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The Nexus Of AI-Driven Technologies, Green Energy, And Economic Growth: Insights From Pakistan's Sustainability Transition

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Abstract

This study uses the ARDL model to capture both short- and long-term dynamics as it examines the interrelated roles of economic growth, environmental sustainability, AI-driven technology, and renewable energy usage in Pakistan. Trade, foreign direct investment, CO2 emissions, ICT adoption, patent filings, and the usage of renewable energy are among the important variables that are examined by four models. The results show that while investment and savings propel GDP development, unused innovations and environmental issues impede long-term advancement. Although it needs funding and legislative changes, renewable energy has the potential to lower emissions. In order to balance sustainability along with growth in Pakistan, this research offers policymakers insights by highlighting the necessity of implementing AI-based technology, energy investments, and environmentally friendly trade regulations.

Keywords: ARDL, AI Technologies and Economic growth, Sustainable, Development, labor force dynamics

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Introduction

In a world increasingly driven by technological innovation and sustainability, developing countries such as Pakistan face difficult difficulties. Economic development, energy efficiency and environmental responsibility are no longer independent goals but rather interrelated drivers of development.

Since it is directly related to raising the population's standard of living and quality of life, economic growth is a primary goal for the majority of nations (Mata et al., 2020). A nation's economic growth is often gauged by its gross domestic product (GDP), and several research have looked into the main drivers of GDP growth (Oluwafemi & Laseinde, 2019; Kakkad & Ray, 2021; Mata et al., 2020; Nguyen et al., 2020).

Previous study has shown that trade and FDI play a favorable effect in driving economic growth, particularly in South Asia, but issues persist in aligning these elements with environmental goals. Rapid industrialization can lead to increased CO_2 emissions and energy consumption, which can harm the environment while promoting economic prosperity. (Fareed et al, 2022). Another study by Sarfraz at all 2008, suggested a mutual and bi-directional long run relationship among output and saving level. In summary, the results supported the capital fundamentalist's theory that savings can increase the output level in Pakistan's case. Likewise, Dao, 2014 also claimed that technological advancement, gross capital formation, initial output per capita, labor productivity growth (calculated as the growth rate of value added per worker), and human capital formation (calculated as the growth rate of the average number of years of formal schooling among all individuals aged 15 and above) all have a linear relationship with GDP. With the exception of one, all coefficient estimates have the predicted sign, and all of these explanatory variables are statistically significant.

For developing countries like Pakistan, where urbanization and fossil fuels contribute to rising pollution levels, the relationship between economic growth,

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environmental deterioration, and renewable energy is very important. Economic expansion raises living standards and productivity, but it frequently comes at the expense of increased CO2 emissions and air pollution, which have a detrimental effect on ecosystems, public health, and long-term sustainability. Numerous South Asian studies show that economic activity associated with energy consumption and industrialization propels both GDP growth and emissions. According to research published by Yapa et all, in 2023, emerging nations have unsustainable growth patterns and rely largely on energy sources that are high in carbon, which raises CO2 emissions and other airborne pollutants. These emissions have been connected to negative effects on public health and labor productivity in addition to climate change.

In the meanwhile, one possible remedy for sustainable growth is the use of renewable energy (REC). Studies on Pakistan, show that renewable energy boosts GDP, despite obstacles to its uptake including insufficient infrastructure, policy implementation, and budgetary limitations (Ayub et all, 2023, Payne et all., 2010, Sdorsky, 2009). The economic shift to cleaner energy sources is crucial, but in the near term, carbon emissions and air pollution continue to be major obstacles that limit the effectiveness of renewable energy projects.

In today's economies, innovation and technology are key forces behind energy efficiency. The connection between ICT diffusion, patent applications, and energy usage is still complicated in nations like Pakistan, though. According to some research, ICT adoption may initially raise energy demand, but by allocating resources optimally, it may also promote long-term energy efficiency (Murshed et al., 2020). Similar to this, due to limited commercialization and governmental hurdles, technological innovations—represented by patent applications—frequently lag behind in impact.

According to a different study on Pakistan, technology developments are essential, but they are still in their early years which limits their ability to support

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environmentally friendly energy transitions (Khaliq et al., 2024). ICT adoption and technology advancements have not yet resulted in noticeable changes in energy consumption habits in many developing nations, such as Pakistan. In their early stages of deployment, ICT infrastructures increase the demand for electricity even though they can reduce energy consumption through automation and smart systems (Wenlong et al., 2022).

A research from developing Asian markets demonstrates that, although this relationship is not instantaneous, innovation and ICT dissemination have a long-term positive impact on energy efficiency. According to a study by Usman et al. (2021), supporting policies and high-quality institutions are essential for maximizing the advantages of ICT. Without these, nations find it difficult to capitalize on innovation's promise to reduce energy use.

It is becoming more widely acknowledged that switching to renewable energy consumption (REC) is crucial to striking a balance between environmental sustainability and economic prosperity. Significant CO2 emissions and environmental degradation are caused by Pakistan's and other developing countries' heavy reliance on non-renewable energy sources. Current study highlights the need for structural reforms and financial investments in nations transitioning to sustainable energy systems. By facilitating both public and private investments, financial flows like wide money are essential to the success of renewable energy projects, according to IRENA (2024). However, because of the high upfront costs and market constraints, the transition to renewables necessitates significant government-led initiatives.

The results of the relationship between REC and CO2 emissions are not entirely consistent. Higher emissions initially raise energy demand, but as countries switch to renewable energy sources, emissions progressively decrease, according to a study conducted on emerging countries. This implies that in order to stop the cycle of high emissions and energy consumption, investments in green technologies are crucial (Abbas et all, 2023). However, in order to sustain growth and achieve sustainability objectives, labor force dynamics and productivity must also be in line with energy policies. Trends in energy consumption in Pakistan are greatly influenced by total labor force participation, especially in metropolitan areas where there is an increasing need for power. Energy consumption rises with GDP growth, but the lack of proper infrastructure and legislative backing prevents the widespread use of renewable technologies.

Hence, it is impossible to avoid the fact that, economic growth, environmental pollution, energy efficiency and innovation all has to be maintained for a healthy growth. Therefore, the first model investigates how the machinery of economic growth— trade, savings investment, and FDI—drives GDP, posing fundamental concerns about how capital flows and open markets may support long-term growth. The second model emphasizes environmental sustainability, acknowledging that economic growth typically leads to increased CO_2 emissions and pollution. With worldwide focus on renewable energy as a problem's solution, this model analyzes whether Pakistan can transition to cleaner energy sources while maintaining economic momentum.

Meanwhile, the third model delves into the impact of digital transformation and technological innovation, showing a paradox: while ICT adoption and patents have the potential to revolutionize energy efficiency, they now contribute little to meaningful change. Are we still on the verge of unlocking energy-efficient technology, or does the country require more robust R&D ecosystems and digital policies? The fourth model analyzes how financial flows, CO_2 emissions, labor force dynamics, and GDP influence renewable energy usage in Pakistan.

Together, these models not only represent Pakistan's current economic and environmental landscape, but also serve as a foundation for aligning policy with upcoming trends. With the energy revolution underway and innovation still in its

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early stages, this paper provides practical answers to help policymakers strike an ideal equilibrium between growth and sustainability, propelling the country toward a greener, more affluent future.

Research Objectives

- To investigate how investment, trade, and savings affect Pakistan's economic expansion.
- To investigate how renewable energy sources and CO2 emissions contribute to sustainability.
- To determine whether changes in energy use are influenced by technological improvements.
- To determine the main forces behind and obstacles to Pakistan's use of renewable energy and offer policy suggestions.

Literature Review

Economic Growth Model

The effect of regional integration on Pakistan's economic growth has been the subject of numerous studies (Siddiqui, 2017). One study examined how agricultural exports contributed to the nation's economic expansion and discovered that they had a major impact on Pakistan's GDP growth. In 2017, Ahmad and Ahmad, another study examined the relationship between exports and economic growth and found that exports contribute significantly to Pakistan's economic expansion. Ali (2017) The body of research highlights how crucial trade and regional integration are to promoting economic growth. Likewise, Zahid and Iqbal 1988, Falki 2009 determined the impact of FDI and other Macro-economic determinants of economic growth in Pakistan. Chaudhary et all, 2009 also explored the significant effect of economic growth and its determinants in Pakistan. Meanwhile, Kanwal and Mirza, 2017 did a dynamic causality analysis on energy consumption, carbon emission and economic growth in Pakistan. However, Akram 2011, found how public debt is affecting Pakistan's economic growth.

When Rafique et all, 2013 explored the positive impact of FDI on Pakistan's economic growth, Junyang, 2016 studied the energy prices and Economic growth in Pakistan. Similarly, Fatima et all, applied ARDL technique to confirm positive and significant impact of physical capital on economic growth in Pakistan.

On the other hand, some other studies like like Acemoglue 2018 introduced us to the modern economic growth theory when Topel 1999 had analyzed Labor markets and Economic growth theories. Barro performed a cross country empirical study to explore the significance level of economic determinants on economic growth. Hong and Lee in 2010 used a growth accounting framework for finding the determinants of economic growth in Asia when Feldkircher et all, 2014 used Bayesian model averaging to find the determinants in 255 European regions. Barro, 1999 used panel data of around 100 countries to find the determinants and provided a global evidence for Chile. In 2021, Batrancia et all, used panel data approach for 34 countries in Africa for a two-decade period in order to find economic determinants and their significance on Economic growth.

Environmental Sustainability

Deyuan et all, 2019 ARDL bound test approach to find the positive and significant relationship of carbon emission, renewable energy consumption and electric power consumption with GDP in Pakistan. Xu et all 2020 performed a long run investigation using FMOLS and suggested that Pakistan needs to focus on energy shifts and invest in renewable energy consumption. Meanwhile, Baig et all, 2022 used ARDL and VECM to confirm the negative significant impact of all environment pollution related variables. However, khan et all, 2016 implied GMM approach and found positive and significant relation of co2 and energy source have negative impact on agriculture value added. Sharif et all, 2021 applied QARDL approach and found positive and significant relation of GDP and CO2 emission. Mujahid et all, 2024 on the other hand studied the nexus among environment sustainability and sectoral carbon dioxide emission in Pakistan by using STRIRPAT and ARDL. Khan et all, 2019 utilized a simultaneous equation approach and showcased the nexus of trade, renewable energy consumption, co2 emission and health expenditure in Pakistan.

On the other hand, Ahmed et all, 2023 assessed the significant impact of environment by using renewable energy source, air pollution and co2 emission and the results revealed the unidirectional significant relationship where renewable energy tend to decrease air pollution in China. Salahodejaev and Mirziyoyeva, 2023 studied the multidimensional relationship among co2, gdp, renewable energy consumption and climate change in high globalized countries. Jo et all, 2021 focused on how economic growth is effected by renewable energy consumption and air pollution by using dynamic panel approach and according to results renewable energy consumption tend to decrease air pollution.

AI-driven Technology and Infrastructure

James et all 2015 aimed to help policy makers with providing an insight of where Pakistan stands now with a review of policy option by digging deep in the ecosystem approach that can measure the effectiveness so that agenda of innovation can move forward. Naqvi 2011, suggested to strengthen the weak links regarding Pakistani industry, government and academia since it is far behind when it comes to innovation system. Lv et all, 2022 figured out how institutional quality and technological innovation affect energy consumption in Pakistan by using 10 control factors and applying dynamic novel ardl technique. Arif 2018 determined how ICT is helping in development of Pakistan and the results showed a pivotal contribution of ICT as it is a key indicator in economic and social development. Batool et all 2021 examined the impact of technological innovation, industrial growth and infrastructure in Pakistan's economy from 1996 to 2020 by applying ARDL for the purpose of empirical estimation.

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By examining the trends of innovation in the green ICT domains using granted EPO patent data from 1986 to 2006, Ozman et al. (2014) sought to provide insight into the dynamics of innovation in this nascent field. The findings show that fast growth and high levels of technical pervasiveness, as well as the significant entry of new innovators and a wide range of actors—with a preponderance of large ICT enterprises and universities—are characteristics of creative activity in green ICT domains. Yu et all 2022 investigated the relationship between China's energy consumption and ICT development level between 2001 and 2030. The findings showed two tendencies in the shift in energy consumption: first, energy consumption continues to rise despite an increase in ICT development.

Drivers of Green Economy

Amin et all 2023 explored the determinants of renewable energy production for Pakistan from 1980 to 2019 by using ARDL and NARDL and the results showcased that a positive change in CO2, GDP and financial development aids for significant increase in renewable energy production. Alvarado 2023 used AARDL and FDC to determine the association among economic expansion, electricity use, urban transition and power consumption, power prices. Lin and Raza 2022 utilized the LMDI for detecting economic activity, intensity, labor and labor output. Kwilinski et all 2021 explored the linkage among renewable energy consumption and economic advancement in European countries by applying GMM. Khan 2024 showcased a long run relation between GDP, labor force, electricity utilization, exports and real capital from 1980 to 2022 by using the method of cointegration involving bound test in Pakistan (Batool, Hassan, Bashir, Arshad, & Khan, 2025). All of the parameters were observed stable.

Shar et all 2023 performed a VEC and the results showed a causal relationship between green finance, renewable energy consumption and economic growth from 2000 to 2020. Renewable Energy Consumption tend to have negative association with emission however, green finance was found positively correlated with GDP. Syed et all, 2023 used a panel quantile regression model for the BRICS countries by including a time frame of 1990-2020 and suggested that policy makers should consider environmental effect. Ayub et all 2023 provided valuable insights by utilizing an approach of panel ardl technique with the exception of co2, all variables showed a significant association among all variables (Ayaz, Khan, & Shad, 2022).

Data & Methodology

In order to investigate the connections among economic growth, technical innovation, environmental sustainability, and the use of renewable energy, this study uses time-series data for Pakistan from 1990 to 2022. Each model's variables are chosen based on empirical data from earlier research as well as theoretical relevance. The World Development Indicators (WDI) are the main source of data, guaranteeing consistency and dependability (Khan, Arshad, ul Hassan, Batool, & Usman, 2024).

Variables	**Measurements**	**Data Source**	**Symbol**
Dependent Variable			
Gross Domestic product	(current US$)	World Development Indicator	GDP
Gross Domestic Product	(current US$)	World Development Indicator	GDP
Energy Use	(kg of oil equivalent per capita)	World Development Indicator	EU
Renewable Energy Consumption	(% of total final energy consumption)	World Development Indicator	REC

Independent Variable			
Foreign Direct Investment	Net Inflows(current US$)	World Development Indicator	FDI
Gross Capital formation	% of GDP	World Development Indicator	GCF
Gross Domestic Saving	(Current US$)	World Development Indicator	GDS
Trade	% of GDP	World Development Indicator	TRADE
CO2 Emission	(kt)	World Development Indicator	CO2
Air Pollution	(micrograms per cubic meter)	World Development Indicator	AIR POLLUTION
Renewable Energy Consumption	(% of total final energy consumption)	World Development Indicator	REC
Patent Application	Residents	World Development Indicator	PATENT APPLICATION
ICT	(% of total goods exports)	World Development Indicator	ICT as proxy of AI

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Electric Power Consumption	(kWh per capita)	World Development Indicator	ELECTRIC POWER CONSUMTPION
Broad money	% of GDP	World Development Indicator	BM
Total labor force		World Development Indicator	TLF
Gross Domestic Product	(Current US$)	World Development Indicator	GDP

GDP = f (GDS, FDI, TRADE, GCF)………. (i)

GDP= f (CO2, AIR POLLUTION, REC)…… (ii)

EU= f (PA, EPC, ICT)……. (iii)

REC= f (CO2, TLF, BM, GDP)….. (iv)

Econometric Model

$$GDP_t = \xi_0 + \xi_{01} FDI_t + \xi_{02} GCF_t + \xi_{03} TRADE_t + \xi_{04} GDS_t + \mu_t \ldots\ldots \text{(i)}$$

$$GDP_t = \xi_0 + \xi_{01} CO2_t + \xi_{02} AP_t + \xi_{03} REC_t + \mu_t \ldots\ldots \text{(ii)}$$

$$EU_t = \xi_0 + \xi_{01} PA_t + \xi_{02} EPC_t + \xi_{03} ICT_t + \mu_t \ldots\ldots \text{(iii)}$$

$$REC_t = \xi_0 + \xi_{01} GDP_t + \xi_{02} BM_t + \xi_{03} TLF_t + \mu_t \ldots\ldots \text{(iv)}$$

In the first equation, GDP denotes Gross Domestic Product, FDI represents foreign domestic services and GDS is the Gross domestic savings. Meanwhile, in the second equation, CO2 represents the CO2 emission and AP as the air pollution while REC represents the renewable energy consumption. Similarly, in the third equation EU represents the Energy use, PA is Patent application, EPC stands for

Electric power consumption and ICT as the information computer technology. Lastly, the in fourth model, BM is the Broad money and TLF is the Total labor force. ICT or Patent application are used as proxies of AI-driven technologies (Khan, Usman, ul Hassan, Student, & Tariq, 2024).

As the Autoregressive Distributed Lag (ARDL) model can handle both I(0) and I(1) variables, it is used in this study to examine both short- and long-term correlations among variables. While the Akaike Information Criterion (AIC) establishes the ideal lag duration, the ADF and PP tests guarantee stationarity. If cointegration is detected by the boundaries test, the Error Correction Model (ECM) accounts for short-term dynamics and adjustment speed (via CointEq(-1)).

The dependability of results is ensured by a number of diagnostic tests, such as the heteroscedasticity test (variance stability), Ramsey RESET (model specification), Jarque-Bera test (normality), and Breusch-Godfrey LM test (autocorrelation). The approach offers solid insights into the technological, economic, and environmental factors influencing Pakistan's development and sustainability, directing sensible policy suggestions.

Unit Root table

Models	Variables	ADF Test Level	ADF 1st Diff.	PP Test level	PP Test 1st Diff
Economic Growth Model	GDP	0.6103	0.0002	0.6103	0.0002
	GDS	0.4206	0.0000	0.1209	0.0009
	FDI	0.3176	0.0041	0.2834	0.0014
	TRADE	0.4379	0.0000	0.4317	0.0000
	GCF	0.6402	0.0002	0.6402	0.0002
Environmental Sustainability Model	CO2 Emission	0.1984	0.0007	0.1984	0.0006
	Air pollution	0.4987	0.0004	0.0113	0.0000
	Renewable	0.5340	0.0001	0.5340	0.0001

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	Energy Consumption				
AI driven-Technology and Infrastructure	Patent application	0.0044	0.0000	0.0521	0.0000
	Energy use	0.1575	0.0061	0.1689	0.0016
	Electric Power Consumption	0.5363	0.0006	0.5428	0.0006
	ICT	0.2601	0.0031	0.3841	0.0048
Drivers of renewable energy consumption	Total labor force	0.5624	0.0029	0.6187	0.0005
	Renewable energy Consumption	0.5340	0.0001	0.5340	0.0001
	Broad Money	0.3018	0.0004	0.2722	0.0003
	CO2 emission	0.1984	0.0007	0.1984	0.0006

In time series analysis, the stationarity of variables is evaluated using the Phillips-Perron (PP) and Augmented Dickey-Fuller (ADF) tests. After first differencing, the majority of variables that were previously non-stationary at levels became stationary. P-values greater than 0.05 in the ADF and PP tests showed that several variables in the Economic Growth Model, including GDP, gross domestic savings (GDS), foreign direct investment (FDI), trade, and gross capital formation (GCF), were non-stationary at levels. However, with p-values less than 0.05, they became stagnant at first difference.

Variables like CO2 emissions, air pollution, and the use of renewable energy showed comparable patterns for the Environmental Sustainability Model.

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Indicating the existence of underlying trends in environmental data, these variables also displayed non-stationarity at levels before becoming stationary at first difference. Patent applications, energy use, and electric power consumption were found to be non-stationary at levels in the Innovation, Technology, and Infrastructure Model. However, after differencing, they remained still.

For the Environmental Sustainability Model, variables such as CO2 emissions, air pollution, and the utilization of renewable energy displayed similar trends. Additionally, these variables showed non-stationarity at levels before becoming stationary at first difference, suggesting the presence of underlying patterns in environmental data. At the Innovation, Technology, and Infrastructure Model levels, patent applications, energy use, and electric power consumption were found to be non-stationary. But they didn't move after differencing.

To sum up, the ADF and PP tests show that most variables are I(1), which supports the application of ARDL modeling.

Bound Test

Model	Dependent Variable	F-statistics	Critical value (1%)	Critical value (5%)	Critical value (10%)
1	GDP	7.4933	4.37	3.049	3.09
2	GDP	5.2096	4.66	3.67	3.2
3	Energy Use	3.9184	4.66	3.67	3.2
4	Renewable Energy Consumption	4.2560	4.37	3.49	3.09

There are four independent variables in Model 1 (F = 7.4933) having a high cointegration connection with GDP, as evidenced by the F-statistic above the 1%, 5%, and 10% critical levels. Cointegration is likewise evident in Model 2 (F = 5.2096), however its critical values are marginally larger because there are three

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independent variables as opposed to four in Model 1.

The F-statistic, on the other hand, is within the 10% range but below the crucial threshold at the 1% and 5% levels in Model 3 (F = 3.9184), which has four independent variables. This implies that there is some, albeit weak, evidence of cointegration. Cointegration is demonstrated by Model 4 (F = 4.2560), which also has four independent variables and passes the 5% and 10% standards.

Short Run Table

Models	**Dependent Variable**	**Independent Variable**	**Coefficients**	**S.E**	**T-Ratio**	**P-value**
1. Economic Growth Model	GDP	GDS	0.0948	0.0582	1.6275	0.1201
		GCF	0.5720	0.0674	8.4762	0.000
		TRADE	-0.0458	0.1019	-0.4499	0.6578
		FDI	-0.0302	0.0178	-1.6995	0.1055
		CointEq(-1)	-0.3253	0.0431	-7.5630	0.0000
2. Environmental Sustainability	GDP	CO2	1.8136	0.5310	3.4154	0.002
		Air pollution	-0.4143	0.4296	-0.9644	0.3453
		REC	2.993	1.1734	2.550	0.018

					7	2
		CointEq(-1)	-0.2770	0.0499	-5.5483	0.0000
3. AI-driven Technology and Infrastructure	Energy Use	Patent Application	-0.0185	0.0071	-2.5981	0.0158
		ICT	0.0723	0.0365	1.9793	0.059
		Electric Power Consumption	0.2875	0.0730	3.9370	0.0006
		CointEq(-1)	-0.1252	0.0303	-4.1260	0.0004
4. Drivers of Renewable Energy Consumption	Renewable Energy Consumption	CO_2 Emission	-0.4238	0.0571	-7.4183	0.0000
		Broad Money	-0.0090	0.0249	-0.3611	0.7212
		Total Labor Force	0.3318	0.19234	1.7254	0.0973
		GDP	0.0325	0.0189	1.7221	0.0979
		CointEq(-	-0.5299	0.1310	-	0.000

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	1)	4.044 2	5

Interpretation

Although GDS's coefficient is positive (0.0948), it is not statistically significant ($p = 0.1201$).GDP is positively impacted by GCF in a highly substantial way (coefficient = 0.5720, $p = 0.000$). This suggests that physical capital investments play a major role in economic expansion. Trade has a significant ($p = 0.0657$) but negative coefficient (-0.0458), indicating that trade openness has a short-term, meaningful effect on GDP.

Additionally, FDI has a marginally negligible negative influence ($p = 0.1055$, coefficient = -0.0302). This implies that FDI inflows might not immediately result in economic growth, either as a result of insufficient integration or structural impediments. Coefficient = -0.3253, $p = 0.0000$, indicates that the error correction term (CointEq(-1)) is negative and extremely significant. This demonstrates the existence of a long-term equilibrium connection and the correction of roughly 32.5% of equilibrium deviations per cycle.

GDP is positively and significantly impacted by CO_2 emissions (coefficient = 1.8136, $p = 0.002$). This implies that carbon-intensive activities, such as the use of fossil fuels, which promote short-term growth but may present sustainability issues in the future, are a major contributor to Pakistan's economic growth. The impact of air pollution is negative but substantial ($p = 0.0453$, coefficient = -0.4143). The positive and substantial effect of renewable energy consumption (REC) (coefficient = 2.993, $p = 0.0182$) suggests that investments in renewable energy have a favorable impact on economic growth. A long-term equilibrium relationship is confirmed by the significant and negative error correction term (CointEq(-1)) (coefficient = -0.2770, $p = 0.0000$). According to the coefficient, each period's divergence from long-run equilibrium is corrected by 27.7%, indicating a steady process of adjustment toward sustainability over time.

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Energy use is significantly and negatively impacted by patent applications (coefficient = -0.0185, p = 0.0158). Given that new technologies frequently enhance existing ones, this implies that technical advancements could result in increased energy efficiency. Information and communication technology (ICT) has a marginally significant but beneficial influence (p = 0.059), with a coefficient of 0.0723. This may indicate that the first adoption of ICT leads to an increase in energy consumption, perhaps as a result of increased electrical demand from infrastructure, devices, and data centers. Electric power consumption has a favorable and statistically significant effect (p = 0.0006, coefficient = 0.2875).But over time, ICT can also promote energy efficiency.

Electric power consumption has a substantial and favorable effect (p = 0.0006, coefficient = 0.2875). The significant and negative error correction term (CointEq(-1)) has a coefficient of -0.1252 and a p-value of 0.0004. This confirms the existence of a long-run equilibrium relationship and suggests that 12.5% of the disequilibrium in energy use is corrected each period, indicating a gradual adjustment process toward long-term stability

Higher emissions are linked to decreased consumption of renewable energy, as evidenced by the negative and highly significant impact of CO_2 emissions (coefficient = -0.4238, p = 0.0000). The influence of broad money is negative but negligible (coefficient = -0.0090, p = 0.7212). This could indicate that institutional obstacles or a lack of policy emphasis are preventing the effective allocation of existing financial resources toward investments in renewable energy.The total labor force exhibits a positive and marginally significant influence (coefficient = 0.3318, p = 0.0973), indicating that the use of renewable energy may rise in tandem with the work force's growth. Additionally, GDP has a marginally significant beneficial impact (p = 0.0979, coefficient = 0.0325).A long-term

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equilibrium relationship is confirmed by the significant and negative error correction term (CointEq(-1)) (coefficient = -0.5299, p = 0.0005).

Long Run Table

Models	**Dependent Variable**	**Independent Variable**	**Coefficients**	**S.E**	**T-Ratio**	**P-value**
1. Economic growth Model	GDP	GDS	0.7787	0.2638	2.9519	0.0082
		GCF	0.7406	0.1528	4.8448	0.0001
		TRADE	0.4399	0.2957	1.4874	0.1533
		FDI	-0.038	0.0619	-0.6160	0.5452
		C	-1.5350	0.6598	-2.3265	0.0312
2. Environmental Sustainability	GDP	CO2	6.5471	3.3799	1.9370	0.0065
		Air pollution	-2.1797	3.4243	-0.6365	0.0531
		REC	16.5738	11.329	1.4629	0.157
		C	-46.2202	30.5847	-1.5112	0.1450
3. AI-driven	Energy Use	Patent	-0.1478	0.1690	-	0.090

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Technology and Infrastructure		Application			0.8749	3
		ICT	-0.0706	0.2677	-0.2640	0.0940
		Electric Power Consumption	1.0970	0.9849	1.1137	0.2764
		C	0.0865	2.2090	0.0391	0.0969
4. Drivers of Renewable Energy Consumption	Renewable Energy Consumption	CO2 Emission	-0.4457	0.0758	-5.8757	0.0000
		Broad Money	-0.0170	0.0475	-0.3578	0.0723
		Total Labor Force	0.1017	0.1064	0.9553	0.3489
		GDP	0.0614	0.0420	1.4629	0.1564
		C	2.5074	0.3982	6.2967	0.0000

The coefficients in the Economic Growth Model show the relationship between GDP and each independent variable. With p-values less than 0.05, GDS (Gross Domestic Savings) and GCF (Gross Capital Formation) have positive and statistically significant effects on GDP. This implies that economic growth is a direct result of increased savings and investments. Conversely, trade (p = 0.1533) and foreign direct investment (FDI, p = 0.5452) are statistically insignificant, suggesting that their influence on GDP is insufficient in the context of this model. Pakistan's trade policies or FDI flows might not be well-aligned with growth-enhancing sectors.

CO_2 emissions (p = 0.0065) in this model had a significantly positive effect on GDP, suggesting that economic activity that generates emissions may support short-term growth, maybe as a result of Pakistan's reliance on energy-intensive industries. Air pollution, on the other hand, has a detrimental but barely noticeable impact (p = 0.0531). This implies that although pollution has a negative economic impact, this effect may not be completely realized or may take longer to show up as productivity or health expenses.

Despite being statistically insignificant, the renewable energy consumption (REC) coefficient is positive (p = 0.157). This might be a reflection of Pakistan's nascent renewable energy shift, where the full benefits have not yet been experienced. Last but not least, the constant (C) is negative and negligible (p = 0.145), suggesting that the system may have underlying structural issues or inefficiencies. ICT (p = 0.0940) and patent applications (p = 0.0903) both have negative coefficients and are marginally significant, indicating that both factors gradually lower energy use. This may suggest that while ICT and technology advancements are starting to help with energy efficiency, their influence is still quite small. Despite having a positive coefficient (1.0970), electric power consumption is still statistically negligible (p = 0.2764).Additionally, the constant (C) has a marginal significance level of 0.0969.

The use of renewable energy is significantly impacted negatively by CO2 emissions (p = 0.0000). This implies that lesser utilization of renewable energy is linked to higher emissions, which may signal that Pakistan is still largely dependent on fossil fuels for energy production. Despite being barely significant,

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broad money has a negative coefficient (p = 0.0723). This may indicate insufficient investment in green technologies and inefficient use of financial resources for the development of renewable energy. The GDP and the total labor force show positive but negligible coefficients (p = 0.1564 and 0.3489, respectively).The GDP and the total labor force show positive but negligible coefficients (p = 0.1564 and 0.3489, respectively). The insignificant labor and GDP effects would suggest that the use of renewable energy is still in early stages and that other industries are propelling economic expansion.

Diagnostic Test

Models	GDP	GDP	Energy Use	Renewable Energy Consumption
R square	0.9986	0.9932	0.9564	0.9860
Adj. R square	0.9979	0.9908	0.9455	0.9819
Durbin Watson	3.0487	2.2376	1.7674	1.9285
LM test	2.1456(1.3740)	0.4280(0.2834)	0.2252(0.1042)	0.6821(0.5401)
Jarque-Bera	4.8531(0.0880)	6.4753(0.039)	12.1035(0.0020)	4.1369(0.1263)
Hetero	0.4089(0.3570)	0.5230(0.7625)	0.7419(0.6860)	0.378(0.3350)
Ramsey Reset	0.9950(0.9950)	0.3070(0.3070)	0.3478(0.918)	0.0158(0.7940)

The models' high R-squared and modified R-squared values demonstrate their significant explanatory power. With the exception of minor reservations regarding the normality of residuals in the Energy Use model, no significant problems with autocorrelation, heteroscedasticity, or serial correlation were found.

All things considered, these diagnostics show that the models are accurate and

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well-defined, however the Energy Use and Renewable Energy models might need a few small tweaks.

Conclusion & Policy suggestion

This study shows that, although impacted by distinct factors, Pakistan's economic growth, environmental sustainability, innovation, and adoption of renewable energy are all interconnected. The findings emphasize the role that trade, investment, and savings play in boosting GDP growth; nonetheless, environmental issues like CO2 emissions and air pollution stand out as major obstacles to sustainable development. Furthermore, there is a need for greater policy focus in these areas because technology breakthroughs, such as ICT and patent applications, have not yet made a significant contribution to energy efficiency. Although using renewable energy has the potential to lower emissions, infrastructure and financial limitations limit its effectiveness.

Pakistan must put certain policy measures into place in order to achieve sustained growth. First, the shift to green energy will be accelerated by encouraging investments in renewable energy by financial incentives and public-private partnerships. Long-term energy efficiency will be driven by bolstering innovation ecosystems through promotion of patent commercialization, R&D, and ICT usage. Environmental regulations must also concentrate on cutting emissions through the imposition of carbon prices and the development of sustainable energy infrastructure. Lastly, in order to improve economic performance and make sure that FDI inflows and trade openness are in line with environmental objectives, the government should give priority to these initiatives. Pakistan will be able to manage technical advancement, environmental preservation, and economic growth with this all-encompassing strategy, setting it up for long-term sustainable growth.

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Online ISSN: 3006-466X

References

Iqbal, Z., & Zahid, G. M. (1998). Macroeconomic determinants of economic growth in Pakistan. *The Pakistan Development Review*, 125-148.

Falki, N. (2009). Impact of foreign direct investment on economic growth in Pakistan. *International Review of Business Research Papers*, *5*(5), 110-120.

Shahbaz, M., Ahmad, K., & Chaudhary, A. R. (2008). Economic growth and its determinants in Pakistan. *The Pakistan Development Review*, 471-486.

Mirza, F. M., & Kanwal, A. (2017). Energy consumption, carbon emissions and economic growth in Pakistan: Dynamic causality analysis. *Renewable and Sustainable Energy Reviews*, *72*, 1233-1240.

Akram, N. (2011). Impact of Public Debt on the economic growth of Pakistan. *The Pakistan Development Review*, 599-615.

Saqib, N., Masnoon, M., & Rafique, N. (2013). Impact of foreign direct investment on economic growth of Pakistan. *Advances in Management & Applied Economics*, *3*(1), 35-45.

Arshad, A., Zakaria, M., & Junyang, X. (2016). Energy prices and economic growth in Pakistan: A macro-econometric analysis. *Renewable and Sustainable Energy Reviews*, *55*, 25-33.

Afzal, M., Malik, M. E., Begum, I., Sarwar, K., & Fatima, H. (2012). Relationship among education, poverty and economic growth in Pakistan: An econometric analysis. *Journal of Elementary Education*, *22*(1), 23-45.

Acemoglu, D. (2008). *Introduction to modern economic growth*. Princeton university press.

Topel, R. (1999). Labor markets and economic growth. *Handbook of labor economics*, *3*, 2943-2984.

Barro, R. J. (1996). Determinants of economic growth: A cross-country empirical study.

Journal of Social Signs Review
Print ISSN: 3006-4651
Online ISSN: 3006-466X

Lee, J. W., & Hong, K. (2010). Economic growth in Asia: determinants and prospects. *Asian Development Bank Economics Working Paper Series*, (220).

Cuaresma, J. C., Doppelhofer, G., & Feldkircher, M. (2014). The determinants of economic growth in European regions. *Regional Studies*, *48*(1), 44-67.

Barro, R. J. (1999). Determinants of economic growth: implications of the global evidence for Chile. *Cuadernos de economía*, 443-478.

Batrancea, L., Rathnaswamy, M. M., & Batrancea, I. (2021). A panel data analysis of economic growth determinants in 34 African countries. *Journal of Risk and Financial Management*, *14*(6), 260.

Siddiqui, K. S. (2017). Defying the activity–stability trade-off in enzymes: taking advantage of entropy to enhance activity and thermostability. *Critical reviews in biotechnology*, *37*(3), 309-322.

Siddiqui, A., & Rehman, A. U. (2017). The human capital and economic growth nexus: in East and South Asia. *Applied Economics*, *49*(28), 2697-2710.

Ahmad, D., Afzal, M., & Khan, U. G. (2017). Impact of exports on economic growth empirical evidence of Pakistan. *International Journal of Applied*, *5*(2), 9.

Ahmad, S., & Malik, A. H. (2017). China-Pakistan economic corridor: impact on regional stability of South Asia. *International Journal of Political Science and Development*, *5*(6), 192-202.

Abid, N., Wu, J., Ahmad, F., Draz, M. U., Chandio, A. A., & Xu, H. (2020). Incorporating environmental pollution and human development in the energy-growth nexus: a novel long run investigation for Pakistan. *International Journal of Environmental Research and Public Health*, *17*(14), 5154.

Rehman, A., Rauf, A., Ahmad, M., Chandio, A. A., & Deyuan, Z. (2019). The effect of carbon dioxide emission and the consumption of electrical energy, fossil fuel energy, and renewable energy, on economic performance: evidence from Pakistan. *Environmental Science and Pollution Research*, *26*, 21760-21773.

Mohsin, M., Naseem, S., Sarfraz, M., Zia-UR-Rehman, M., & Baig, S. A. (2022). Does energy use and economic growth allow for environmental sustainability? An empirical analysis of Pakistan. *Environmental Science and Pollution Research*, *29*(35), 52873-52884.

Qureshi, M. I., Awan, U., Arshad, Z., Rasli, A. M., Zaman, K., & Khan, F. (2016). Dynamic linkages among energy consumption, air pollution, greenhouse gas emissions and agricultural production in Pakistan: sustainable agriculture key to policy success. *Natural Hazards*, *84*, 367-381.

Chien, F., Ajaz, T., Andlib, Z., Chau, K. Y., Ahmad, P., & Sharif, A. (2021). The role of technology innovation, renewable energy and globalization in reducing environmental degradation in Pakistan: a step towards sustainable environment. *Renewable Energy*, *177*, 308-317.

Ali, S. R., & Mujahid, N. (2024). Sectoral carbon dioxide emissions and environmental sustainability in Pakistan. *Environmental and Sustainability Indicators*, *23*, 100448.

Ullah, I., Rehman, A., Khan, F. U., Shah, M. H., & Khan, F. (2020). Nexus between trade, CO2 emissions, renewable energy, and health expenditure in Pakistan. *The International journal of health planning and management*, *35*(4), 818-831.

Chen, X. H., Tee, K., Elnahass, M., & Ahmed, R. (2023). Assessing the environmental impacts of renewable energy sources: A case study on air pollution and carbon emissions in China. *Journal of environmental management*, *345*, 118525.

Mirziyoyeva, Z., & Salahodjaev, R. (2023). Renewable energy, GDP and CO2 emissions in high-globalized countries. *Frontiers in Energy Research*, *11*, 1123269.

Xie, J. Y., Suh, D. H., & Joo, S. K. (2021). A dynamic analysis of air pollution: implications of economic growth and renewable energy consumption. *International journal of environmental research and public health*, *18*(18), 9906.

Speakman, J., Afzal, K., Yuge, Y., & Hanna, J. (2012). Toward an innovation policy for Pakistan.

Naqvi, I. B. (2011). National innovation system in a least developing country: the case of Pakistan. *International Journal of Technology, Policy and Management*, *11*(2), 139-154.

Zheng, L., Abbasi, K. R., Salem, S., Irfan, M., Alvarado, R., & Lv, K. (2022). How technological innovation and institutional quality affect sectoral energy consumption in Pakistan? Fresh policy insights from novel econometric approach. *Technological Forecasting and Social Change*, *183*, 121900.

Arif, M. (2018). ICTs and development in Pakistan: A review. *Journal of Innovations and Sustainability*, *4*(3), 7-25.

Ali, H., Shaukat, P., Aisha, Z., & Batool, S. (2022). Accessing the Impact of Infrastructure on Industrial Development and Technological Innovations; Evidence from Pakistan. *The journal of contemporary issues in business and government*, *28*(3), 524-536.

Jahangir, M. N., & Shah, A. A. (2016). Tracing ICT innovation ecosystem of pakistan. *Bahria University Journal of Information & Communication Technologies (BUJICT)*, *9*(2).

Cecere, G., Corrocher, N., Gossart, C., & Ozman, M. (2014). Technological pervasiveness and variety of innovators in Green ICT: A patent-based analysis. *Research Policy*, *43*(10), 1827-1839.

Wang, P., Zhong, P., Yu, M., Pu, Y., Zhang, S., & Yu, P. (2022). Trends in energy consumption under the multi-stage development of ICT: Evidence in China from 2001 to 2030. *Energy Reports*, *8*, 8981-8995.

Iqbal, S., Wang, Y., Ali, S., Haider, M. A., & Amin, N. (2023). Shifting to a green economy: Asymmetric macroeconomic determinants of renewable energy production in Pakistan. *Renewable Energy*, *202*, 234-241.

Xu, D., Abbasi, K. R., Hussain, K., Albaker, A., Almulhim, A. I., & Alvarado, R. (2023). Analyzing the factors contribute to achieving sustainable development goals in Pakistan: A novel policy framework. *Energy Strategy Reviews*, *45*, 101050.

Raza, M. Y., & Lin, B. (2022). Energy efficiency and factor productivity in Pakistan: Policy perspectives. *Energy*, *247*, 123461.

Polcyn, J., Us, Y., Lyulyov, O., Pimonenko, T., & Kwilinski, A. (2021). Factors influencing the renewable energy consumption in selected European countries. *Energies*, *15*(1), 108.

Khan, W. A. (2024). Effect of Energy Utilization on Pakistan's Economic Development: A Time Series Analysis. *iRASD Journal of Energy & Environment*, *5*(1), 37-61.

Bughio, A., Teng, Y., Tunio, R. A., Das, G., Jamali, R., & Shar, R. U. (2023). The short-and long-run causal correlation between green finance, renewable energy consumption, and economic growth. *Energy & Environment*, 0958305X231187036.

Durani, F., Bhowmik, R., Sharif, A., Anwar, A., & Syed, Q. R. (2023). Role of economic uncertainty, financial development, natural resources, technology, and renewable energy in the environmental Phillips curve framework. *Journal of Cleaner Production*, *420*, 138334.

Nagra, S. U., Batool, S., Bashir, I., & Ayub, M. (2024). Exploring the Dynamics of Trade in Developing Countries: A Panel ARDL Analysis of Renewable Electricity, Labor Force, and Economic Factors. *Bulletin of Business and Economics (BBE)*, *13*(2), 418-423.

https://doi.org/10.5709/ce.1897-9254.400

I.J. Oluwafemi and O. T. Laseinde 2019 *J. Phys.: Conf. Ser.* **1378** 042073

Kakkad, A., & Ray, A. K. (2023). Global dynamics of GDP and trade. *International Journal of Modern Physics C*, *34*(02), 2350020.

Tran Thai Ha, N., M. Johari, S., Thi Huyen Thuong, T., Thi Minh Phuong, N., & Hong Anh, L. T. (2020). THE IMPACT OF INNOVATION ON ECONOMIC GROWTH: THE SPILLOVER EFFECT OF FOREIGN DIRECT INVESTMENT. *Humanities & Social Sciences Reviews*, *8*(2), 708–714. https://doi.org/10.18510/hssr.2020.8279

Zeeshan M, Han J, Rehman A, Ullah I, Afridi FEA and Fareed Z (2022) Comparative Analysis of Trade Liberalization, CO_2 Emissions, Energy Consumption and Economic Growth in Southeast Asian and Latin American Regions: A Structural Equation Modeling Approach. *Front. Environ. Sci.* 10:854590. doi: 10.3389/fenvs.2022.854590

Sajid, G. M., & Sarfraz, M. (2008). Savings and economic growth in Pakistan: An issue of causality. *Pakistan Economic and Social Review*, 17-36.

Shaikh, F. M. (2010, August). Causality relationship between foreign direct investment, trade and economic growth in Pakistan. In *International Conference on Applied Economics ICOAE* (Vol. 2010, pp. 717-722).

Nasim, I., Bashir, F. ., Munir, F. ., & Kiran, I. . (2023). Foreign Direct Investment, Industrial Value Added, Trade Liberalization and Environmental Degradation in South Asian Countries. *Pakistan Journal of Humanities and Social Sciences*, *11*(1), 646–654. https://doi.org/10.52131/pjhss.2023.1101.0381

Dao, M. Q. (2014). Drivers of economic growth in developing countries. *Studies in Economics and Econometrics*, *38*(1), 75-85.

Dissanayake H, Perera N, Abeykoon S, Samson D, Jayathilaka R, Jayasinghe M, et al. (2023) Nexus between carbon emissions, energy consumption, and economic growth: Evidence from global economies. PLoS ONE 18(6): e0287579. https://doi.org/10.1371/journal.pone.0287579 https://link.springer.com/article/10.1007/s11356-023-19078-0

Sadorsky, P. (2009). Renewable energy consumption and income in emerging economies. *Energy policy*, *37*(10), 4021-4028.

Apergis, N., & Payne, J. E. (2010). Renewable energy consumption and growth in Eurasia. *Energy economics*, *32*(6), 1392-1397.

Murshed, M. (2020). An empirical analysis of the non-linear impacts of ICT-trade openness on renewable energy transition, energy efficiency, clean cooking fuel access and environmental sustainability in South Asia. *Environmental Science and Pollution Research*, *27*(29), 36254-36281.

The International Journal of Sustainable Development and World Ecology, Volume 31, Number 3, 2 April 2024, pp. 279-297(19)

Wenlong, Z., Tien, N. H., Sibghatullah, A., Asih, D., Soelton, M., & Ramli, Y. (2023). Impact of energy efficiency, technology innovation, institutional quality, and trade openness on greenhouse gas emissions in ten Asian economies. *Environmental science and pollution research*, *30*(15), 43024-43039.

Mehmood, U. (2021). Renewable-nonrenewable energy: institutional quality and environment nexus in South Asian countries. *Environmental Science and Pollution Research*, *28*(21), 26529-26536.

https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2016/IRENA_Measuring-the-Economics_2016.pdf

Karimi, M. S., Ahmad, S., Karamelikli, H., Dinç, D. T., Khan, Y. A., Sabzehei, M. T., & Abbas, S. Z. (2021). Dynamic linkages between renewable energy, carbon emissions and economic growth through nonlinear ARDL approach: Evidence from Iran. *Plos one*, *16*(7), e0253464.

Ayaz, B., Khan, Y., & Shad, F. (2022). Investigating the Spillover Effects of the US Interest Rate on CO2 Emissions. A Case of a Developing Country. *Abasyn University Journal of Social Sciences, 15*(2).

Batool, S., Hassan, J. U., Bashir, F., Arshad, M. W., & Khan, Y. (2025). Impact of Green Energy on Commodity Producing Sector in Developing Countries. *Dialogue Social Science Review (DSSR), 3*(1), 1049-1068.

Khan, Y., Arshad, M. W., ul Hassan, J., Batool, S., & Usman, M. (2024). The Influence of Various Corporate Governance Dimensions on Financial Performance Indicators: An Empirical Study of Cement Companies Listed on the Pakistan Stock Exchange. *Dialogue Social Science Review (DSSR), 2*(5), 233-254.

Khan, Y., Usman, M., ul Hassan, J., Student, I. B., & Tariq, M. (2024). Understanding the Influence of ESG Pillars on Financial Returns and Firm Value: The sequel of Theory and Empirical evidence. *Dialogue Social Science Review (DSSR), 2*(4), 107-130.