., 2011; Shabbir&Yaqoob, 2019; Weqar et al., 2021).

The Economic Growth Center Theory introduces the idea of "endogenous technological change" to explain how economies develop and flourish. Experts and policymakers deem innovation crucial to economic success as it transcends mere

availability of capital, impacting growth across all products and production (Total Factor Productivity, TFP, in general). There are two primary types of innovation: technological and nontechnological. Technological innovation entails the creation of new products and services, whereas nontechnological innovation involves changes in organizational or business strategies. Achieving rapid economic growth necessitates more than just augmenting resources in the production process; it entails finding ways to enhance output without commensurately increasing input. Theoretical discourse increasingly acknowledges that productivity growth stems from economic activity. Nevertheless, economists remain concerned about the explanatory power of traditional neoclassical models in elucidating economic growth (Prescott, 1988; Solow, 1988). What eludes explanation is labeled as a "residual," typically reflecting the impact of technological change on production levels. Therefore, the empirical analysis seeks to identify various indicators of technological change (e.g., R&D activity, productivity, and capital improvement) to discern residual effects (Griliches, 2007; Huelgo and Jaumandreu, 2004; Tsai and Wang, 2004; Wakelin, 2001).

The research underscores the positive impact of innovation on Pakistan's economy and underscores the country's ongoing commitment to innovation. It delves into various new metrics and their correlation with economic growth. Factors such as high-technology exports, research expenditures, productivity, ICT exports, enrollment in education, employment, capital investment, poverty, and unemployment demonstrate a close and consistent relationship with Pakistan's international products. This underscores their significant role in bolstering the economy and enhancing livelihoods. Analyzing data from 1985 to 2016, the study divides indicators into input and output groups and employs statistical methods such as ARDL and GMM. It also uses these adjustments to compute performance or product innovation, demonstrating their positive effects on corporate expansion and innovation. So, in an economy such as Pakistan technology has a substantial economic impact through innovations and advancements in telecommunications, IT, manufacturing, and other industries all have a positive impact on productivity and GDP (Bilal et al., 2021).

Literature Review

Shabir and Yaqoob (2019) examined the productive growth of cotton which has a major role in increasing the production capabilities of the textile industry in India and Pakistan. Further, the scenario of the paper showed that the contribution ratio of Pakistan's cotton growth in the textile industry decreased as compared to the country growth of India. In India, its growth is higher but in Pakistan, its growth gradually slowed not increased. Different factors contribute to the decrease in the growth of cotton production and badly affect the global markets have negative effects on the growth of the economy. However, the adaptation of new technologies improved the performance of cotton in both countries. The sources were collected by time series analysis from the period of 1954 to 2017. The index of Tornquist-Til was used to measure the total production of cotton in each economy of India and Pakistan. The distributed lag model of autoregressive was used to check the performance of both economy contributors. The adaptation of new technologies increases the per hectare growth of cotton in both economies but better results were found in the economy of Pakistan that increased the per hectare area growth of cotton production (Shaukat& Ali, 2024; Ahmad et al., 2021).

Awan and Mushtaq (2020) analyzed the progress of technologies have an important role in different employment sectors that increase the productive growth of the economy. The data was collected from different sources of development indicators of economic surveys and bank of State. The short run analysis was used to estimate the relationship of variables. The variable employment is taken as a main outcome variable and others are taken as an input variable. The results of both variables showed that progress improved with the adaptation of new technologies. The role of government and non-formal sectors are

very important in the adaptation of new technological terminology that increases the lead and growth of the employment sectors (Imran, Hameed, and Haque, 2018; Li et al., 2021; Ali et al., 2022).

Chien et al. (2021) examined the use of new technologies that reduce the burden of air pollution in the environment. The scenario used the time period of 1980 to 2018 with contribution of different quantile techniques of autoregressive model to make good predictions about the future. And in the next step check the performance of environment Kuznets curve in Pakistan. That showed that the good terminologies of technologies that adaptation have negative effects on the pollution of the environment. However, the final estimation of that scenario revealed that air pollution's negative effects on the growth of the economy are only due to the not good performance and lower adaptation of technologies of foreign trade in that region that raise the carbon emission level in the environment. So, the use of clean energy resources lowers the carbon emission level in the air and improved the quality of air (Lee and Wang, 2022; Wenlong et al., 2025).

Abid and colleagues (2022) investigated the different effects of innovation in lower developing countries from the period of 1991 to 2011. However, the relationship found very good in these developing countries between innovation and growth of different employment sectors. The export of good quality products and technologies not only raises the performance of sectors but also increases the awareness of different employment sectors the adaptation of these terminologies improves the growth of the economy. As a result, the research recommends the development of strong regulations targeted at drawing in foreign capital and encouraging investments in the transfer of technology within the host nations (Haq, 2018; Faridi et al., 2022).

Khan and Malik (2022) delved into investigating the influence of technological development on manufacturing exports in Pakistan. Employing PseudoPoisson Maximum Likelihood (PPML) estimation and analysis of absorption patterns, the study focused on Pakistan's manufacturing exports to 65 major trading partners from 2011 to 2018. The research findings indicate that technological advancement in Pakistan and among its import partners has a positive and significant impact on Pakistan's manufacturing exports. Moreover, the study underscores the pivotal role of energy resources in determining export efficiency. Furthermore, this paper contributes to existing literature by exploring new dimensions of the impact of technological innovation on exports, thus filling a research gap in Pakistan. Previous studies have not examined the relationship between innovation and manufacturing exports. Consequently, this study lays the groundwork for future research in this area (Weqar et al., 2021; Ikram et al., 2021).

Khan et al. (2022) present a case study on the impact of science, technology, and innovation (STI) on economic growth and development. Through a survey, responses were collected from 305 researchers, with 94% (288 individuals) expressing belief in the impact of technological development on business and development. Moreover, 85% (260 researchers) supported the notion that technological development yields positive results for economic growth. The study also evaluates Pakistan's STI system, identifying it as weak, and recommends the necessity of a long-term STI policy to bolster this initiative. Consequently, the study concludes with recommendations and insights based on research findings and indicators of the potential of science and technology. These recommendations hold significance for STI policymakers and planners seeking to advance STI fields in Pakistan and other nations (Eli and Hamou, 2022; Huang, Sadiq, and Chien, 2021). In a separate study, Akram & Rasool (2025) investigate the impact of science and technology education on Pakistan's economy. Utilizing data from 1985 to 2018 and employing various methods such as the ADF test, ARDL, and error correction model, the study examines the long-term relationship between GDP (dependent variable) and factors such as productivity, employment, health, education, and fertility (independent variables). To increase the performance of global markets Pakistan needs innovation terminologies that not only raise

the performance of the growth of the economy but also increase the productive capacities of research and development centers.

Awan et al. (2025) focused on different innovative factors and techniques that have a positive role in increasing the performance of different employment sectors and raising the growth of the different economic sectors. The ARDL and GMM were used for data assessment from the period of 1985 to 2016. Two categories were made to assess the output and production performance but this performance showed slow growth progress. The index of the portfolio was used to assess the performance growth of Pakistan the result showed that good productive capabilities are needed to increase the performance growth of innovation in different employment sectors.

Khan et al. (2025) analyzed the positive effects of technical education in different employment sectors of Pakistan. The good long run relationship found between input and output growth variables that revealed that overall positive outcomes of all development sectors increased the performance and growth of domestic products was taken from the data from 1985 to 2018. So, to increase the growth of domestic products and research and development centers different innovative techniques are very important for expansion in growth sectors in upcoming times (Amin et al., 2025; Gul, Khan, & Iqbal, 2022).

Hamid and Wang (2022) analyzed different important factors that increase the chances of trade openness and enhance the growth of different productive sectors. The 5% productive growth faces many hurdles in preceding years. Parts of the economy that are focused on industry and technology are crucial to the nation's economic growth. The World Development Indicators (WDI) annual data from 1972 to 2016 are used in the study, which uses the Cobb-Douglas production function to calculate total productivity. The study reveals that almost all examined factors exhibit statistical significance. Notably, innovation emerges as a crucial determinant in enhancing economic growth and productivity levels in Pakistan. This analysis holds significance in comprehending the economic development trajectory of Pakistan.

Liu, Hu, and Ullah (2025) conducted an in-depth study on the impact and asymmetry of new technologies on environmental quality. Utilizing time series data spanning from 1999 to 2018, the study employed linear and nonlinear ARDL models to assess the symmetric and asymmetric effects of technological development on carbon emissions in Pakistan. In this analysis, carbon emissions, which directly affect the environment, were utilized as variables, while technology usage served as another variable. The findings reveal that patents exert a positive impact on the environment, whereas trademarks demonstrate a negative impact in the short term. However, the long-term impact of patents and trademarks remains uncertain. So, technological efforts to favorable environment possible such as implications for emissions i.e., carbon by reducing pollution of energy consumption and also developing new technology for lower-cost material burn-based carbon alternatives.

Material and Methods

The economy of Pakistan has been chosen by the researcher for the empirical analysis. Time series information from 1990 to 2025 is remembered for this review. The time series data came from a variety of sources, including the Global footprint network, World Development Indicator (WDI), and World Intellectual Property Organization (WIPO). Table 1 provides a summary of the all variables that this study examines.

This study uses the following equation:

$$LEf = \alpha_0 + \alpha_1LPPIE + \alpha_2LTI + \alpha_3LGDP + \alpha_4LTOP + \mu_t$$

Where EF (Ecological footprint) is the outcome variable and PPIE (Partnership between public private investment in energy), TI (technological innovation), GDP, and TOP (openness trade) are all input variables.

Table 1
Description of the Data

All Variable	Definition	Source of Data
EF (Ecological footprint)	It consists of six dimensions such as carbon, land build up, grazing, forest, fishing grounds, and cropland, (all variables are in form of global hectares per capita)	GFN (Global footprint networks)
PPIE (partnership b/w public, Private investment Energy)	Partnership between public private investment in energy (in terms of current USD)	WDI (World Development Indicators)
TI (technological innovation)	total quantity of patent applications submitted by annually	WIPO (World intellectual property organizations)
GDP (Gross domestic products)	Gross domestic products (in form of current USD)	(WDI)
TOP (trade-openness)	openness trade (percent of GDP)	(WDI)

Table 2
Descriptive Statistics

Variables	Mean	Std. dev.	Maxim.	Mini.	Kurt'	Skew'
EF	0.443	0.039	0.533	0.366	2.701	-.208
PPIE	20.468	1.396	22.531	15.718	5.053	-1.282
TI	4.471	1.022	6.054	2.773	1.862	-.098
GDP	25.688	0.742	26.65	24.412	1.589	-.275
TOP	0.203	0.039	.258	0.114	2.271	-.492

Descriptive statistics typically include measures such as mean, median, standard deviation, minimum, maximum, and sometimes skewness and kurtosis. The maximum and minimum values offer insights into the range of the data, while the standard deviation indicates the deviation of the data from the mean. Skewness values indicate the asymmetry of the data distribution, with EF, PPIE, TI, GDP, and TOP negatively skewed. Furthermore, the kurtosis values reflect the peakedness of the data distribution, with PPIE having leptokurtic distributions (values more than 3), whilst the other variables such as EF, TI, GDP and TOP are platykurtic.

Correlation Matrix

A correlation matrix is commonly used to demonstrate the degree and form of connection between two parameters. Its value varies between 0 and 1.

Table 3
Correlation Matrix

Variables	EP	PIIE	TI	GDP	TOP
EF	1.00				
PPIE	0.05*	1.00			
TI	0.86*	-0.133	1.00		
GDP	0.89*	-0.058	0.95	1.00	
TOP	0.45*	-0.06	0.43	0.44	1.00

* p<1%, ** p<5% & ***p<10%

Figure 1 depicts the associations between all variables using a matrix plot. To analyze the relationship between numerous pairs of variables, a matrix plot is used. Figure 1 depicts the lower diagonal of the figure, and it shows that all of the variable's EF, PPIE, TI, GDP, and TOP are positive and linear.

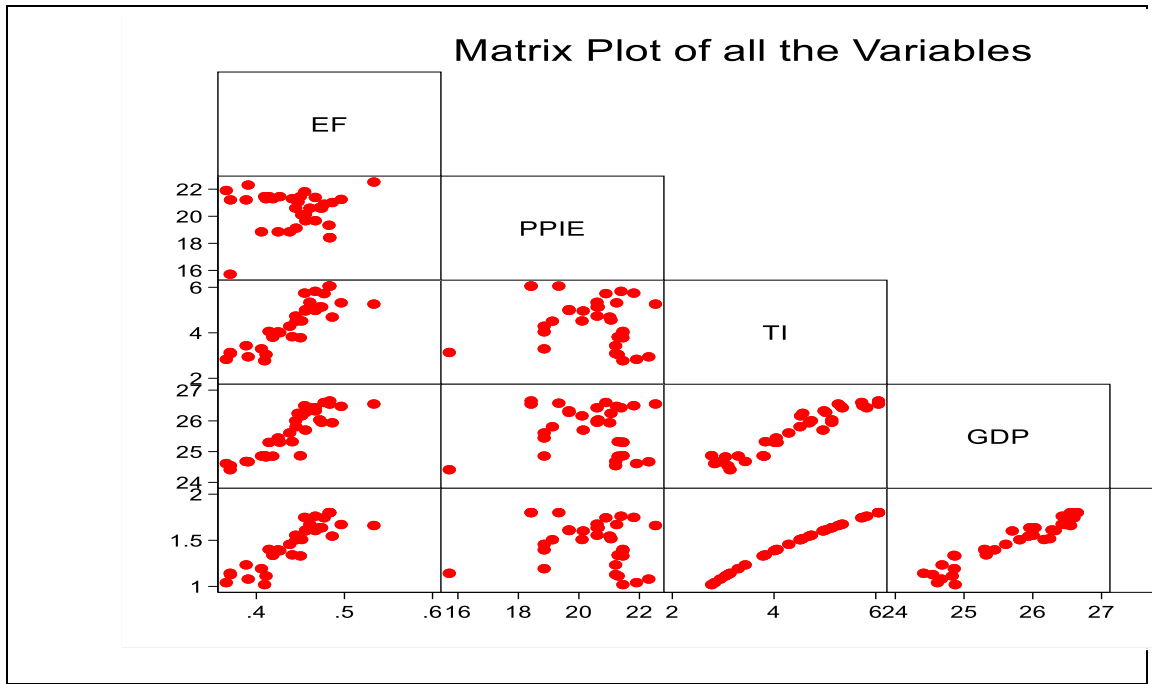


Figure 1: Matrix Figure of all the Variables

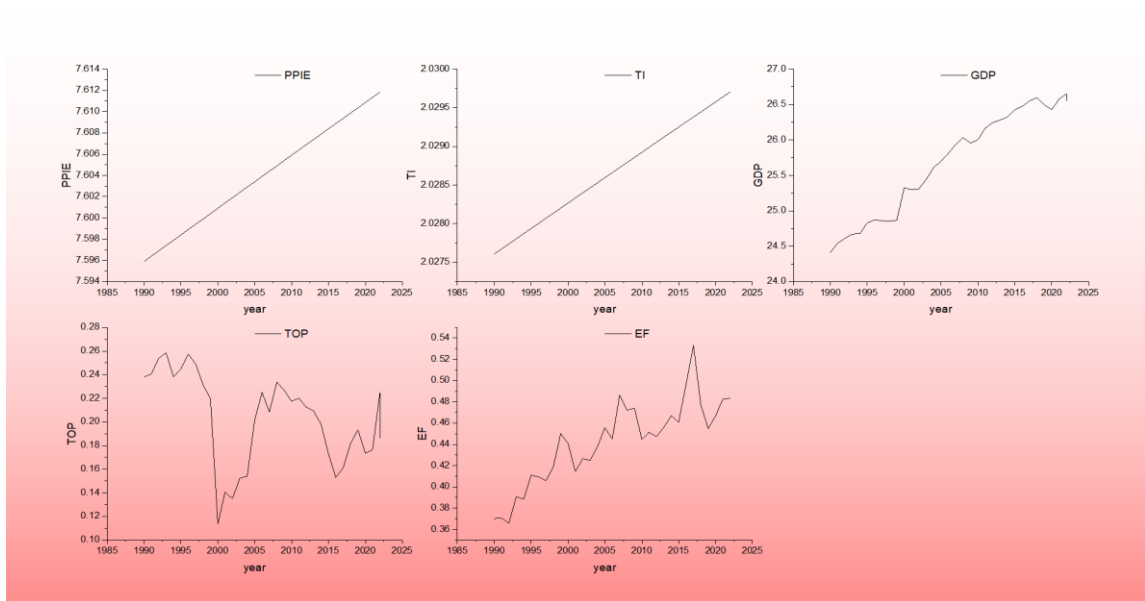


Figure 2: Time Series Figure of all the Variables

The above exhibited figure displays PPIE (Public-private partnership investment in energy), TI (Technological innovation), GDP, TOP (Trade openness) and EF (Ecological footprint) trends over the time 1990 to 2025, for the case of Pakistan.

3D Diagram of all the Variables

This section explains the 3D bars and trajectory (depicts the evolution of a parameter or a variable over time) for all variables employed in model estimation shown in Figure 3. The x-axis and y-axis show all input variables such as PPIE (partnership among public private investment in energy), TI (technological innovation), GDP, and TOP (openness trade) and the z-axis shows the outcome variables that is EF (Ecological footprint). Greater bars indicate superior performance in different input variables and output. The maximum point on the 3D trajectory may suggest the optimal outcome or maximum yield comes from input variables that affect the output.

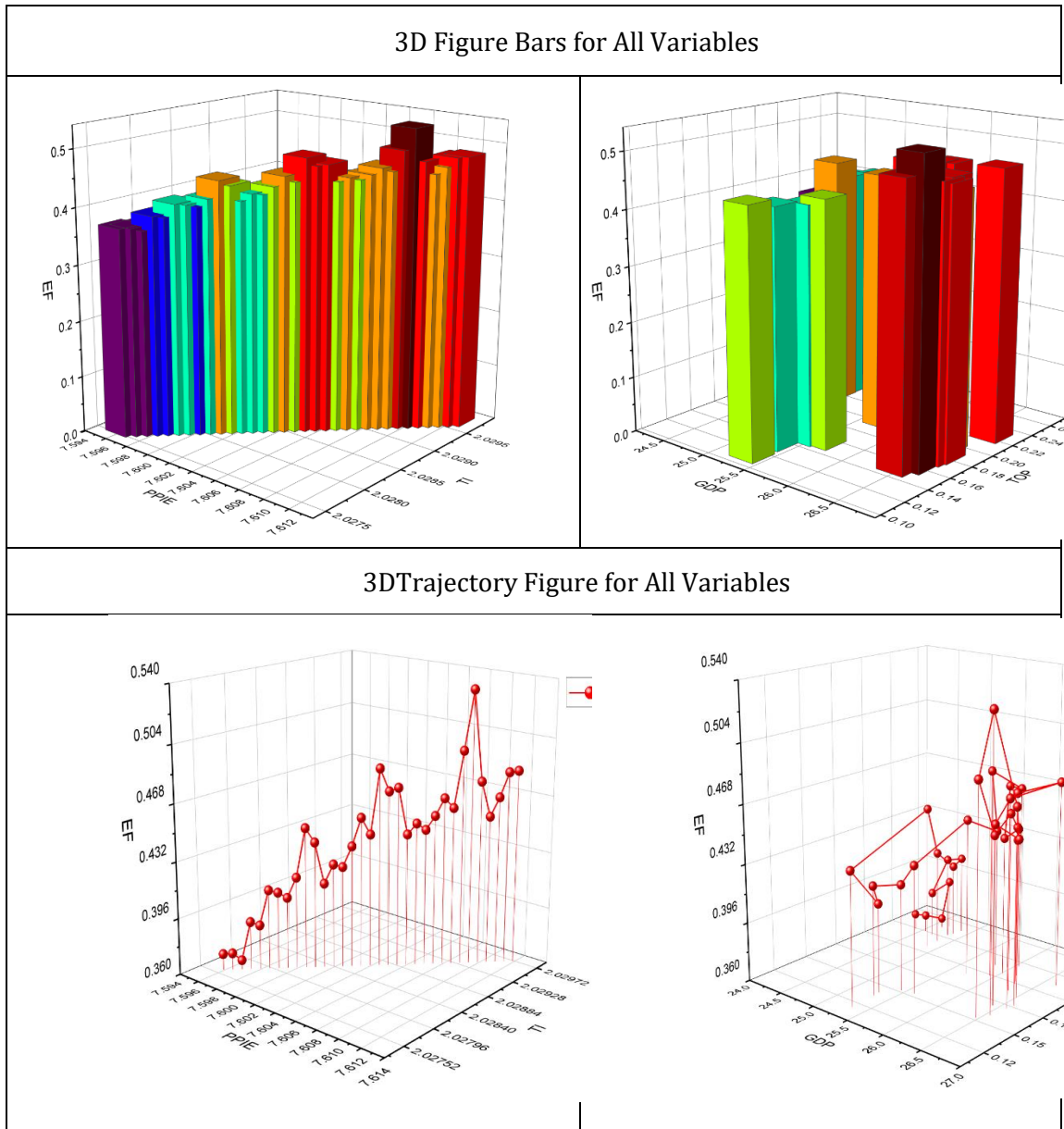


Figure 3: 3D Diagram of all the Variables

Table 3
Results of ARDL Bound Test Approach

Estimated Model	Lag Selection	F-Value	Remarks
EF = f(PPIE, TI, GDP, TOP) Critical value bounds	3,3,2,0,0	4.6441 **	Conclusive
Significance	(I0) bound	(I1) bound	
10(%)	1.5	3.5	
05(%)	2.9	4.0	
2.5(%)	3.3	4.5	
01(%)	3.7	5.1	

Table 3 displays the outcomes of the ARDL bounds test, which indicates that over long time period, all variables are co-integrated. Subsequently, we investigated the long-term and short-term relationships among the ecological footprint, population density, partnerships among public private, innovation in technology, economic growth, and trade openness, after establishing a common relationship between the variables. Using the ARDL approach, we examined the influence of public sector involvement in energy investment, technological advancements, economic growth, and trade openness on the ecological footprint within the context of Pakistan. The findings from the ARDL long-term forecasts are summarized as follows:

Firstly, the results suggest that investment in public-private partnerships (PPP) in the energy sector is advantageous for Pakistan's environmental sustainability. A rise in PPP energy investment, holding other variables constant, is associated with a decrease in environmental degradation by 0.0175%. This outcome is consistent with prior research Lee and Wang (2021) indicating a positive correlation between PPP investment and air pollution in East Asia and the Pacific. The significance of this finding lies in Pakistan's limited investment in energy generation and new technology through public-private partnerships, which detrimentally affects the environment. Notably, Pakistan's energy PPP budget was estimated at \$200 billion from 1990 to 2021, with Energy PPP investment reaching \$6.098 billion in 2017. However, due to conflicts in mid-2017, PPP investments in Pakistan experienced a significant decline. Therefore, the Pakistani government should prioritize investments in public power generation and environmental improvement through technology development and renewable energy projects.

Secondly, we observe that technological development has a notable ecological impact. A 1% increase in technological development corresponds to a 0.1241% rise in the ecological footprint. Technological advancements have led to improvements in Pakistan's air quality. However, this finding contradicts previous studies by Ali et al. (2022) conducted in the middle east and north Africa and economies of BRICS, which suggested that new technologies contribute positively to the environment. Conversely, our results oppose findings from studies by Chien et al. (2021), Griliches (2007) and Khan and Malik (2022), which indicated that technological innovations benefit the environment. According to our findings, Pakistan's rapid development has led to less favorable environmental outcomes. Hence, the Pakistani government should enhance the utilization of green technology to safeguard the environment in the future.

Table 4
Results of ARDL Estimation.

Regressor	Coefficient(Standard Error)			
	Long-term estimate	Short-term estimate		
PPIE	0.01 ** (0.00)	0.00 ** (0.00)		
TI	0.12 *** (0.02)	0.08 *** (0.02)		
GDP	0.58 *** (0.01)	0.10 *** (0.02)		
TOP	0.42 *** (0.02)	0.13 *** (0.03)		
C		-3.02 *** (0.16)		
CointEq(-1)		-0.17 *** (0.03)		
R-Square		0.99		
F-Statistics	DW	Serial Test	ARCH	Ramsey RESET
		(P-Value)		
4340.27 (0.00)	2.06	1.26 (0.28)	0.14 (0.70)	1.34 (0.18)

Table 4 provides a summary of the short-term results and underscores the long-term outcomes. Notably, PPP investment, particularly in the energy sector, exhibits a significant 5% positive impact on the ecological footprint. Technological development demonstrates a positive relationship with the ecological footprint at a significance rate of 1%. Similarly, economic growth and trade openness both display positive associations with the ecological footprint at the 1% rate of significance. Furthermore, the value of the error correction term (CointEq(1)) signifies the adjustment process and is statistically significant at the 1% level. This indicates that any short-term deviations from the long-term equilibrium are rectified by 17.99% annually. A negative sign in this context indicates a long

terms relationship. Likewise, the R-squared value of 0.99 suggests that the independent variables account for 99% of the variance in the ecological footprint. The remaining 1 percent is attributed to time-related errors.

Conclusions

In today's global landscape, environmental security challenges have garnered significant attention from international organizations, governments, and researchers worldwide. However, the long-term ramifications of public-private sector engagement in energy utilization and new technology adoption on Pakistan's ecological trajectory remain largely unexplored. The main goal of this research is to release different social and economic factors that are responsible for facing many problems in achieving that type of innovative technologies. Addressing this research gap, the present study employs Bayer & Hanck integration and ARDL estimation methods. The cointegration test results conducted by Bayer & Hanck reveal that the variables are not all cointegrated, yet exhibit a positive relationship among them. The findings underscore those public investments in energy, new technology, economic growth, and market openness positively contribute to Pakistan's ecological economy in both the long and short term. This aligns with prior research, affirming the significance of these factors in influencing environmental quality in Pakistan. Furthermore, the performance evaluation of the generalized least squares regression and ordinary least squares methods corroborates the outcomes of the autoregressive distributed lag model.

Recommendations

This study underscores the imperative of addressing the environmental implications of public-private investment collaboration, technological advancement, economic growth, and economic openness in Pakistan. It emphasizes that policies can be formulated in alignment with the United Nations Development Sustainable Goals based on these findings.

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