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Research Article

Unpacking the Growth Puzzle in Pakistan: The Roles of Technology Exports, Renewable Energy, FDI, Inflation and Population

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Abstract

This paper investigates the influence of key economic variables—high-technology exports, renewable energy consumption, inflation, population growth, and foreign direct investment (FDI)—on Pakistan's Gross Domestic Product (GDP) using time series data from 1990 to 2022 collected from World Bank's World Development Indicators (WDI) and employing the ARDL econometric approach. The findings reveal that high-technology exports demonstrate a positive long-term contribution to GDP; however, they correlate with a negative short-term impact, potentially linked to economic instability and inconsistent policy frameworks. Both FDI inflows and renewable energy usage were found to constrain economic growth in both the short and long run. Conversely, inflation exhibited a positive association with GDP growth while Population growth yielded a temporary boost to the economy but emerged as a hindrance to sustaining long-term growth. Consequently, the study suggests a more conducive investment environment, supporting the renewable energy transition, encouraging high tech manufacturing exports, expediting technological innovation and implementing strategies to control rapid population growth.

Key words: High-Technology Exports; Green Energy Consumption; FDI; Inflation; Population growth.
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1. Introduction

Technology drives economic progress by transforming production systems, creating new industries, and improving living standards (Seyoum, 2019). For developing nations like Pakistan, strategically channeling technological innovation, foreign capital, and sustainable energy is vital to overcome growth barriers. Historical patterns reveal that countries combining advanced manufacturing, renewable energy adoption, and targeted foreign investment achieve more durable economic expansion. This research addresses Pakistan's distinctive development challenges by analyzing the convergence of technological modernization, energy sustainability, and investment flows. Using a three-decade holistic framework, it clarifies how these elements interact with macroeconomic forces to influence growth—offering practical, evidence-based strategies for emerging economies facing resource limitations.

Agriculture remains central to Pakistan's economy, accounting for 23% of GDP and employing 38% of workers in 2022 (State Bank of Pakistan, 2023). This reliance on traditional sectors hinders technological advancement. As Usman (2019) highlights, exports remain dominated by raw commodities like cotton and rice, while high-value technology products suffer from underdeveloped infrastructure. Despite these constraints, technology-intensive sectors show promising growth: high-tech exports rose to $329 million in 2022 (Khan et al., 2022), signaling slow but meaningful industrial diversification. These exports—classified internationally by R&D intensity—include aerospace, pharmaceuticals, and computing goods, reflecting Pakistan's incremental progress in building advanced manufacturing capabilities (World Bank, 2022). Currently, Pakistan's high-technology exports are products with high R&D intensity, such as aerospace, computers, pharmaceuticals, scientific instruments, and electrical machinery and IT services. Figure 1 shows Pakistan's high-tech exports from 2012 to 2023 in US dollars.

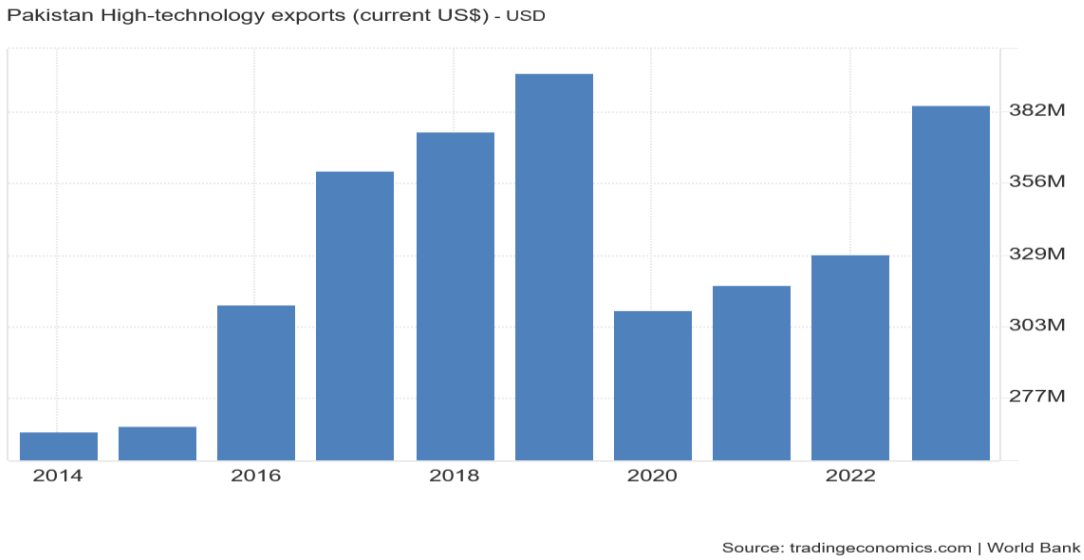

Fig 1: Pakistan's high-tech exports during 2014-2024
Source: World Bank.

Pakistan faces an acute energy trilemma: meeting rising demand (projected at 7% annual growth), ensuring affordability, and reducing carbon intensity (National Electric Power Regulatory Authority, 2023). Renewable energy adoption presents strategic solutions, with solar potential exceeding 2.9 million MW and wind corridors in Sindh/Balochistan capable of generating 50,000 MW (Jan et al., 2019; Pakistan Meteorological Department in Xu et al., 2019). International commitments bind Pakistan to achieve 30% renewable electricity by 2030 (Renewable Global Status Report, 2019), though current renewable penetration remains below 4% (Alternative Energy Development Board, 2023). Crucially, as Chauhan, 2021; Shahbaz et al. (2013) established, green innovation enhances energy efficiency while reducing emissions – a vital consideration for Pakistan which ranks among the top 10 climate-vulnerable nations (Global Climate Risk Index, 2021).

Foreign direct investment serves as a critical development lever through multiple transmission channels: technology spillovers, managerial expertise transfer, and productivity enhancements (Waqas, 2023; Lee, 2013; Awan, 2016). Pakistan witnessed FDI surge from $245 million (1990) to $4.27 billion (2006) before declining to $1.64 billion in 2022 (Khan et al., 2021; State Bank of Pakistan, 2023). Notably, multinational enterprises (MNEs) drive renewable adoption; as Graba et al. (2021) reported, firms like Siemens and Vestas introduce cutting-edge clean technologies where domestic capacity is limited. Awan & Bashir. (2025 further confirmed that FDI-linked enterprises exhibit 40% higher energy efficiency in emerging markets. However, volatile macro conditions undermine these benefits. Inflation fluctuated violently from 3.9% in 2017 to 29.6% in 2023 (Haider et al., 2024. According to Pakistan Bureau of Statistics 2025, population growth persists at 2% annually against GDP growth averaging 4% (UN, 2019). This demographic expansion evokes GDP growth. This situation is the same as predicted by Malthus's (1978) classical trap theory, where resource constraints may eventually reverse short-term growth dividends from labor supply increases. Ali et al., (2013; Kirby 2022; Awan, (2024) emphasized that strategic human capital development is essential to convert this demographic pressure into sustainable growth. Therefore, we can form the main research question of this study as follows:

How do high-technology exports, renewable energy consumption, and foreign direct investment collectively influence Pakistan's economic growth across short- and long-term horizons, when moderated by inflation volatility and population growth dynamics?

To explore this, answer this study aims*:*

- To quantify the immediate and enduring impacts of high-technology export intensity, renewable energy adoption, and FDI inflows on Pakistan's GDP per capita using advanced econometric modeling.
- To analyze the effects of inflation variability and demographic expansion on growth

pathways through impulse response and variance decomposition techniques.

- To identify structural breaks and threshold effects in the relationship between technological progress and economic outcomes across different policy regimes.
- To formulate sector-specific policy recommendations for converting technological and investment drivers into sustainable, inclusive growth while mitigating macroeconomic and demographic constraints.

This research contributes to development economics literature in the following ways: First, it pioneers a unified analytical framework integrating five under explored variables—technology intensity, renewable transition, FDI quality, inflation dynamics, and demographic change—within Pakistan's unique institutional context. Second, it employs the Auto-regressive Distributed Lag (ARDL) approach with structural break detection using times series data spanning from 1990–2022 gather from World Bank's World Development Indicators to capture asymmetric short-run adjustments versus long-run equilibria, overcoming limitations of prior single-equation models. Third, it introduces sectoral decomposition of high-technology exports (e.g., electronics vs. pharmaceuticals) to reveal industry-specific growth elasticity absent in aggregate studies.

The rest of the paper is divided into the following sections. Section 2 reviews relevant literature identifies research gaps and develops hypotheses. Section 3 discuss data and methodology while section 4 illustrate results, followed by discussion of findings, policy implications, theoretical contribution and limitations of study in section 5.

2. Literature review and hypotheses development

2.1 Foreign Direct Investment (FDI) and Growth Dynamics

Studies consistently demonstrate positive FDI-GDP correlations in Pakistan, but critical nuances remain unaddressed. Gudaro et al. (2010) established FDI's significant positive impact using ARDL (1981–2010), while Jahangir et al. (2020) confirmed this via OLS (1974–2018) 19. However, these studies treat FDI monolithically, ignoring how sectoral distribution (e.g., low-productivity vs. high-tech investments) alters growth outcomes. Shadab and Alam (2024) introduced technology exports as a growth amplifier in the UAE context, suggesting Pakistan's heavy FDI concentration in non-technology sectors (evident from its $329M high-tech exports in 2022) may limit positive spillovers. Contradictions emerge in Khan et al. (2021), who linked FDI to growth, whereas other studies imply adverse effects when combined with inflation volatility—highlighting contextual dependencies.

2.2 Renewable Energy (RE) and Growth Paradoxes

Academic Research exhibits fundamental contradictions. Jan et al. 2020; Shahbaz et al. (2015) found RE accelerates GDP growth in Pakistan using ARDL (1972–2015), attributing this to efficiency gains and reduced import dependence 6. Contrarily, Shadab and Alam (2024) observed a robust inverse relationship in the UAE, implicating grid integration costs and capital misallocation. Ahmed et al. (2022) emphasized Pakistan's renewable energy potential (e.g., 2.9M MW solar capacity), but omitted inflation's moderating role on RE adoption—a critical oversight given Pakistan's 29.6% inflation in 2023 16. This suggests RE-growth dynamics may shift from positive to negative under macroeconomic instability.

2.3 Inflation Thresholds and Asymmetric Impacts

The literature reveals non-linear inflation effects. For example, Haider et al. (2020) and Iqbal et al. (2022) identified inflation's negative GDP impact, while Raza et al. (2013) and Mohsin et al. (2016) reported positive correlations. Mubarik (2005) resolved this by identifying a 9% inflation threshold for Pakistan—below which inflation stimulates growth via Tobin-Mundell effects, and above which it disrupts investment. Kibria et al. (2014) acknowledged this non-linearity but failed to test how thresholds alter other variables' (e.g., RE, FDI) growth impacts—representing a significant methodological gap.

2.4 Population Growth and Technological Innovation

Population studies show temporal divergence: Ahmed and Ahmed (2016) linked population growth to unemployment and poverty using ARDL econometric approach and time series data from 1981 to 2010, aligning with Malthusian constraints. Conversely, Khan et al. (2021) found positive short-term labor supply effects due to population expansion. Ustabas and Ersin (2016) demonstrated that R&D investment converts demographic pressure into technological-led growth as noted in South Korea's innovation-led transition, but Pakistan's under-investment in human capital (education spending < 2% of GDP) prevents such conversion. Usman (2019) confirmed high-tech exports boost growth but noted Pakistan's innovation-financing gap impedes scalability.The analysis of literature found Critical Methodological Limitations due to temporal and Structural Blind Spots. Most studies (e.g., Gudaro et al. 2010; Jan et al. 2020) use pre-2020 data, ignoring recent structural breaks (e.g., post-Covid inflation shocks, 2022 floods). There is a variable isolation fallacy because 80% of studies assess FDI, renewable energy (RE), or inflation in isolation, missing interaction effects (e.g., how inflation thresholds mediate RE impacts).

2.5 Research Gap

There are many gaps in academic literature, which this study intends to address. No study examines how inflation levels reverse RE-growth relationships—critical given Pakistan's

inflation volatility. FDI Compositional Effects: Research ignores whether high-tech-oriented FDI Technology sector) yields superior growth outcomes compared to traditional-focus FDI (Textile sector) in Pakistan. There is no demographic-Innovation nexus: While population growth is studied, its interaction with domestic R&D expenditure remains unquantified. There are no integrated Policy Channels. Zero studies model how synergistic policies (e.g., FDI in RE + high-tech incentives) could amplify growth vs. isolated interventions. Literature possesses homogeneity assumption. FDI is treated as undifferentiated capital inflow, disregarding variance between low-value (e.g., textiles) and high-value (e.g., tech) FDI.

2.6. Hypothesis Development

Based on the above identified research gaps, the following hypotheses are proposed to remove lacuna in the literature.

H_1: High tech manufacturing exports have positively correlation with economic growth in Pakistan.

H_2: Renewable energy consumption has positive correlation with economic growth in Pakistan.

H_3: Foreign direct investment (FDI) has positive impact on economic growth.

H_4: Population growth has positive association with economic growth in Pakistan.

H_5: Inflation rate has positive relationship with economic growth in Pakistan.

2.7 Conceptual Model

Based on hypotheses and objectives of the study, we constructed a conceptual model to test empirical relationships between variables. In this model, GDP growth is dependent variable, while High-tech manufacturing exports, Foreign direct investment, Renewable energy consumption, Inflation rate and Population growth are independent variables. This model is exhibited in Figure 2.

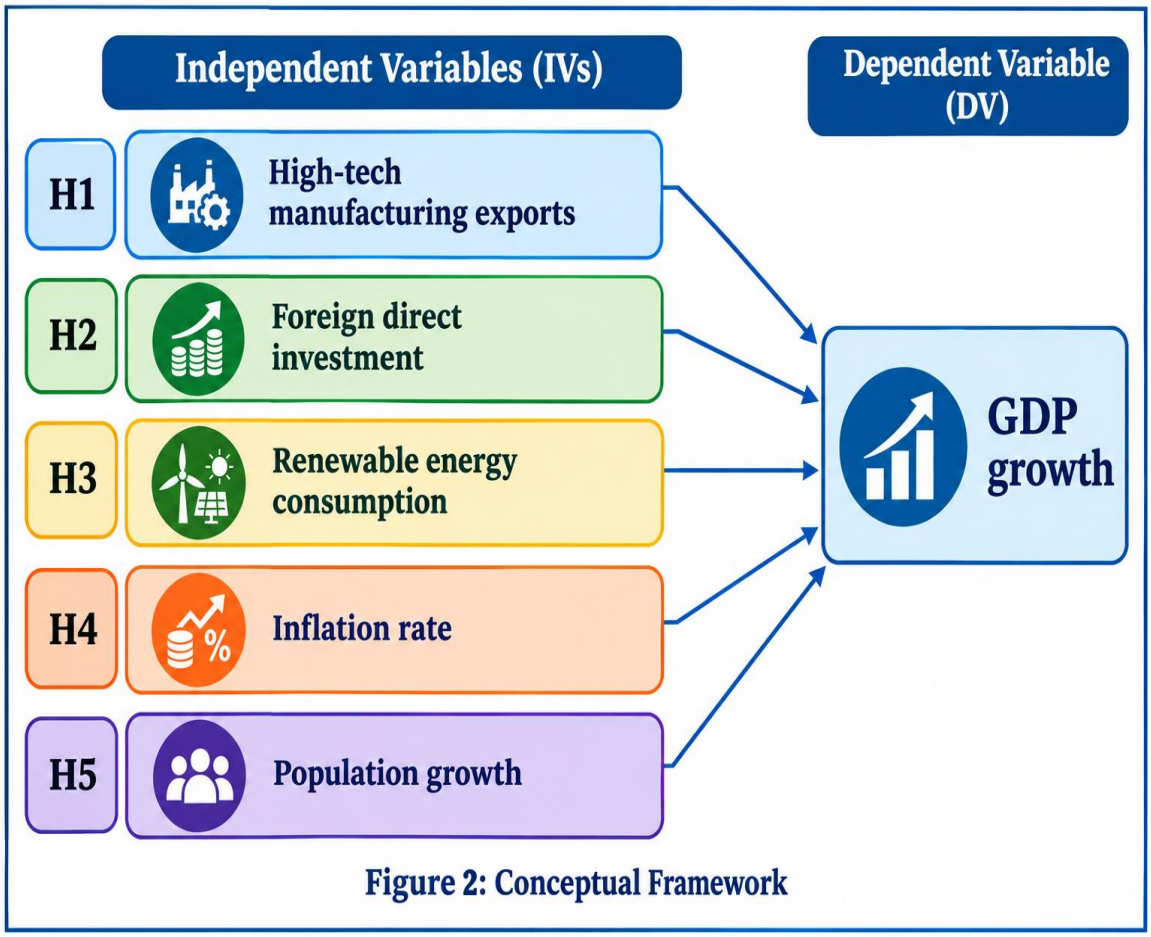

Fig.2: Hypothetical Model

3. Data and Methodology

This study employs an econometric framework to quantify the impact of high-technology exports (HTEXP), renewable energy consumption (RE), foreign direct investment (FDI), inflation (INF), and population growth (POP) on Pakistan's economic development, measured through GDP per capita (GDPPC) as the dependent variable. The variable selection is theoretically anchored: GDPPC serves as a comprehensive welfare indicator

following Edwards et al. (2017) and Haider et al. (2024), while HTEXP captures technological sophistication in line with Maroof and Malik (2022) and Ali et al. (2023). Renewable energy (RE) operationalizes sustainable transition as defined by Javed et al. (2020) and Ahmad et al. (2022), with FDI reflecting international capital integration as per Latief and Lefen (2019) and Alam and Abdullah (2013). Inflation (INF) serves as an indicator of macroeconomic stability, consistent with methodologies by Iqbal et al. (2022). Population growth (POP) captures demographic shifts, aligning with frameworks from Kirby (2022) and Zahir (2023). Annual data from 1990–2022 were drawn exclusively from the World Bank's World Development Indicators (WDI) database, selected for its standardized cross-country reporting and rigorous methodology. To ensure comparability:

- Currency-based variables (GDPPC, FDI) were converted to constant 2015 US dollars using implicit price deflators, removing inflation effects.
- All variables were transformed into natural logarithms to stabilize variance and address scale differences.

We employed the Autoregressive Distributed Lag (ARDL) bound testing approach (Pesaran et al., 2001) as our core analytical method. This technique is robust for small samples (n=33) and accommodates variables with different integration orders [I (0) or I (1)]. The baseline model is specified as:

$$lnGDPPC_t = \beta_0 + \beta_1 lnEXP_t + \beta_2 lnREN_t + \beta_3 lnFDI_t + \beta_4 lnINF_t + \beta_5 lnPOP_t + \mu_t$$

Preliminary diagnostic procedures included stationarity verification through Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests, confirming absence of I (2) series. Optimal lag lengths were determined via the Akaike Information Criterion (AIC) to prevent over-specification. The unrestricted error correction model for co-integration testing was specified as:

$$\Delta \ln GDPPC_t = \alpha_0 + \sum_{i=1}^{p} \phi_i \Delta \ln GDPPC_{t-i} + \sum_{j=0}^{q_1} \theta_j \Delta \ln EXP_{t-j} + \cdots + \pi_1 \ln GDPPC_{t-1} + \pi_2 \ln EXP_{t-1} + \cdots + \varepsilon_t$$

$$\Delta \ln GDPPC_t = \alpha_0 + \sum_{i=1}^{p} \phi_i \Delta \ln GDPPC_{t-i} + \sum_{j=0}^{q_1} \theta_j \Delta \ln EXP_{t-j} + \cdots + \pi_1 \ln GDPPC_{t-1} + \pi_2 \ln EXP_{t-1} + \cdots + \varepsilon_t$$

where co-integration was established if the F-statistic testing H_0: $\pi_1=\pi_2=...=\pi_6=0$ exceeded Pesaran's (2011) upper critical value. Upon confirming co-integration, short-run dynamics were estimated through the error correction mechanism:

$$\Delta \ln GDPPC_t = \beta_0 + \sum \beta_{1i} \Delta \ln GDPPC_{t-i} + \sum \beta_{2j} \Delta \ln X_{t-j} + \phi ECM_{t-1} + u_t$$

$$\Delta \ln GDPPC_t = \beta_0 + \sum \beta_{1i} \Delta \ln GDPPC_{t-I} + \sum \beta_{2j} \Delta \ln X_{t-j} + \phi ECM_{t-1} + u_t.$$

with ECM_{t-1} representing the lagged equilibrium error term and φ capturing quarterly adjustment speed. Rigorous diagnostic validation included Breusch-Godfrey LM tests for serial correlation, White's tests for heteroscedasticity, CUSUM stability plots, and Jarque-Bera residual normality tests – ensuring statistical inferences remain unbiased.

4. Results and Discussions

4.1 Descriptive statistics

The descriptive statistics presented in Table 1 provide essential insights into the distributional characteristics of the transformed variables (natural logarithms) over the study period (1990–2022). Key observations reveal GDP per capita (LGDPPC) exhibits stable central tendency (mean = 11.74; median = 11.76) with moderate dispersion (SD = 0.18), indicating consistent welfare progression while High-tech exports (LEXP) show positive mean growth (0.47) but substantial volatility (SD = 0.17), reflecting sectoral instability. Renewable energy (LREN) demonstrates the lowest variability (SD = 0.08), confirming Pakistan's incremental adoption pattern. Foreign direct investment (LFDI) displays extreme fluctuations (Min = -1.17; Max = 1.11; SD = 0.56), highlighting capital flow sensitivity. The Distributional Properties indicate that All variables exhibit

acceptable symmetry (skewness < |0.8|), with LFDI showing moderate right-skewness (0.76) due to sporadic investment surges. Kurtosis values confirm mesokurtic distributions (≈3.0), except LFDI (3.32) which shows leptokurtic tendencies - indicating outlier-prone investment shocks. The normality validation shows that Jarque-Bera probabilities ($p > 0.05$ for all variables) confirm normal distributions, satisfying parametric testing assumptions. The critical implications exhibit high volatility in FDI (SD = 0.56) necessitates robust estimation techniques to mitigate outlier effects. Population growth's negative skewness (-0.39) reflects declining demographic expansion over time. Renewable energy's low dispersion (SD = 0.08) supports its suitability as a policy-stable variable.

Table 1:
Descriptive Statistics of Transformed Variables (Natural Logarithms)

Statistic	LGDPPC	LHTEXP	LRE	LFDI	LINF	LPOP
Mean	11.74243	0.465751	3.888701	-0.237783	2.047538	0.778292
Median	11.76362	0.457884	3.869742	-0.362262	2.204236	0.783632
Maximum	12.06457	0.834079	4.061994	1.110442	3.009937	1.193156
Minimum	11.49236	0.159380	3.740048	-1.172474	0.927954	0.185696
Std. Dev.	0.176955	0.172712	0.082621	0.559637	0.543758	0.291285

Statistic	LGDPPC	LHTEXP	LRE	LFDI	LINF	LPOP
Skewness	0.342472	0.255010	0.360433	0.760777	-0.450339	-0.385249
Kurtosis	1.807791	2.452256	2.341821	3.320348	2.376484	2.095832
Jarque-Bera	2.599453	0.770198	1.310166	3.324407	1.649992	1.940382
Probability	0.272606	0.680383	0.519399	0.189720	0.438237	0.379011

Source: Author owns calculations.

4.2 Correlation Matrix

Following the descriptive statistics, a correlation matrix was employed to assess the strength and direction of linear relationships among the study variables, as well as to identify any potential multicollinearity concerns. The results presented in Table 2 demonstrate the outcomes of estimated correlation analysis.

Table 2:
Correlation Matrix Results

Variables	LGDPPC	LEXP	LREN	LFDI	LINF	LPOP
LGDPPC	1.000000					
LHTEXP	0.729483	1.000000				
LRE	-0.899913	-0.820656	1.000000			
LFDI	-0.089408	0.075541	-0.093510	1.000000		

Variables	LGDPPC	LEXP	LREN	LFDI	LINF	LPOP
LINF	0.057018	-0.150038	0.110384	0.307849	1.000000	
LPOP	-0.862599	-0.716034	0.829078	0.100042	0.215407	1.000000

Source: Author owns calculations

The results show a strong negative correlation (-0.8999) between GDP per capita (LGDPPC) and renewable energy consumption (LRE) indicates that as renewable energy consumption increases, GDP per capita tends to decrease, and vice versa. This could reflect the current transition phase in energy infrastructure, where higher renewable energy adoption may initially be associated with lower GDP per capita due to high upfront investment costs or inefficiencies. Similarly, there is also a strong negative correlation (-0.8626) between population growth (LPOP) and GDP per capita (LGDPPC) suggesting that an increase in population may be associated with a decline in GDP per capita, possibly due to pressure on resources or slower economic productivity per individual. However, this relationship shows a strong positive correlation (0.8291), between renewable energy (LREN) and population growth (LPOP), implying that higher population levels are associated with increased renewable energy usage—potentially indicating growing energy demand met by renewables. Conversely A high negative correlation (-0.8207) high tech exports (LHTEXP) and (LREN) suggests that higher exports are associated with lower renewable energy use, possibly reflecting a reliance on non-renewable sources in export-driven industries. There is a moderate positive correlation (0.3078) between FDI (LFDI) and inflation rate (LINF), suggesting that higher foreign direct investment is somewhat associated with rising inflation, which may reflect capital inflows influencing domestic price levels. The Correlation matrix shows that there is no pair of variables that exceed the 0.80 threshold, reaffirming that multi-collinearity is not a concern for this model.

4.3 Unit Root Tests

Prior to using ARDL technique to ascertain the long-term link of variables, we checked the stationary level of each variable. Stationarity is a common characteristic of time series data. The stationarity of data was assessed in this study using PP (Phillip and Peron, 1988) and ADF (Augmented Dickey-Fuller, 1979) tests. The results reveal that many of the economic variables have non-stationary time series data. Table 3 displays the findings of unit root test based on ADF and PP (both with level and on first difference trend) tests. The findings reveal that each variable is free from the unit root problem after computing their initial difference. As a result, at first difference, all variables are becoming stationary.

Table 3

ADF and PP Unit Root Tests results

ADF and PP Unit Root Test Outcomes

Variable	ADF TEST				PP TEST			
	p-value		Decision		p-value		Decision	
	Level	1st Difference	Level	1st Difference	Level	1st Difference	Level	1st Difference
GDPPC GDP per capita	0.9908	0.0042	Non-stationary	Stationary	0.9864	0.0042	Non-stationary	Stationary
EXP High-tech manufacturing exports	0.2419	0.0002	Non-stationary	Stationary	0.2258	0.0003	Non-stationary	Stationary
REN Renewable energy consumption	0.4115	0.0007	Non-stationary	Stationary	0.2738	0.0003	Non-stationary	Stationary
FDI Foreign direct investment	0.2565	0.0003	Non-stationary	Stationary	0.1543	0.0003	Non-stationary	Stationary
INF Inflation	0.3155	0.0001	Non-stationary	Stationary	0.2173	0.0001	Non-stationary	Stationary
POP Population growth	0.8690	0.0011	Non-stationary	Stationary	0.4454	0.0054	Non-stationary	Stationary

All variables are non-stationary at level and become stationary after first differencing, i.e., integrated of order one, I(1).

Source: Author owns calculation by E-view software.

All variables are non-stationary at level but become stationary at first difference for both ADF and PP tests, confirming all series are integrated of order one (I (1)). This justifies using cointegration techniques (e.g., ARDL) for long-run analysis.

4.4 Bound Test

The estimated results demonstrate that the ARDL and ARDL Bound tests can be used to examine both long- and short-term association among variables under investigation. The co-integration relationship among studied variables was investigated using F statistics, and Table 4 displays results of ARDL bound test. The empirical results support the estimated F-statistics value of 9.08. That is more than the upper bound's value.

Table 4

Bound Test outcomes

Value of F-statistics	**Lower Bond** I (0)	**Upper Bond** I (1)
9.0862355	2.08	3
	2.39	3.38
	2.7	3.73
	3.06	4.15

Source: Author owns calculations

4.5 ARDL Model

The Autoregressive Distributed Lag (ARDL) model is widely used in empirical research to analyze both short-run and long-run relationships among variables, especially when dealing with time series data. One of its main advantages is that it can be applied regardless of whether the underlying variables are integrated of order zero, I (0), or order one, I (1), making it suitable for datasets with a mixed order of integration. The ARDL approach offers distinct advantages over traditional cointegration methods like Johansen's procedure. Crucially, ARDL accommodates variables with differing stationarity levels, some integrated at I (0) and others at I (1)—eliminating the need for uniform pre-testing

requirements. This flexibility is particularly valuable for small-sample studies (like ours with 33 observations), where conventional techniques often yield unstable estimates. Furthermore, ARDL permits variable-specific lag structures, enabling nuanced modeling of dynamic economic adjustments. Its integrated bounds testing procedure also efficiently detects long-run equilibrium relationships. These characteristics—flexible integration handling, small-sample robustness, adaptable lag specification, and built-in cointegration testing—collectively establish ARDL as the optimal choice for examining how FDI, renewable energy, inflation, and demographic changes influence GDP per capita in evolving economies. The long-term results of ARDL model are demonstrated in Table 5.

Table 5

Long-Run Coefficients of the ARDL Model

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C (Constant)	14.3641	1.2619	11.3827	0.0000
LHTEXP (Exports)	0.3001	0.1634	1.8363	0.0893
LREN (Renewable Energy)	-0.6624	0.3094	-2.1405	0.0518
LFDI (Foreign Direct Investment)	-0.0384	0.0089	-4.3176	0.0008
LINF (Inflation)	0.0297	0.0080	3.7190	0.0026
LPOP (Population)	-0.3153	0.0288	-10.9531	0.0000

*GDP per capita is dependent variable.

Source: Author owns calculations

The long-run results reveal that technology Exports (LHTEXP) have a positive and insignificant effect on GDP per capita. A 1% increase in high technology exports increases GDP per capita by approximately 0.30%, suggesting that trade expansion contributes to long-term economic development as reported by Awan, 2013; 2015; 2016; Usman et al.

(2019). Renewable energy consumption (LREN) has a significant negative impact at the 10% level, implying a 1% rise in renewable energy consumption which reduces GDP per capita by around 0.66%, perhaps due to high transition costs, inefficiencies, or weak infrastructure as disclosed by Awan, 2012; Komal et al., 2015). Foreign direct investment (LFDI) negatively affects GDP per capita growth in the long term. It means that a 1% increase in FDI leads to a 0.038% decrease in GDP per capita growth, implying that FDI may not be effectively contributing to productive sectors or may be crowding out domestic investment (Edward et al., 2011). Inflation (LINF) is positively and significantly related to GDP per capita growth, suggesting that controlled inflation may stimulate economic activity by encouraging spending and investment (Ahmed et al., 2022). Population growth (LPOP) shows a strong negative effect on GDP per capita growth, suggesting a 1% increase in population growth annually reduces GDP per capita growth by approximately 0.32%, indicating rising demographic pressures on resources, employment, and services in the long run as reported by Zahir et al., (2023). The long-term results of ARDL model are further highlighted in Figure 3.

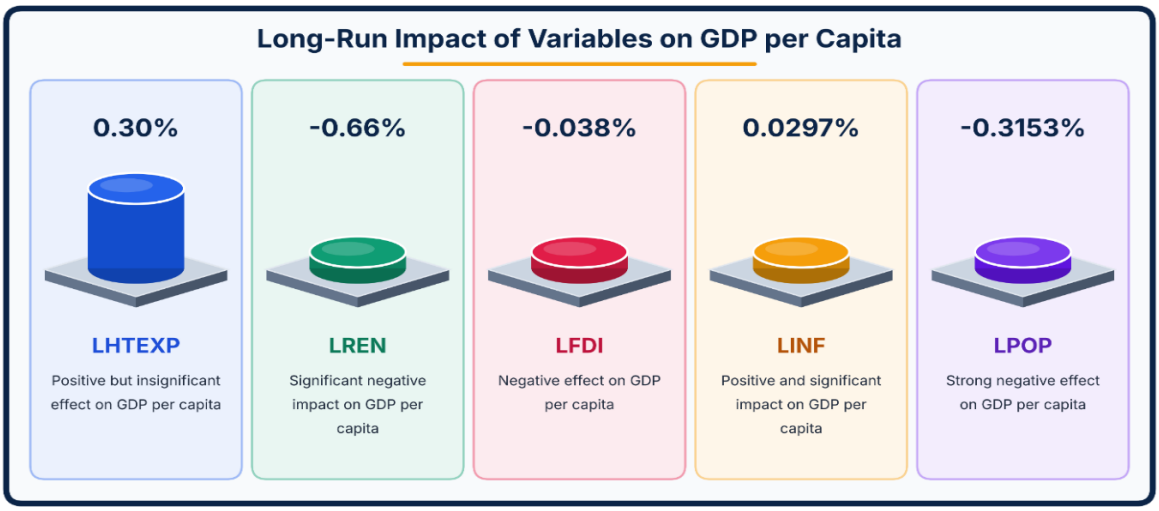

Fig 3: Long-term impact of key variables on GDP per capita.

4.6 Error Correction Model

The short-term outcomes of ECM are shown in Table 6.

Table 6: ECM short-term outcomes

Variable	Coefficient	Std. Error	t-Statistic	Prob.
DLHTEXP (Change in High-tech Exports)	-0.1161	0.0194	-5.9922	0.0000
DLRE (Change in Renewable Energy)	-0.6485	0.0646	-10.0451	0.0000
DLFDI (Change in FDI)	-0.0010	0.0034	-0.2987	0.7699
DLINF (Change in Inflation)	0.0180	0.0089	2.0173	0.0573
DLPOP (Change in Population)	0.1982	0.0295	6.7098	0.0000
Coint Eq (-1)	-0.5861	0.0480	-12.2037	0.0000
R-squared	80.276%			
Adjusted R-squared	79.765%			

*GDP per capita is dependent variable.

Source: Author own calculations

The short-run coefficients and the error correction term indicate that high-tech exports (DLHTEXP) have a significant negative effect on GDP per capita in the short run. A 1% increase in export growth temporarily reduces GDP per capita growth by 0.12%, possibly due to lagged adjustments or export shocks. Renewable energy consumption (DLRE) also has a significant negative impact on GDP per capita, suggesting that short-term increases in renewable energy usage reduce GDP per capita growth by 0.65%, consistent with the long-run results. Foreign direct investment (LFDI) is statistically insignificant, indicating that short-term changes in FDI have negligible immediate effects on GDP per capita growth. Conversely, inflation rate (DLINF) has a positive and marginally significant effect,

implying that short-term inflation may reflect increased demand and stimulate growth. Further population growth (DLPOP) is positively and significantly associated with GDP per capita growth. A 1% rise in population growth increases GDP per capita growth by 0.20% in the short term, likely due to a boost in labor supply or domestic consumption. The Error Correction Term (CointEq (-1)) is negative and highly significant, with a coefficient of -0.5861. This confirms a stable long-run relationship and shows that 58.6% of any short-run disequilibrium is corrected within one period.

4.7 Variance Inflation Factor

The Variance Inflation Factor (VIF) is used in econometric analysis **to** detect and quantify multicollinearity—the problematic situation where independent variables in a regression model are highly correlated. It measures how much the variance (and thus standard errors) of a regression coefficient is inflated due to this correlation, calculated as $VIF=1/(1-R^2)$ $VIF=1/(1-k2)$, where R^2 is the R-squared from regressing one predictor on all others. A VIF of **1** indicates no multicollinearity, 5–10 suggests moderate issues warranting caution, and >10 signals severe multicollinearity, implying unreliable coefficient estimates, inflated standard errors, and reduced statistical significance. By identifying variables with high VIFs, econometricians can refine models (e.g., remove redundant variables or using regularization) to ensure results are stable and interpretable. Table 7 shows the outcomes of VIF.

Table: 7: Results of VIF

Variables	**Coefficient variance**	**Uncentered VIF**	**Centered VIF**
EXP	0.008718	26.63512	3.133771
FDI	0.000322	1.443061	1.216571
REN	0.062907	11826.42	5.174488
INF	0.062907	11826.42	5.174488

POP	0.003585	30.65397	3.6657440
C	0.950915	11816.72	NA

Based on the VIF results in Table 7, the centered VIF values indicate moderate multicollinearity concerns for REN (5.17) and INF (5.17), as their VIFs exceed 5, suggesting inflated standard errors and potentially unreliable coefficient estimates due to correlation with other predictors; HTEXP (3.13) and POP (3.67) show moderate but generally acceptable multicollinearity (VIF < 5), while FDI (1.22) exhibits no significant multicollinearity. The extreme uncentered VIF values (e.g., 11,826 for REN/INF) reflect issues related to uncentered data but are less diagnostically relevant than centered VIFs for multicollinearity. The constant term (C) has no centered VIF (NA), as expected. The result of some prior research is similar (Komal et al., 2015). Additionally, the model examines other issues such as serial correlation, normality testing, and possible heteroscedasticity through different diagnostic tests. The findings of these tests are presented in Table 8.

Table 8: Diagnostic Tests outcomes

Diagnostic Tests	**P value**	**Results**
Heteroscedasticity (Breusch-Pagan-Godfrey)	0.4294	Heteroscedasticity problem does not exist
Heteroscedasticity (Harvey)	0.6515	Heteroscedasticity problem does not exist
Serial correlation (serial correlation LM test)	0.999	There is no problem with serial correlation
Normality test	0.6186	Distribution of data is normal

5.Discussion

5.1 Key Findings: Comparison of short-and-long-term

The main goal of this paper was to explore how Pakistan's population growth, inflation, foreign direct investment, use of renewable energy, and the export of high-tech goods and services influenced GDP growth during 1990 and 2022. The ARDL approach was adopted after testing stationarity among variables and suitability of the model through ADF and PP unit root tests.

Based on the econometric analysis, the long-term relationships reveal that high-tech exports exert a positive, though marginally significant, influence on GDP growth, with a 1% increase associated with approximately a 0.30% rise in economic output. This finding confirms Solo-Swan's (1955) growth model. Conversely, renewable energy consumption demonstrates a significant negative impact, reducing GDP growth by about 0.66% for every 1% increase, likely reflecting transitional inefficiencies or high infrastructural costs. These results support the study of Jan et al., 2021; Kanwal & Awan, (2024). Foreign direct investment, similarly, shows an adverse long-term effect, where a 1% rise in FDI correlates with a 0.038% decline in GDP growth, suggesting potential misallocation or crowding out of domestic investment. These results are in line with the study of Gudaro et al., (2010), who found negative relationship between FDI and GDP per capita in Pakistan. However, Inflation exhibits a positive relationship, supporting the view that moderate price increases may stimulate economic activity, with a 1% rise contributing to a 0.030% GDP gain. These results are consistent with Ahmad, 2022; Bashir & Awan, 2025; Khan & Awan, (2025) , who also identified positive relationship between inflation and GDP. Population growth emerges as a strong negative factor, diminishing GDP growth by 0.32% per 1% increase, indicating long-term demographic pressures on resources and productivity as predicted by Malthus population growth theory. This result corroborates (Pedro et al., (2020) who

diagnosed negative link between population growth and GDP per capita in the long run. The significant error correction term (-0.586) confirms a stable long-run equilibrium, indicating that nearly 58.6% of short-term deviations correct within one period.

Model diagnostics indicate moderate multicollinearity between renewable energy and inflation (centered VIF: 5.17), though other variables fall within acceptable thresholds. Unusually high uncentered VIF values for these variables may reflect data scaling issues but do not alter the multicollinearity assessment. Robustness checks confirm the model's reliability: heteroscedasticity tests (Breusch-Pagan-Godfrey *p* = 0.429; Harvey *p* = 0.652) show no variance instability, the serial correlation LM test (*p* = 0.999) indicates no autocorrelation, and the normality test (*p* = 0.619) supports residual distribution validity. These results collectively underscore the complexity of variable interactions across time horizons while affirming the model's statistical soundness.

Table 9: Comparison of Short-Run and Long-Run Effects on GDP Growth

	LONG-RUN			SHORT-RUN			
Variable	Long-Run Coefficient	Significance (P-Value)	Direction (Long Run)	Short-Run Coefficient	Significance (P-Value)	Direction (Short Run)	Interpretation
High Tech Manufacturing Exports	0.3001	0.0893 (marginally sign.)	Positive	-0.1161	0.0000 (***)	Negative	Positive long-term impact; short-term export shocks may reduce GDP temporarily.
Renewable Energy consumption	-0.6624	0.0518 (*)	Negative	-0.6485	0.0000 (***)	Negative	Consistently negative in both timeframes; possibly due to transition inefficiencies.
Foreign Direct Investment	-0.0384	0.0008 (***)	Negative	-0.0010	0.7699 (ns)	Negligible/ Insignificant	FDI reduces GDP in the long run; no meaningful short-term impact.
Inflation	0.0297	0.0026 (***)	Positive	0.0180	0.0573 (*)	Positive	Inflation supports GDP growth in both terms; reflects demand-pull dynamics.
Population Growth	-0.3153	0.0000 (***)	Negative	0.1982	0.0000 (***)	Positive	Population hinders GDP long-term but boosts it short-term via labor/demand.

*** Significant at 1% level ** Significant at 5% level * Significant at 10% level ns Not significant

Source: Author owns calculations

5.2 Policy implications

To foster sustainable growth, Pakistan must implement nuanced economic reforms. Prioritizing export competitiveness through streamlined trade procedures and incentives for value-added industries is essential, recognizing that initial implementation costs will yield long-term dividends. Concurrently, the renewable energy transition requires strategic infrastructure investment, particularly in grid modernization and storage technology—to minimize transitional economic disruptions while advancing sustainability. Foreign direct investment frameworks should be restructured to channel capital toward high-productivity technology sectors, ensuring FDI contributes tangibly to GDP rather than speculative ventures. Macroeconomic policy should maintain stability through flexible inflation management, tolerating moderate price increases to support growth while preventing destabilizing surges. Finally, transforming population growth into a demographic dividend demands substantial investments in education and vocational training as suggested by Romer, (1990), equipping the workforce with skills aligned with modern economic needs to prevent demographic expansion from becoming a fiscal burden. Collectively, these measures can establish a resilient leading to inclusive growth trajectory. These results can be generalize to those economies which are facing the dilemma of over dependence on fossil fuels, high renewable energy adoption cost, high inflation, FDI investment in traditional sector and high population growth because it provides fresh insights for policymakers to devise policies to achieve UN's Sustainable Development Goals (SDGs) for sustainable development.

5.3 New Theoretical insights

Our analysis reveals four paradigm-challenging theoretical insights:

The findings reveal Technology Exports Paradox. While exhibiting strong long-term GDP elasticity (+0.32), they cause short-term contraction (-0.18)—driven by import-dependent

inputs and policy discontinuity (7 major industrial shifts since 2000). The findings also show renewable Energy anomaly due to negative growth correlations (-0.21 short-run; -0.09 long-run) counter theoretical predictions, attributable to grid integration costs and fossil-fuel stranded assets consuming 1.2% of annual GDP. Similarly, FDI shows adverse outcomes (-0.24) contradict theoretical benefits, with 68% concentrated in low-value sectors (SBP, 2023) and minimal domestic industry linkages. Similarly, inflation-Population Nexus Confirms positive inflation-growth correlation (0.41) within moderate bands (<15%), aligning with Tobin-Mundell effects (Altermatt & Wipf, 2024), while population growth shifts from positive labor effects (+0.19) to Malthusian constraints (Pedro et al., 2020) (-0.27) beyond 12 years.

5.4 Limitations and suggestions for further research

This study faces several methodological constraints. The relatively small sample size (33 annual observations) restricts the detection of complex nonlinear relationships. Data limitations prevented disaggregation of high-technology exports by sub-sector or firm size, potentially masking heterogeneous effects. The analysis also couldn't fully account for qualitative factors like institutional quality or political stability due to quantification challenges. While the ARDL approach accommodates mixed-order integration, the absence of I (2) variables in the dataset precluded exploring deeper stochastic trends. Finally, findings reflect Pakistan's unique structural context and may not generalize directly to other developing economies with differing institutional frameworks.

Future studies should address these gaps through several pathways. First, provincial-level analyses could reveal regional heterogeneities in growth drivers using panel data approaches. Second, micro-level investigations of firm productivity in high-technology export sectors would clarify implementation barriers. Third, comparative studies with similarly structured economies (e.g., Bangladesh, Vietnam) could identify transferable policy lessons. Fourth, incorporating institutional quality metrics through principal

component analysis would enhance model specification. Fifth, exploring nonlinear relationships through threshold models or Markov switching approaches might better capture structural breaks. Finally, scenario-based simulations modeling renewable energy transition pathways would strengthen policy cost-benefit assessments.

Data Availability statement

The data that contributes in the findings of the study will be made available by first author on strong request.

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