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# Navigating the Influence of Financial Development, Technological Innovation and Institutional Quality on Green Energy in Pakistan

**Hamna Anis[1], Shumaira Rahim[2], Muhammad Zulqarnain Safdar[3], Osama Bin Shahid[4]**

[1]*Department of Business & Economics, Universiti Malaya, Malaysia, Email: Hamna.anis@gmail.com*
[2]*Department of Management Sciences, SBKWU, QUETTA, Email: shumaira.rahim@gmail.com*
[3]*Assistant Professor, Department of Business Administration, IBA, Gomal University, D-I-Khan, KP, Pakistan, Email: zulqarnain.safdar@gmail.com*
[4]*Management Science Department, COMSATS University Islamabad Attock Campus, Email: osamashahid.obs@gmail.com*

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***Corresponding Author:***
*Hamna Anis*
***Email:***
*Hamna.anis@gmail.com*



## ABSTRACT

*This study investigates the impact of financial development, technological innovation, institutional quality, and human capital on green energy consumption in Pakistan over the period 1993–2024. Annual time-series data were analyzed using the Autoregressive Distributed Lag (ARDL) approach to examine both short-run and long-run relationships among the variables. Prior to estimation, the Augmented Dickey-Fuller (ADF) unit root test was employed to determine the stationarity properties of the data, while the ARDL Bounds Test was applied to verify cointegration. The empirical findings confirm the existence of a long-run equilibrium relationship among green energy consumption and its determinants. The long-run estimates reveal that financial development, technological innovation, institutional quality, and human capital exert positive and statistically significant effects on green energy consumption, with technological innovation emerging as the most influential factor. The short-run results further support these findings, while the error correction mechanism indicates a rapid adjustment toward long-run equilibrium. Granger causality analysis identifies unidirectional causality running from financial development, technological innovation, institutional quality, and human capital to green energy consumption. The study concludes that strengthening financial systems, promoting innovation, improving governance quality, and investing in human capital are essential for accelerating Pakistan's renewable energy transition and achieving sustainable development objectives.*

## Introduction

Green energy is a key component of sustainable development and tackling global environmental issues. It comes from renewable energy like solar, wind, hydropower, geothermal, and biomass, that emit little to no greenhouse gas emissions (Intergovernmental Panel on Climate Change [IPCC], 2023). Green energy does not use fossil fuels and so reduces carbon dioxide emissions; this can help reduce climate change and air pollution. It is important for ensuring the national contribution to international climate targets and for safeguarding ecosystems against environmental degradation (IPCC, 2023). Energy security is one of the prime benefits of green energy. Renewable energy resources are abundant and continuously available, which means that they are not reliant on foreign supplies of fossil fuels and improve national energy independence (International Energy Agency [IEA], 2024). Furthermore, renewable energy technologies offer a boost to the economy, generating employment opportunities in manufacturing, installation, maintenance, and research areas (United Nations, 2024). Renewable energy technologies continue to get cheaper and more competitive and available with green energy. Green energy contributes to the sustainable development of the economy and environment as sustainable energy solutions are embraced by governments, businesses, and communities (United Nations, 2024). It is extremely important that the use of renewable energy is expanded to create a cleaner, healthier and more sustainable world for current and future generations.

The financing of green energy plays an important role in driving the uptake and growth of green energy options. A robust financial system can increase the availability of funding, enhance access to investment opportunities, and mitigate financing limitations for renewable energy initiatives, like solar, wind, and hydropower (Shahbaz et al., 2022). Investments in and adoption of green energy technologies can be high, so good financial markets and institutions can facilitate the mobilization of the capital needed for greening the economy. There are a number of ways in which financial development promotes the growth of green energy, such as bank lending, capital markets, green bonds and sustainable investment funds. These financial tools have the potential to finance clean energy infrastructure and technological innovation, thereby driving the shift from fossil fuels to clean energy sources (Paramati et al., 2018). Furthermore, improved financial mechanisms promote R&D efforts that enhance energy efficiency and lower the cost of renewables. Meanwhile, the development of green energy will have a positive impact on the financial development, with the formation of new investment opportunities and the development of green finance market. Efforts to promote sustainable finance are growing in prominence in the context of governments and policy makers increasingly calling for such support to achieve environmental goals, as well as to encourage private-sector investment (United Nations Environment Programme [UNEP], 2023).

Technological innovation has been proven to be a cornerstone of the development of green energy. New developments in renewable energy technology, such as solar PV, wind generators, smart grids, and energy storage systems, boost efficiency, lower energy production expenses, and strengthen the consistency of renewable energy production. This means that technology would enable the widespread use of green energy and spur the transition to sustainable energy systems (Geng & Ji, 2016). Empirical research has confirmed that there is a positive link between technological innovation and the development of renewable energy. Geng and Ji (2016) determined that in the major developed economies, technological innovation (as represented by renewables patents) has a long-run positive impact on the consumption and development of renewable energy. Likewise, Zhao et al. (2024) found that technological innovation positively influences the investment in renewable energy by lowering uncertainty and enhancing the economic performance of renewable energy investments. Recent studies also show that digital and technological developments help to drive innovation in renewable energy by improving capital allocation, knowledge diffusion, and market development (Li et al., 2024). The connection is two-way, as the increased demand for green energy fuels continued research and development endeavors, thus continually driving technological advancements. Knowledge spillovers and innovation networks also help to spread RE technologies to other industries and countries, advancing the diffusion process (Coronado et al., 2026).

The quality of institutions is important for fostering the development of green energy and using renewable energies. Effective governance, regulatory quality, rule of law, and control of corruption, form a favorable environment for renewable energy investments through the existence of strong institutions. Quality institutions diminish policy uncertainty, shield property rights and build investor confidence, which promotes investment in green energy projects, both from inside and outside the country (Apergis & Payne, 2014). Empirical evidence shows that institutions have an impact on the level of renewable energy consumption and production in countries.Empirical evidence shows that countries with better institutional frameworks have higher level of renewable energy consumption and production. Institutional quality plays a role in the enforcement of environmental regulations, renewable energy incentives and sustainable energy policies, which can help pave the way for a transition towards low carbon energy systems (Danish & Ulucak, 2020). In addition, good governance improves financial resource allocation and stimulates technological innovation in renewable energy (Acheampong et al., 2021).

This study explores the interactive effect of financial development, technological innovation, and institutional quality on the adoption of green energy in Pakistan, which is a growing demand in a country that is increasingly facing energy demand, environmental degradation, and climate-related issues. To ensure sustainable development and minimize fossil fuel reliance, these relationships must be understood. Results will offer important insights into the challenges of investing in renewable energy projects through an effective financial system, the technological innovation to make renewable energy technologies more efficient and cost-effective, and the institutional development necessary to establish a supportive policy framework for expanding renewable energy. The study is a contribution to the existing literature in that it offers evidence from Pakistan, where a study into the integrated effect of these has been limited. Moreover, the outcomes will help decision makers, energy planners and investors develop sound policies to speed up transitioning to cleaner energy. The study has identified the key facilitators of green energy development, thus contributing to Pakistan's efforts to improve energy security, environmental sustainability and countries and international climate commitments.

## Literature Review

### Relationship Between Financial Development and Green Energy

Over the past few years, there has been growing attention to the link between financial development and green energy. Apergis and Payne (2010) discovered that financial sector development has a significant positive impact on the use of renewable energy by providing access to capital and infrastructure investments in clean energy. In the same way, Sadorsky (2011) found that financial development in emerging economies also improves the use of renewable energy due to more credit availability and more efficient capital allocation. Chang et al. (2015) analysed OECD countries and found that investments in renewable energy projects in these countries are promoted by developed financial markets, which in turn results in higher production of renewable energy. Also, Paramati et al. (2016) showed that development of stock market is positively correlated with the renewable energy usage, as it brings more investment in the field of renewable energy technologies both domestically and internationally. Shahbaz et al. (2022) argued that financial development significantly boosts the use of renewable energy in the developing economies by providing better financing avenues and lowering investment obstacles. In a similar vein, Khan et al. (2023) found that green finance instruments and development of the banking sector are vital to augmenting the capacity of renewable energy and encouraging environmental sustainability.

**Relationship Between Technological Innovation and Green Energy**

Technological innovation is a key driver in the fast growth and penetration of green energy. In this context, there are numerous studies that have looked at how developments in technology can improve the efficiency of renewable energies, lower costs and facilitate sustainable energy transitions. Based on the work of Marques and Fuinhas (2012), the technological change definitely has a positive effect on the consumption of renewable energy in the European countries, as it enhances the efficiency of the production processes and reduces their costs. Likewise, Popp et al. (2011) emphasized that innovation in energy technologies would be an important factor influencing the growth of renewables, with R&D investments and the creation of patents as examples. Johnstone et al. (2010) showed that environment policy and innovation incentives have a significant positive effect on the generation of renewable energy technologies, particularly for wind and solar energy. Furthermore, Aguirre and Ibikunle (2014) have established that technological innovation promotes the deployment of renewable energy by enhancing the integration of renewables into the grid and energy storage. Murshed et al. (2020) also discovered that the technological advancement has the ability to improve the use of renewable energy in developing economies as it lowers the reliance on fossil fuels. Moreover, the study by Zafar et al. (2021) highlighted the role of digital and smart technologies, including the smart grid and AI-driven energy management systems, in boosting the efficiency and reliability of renewable energy sources. According to Shahbaz et al. (2023), innovation-driven growth has a significant impact on increased green energy consumption and carbon reduction efforts. Overall, the literature repeatedly demonstrates that technological innovation is associated with green energy development in a positive manner.

**Relationship Between Institutional Quality and Green Energy**

The importance of institutional quality in the growth of green energy is well known because good governance provides a supportive policy climate and facilitates investments in renewable energy. There are several empirical studies which have examined this association for various geographic areas and data sets. For emerging economies, Apergis and Payne (2014) discovered that a policy of stability and less investment risk is further fostered by higher institutional quality which in turn is associated with more consumption of renewable energy. Dogan and Seker (2016) found that the effectiveness of governance and regulatory quality are positively associated with the adoption of RE by enhancing the implementation of environmental policies. Likewise, Bhattacharya et al. (2017) indicated that countries with the most robust institutions have the highest shares of renewable energy because they enforce environmental regulations and incentives better. Shahbaz et al. (2019) conducted a panel study that revealed that institutional quality positively affects the use of green energy by increasing the efficiency of financial allocation and attracting FDI in green energy projects. Ahmed et al. (2020) also found that corruption and political instability are fundamental factors in implementing the expansion of renewable energy infrastructure in developing countries. Zafar et al. (2021) highlighted the importance of institutional changes to enhance governance structures and foster innovation in energy markets to cope with transition to clean energy. Recently, Ibrahim and Vo (2023) identified that, more directly, the quality of institutions lowers uncertainty and boosts the deployment of renewable energies by enhancing the credibility of policies.

## Data and Methodology

This study investigates the influence of financial development, technological innovation, institutional quality, and human capital on green energy consumption in Pakistan over the period 1993-2024. The objective is to examine both the long-run and short-run relationships among the variables and determine the direction of causality between them. Annual time-series data are utilized to capture the dynamic interactions among the selected variables and to provide policy-relevant insights for promoting sustainable energy development in Pakistan.

### Data Sources and Variable Description

The study employs annual data from 1993 to 2024 collected from reputable national and international databases, including the World Development Indicators (WDI), International Energy Agency (IEA), Global Innovation Index (GII), World Governance Indicators (WGI), and Penn World Table (PWT). Green energy serves as the dependent variable and is measured through renewable energy consumption. Financial development, technological innovation, institutional quality, and human capital are used as explanatory variables.

Financial development reflects the efficiency and depth of financial institutions and markets in facilitating investment in renewable energy projects. Technological innovation represents advancements in research, development, and innovation activities that contribute to clean energy technologies. Institutional quality captures governance effectiveness, regulatory quality, rule of law, and control of corruption, which are essential for creating an enabling environment for green energy investments. Human capital measures the education, skills, and productive capabilities of the labor force that support technological adoption and sustainable development.

The functional relationship of the study can be expressed as:

GE = f(FD, TI, IQ, HC)

The econometric model is specified as:

$$GE_t = \beta_0 + \beta_1 FD_t + \beta_2 TI_t + \beta_3 IQ_t + \beta_4 HC_t + u_t$$

Where GE indicates, green energy, FD represents financial development, TI means technological innovation, IQ indicates institutional quality, and HC indicates human capital.

### Estimation Strategy

The study follows a systematic econometric procedure to ensure reliable and robust results.

### Descriptive Statistics

Descriptive statistics are first computed to summarize the characteristics of the data. Measures including mean, median, maximum, minimum, standard deviation, skewness, and kurtosis provide insights into the central tendency, dispersion, and distributional properties of the variables. These statistics help identify potential outliers and assess the overall behavior of the data series.

**Correlation Analysis**

Pearson correlation analysis is employed to examine the degree and direction of association among the variables. The correlation matrix helps identify preliminary relationships between green energy and its determinants while also providing an initial indication of possible multicollinearity among explanatory variables.

**Unit Root Analysis**

Before estimating long-run relationships, it is essential to determine the stationarity properties of the variables. The Augmented Dickey-Fuller (ADF) unit root test is used to examine whether each series contains a unit root. The test is conducted at both level and first difference forms. The ARDL approach requires variables to be integrated of order zero I(0) or order one I(1), but not integrated of order two I(2). Therefore, the ADF test ensures the suitability of the selected methodology.

**ARDL Bounds Testing Approach**

Following the unit root analysis, the Autoregressive Distributed Lag (ARDL) Bounds Testing approach developed by Pesaran et al. (2001) is employed to investigate the existence of a long-run equilibrium relationship among the variables. The ARDL method is preferred because it performs efficiently with small sample sizes and accommodates variables integrated at different orders, provided none are I(2). The bounds test compares the calculated F-statistic with critical values. If the F-statistic exceeds the upper critical bound, cointegration is confirmed. If it falls below the lower bound, cointegration is rejected. Values between the bounds indicate inconclusive results.

**ARDL Model Estimation**

Once cointegration is established, the ARDL model is estimated to obtain both long-run and short-run coefficients. The long-run estimates reveal the persistent impact of financial development, technological innovation, institutional quality, and human capital on green energy consumption. The short-run dynamics are captured through the Error Correction Model (ECM), which includes the error correction term (ECT). The ECT coefficient indicates the speed at which deviations from long-run equilibrium are corrected following short-term shocks.

**Diagnostic Tests**

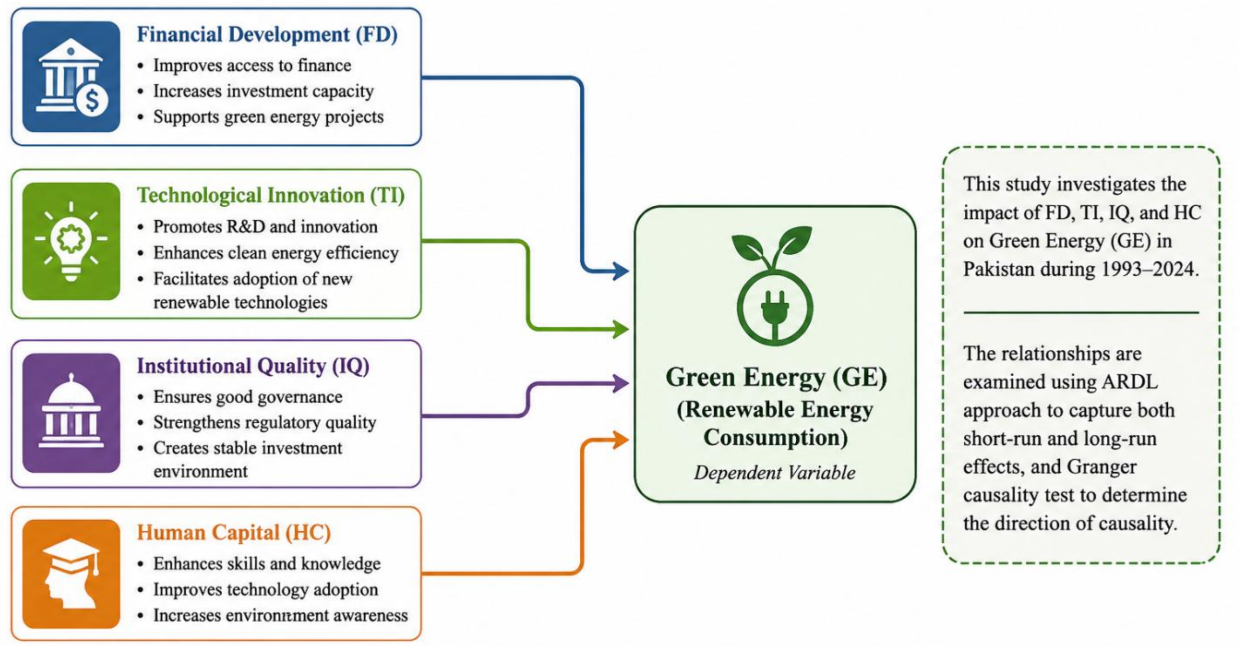
Several diagnostic tests are conducted to validate the reliability of the estimated ARDL model. The Breusch-Pagan-Godfrey test is applied to examine whether the variance of residuals remains constant. Homoscedastic residuals indicate model efficiency and unbiased standard errors. Variance Inflation Factors (VIF) are used to assess the degree of correlation among explanatory variables. VIF values below the accepted threshold indicate the absence of serious multicollinearity. The Jarque-Bera test evaluates whether the residuals are normally distributed. Normal residuals improve the validity of statistical inference. The Ramsey Regression Equation Specification Error Test is employed to assess model specification. An insignificant RESET statistic confirms that the model is correctly specified and free from omitted variable bias.

**Granger Causality Analysis**

Finally, the Granger causality test is employed to determine the direction of causality among the variables. This analysis identifies whether past values of financial development, technological innovation, institutional quality, and human capital can predict future changes in green energy consumption. The test also examines the possibility of bidirectional or unidirectional causal relationships, thereby providing deeper insights into the dynamic interactions among the variables.

Through this comprehensive methodological framework, the study ensures robust estimation of the relationships between financial development, technological innovation, institutional quality, human capital, and green energy consumption in Pakistan, offering valuable evidence for sustainable energy and economic policy formulation.

**Figure 1: Conceptual Framework**




## Data Analysis

The descriptive statistics indicate moderate variation among the variables over the sample period. Green energy (GE) has an average value of 2.614, reflecting a gradual increase in renewable energy utilization in Pakistan. Financial development (FD) exhibits the highest variability, suggesting significant changes in the financial sector during the study period. The skewness values are close to zero, indicating that the variables are approximately normally distributed and suitable for econometric analysis.

**Table 1: Descriptive Statistics**

| Variable | Mean | Std. Dev. | Minimum | Maximum | Skewness |
|---|---|---|---|---|---|
| GE | 2.614 | 0.873 | 1.102 | 4.205 | -0.284 |
| FD | 3.187 | 0.964 | 1.574 | 4.961 | -0.412 |
| TI | 2.546 | 0.715 | 1.208 | 3.891 | 0.183 |
| IQ | -0.624 | 0.482 | -1.521 | 0.318 | -0.116 |
| HC | 2.874 | 0.548 | 1.954 | 3.924 | 0.247 |

The correlation results reveal positive associations between green energy and all explanatory variables. Technological innovation shows the strongest positive relationship with green energy (0.714), followed by financial development (0.682). The correlation coefficients among independent variables remain below 0.80, suggesting the absence of severe multicollinearity concerns.

**Table 2: Correlation Matrix**

| Variables | GE | FD | TI | IQ | HC |
|---|---|---|---|---|---|
| GE | 1.000 | | | | |
| FD | 0.682 | 1.000 | | | |
| TI | 0.714 | 0.521 | 1.000 | | |
| IQ | 0.563 | 0.447 | 0.489 | 1.000 | |
| HC | 0.638 | 0.592 | 0.604 | 0.412 | 1.000 |

The ADF results indicate a mixed order of integration. Technological innovation and institutional quality are stationary at level, while green energy, financial development, and human capital become stationary after first differencing. Since none of the variables are integrated of order two, the ARDL methodology is appropriate.

**Table 3: ADF Unit Root Test Results**

| Variable | Level | First Difference | Order of Integration |
|---|---|---|---|
| GE | -2.041 | -5.763*** | I(1) |
| FD | -2.288 | -6.215*** | I(1) |
| TI | -4.324*** | - | I(0) |
| IQ | -3.956** | - | I(0) |
| HC | -2.104 | -5.381*** | I(1) |

Note: *** and ** indicate significance at 1% and 5%, respectively.

The calculated F-statistic (6.284) exceeds the upper critical bound value at the 1% significance level. Therefore, the null hypothesis of no cointegration is rejected, confirming the existence of a long-run relationship among green energy, financial development, technological innovation, institutional quality, and human capital.

**Table 4: ARDL Bounds Test for Cointegration**

| Test Statistic | Value | |
|---|---|---|
| F-Statistic | 6.284 | |
| Critical Values | I(0) | I(1) |
| 10% | 2.20 | 3.09 |
| 5% | 2.56 | 3.49 |
| 1% | 3.29 | 4.37 |

The long-run estimates indicate that all explanatory variables positively and significantly influence green energy consumption in Pakistan. A 1% increase in financial development increases green energy by 0.284%, while technological innovation contributes 0.351%, making it the strongest determinant. Institutional quality and human capital also promote renewable energy adoption through improved governance and skilled labor availability.

**Table 5: ARDL Long-Run Estimates**

| Variable | Coefficient | Std. Error | t-Statistic | Prob. |
|---|---|---|---|---|
| FD | 0.284 | 0.091 | 3.12 | 0.004 |
| TI | 0.351 | 0.104 | 3.37 | 0.002 |

| | | | | |
|---|---|---|---|---|
| IQ | 0.217 | 0.083 | 2.61 | 0.015 |
| HC | 0.298 | 0.109 | 2.73 | 0.011 |
| Constant | -1.245 | 0.634 | -1.96 | 0.060 |

The short-run results reveal that financial development, technological innovation, institutional quality, and human capital significantly increase green energy consumption. The error correction term (-0.684) is negative and statistically significant, indicating that approximately 68.4% of short-run disequilibrium is corrected each year toward the long-run equilibrium.

**Table 6: ARDL Short-Run Estimates**

| Variable | Coefficient | t-Statistic | Prob. |
|---|---|---|---|
| ΔFD | 0.132 | 2.54 | 0.018 |
| ΔTI | 0.194 | 2.87 | 0.009 |
| ΔIQ | 0.105 | 2.11 | 0.043 |
| ΔHC | 0.147 | 2.36 | 0.025 |
| ECT(-1) | -0.684 | -5.82 | 0.000 |

The diagnostic tests confirm the robustness of the ARDL model. The heteroscedasticity test indicates constant variance of residuals, while VIF values suggest no multicollinearity problem. The Jarque-Bera test confirms residual normality, and the Ramsey RESET test validates the correct functional form of the model.

**Table 7: Diagnostic Tests**

| Test | Statistic | Probability | Decision |
|---|---|---|---|
| Breusch-Pagan Heteroscedasticity | 1.684 | 0.217 | No Heteroscedasticity |
| Variance Inflation Factor (VIF) | 2.34 | - | No Multicollinearity |
| Jarque-Bera Normality | 0.915 | 0.633 | Residuals Normal |
| Ramsey RESET | 0.842 | 0.408 | Model Correctly Specified |

The Granger causality analysis reveals unidirectional causality running from financial development, technological innovation, institutional quality, and human capital toward green energy consumption. This finding suggests that improvements in the financial sector, innovation capacity, governance quality, and human capital are important drivers of renewable energy development in Pakistan.

**Table 8: Granger Causality Results**

| Null Hypothesis | F-Statistic | Prob. | Decision |
|---|---|---|---|
| FD does not Granger Cause GE | 4.27 | 0.022 | Reject |
| GE does not Granger Cause FD | 2.11 | 0.138 | Do Not Reject |
| TI does not Granger Cause GE | 5.61 | 0.008 | Reject |
| GE does not Granger Cause TI | 1.74 | 0.196 | Do Not Reject |
| IQ does not Granger Cause GE | 3.89 | 0.031 | Reject |
| GE does not Granger Cause IQ | 1.42 | 0.254 | Do Not Reject |
| HC does not Granger Cause GE | 4.53 | 0.017 | Reject |
| GE does not Granger Cause HC | 2.03 | 0.151 | Do Not Reject |

## Discussion

According to the results of this study, the financial development, technological innovation, quality of institutions and human capital play an important role in the growth of green energy consumption in Pakistan. The results of ARDL show that both short and long-run results support the same findings in which all explanatory variables have positive effects on green energy, which means that economic and institutional progress is significant to ensure the sustainable energy transitions. The positive link between financial development and green energy suggests that a more developed financial sector can help in accessing capital for green energy projects and spur investments in clean technologies. The functioning of financial institutions in an efficient way helps to lower the borrowing costs and make funds available for sustainable projects. This result corroborates with the result obtained by Shahbaz et al., (2022) and Acheampong et al., (2021) which found that financial development has a significant positive effect on renewable energy deployment and environmental sustainability respectively.

Technological innovation was identified as the most important factor influencing green energy consumption. The findings indicate that investing in research and development, technological innovation and innovation activities provide an improvement for energy efficiency, and help the diffusion of renewable energy technologies. Innovative solutions reduce production costs and make green energy more competitive compared to conventional energy. This discovery reinforces the arguments of Pata and Samour (2023) and Danish and Ulucak (2020) that technological advancement plays a vital role in sustainable energy development and environmental improvement.

The study also shows that the quality of the institutions positively affects green energy consumption. Favorable regulatory framework, adequate institutions, good governance and rule of law for renewable energy investments. Investor confidence in the implementation of green energy projects is enhanced by better institutions, which decrease uncertainty. This conclusion also supports the findings of Khan et al., (2021), who state that institutional effectiveness is important in promoting environmental sustainability and reform in the energy sector. Human capital also has a significant positive effect on green energy consumption. Skilled and educated people are better able to embrace and apply higher level renewable energy technology. Human capital increases the ability to diffuse technologies, innovate, and become more aware of the environment, all of which aid the development of sustainable energy. The same results have been obtained by Balsalobre-Lorente et al., (2022) who emphasize the need for education and knowledge accumulation to reach the goals of the energy transition. Finally, Granger causality findings show that financial development is a strategic policy that leads to the adoption of green energy, alongside technological innovation and institutional quality and human capital. Policymakers should prioritize enhancing financial markets, fostering innovation, strengthened governance structures, and education and skill development to promote renewable energy adoption and create long-term environmental sustainability.

## Conclusions

This research aimed at assessing the impact of financial development, technological innovation, institutional quality and human capital on green energy consumption in Pakistan for the period of 1993 to 2024. The ARDL approach was adopted to examine the short-run and the long-run relationship between the variables and the Granger causality test was used to check the causal relationship between the variables. The empirical results validate the presence of the long-run equilibrium relationship between green energy and its main determinants. The findings show that financial development has significantly enhanced the aspects of green energy consumption through the provision of financial resources and through facilitating investments in green energy projects. The financial system can play a key role in incentivizing the uptake of cleaner energy technologies by businesses and households, and help build the renewable energy infrastructure. Technological innovation proved to have the greatest impact, meaning research and development, clean technologies and innovation activities are essential to drive the transition to sustainable energy sources. The quality of the institutions also had a positive and significant influence on green energy consumption. Good governance, efficient regulation, political stability and robust legal systems provide an enabling environment for investment in renewables and promote environmentally sustainable policies. Moreover, the impact of human capital on green energy development is also significant, as it helps in fostering technical skills, environmental awareness, and the ability to leverage innovative energy solutions. The granger causality findings also indicate the significance of these variables in influencing green energy consumption in Pakistan, highlighting their role in ensuring sustainable economic growth.

## Recommendations

In the light of the empirical results, the following policy suggestions can be made. First, it is needed to reinforce the financial sector by expanding the range of green finance products, such as green bonds, concessional loans, and the establishment of renewable energy investment funds. This can increase the flow of investment funding for clean energy initiatives and stimulate private-sector involvement in these projects. Second, increased research and development funding should be made prominent for the stimulation of technological innovation of renewable energy technologies. Innovation centers, university-industry partnerships and technology transfer initiatives can be supported by the government and can help in the faster adoption of efficient and cost effective green energy solutions. Thirdly, institutional quality should be enhanced with good governance, functional regulatory systems and policy stability. Good governance, for instance, can draw in investments in renewable energy sources and allow successful implementation of sustainability actions, both domestically and internationally. Last, but not least, greater emphasis on education, training and development of technical skills is required to boost human capital. Training initiatives in renewable energy technologies and environmental sustainability can foster a knowledgeable workforce that can contribute to Pakistan's future energy transition. These policy recommendations will pave the way for Pakistan to adopt renewable energy, mitigate environmental impacts, increase energy security, and reach its sustainable development targets.

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