Role of Public Debt and Green Technology in Energy Consumption: Evidence from Pakistan

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Abstract

This study addresses a significant gap in the literature by investigating the impact of public debt and green technology and other variables on energy consumption in Pakistan using 33 years' time series data from 1990-2023 sourced from the World Bank, OECD, IMF, and ICRG and employing statistical techniques such as Correlation matrix and ARDL model to identify long-term relationship between public debt, green technology and energy consumption. The findings reveal public debt and natural resources exert positive impact on energy consumption while green technology, institutional quality and GDP growth have negative impact on it in the long-term. This suggests that while green tech contributes to sustainability and indicates pathways to reduce energy production costs through enhanced efficiency and structural optimization, it does not lead to reduce aggregate energy consumption immediately. These findings imply that for developing economies like Pakistan, green technology, supported by prudent debt management, is vital for long-term energy sustainability despite its complex short-term effects on consumption.

Keywords: Energy Consumption; Public Debt; Green Technology; Natural Resources.

Introduction

The escalating global demand for energy, fueled by rising living standards, economic advancement, and industrial expansion, places immense pressure on resource-constrained nations. Pakistan exemplifies this challenge, where the energy sector—vital for development—contributes significantly to public debt (5.6% of total) and GDP (3.8%). Despite energy's critical role, approximately 30 million citizens (15% of the population) lack electricity access, hindering inclusive growth. Compounding this, circular debt exceeds Rs 2.31 trillion, driven by over-reliance on imported fossil fuels that expose the sector to price volatility and supply risks. While investment initiatives exist, robust mechanisms for monitoring and managing these investments remain deficient. Concurrently, green technology emerges as a solution to environmental degradation, resource conservation, cost reduction, and enhanced grid resilience. Its adoption is increasingly urgent given finite natural resources and climate imperatives, with institutions like Pakistan's Global Change Impact Studies Centre (GCISC) and Pakistan Council for Science and Technology actively promoting green innovation across industries to address environmental and economic challenges.

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What specific relationship exists between public debt, energy consumption patterns (particularly green technology adoption), and environmental degradation in Pakistan, and how can this nexus be leveraged for sustainable economic growth?
This study pursues three core objectives: First, to empirically investigate how Pakistan's historic public debt accumulation influences energy consumption and environmental outcomes. Second, to evaluate the efficacy of green technology investments—potentially debt-financed—in mitigating environmental harm while improving energy security and economic efficiency, contextualized within Pakistan's institutional framework. Third, to reconcile contradictory empirical findings on the debt-energy-environment nexus, such as those by Akam et al. (2021) showing debt's potential to alleviate environmental stress in highly indebted nations versus Boly et al. (2022) reporting opposing results across 22 economies, while integrating insights from Abbas et al. (2021), Raouf (2022), and Jianhua (2022) on macroeconomic interactions.
This research offers critical contributions by resolving ambiguities in existing literature through a focused analysis of Pakistan's unique energy-debt paradox. It provides evidence-based strategies for deploying public debt—as theorized by Hashemizadeh et al. (2021) and Wang et al. (2021) for intergenerational benefits—toward green technology projects that simultaneously reduce fossil fuel dependence (linked to debt by Katircioglu and Celebi 2018), curb environmental degradation, and manage circular debt. By incorporating institutional quality dimensions highlighted by Salman et al. (2019) and debt overhang adaptations examined by Vargas et al. (2015), the findings deliver actionable pathways for Pakistan to align energy investments with sustainable growth, fiscal stability, and climate resilience.

Literature Review

Studies exhibit significant methodological diversity but lack comparability due to inconsistent analytical frameworks. Raouf (2022) employs Generalized Least Squares (GLS) and Panel Quantile Regression (PQR) for OECD countries, revealing public debt's positive effect on renewable energy consumption and negative impact on non-renewables. However, this approach fails to capture potential nonlinearities evidenced in later studies. Jianhua (2022) addresses temporal dynamics using Fully Modified Ordinary Least Squares (FMOLS) and Autoregressive Distributed Lag (ARDL) models for Asian economies, finding mixed positive/negative effects that suggest contextual dependencies. By contrast, Farooq et al. (2023) utilize two-step System GMM estimators for OIC economies, which better accounts for endogeneity but obscures threshold effects visible in developing-economy-specific analyses.
Recent advanced methods like Quantile Autoregressive Distributed Lag (QARDL) in Chien et al. (2021) and dynamic ARDL simulations in Abbasi et al. (2022) represent methodological improvements by capturing parameter heterogeneity across quantiles and time horizons. However, most studies neglect cross-market interdependencies highlighted in contemporary research, which reveals dynamic correlations between renewable energy, technology, and carbon markets using nonparametric time-frequency approaches. The almost exclusive reliance on country-level aggregates (excluding Ali et al.'s firm-level survey) limits understanding of micro-level decision-making mechanisms driving investment in green technologies. The literature demonstrates pronounced geographical fragmentation with insufficient comparative frameworks:

Table1: Summary of reviewed literature

Study Focus	Representative Studies	Key Limitations
OECD Economies	Raouf (2022)	Ignores debt sustainability constraints
Emerging Asian Economies	Jianhua (2022), Chien et al. (2021)	Over-generalizes diverse developmental contexts
Single-Country Analyses	Shan (2021/Turkey), Song (2023/Australia)	Limits transferability of findings
Islamic Cooperation (OIC)	Farooq et al. (2023)	Treats heterogeneous economies as monolithic bloc

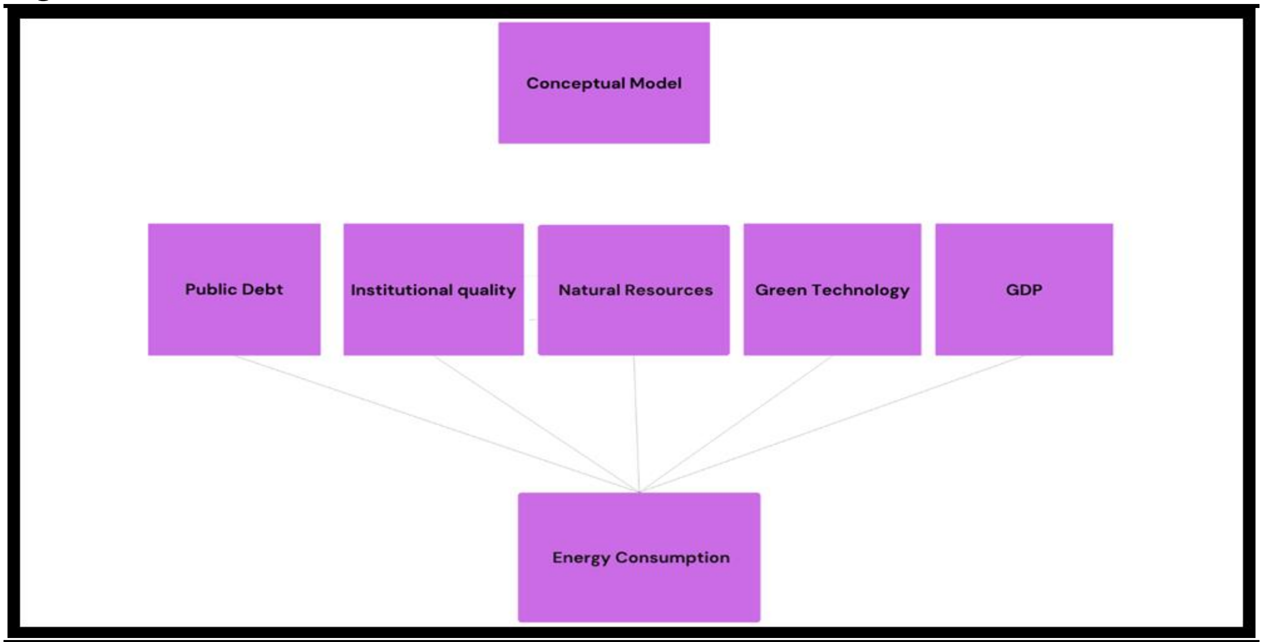
This fragmentation obscures crucial developmental thresholds where public debt shifts from enabling to constraining renewable investments. Research on low-income debt-distressed nations (over 50% of which face debt sustainability challenges) remains conspicuously absent despite evidence that debt impacts differ fundamentally across income levels. The literature also neglects regional interconnection effects, particularly relevant for regions with integrated energy markets like the EU, where renewable asset returns correlate dynamically with technology and carbon markets. Studies exhibit three critical limitations in conceptualization:

- Oversimplified debt representations: Most treat public debt as a monolithic variable despite evidence that debt composition (concessional vs commercial) differentially impacts renewable investments. Debt thresholds identified as approximately 60-80% of GDP in developing economies trigger investment reduction mechanisms but remain unexplored in energy studies.
- Institutional black boxes: While Farooq et al. (2023) and Abbasi et al. (2022) acknowledge institutional quality, they fail to specify governance mechanisms (e.g., procurement transparency, debt monitoring) that determine whether debt financing enables or undermines renewable projects. Research indicates countries with effective governance utilize external resources 30-50% more efficiently.
- Technological innovation oversights: Despite recognizing green technology's importance (Song 2023, Ali 2021), no study quantitatively examines how innovation mediates the debt-renewables relationship. This is particularly problematic given evidence that 1% innovation increases renewable energy by 0.33% long-term in G-20 nations, potentially altering debt productivity. Additionally, Theoretical integration remains fragmented across four domains in reviewed literature.
- Debt overhang theory: Only indirectly referenced despite evidence that high debt discourages public investment in renewables when exceeding 75% of GDP.
- Energy transition financing: Neglects how debt interacts with carbon pricing mechanisms that make renewables competitive when carbon prices exceed $50/ton
- Intergenerational equity: Payor-payee mismatches in debt-financed green investments require explicit justice frameworks absent in current literature.
- Innovation systems: Fails to incorporate how debt allocation to R&D versus deployment creates divergent renewable scaling pathways.

Zero studies examine the institutional micro-foundations determining debt effectiveness and lacks monitoring mechanisms to identify how project-level tracking systems prevent debt diversion in renewable projects. There is no study on fiscal institution quality to examine whether medium-term expenditure frameworks improve debt utilization efficiency. There is no study on Corruption interfaces to monitor how governance failures convert renewable debt into stranded assets.

The literature establishes public debt as a significant determinant of renewable energy deployment but suffers from methodological fragmentation, geographical biases, and theoretical simplification. The most critical gap concerns the institutional mechanisms through which debt transforms into effective renewable investment—a process mediated by governance quality, innovation systems, and financial architectures. This gap emphasizes on the adoption of multi-market approaches that reflect the dynamic interdependencies between debt instruments, renewable assets, carbon prices, and technology stocks. Without addressing these gaps, policymakers lack evidence to design debt-financed renewable transitions that simultaneously achieve fiscal sustainability, climate goals, and equitable development. We constructed a conceptual model showing relationship between independent and dependent variables. This model is presented in Figure 1.

Figure 1: Research Model



Data and Methodology

This is exploratory study in which we used time series data covering the period from 1990 to 2023 sourced from OECD statistics, Historical Public Debt Database from the International Monetary Funds, ICRG (International country risk guides) and World development indicators (WDI). All these sources are authentic and widely used by researchers. There were fully related to the study's variables. Energy consumption was dependent variable while independent variables include public debt, green technology, gross domestic product (GDP), Institutional quality and total natural resources. The selected variables, their symbols and sources are presented in in Table 2.

Table 2: Selected Variables, their symbols and sources

S. No.	Variable	Symbol	Data source
1.	Energy Consumption.	EC	World development indicators (WDI).
2.	Public Debt	PD	Historical Public Debt Database from the IMF (International Monetary Fund).
3.	Green Technology.	GT	OECD statistics.
4.	Gross Domestic Production.	GDP	World development indicators (WDI).
5.	Institutional Quality.	IQ	ICRG (International country risk guide).
6.	Total Natural Resources.	TNR	World development indicators (WDI).

To ascertain how the selected variable influenced by the explained variable we used the ARDL approach suggested by Jordan & Philips, (2018) and extensively used by other scholars in their empirical research. We also used unit root test to determine whether each variable in the model is stationary or non-stationary. The results of this test may vary if any or all of the variables become non-stationary. To use ARDL simulation it is necessary that al variables must be stationary at I (0) and I (I). For this testing we used both the Phillips-Perron unit root test and the Dickey-Fuller test suggested by Dickey & Fuller, (1979) and Phillips & Perron, (1988).

We constructed a model based on the study variable in order to determine empirical relationships between them. The model is given below: -:

EC= F (PD, GT, GDP, TNR, IQ) (1)

In order to analyze the research findings, the study formulated the following functional equation:

$$EC_t = \text{F}\ (PD_t, GT_t, GDP_t, TNR_t, IQ_t) \quad (2)$$

Here EC_t (Energy consumption) is a dependent variable, PD_t (Public debt) and GT_t (Green technology) are independent variables. GDP_t (Gross domestic products), TNR_t (Total natural resources) and IQ_t(Institutional quality) are control variable.

The above model is transformed into a mathematical equation: -

$$EC_t = \beta_1 + \beta_2 PD_t + \beta_3\ GT_t + \beta_4\ GDP_t + \beta_5\ TNR_t + \beta_6\ IQ_t + \mu_t \quad (3)$$

In the above equation β_1, β_2,β_3, $\beta 4$, β_5 and $\beta_6\ parameters$ and the error term is denoted by μt. All of the variables change to logarithmic form in order to eliminate the heteroscedasticity issue as suggested by Khan et al, (2019).

$$EC_t = \beta_1 + \beta_2 lnPD_t + \beta_3\ lnGT_t + \beta_4\ lnGDP_t + \beta_5\ lnTNR_t + \beta_6\ ln\ IQ_t + \mu_t \quad (4)$$

The study's variables and their long-term associations are explained by this model:

$$\Delta EC_t = \varphi_0 + \varphi_1 EC_{t-i} + \varphi_2 PD_{t-i} + \varphi_3 GT_{t-i} + \varphi_4 GDP_{t-i} + \varphi_5 TNR_{t-i} + \varphi_6 IQ_{t-i} + \sum_{i=1}^{q} \beta\Delta\ EC_{t-i} + \sum_{i=1}^{q} \beta\Delta\ PD_{t-i} + \sum_{i=1}^{q} \beta\Delta\ GT_{t-i} + \sum_{i=1}^{q} \beta\Delta\ GDP_{t-i} + \sum_{i=1}^{q} \beta\Delta\ TNR_{t-i} + \sum_{i=1}^{q} \beta\Delta\ IQ_{t-i} + \mu_t \quad (5)$$

It signifies the initial distinction. In both the short-term and long-term ARDL model, $t - i$ denotes optimum lag, β and φ indicating the existence of the relationship among variables over time among in the long and short run in the ARDL model.

Alternative hypotheses and Null hypotheses of Bond test are given below:

$H_1 = \varphi_1 = \varphi_2 = \varphi_3 = \varphi_4 = \varphi_5 = \varphi_6 \neq 0$

$H_0 = \varphi_1 = \varphi_2 = \varphi_3 = \varphi_4 = \varphi_5 = \varphi_6 = 0$

H_1Denote the alternative hypothesis and H_0 denote the Null hypothesis. To accept or reject the alternative hypothesis H_1 or null hypothesis H_0 depend on the F-statistics value. A long-term relationship occurs if the F-statistics value is higher than both the upper and lower values (Pesaran & Shin, 2002).

Pesaran and Shin (2002) suggested the ARDL model for estimating a small sample and time series data. However, this model has some discrepancies. According to Wan et al. (2022), this model is only appropriate for use in situations where all of variables are stationary at higher (0) as well as the lower (I) levels. Co integration in variables is determined using the ARDL bond test. The ARDL long-run model is given below:

$$EC = \alpha_0 + \sum_{i=1}^{q} \sigma_1 PD_{ti} + \sum_{i=1}^{q} \sigma_2 GT_{ti} + \sum_{i=1}^{q} \sigma_3 GDP_{ti} + \sum_{i=1}^{q} \sigma_4 TNR_{ti} + + \sum_{i=1}^{q} \sigma_6 IQ_{ti} + \mu_t \quad (6)$$

σ Shows the long-term variation for all variables, significant lags were identified using t-i. The error correction model is used to determine the short-run association between variables and speed of their adjustment is listed below:

$$EC + \alpha_0 + \sum_{i=1}^{q} \beta_1 \Delta EC_{ti} + \sum_{i=1}^{q} \beta_2 \Delta PD_{ti} + \sum_{i=1}^{q} \beta_3 \Delta GT_{ti} + \sum_{i=1}^{q} \beta_4 \Delta GDP_{ti} + \sum_{i=1}^{q} \beta_5 \Delta TNR_{ti} + \sum_{i=1}^{q} \beta_6 \Delta IQ_{ti} + \mu_t \quad (7)$$

Term in error correction is. -1 to 0 is the error correcting term. Because of the negative sign shows that any shock is modified to reach equilibrium at a subsequent period. The Jarque - Bera verifies the normality of residual in the model (Philips, 2018).

Results and Discussion

This Section elucidates results of descriptive statistics, Unit root tests, correlation analysis, ARDL model, Bound Test and Error Correction Model, CUSUM and CUSUM square tests.

Descriptive Statistics

A comprehensive descriptive analysis of six variables is given in Table 3 Energy consumption, public debt, green technology, GDP, institutional quality, and total natural resources are variables of this study. Information about each variable's distribution and broad trends may be found in its statistical characteristics. The mean and median values, for instance, show the typical range of values for each variable and so give assessments of central tendency. Values at the top and bottom illustrate the dataset's range of variation. Greater variability is indicated by larger standard deviation values, which show how the data points are distributed around the mean. The distributions shape is indicated by skewness and kurtosis. The values are significantly different from symmetry and peaks, respectively, as the table illustrates. We reject the null hypothesis if the Jarque-Berra likelihood is less than 0.05, which indicates that the distribution of data is not normal. We accept null hypothesis and determine that the data distribution is normal if the probability value is greater than 0.05.

Table 3: Descriptive Statistics of Variables

Statistics	LNEC	LNPD	LNGT	IQ	LNGDP	TNR
Mean	5.961209	4.203728	2.420969	0.830943	25.21980	1.812994
Median	5.961527	4.192437	2.409641	-0.021684	25.44508	1.839247
Maximum	6.003153	4.403910	4.605170	29.59982	25.44508	3.435616
Minimum	5.918095	3.950282	0.553885	-3.400183	24.41241	0.965331
Std. Dev.	0.025664	0.114063	0.934717	5.215689	0.340500	0.645480
Skewness	-0.030266	-0.093257	0.348727	5.118366	-1.077295	0.500554
Kurtosis	1.799182	2.532131	3.198030	28.93096	2.528889	2.316015
Jarque-Bera	2.047974	0.359393	0.744684	1101.041	6.890950	2.082575
Probability	0.359160	0.835524	0.689118	0.000000	0.031890	0.353000
Sum	202.6811	142.9267	82.31294	28.25206	857.4732	61.64178
Sum Sq. Dev.	0.021735	0.429346	28.83199	897.7125	3.826028	13.74926

Correlation Matrix

This matrix is used to identify nature of correlation between pairs of variables. The correlation may be positive or negative and its values lie between -1 (perfect negative) and +1 (Perfect positive). Table 4 present the outcomes of correlation matrix.

Table 4: Correlation Analysis

	LNEC	LNPD	LNGT	IQ	LNGDP	TNR
LNEC	1					
LNPD	0.3928	1				
LNGT	0.2033	0.3735	1			
IQ	0.3236	0.0165	0.1242	1		
LNGDP	0.840006	0.6139	0.4822	0.2081	1	
TNR	0.2420	0.3724	0.2297	0.4547	0.4479	1

The results in table 4 indicate that there is a positive correlation between public debt (PD) and energy consumption (EC), as indicated by the correlation coefficient of 0.3928 between the two variables. The amount of energy consumed (EC) varies with changes in the public debt (PD). Public debt (PD) will rise in tandem with energy consumption (EC), and vice versa. With a correlation value of 0.2033, it can be inferred that there is a positive relationship between green technology (GT) and energy consumption (EC), meaning that as green technology (GT) grows, so will energy consumption (EC). It shows energy consumption (EC) and green technology (GT) are positively correlated. There is also a positive correlation between energy consumption (EC) and institutional quality (IQ), denoting by a correlation coefficient of 0. 3236.. There is a positive correlation between GDP and energy consumption (EC). Gross domestic production (GDP) and energy consumption (EC) have a correlation coefficient of 0.840006, suggesting that energy consumption (EC) rises as Gross domestic production (GDP) does, and vice versa. There is a positive correlation between energy consumption (EC) and total natural resources (TNR). A higher value of total natural resources (TNR) will have a correspondingly large influence on energy consumption (EC) as per correlation coefficient between total natural resources (TNR) and energy consumption (EC) of 0.2420.

Unit Root Tests

We used two different unit root tests, ADF and PP, to diagnose stationarity among variables. Table 5 shows the estimated results.

Table 5: Unit root test outcomes

Variables	**Augmented Ducky-fuller (ADF) test**		**Phillips Peron (PP) test**	
	Level	1^{st} difference	Level	1^{st} difference
LnEC	0.9999	0.0000	0.9999	0.0000
LnPD	0.0575	0.0000	0.5646	0.0000
LnGT	0.1737	0.0001	0.2108	0.0000
IQ	0.8675	0.0355	0.8852	0.0510
LnGDP	0.0694	0.0000	0.0356	0.0000
TNR	0.3693	0.0152	0.5590	0.0146

Table 5 demonstrates that energy consumption (EC) in the Augmented Ducky-fuller test shows significance at the value of 0.0000 at 1^{st} difference value, and the value of the level which is 0.9999 is not at stationary point. Public debt (PD) has level value of 0.0575 and significant at 0.0000 at the 1st difference. With the 1st difference value of 0.0001, green technology (GT) is significant, and it is not stationary at the level value of 0.1737. Institutional quality (IQ) is significant with the value of 0.0355 at the 1st difference and 0.8675 at the non-stationary level. At the 1st difference, GDP is significant at 0.0000, and it is not stationary at the level value of 0.0694. Additionally, total natural resources (TNR) are not stationary at the level value of 0.3693 and is significant at the 1st difference of 0.0152. Energy consumption (EC) in the Phillips Peron test was significant at 0.0000, the 1st difference and is not stationary at a level of 0.9999. Public debt (PD) is not stationary at a level value of 0.5646, although it is significant at 0.0000 at the 1st difference. Green technology (GT) is not stationary at a level value of 0.2108 and is significant at 0.0000 at the 1st difference. The 1st difference in institutional quality (IQ) is 0.0510, which is significant, and the level value of 0.8852 is not stationary. Regarding the 1st difference, GDP is significant at 0.0000, at the level value of 0.0356, it is also stationary. Furthermore, total natural resources (TNR) are not steady at the level value of 0.5590 and are significant at the 1st difference of 0.0152. As the variables are stationary at different levels we can use ARDL approach for further analysis.

Table 6: Long run results of ARDL model

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LNPD	0.000776	0.000123	6.314392	0.0000
LNGT	-9.68E-05	1.50E-05	-6.441870	0.0000
IQ	-8.18E-05	9.98E-06	-8.203822	0.0000
LNGDP	-0.001373	0.000110	-12.46379	0.0000
TNR	5.39E-05	1.56E-05	3.453526	0.0035
C	7.010597	0.004068	1723.463	0.0000

Table 6 shows that there is a positive relationship between public debt (PD) and energy consumption suggesting that a one unit increase in public debt (PD) leads to an increase in energy consumption by 0.000776% and vice versa. The relationship between public debt and energy consumption can vary significantly. High levels of public debt typically may have a negative long-term relationship with energy consumption, meaning that as government debt rises, energy consumption tends to fall. But a nation's economic structure and energy policy can have a substantial impact on the link between public debt and energy consumption (Hashemizadeh et al., 2021; Luo Jianhua, 2022). Similarly, Green technology (GT) and energy consumption have a negative relationship, suggesting that increase in green technology leads to decrease in energy consumption. Energy consumption and green technology generally have a negative relationship over the long term. This means that as green technologies advance, overall energy usage tends to decrease because of increased utilizing renewable energy sources and energy efficiency. In other words, the more advanced green technology, the less energy is required to achieve the same level of output (Shan et al., 2021). An increase in institutional quality decreases by 8.18% in energy consumption as the values show negative trend in the long run. It shows that energy usage will decrease as the institutional quality improves (Sun et al, 2022; Ahmad et.al, 2021; Umut Uzar, 2020). A negative correlation exists between GDP (Gross domestic production) and energy consumption. A decline in the Gross domestic production (GDP) by -0.001373 units, increase the energy consumption in the same manners. Generally, there is a positive trend in long-term between Gross domestic production and the energy consumption but many research indicates that there may be a negative long-term relationship between GDP and energy consumption, which means that when energy consumption rises, GDP may not always rise or may even fall. This is particularly accurate when taking into consideration the costs for the environment and the possibility of energy-related disruptions in economic activity. However, the precise relationship can vary depending on the economic structure and the type of energy sources used (Shakeel et al., 2014; Myszczyszyn & Supron, 2021; AKAY et al., 2020; Wu, et al., (2024). Moreover, total natural resources show a positive trend between natural resources and energy consumption with coefficient 5.39E-05. Long-term trends show that total natural resources and energy consumption are generally positively correlated, suggesting that as a nation's natural resource availability rises, so does its propensity to use more energy, mainly because of the direct use of these resources for energy production. However, the precise relationship can vary depending on several other factors, such as the kind of natural resource, technological advancements, and policy decisions regarding resource management and the adoption of renewable energy.

Bound Test

This test is used to determine long-term association between variables. Table 7 presented its estimated results, which confirm the ARDL long-term results.

Table 7: ARDL Bond test

Test statistic	Values	Significant value	Lower Bond value 1(0)	Upper Bond value 1(1)
F-statics	5.851	10%	2.37	3.2
		5%	2.79	3.67
K	3	2.5%	3.15	4.08
		1%	3.65	4.66

Findings from the bound test show that the dependent and independent have a long-term association. It demonstrates that the F-statics value of 5.851is higher than the lowest and upper bond values, proving that this model has a long-term connection.

Error Correction Model

Table 8 shows the short-term association of variables and speed of their adjustment from one period to next period.

Table 8: Short-run results of ECM

Variables	Coefficient values	Standard Error	t-Statistic values	Probability values.
D(LNPD)	2.10E-07	2.49E-07	0.840690	0.4137
D(LNPD(-1)	-1.41E-06	2.60E-07	-5.409279	0.0001
D(LNPD(-2)	-1.61E-06	2.50E-07	-6.462298	0.0000
D(LNGT)	-1.04E-07	2.12E-08	-4.909811	0.0002
D(LNGT(-1)	1.27E-07	1.86E-08	6.825711	0.0000
D(IQ)	-7.44E-10	2.19E-09	-0.338942	0.7394
D(IQ(-1)	2.02E-07	2.62E-08	7.710362	0.0000
D(LNGDP)	-1.54E-06	1.45E-07	-10.60437	0.0000
D(LNGDP(-1)	9.15E-07	1.43E-07	6.384609	0.0000
CointEq(-1)*	-0.002529	1.33E-08	-189557.6	0.0000

The Error Correction model's short-term findings are displayed in Table 8, where the Probability value is the 0.000 and the CointEq (-1) * value is -0.002529, both are significant. The results indicate that our economy or model will be balanced. The economy is in equilibrium as shown by the CointEq value of -0.002529. Additionally, every variable's p-value is significant. P-values of public debt (PD) show a positive relationship with Energy consumption (EC). A positive relationship between public debt and energy consumption, meaning that as public debt increases, so does energy consumption because governments may use debt to fund infrastructure projects or stimulate economic activity, which can lead to increase in energy consumption. Some other researchers have also shown the same results (Raouf 2022) and (Auteri et al, 2024). The green technology (GT) has a negative link with energy consumption. Green technology and energy consumption are generally thought to have a negative short-term relationship, which means as more green technologies are adopted, overall energy consumption tends to decline because green technologies are more energy efficient, requiring less energy to accomplish the same task. Numerous studies also identified that energy consumption and green technologies are negatively correlated (Javed et al., 2023; Behera et al., 2023; Chen et al., 2016). Further, energy consumption and institutional quality are inversely correlated in short run. It means that higher-quality institutions may initially result in lower energy use. A negative relationship may arise because of things like the upfront costs of switching to cleaner energy sources or the unpredictability of policies during institutional reforms, which may temporarily discourage energy use while people and businesses wait for a stable policy framework before making big changes (Xu et al, 2023). The findings indicate a short-term negative relationship between GDP and energy consumption. In other words, a drop in energy consumption may cause a temporary drop in GDP as a result of less economic activity. There may occasionally be a brief negative association, especially when abrupt interruptions in the energy supply or substantial price hikes are taken into account. Similar findings have also been observed in some other studies (Oztuk et al, 2013; Rani Dey and Tareque, 2019; Vicente German-Soto, 2020).

Diagnostic Tests

This study used different diagnostic tests to determine serial correlation, heteroscedasticity and abnormal distribution of residuals in the model. Table 9 shows the estimated outcomes.

Table 9: Diagnostics tests results

Diagnostics test.	p-values	Test Conclusions
Brush-Godfrey LM test	0.000	No problem in serial correlation.
Brush-Pagan- Godfrey	0.0893	No problem with heteroscedasticity.
Jarque-Bera test	3.106921	The residuals are estimated to be normal.

The findings of the Brush-Godfrey LM, Brush-Pagan-Godfrey, and Jarque-Bera tests demonstrate the normality of the calculated residuals and there is no heteroscedasticity issue because all of the probability values are insignificant. Additionally, the serial correlation value is insignificant, indicating that autocorrelation is not the problem. The model's stability is explained by the normality test. We observe that the Jarque-Bera test result, p-value is 3.106921, which indicates that the model is stable, negligible, and not problematic. There is no issue of serial correlation, heteroscedasticity and residual distribution.

Variance Inflation Factors

This test is used to identify multicollinearity problem in the variables of the study's model. Table 9 shows the outcomes of this test.

Table 9: Variance Inflation Factors

Variable	Coefficient Variance	Un-centered VIF	Centered VIF
LNPD	0.000518	2509.427	1.791940
LNGT	5.70E-06	10.47200	1.323615
IQ	1.89E-07	1.400112	1.364431
LNGDP	6.53E-05	11379.01	2.012861
TNR	1.45E-05	14.62771	1.602483
C	0.069973	19159.21	NA

The results shows that VIF's values are between 0 and 10 confirming no multicollinearity in our model. It also confirms that every independent variable has a unique impact on dependent variable.

Discussion

The study reveals a nuanced relationship between Pakistan's public debt and energy consumption. While the long-run analysis shows an overall inverse connection, the impact depends critically on the nature of the debt shock and how borrowed funds are utilized. Short-term increases in debt might stimulate economic activity and energy demand, but without strategic direction, this can lead to long-term drawbacks like crowding out private investment. Crucially, when public borrowing is specifically channeled into investments for green technology research and development, energy efficiency initiatives, and clean energy infrastructure, a positive long-term relationship emerges. This strategic use promotes a shift towards sustainable energy sources, potentially yielding benefits such as reduced carbon emissions, enhanced energy security, and improved environmental quality, though it requires careful debt management to avoid unsustainable burdens.

The relationship between green technology adoption and energy consumption evolves over time. Initial implementation may involve a marginal or insignificant rise in energy use due to upfront manufacturing and integration costs. However, as these technologies mature and achieve scale, a significant long-term negative correlation dominates, driven by substantial gains in energy efficiency and falling clean energy production costs. Furthermore, the study consistently finds a negative relationship between GDP and energy consumption in both the short and long run. This suggests Pakistan's economy is becoming more energy-efficient as it grows, indicating a decoupling potentially driven by technological progress, structural shifts, conservation practices, or green energy policies. Enhanced institutional quality – governance, regulation, policy stability – is also significantly and negatively correlated with energy consumption across both timeframes, underscoring its foundational role. Conversely, a positive link exists between natural resource availability and energy consumption, reflecting the energy-intensive nature of resource extraction and processing activities, though this can be moderated by innovation and sustainable management.

Conclusion

In conclusion, this research highlights the critical interplay between fiscal policy, technological advancement, and energy use in Pakistan. Public debt presents a double-edged sword;

unsustainable levels pose risks, but strategically deployed debt financing for green investments is indispensable for transitioning to sustainable energy systems, delivering environmental and security benefits, provided it is managed prudently. Green technology, despite potential short-term adjustment costs, is confirmed as essential for achieving significant long-term reductions in energy consumption and costs. The foundational importance of robust institutional quality cannot be overstated for enabling effective transitions and attracting investment. The observed negative GDP-energy consumption correlation signals the potential for continued economic growth with improving energy efficiency. Finally, managing the inherent link between natural resource abundance and energy consumption requires sustainable practices and cleaner technologies within the resource sector itself. Achieving Pakistan's sustainable energy and environmental goals demands a coherent policy framework that strategically utilizes public finance for green investments, actively enables private sector participation, strengthens institutions, and relentlessly pursues energy efficiency alongside renewable energy expansion, carefully balancing short-term costs against vital long-term benefits.

Policy Implications

These findings lead to clear policy imperatives. Policymakers must strategically leverage public debt as a catalyst for the green energy transition. Borrowed funds should be explicitly prioritized for large-scale renewable energy projects, green technology R&D, and nationwide energy efficiency programs. Simultaneously, the government must actively enable private sector participation by removing legal and regulatory barriers, establishing stable long-term policy frameworks, and using de-risking instruments like guarantees to attract private capital into green infrastructure and innovation. Strengthening institutional capacity for effective policy design, implementation, and monitoring is paramount. Additionally, integrated natural resource management strategies incorporating sustainability and efficiency, alongside rigorous enforcement of building codes, appliance standards, and industrial efficiency programs, are essential to mitigate inherent energy intensity and reduce demand growth.

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