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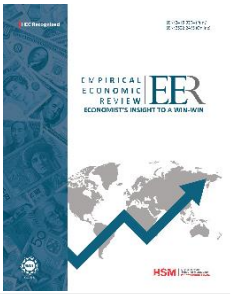

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Role of Energy Accessibility in Human Development: Evidence from Empirical Analysis of Pakistan

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Abstract

Energy is essential to human advancement since it boosts social growth and production. Numerous studies have demonstrated a long-term correlation concerning energy use and economic expansion, which is frequently gauged by financial metrics. Building on this framework, the current study applied the Autoregressive Distributed Lag (ARDL) approach to explore the long-term association between energy accessibility and human progress in Pakistan for the time period 1998-2020. The results showed that increased admittance to electricity has a long-term positive impression on the Human Development Index (HDI). Likewise, increased use of clean fuels improves household health and living standards, which have a favorable impact on HDI. Additionally, trade openness, employment, and Foreign Direct Investment (FDI) all take positive effects on human development. Based on the results, the study suggested that there is a need for policymakers to increase access to dependable power and encourage the use of clean energy sources as crucial tactics in order to enhance human welfare and attain sustainable development in Pakistan.

***Keywords*:** clean fuel, energy use, foreign direct investment, human development index, human welfare

Introduction

Energy is the driving force behind human progress, and it boosts productivity by hastening social advancement. Without guaranteeing and gaining contact to clean, reliable, and low-cost energy, it is impossible to fulfill sustainable communal and financial development goals. A household with reliable and affordable access to clean cooking services and electricity that meets initially basic energy needs and progressively improve to achieve the average level of energy services within the local community. (International Energy Agency [IEA], 2020). Energy has a direct impact on mankind, groups, and nations in terms of economic development, security,

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atmosphere, and education (Mohamadi et al., 2019; Sasmaz et al., 2020).

Energy accessibility is widely acknowledged as a key factor in human growth, impacting health, education, economic productivity, and living standards. Reliable and reasonably price energy is still not fairly distributed throughout socioeconomic categories and geographical areas in emerging nations, such as Pakistan. This leads towards differences in opportunities and well-being. In addition to helping businesses and organizations, access to contemporary energy services allows households to enhance their quality of life through improved lighting heating, communication and information access. Resultantly, energy is not just a production input but also a vital enabler of human potential.

Global energy demand has risen as a result of development, population increase, and economic expansion. The world's energy usage increased by almost 44% between 1971 and 2014 (Sasma et al., 2020). However, there is a shortage of energy resources worldwide as compared to its demand. For instance, in 1990, there were about 1.5 billion people without admittance to electricity; by 2015, there were 952 million (Ritchie et al., 2019). Recent wave of COVID-19 pandemic had an inverse effect on this energy demand. Around 1% less electricity was spent globally in 2020, with COVID-19 lockdown limiting commercial and industrial events during the first part of the year. With the economic condition probably to choice up and emerging economies like China facing strong growth, the demand for electricity was predictable to rise by 4.5% in 2021 (IEA, 2021).

Human development is a multifaceted notion that gauges the wealth, health, and education of nations (United Nations Development Programme [UNDP], 2022]. All these indicators are related with energy availability nowadays. Efficient energy availability creates new opportunities for production, income, and human capital. It has been widely acknowledged that there is a long-term cointegration and causality between energy depletion and economic growth, as measured by financial measures, such as Gross Domestic Product (GDP), Gross National Product (GNP), or GDP per capita (Lee 2005; Soytas & Sari, 2003; Simionescu, 2020; Skare et al., 20220). Better energy accessibility also contributes to higher human growth of a state (Nussbaumer et al., 2013; Sarkodie & Adams 2020).

Recent literature has increasingly focused on the connection between Human Development Indicators (HDI) and energy. Research has

demonstrated that energy access improves health and education results by facilitating cleaner home environments, better lighting, and better healthcare services (Adjei-Mantey, 2024; Chowdhury & Hossain, 2025). Similarly, switching to clean fuels lowers indoor pollution, lowers health risks, and improves sustainable economic growth. Living standards and productivity have increased rapidly in nations around the world that have guaranteed universal admittance to contemporary energy services (Li et al., 2024). However, in developing nations, such as Pakistan, access to energy is still unequal and the energy mix is largely conquered by unclean fuels. Regular power outages, low rates of electrification in rural regions, and a slow uptake of clean fuels limit economic potential and impede the advancement of humankind.

Due to infrastructure deficiencies, budgetary limitations, and problems with power sector governance, Pakistan continues to struggle to guarantee fair access to energy. Indicators of human growth, such as income levels, health outcomes, and educational achievements are affected by these issues. Therefore, it becomes essential to empirically comprehend the bond between energy accessibility and human development in order to create policies that effectively support social welfare and inclusive growth. This study added to the current discussion on ecological development and changes to energy policy by offering empirical data on how energy accessibility affects human development outcomes in Pakistan.

Despite its importance, energy accessibility in Pakistan is marked by severe regional and rural-urban discrepancies. While many villages still face frequent power outages, poor grid connectivity, or reliance on conventional biomass fuels, urban regions typically have higher electrical coverage and dependability. These disparities can impede the development of human capital by impacting study time, access to digital technology, and provision of health services. Moreover, inconsistent energy supply constrains industrial and service-sector operations, reducing employment prospects and revenue production, which are fundamental components of human development.

From a policy perspective, improving energy accessibility is closely aligned with Pakistan's assurances to the Sustainable Development Goals (SDGs), mainly SDG 7(affordable and clean energy), SDG 3, and 4, which are related to health and education. Empirical analysis of the energy-human development nexus can provide evidence-based insights for policymakers

to prioritize investments in energy structure, renewable energy expansion, and inclusive energy policies. By quantifying the impact of energy openness of human development, this study aimed to inform strategies that foster sustainable and inclusive development in Pakistan.

Over the past 20 years, Pakistan has made significant strides towards increasing access to electricity. Recent development indicators show that majority of the population now has access to electricity, and the use of clean cooking fuels has increased especially in metropolitan areas. Nonetheless, there are still considerable differences between rural and urban areas, and many people continue to use conventional biomass fuels. Pakistan is still dealing with issues including energy security, power outages, and growing energy consumption brought on by economic expansion and population growth. Future energy accessibility is anticipated to be significantly enhanced by continued investment in clean energy infrastructure, grid expansion, and renewable energy.

Energy accessibility in Pakistan is expected to improve in the upcoming years due to increased expenditures in clean cooking energy efforts, rural electrification programs, and renewable energy projects, based on existing trends and national energy policies. Since increased access to contemporary energy services improves socioeconomic possibilities and general quality of life, it is reasonable to expect additional advances in the Human Development Index (HDI).

The current study aimed to investigate the association between energy accessibility (by using access to electricity as its proxy) and HDI in Pakistan. Furthermore, this study used other control variables to evade biasness in model. The remaining part of the study discussed literature review, data sources, econometric model and technique, as well as results and conclusion.

Problem Statement

A sizeable section of Pakistan's population still struggles with access to clean cooking fuels and a consistent supply of electricity, despite tremendous advancements in country's energy infrastructure. Human progress can be hampered by limited energy accessibility, which may have a negative impact on productivity, health, education, and general living standards. The relationship between energy consumption and economic growth has been thoroughly studied in the past. However, how energy

accessibility affects more general aspects of welfare as determined by the HDI has received comparatively less attention. Therefore, it is necessary to look at whether increased access to energy benefits Pakistan's human development.

Research Objectives

The primary goal of the current study was to investigate how energy accessibility has affected Pakistan's population growth between the years 1998-2020. In particular, the study sought to:

- Examine the long-term connection between human progress and energy access.
- Analyze how HDI is affected by the availability of clean fuels and technology.
- Examine how employment, trade openness, and Foreign Direct Investment (FDI) contribute to human development.
- Make policy suggestions to advance human growth by making energy more accessible.

Literature Review

Theoretical Review

Amartya Sen's Capability Approach served as the main theoretical basis for this investigation. This method emphasizes that progress should be seen as the growth of people's capacities and liberties rather than only an increase in revenue. By boosting educational possibilities, healthcare services, productivity, and information access, access to contemporary energy services is essential to strengthening these capacities. Better learning environments, healthcare facilities, and commercial activities are all made possible by reliable energy, which enhances human well-being. Therefore, it is anticipated that increased energy accessibility would advance human development as determined by the HDI.

Sustainable development theory, which emphasizes striking a balance between social welfare, economic progress, and environmental sustainability, also lends support to this study. Modern and clean energy services are seen as crucial elements of sustainable development. This is because these raise standards while lowering the risks to the environment and human health connected with traditional energy sources. Access to

dependable power and clean cooking fuels promotes social inclusion, increased productivity, and better health outcomes, all of which support sustainable human development. According to the hypothesis, reaching long-term development objectives requires an increased access to contemporary energy services.

Empirical Review

Energy impacts all facets of human activity and growth. It is fundamental to understand human well-being (Singh et al., 2015). Additionally, energy is important to reduce scarcity, enhance human well-being, and enrich living standards. However, the mainstream of the current electricity supply and usage patterns is indefensible (Vera & Langlois, 2007). Access to natural resources (such as water, power, and fuel) is crucial to enhance both the short and long-term welfare of individuals as well as households. Utilizing resources helps raise people's standards of living (Panigrahi, 2021).

The manufacturing sector of a country largely relies on energy accessibility. Production increases GDP or economic growth of a nation that enhances human development (Grimm et al., 2013; Ray et al., 2016). It is quite challenging to imagine development of a nation without the use of energy in this era of digital economy. For economic and social development, modern energy sources, such as electricity are essential (Wolde-Rufael, 2006). Ateba et al. (2019) sought to identify the link between South Africa's electricity supply and industrial development as well as to assess the impact of an unbalanced supply on business operations. The study also evaluated administrative and industrial initiatives to ensure a steady supply of electricity for industry.

Efficient access to energy brings job opportunities in an economy. This job creation due to energy availability can improve household income level and economic growth as an end effect (Acheampong et al., 2021; Abbasi et al., 2022). Rehman and Alam (2021) explored the impact of admittance to electricity and health facilities on women's well-being. Women's life expectancy at birth is positively impacted by access to electricity, public health spending, and immunization rate, while the rate of female adult mortality is negatively impacted by these same factors.

An increasing amount of research emphasizes how important energy access is for advancing human development in both industrialized and

emerging nations. According to early research, having admittance to electricity and contemporary energy facilities enhances domestic welfare by facilitating improved heating, lighting, as well as information and communication technologies (Ajide et al., 2025). By improving productivity, health, and educational performance, these advancements support human progress as a whole. Researchers have also observed that energy is a crucial component of sustainable development plans since it is a necessary input for accomplishing a number of development goals.

The HDI, life expectancy, and educational outcomes are all positively correlated with energy use, according to empirical research employing cross-national and panel data methods. Higher per capita power usage, for instance, is linked to better health and educational outcomes, particularly in, low- and middle- income nations conferring to various researches (Quarcoo et al., 2025). Some academics contend that the relationship is not exactly linear. This highlights the significance of energy efficiency and renewable energy sources.

Research indicates that inadequate access to dependable electricity and energy poverty impedes socioeconomic development in emerging nations. Traditional biomass fuels, which are linked to poor health outcomes and poverty, especially for women and children, are frequently used by low-income households and rural people. Expanding access to electricity can boost human development outcomes by increasing school attendance, lowering health hazards from indoor air pollution, and supporting income-generation activities according to studies on South Asia and Sub-Saharan Africa (Julistia et al., 2025).

Recent literature has highlighted enduring issues with energy infrastructure, affordability, and governance that limit development results, particularly from Pakistan. Few studies have specifically addressed energy accessibility and human development. However, earlier empirical research on Pakistan has examined the effects of energy use on economic growth and environmental quality. This resulted in a research break that this study aimed to fill by offering actual data on the impact of energy accessibility on human development in Pakistan. Moreover, this study added to a more thorough information of connection between energy and development in the Pakistani setting by including HDIs in the analysis.

Bano et al. (2018) examined the association between human capital and

carbon emissions in Pakistan's economy during the years 1971-2014. The "Cointegration-effect" and casual relationship between the research variables were examined using the ARDL model. The research revealed long-term correlation between carbon emissions and human capital. Additionally, Pakistan's economy would produce less CO2 due to the increase in the value of human capital. The study also addressed environmental sustainability through investment in human capital.

Komal and Abbas (2015) conducted research to examine the connection between money, progress, and energy for Pakistan for the time period 1972-2012. The study used the system GMM estimate technique and incorporated energy pricing and urbanization into the structural model in an effort to understand the influence of monetary development over energy utilization through the economic growth strait. Saepudin (2018) observed the relationship between the electrification rate and the HDI in the West Java Province's rural areas. In order to rise the attainment of the electrification relation and HDI, a rural electric program was developed using an analytical descriptive method. West Java Province's electricity rate could increase more quickly. The HDI's component parts were calculated using per capita spending, life expectancy, regular length of schooling, and school life expectancy. HDI exhibited a rising value despite being less than the normal national HDI (Indonesia).

Macro-level empirical research continuously shows that energy access and consumption are positively correlated with a number of development metrics. While panel studies show a long-term connotation between energy use and various welfare measures, cross-country analyses suggest that countries with higher per capita energy consumption tend to achieve higher level of living, literacy, and per capita income (Elom etb al., 2024; Ma et al., 2024; Tian et al., 2024). An increasing body of research distinguishes between energy quantity and quality. This emphasizes that clean, inexpensive, and dependable energy services are more important for human outcomes (Djoudji & Nguea, 2025).

In developing nations, indoor air pollution from conventional biomass fuels has been recognized as a serious health risk. Adaptation of clean fuels (such a s LPG, electricity and biogas) results in quantifiable improvements in respiratory health, lower rates of premature mortality, and better time allocation. All of these increase opportunities for income generation and educational activities, according to studies that focus on household level

data. The study also emphasized how adopting clean fuels has generated benefits, with women and young children frequently seeing most of the improvement in terms of time and health. Therefore, clean fuel policies act as tools for human growth as well as environmental action.

Methodology

Model Specification

The current research aimed to explore the relationship between accessibility to energy and HDI in the context of Pakistan. Therefore, the study specified the equation as: HDI is associated with access to electricity, clean energy, and other independent variables.

$$HDI=f(access, clean, X)$$

The study transformed this function into econometric equation to empirically evaluate the thorough influence of accessibility to energy on human development.

$$HDI_t= \beta0 + \beta1ACCESS_t+ \beta2CLEAN_t+ \beta3EMPLOYMENT\ t+\beta4FDI_t + \beta5TRADE_{t+}\ \varepsilon t$$

Access to electricity and HDI should be significantly and favorably correlated ($\beta1 > 0$). Similar to this, it is anticipated that access to clean fuel would have a favorable and considerable impact on HDI ($\beta2 > 0$). The projected impact for employment and FDI is ($\beta3 > 0$), and ($\beta4 > 0$), respectively. Similar to this, trade is anticipated as ($\beta5 > 0$).

Previous studies have examined the relationship of HDI with GDP, population, tourism, and globalization (Acheampong et al., 2021; Minhaj et al., 2007; Singh et al., 2015). Energy accessibility creates job opportunities. By increasing income level, energy access improves human well-being. The welfare of a country can be measured through HDI. Therefore, it can be said that energy access has an important impact on HDI of a country (Acheampong et al., 2021; Vera & Langlois, 2007). Entrance to clean energy also has an important effect on environment, health, and socio-economic well-being of human beings (Mamidi et al., 2021). All these factors affect HDI as it incorporates health, income, and literacy level. Trade and FDI promote economic development and the labor market (Hoang et al., 2010). Additionally, trade and FDI endorse surroundings with substantial tax motivations. Moreover, it promotes national import and export of goods and services and makes resilient commodities accessible

(Goldar & Banga, 2007). Similarly, trade and FDI provide employment prospects in society, according to Messerlin (1995) and Hoekman (2005). This may promote the process of human development.

Data Source

The UNDP and World Bank database, which cover the years 1998-2020, provided the data for this study. The time period was chosen depending on the data availability. The UNDP served as the source of the information for the HDIt. Access to electricity was used as a proxy of accessibility of energy. In this study, access to clean energy referred to clean fuels and technology used for cookery. Employment level was taken as percentage of population who were employed.

Table 1

Variables, Definitions, Indicators, and Data Collection Sources

Variables	Sign	Definition	Source
Human Development Index	HDI	Human development index (HDI)	UNDP
Accessibility to Electricity	Access	Access to electricity (% of population)	WDI
Accessibility to Clean Energy	Clean	Access to clean fuels and technologies for cooking (% of population)	WDI
Employment Level	Employment	Employment to population ratio, 15+, total (%)	WDI
Foreign Direct Investment (FDI)	FDI	FDI, net inflows (% of GDP)	WDI
Trade Openness	Trade	Trade (% of GDP)	WDI

There are other methods for calculating cointegration, such as the Engle and Granger (1987) test based on residuals and the Johansen (1991) and Johansen and Juselius (1990) tests based on maximum likelihood. To use techniques, all variables must be stationary at the same level. The ARDL bounds testing approach to cointegration was created by Pesaran et al. (2001) and is better suited to small samples. According to Pesaran et al., (2001), *F*-statistic values are produced for the correlations between the selected variables' critical bound values in order to verify the cointegration

between them.

The series are cointegrated in the ARDL bounds testing if the estimated *F*-statistic surpasses the upper critical bound, and there is no co-integration if it is below the lower critical limit. By means of the minimum values of both AIC and SBC14, the lag length is chosen. The diagnostic tests look for white heteroscedasticity, serial correlation, ARCH, the functional form of the model, and residual normalcy. Using the Cumulative Sum of Recursive Residuals (CUSUM) and the Cumulative Sum of Squares (CUSUMsq) of recursive residuals, the constancy test of long and short-run constraints is inspected.

Results and Discussion

This study was conducted to build a connection between human development and energy accessibility in the case of Pakistan by implementing time series data for the time period 1998-2020. HDI was used as dependent variable, and access to electricity, clean energy, employment, FDI, and trade were used as independent variables. Before running the regression, correlation matrix was constructed to examine the multicollinearity of variables.

Pesaran et al. (2001) developed the ARDL modelling approach. This approach is frequently used to examine the short and long-term interactions between time series data, as long as none of the variables are integrated at order I(2). One of the main benefits of the ARDL technique is that it can be used when the variables are integrated at various orders, that is, is I(0) and I(1). Due to its adaptability, ARDL is especially well-suited for macroeconomic research in emerging nations, where variables frequently display heterogeneous orders of integration.

Using the ARDL model, the current study examined the relationship between energy accessibility and human development in Pakistan. The dependant variable and explanatory variable lags were included in this generic ARDL specification, which enabled the model to capture dynamic changes across time. This concept is helpful because advances in human development may not always result from changes in energy accessibility; rather, institutional, social, and economic adjustment processes may lead the effect to appear gradually.

Table 2
Descriptive Statistics (N = 23)

	HDI	Access to Clean Energy	Access to Electricity	Employment	FDI	Trade
Mean	0.50	34.576	71.157	49.85783	1.13	30.29
Median	0.51	33.9	70.69711	50.067	0.77	30.90
Maximum	0.58	49.3	75.37969	50.669	3.67	35.68
Minimum	0.42	22.25	70.26535	47.729	0.38	24.70
Std. Dev.	0.04	8.587	1.273569	0.618518	0.94	3.358
Skewness	-0.04	0.147172	2.28501	-1.94005	1.77	-0.09
Kurtosis	2.04	1.752004	7.332958	7.270256	4.79	1.74
Jarque-Bera	0.88	1.575626	38.00712	31.90323	15.09	1.54
Probability	0.64	0.454839	0	0	0.0005	0.46
Sum	11.59	795.25	1636.613	1146.73	25.90	696.73
Sum Sq. Dev.	0.03	1622.454	35.68353	8.416408	19.27	248.01

The descriptive statistics indicate that, over the 23-year period, the average HDI is 0.504, showing a moderate level of human development in the selected sample. Access to clean energy has an average value of 34.58%, whereas access to electricity is much higher at 71.16%. This suggests that electricity access is relatively widespread compared with clean energy use. The employment rate remains fairly stable around 49.86%, with only slight fluctuations over time. In contrast, FDI appears more unstable, as its values vary more noticeably across the years. Trade records an average of 30.29%, reflecting a moderate contribution to the economy. Overall, the results suggest that while human development, employment, and trade remain relatively steady, energy-related variables and FDI show greater variation during the study period.

Table 3
Correlation Matrix

Correlation	HDI	Access	Clean	Employment	FDI	Trade
HDI	1					
Access	0.749	1				
Clean	0.99	0.76	1			
Emply	-0.56	-0.84	-0.57	1		
FDI	-0.11	-0.23	-0.20	0.06	1	
Trade	-0.23	-0.32	-0.28	0.29	0.56	1

Table 3 shows that access to electricity and clean energy are positively correlated with HDI. This correlation is significant also. Employment, FDI,

and trade are negatively correlated with HDI but insignificantly. Employment, trade, and FDI are negatively correlated with clean energy. The relationship of employment and access to energy is significant. All other variables are definitely connected with each other.

Table 4
Variance Inflation Factor (VIF)

Variables	Coefficient Variance	Uncentered VIF	Centered VIF
Access	3.80E-06	19827.66	6.073542
Clean	3.42E-08	44.58115	2.483968
Emply	1.04E-05	26492.68	3.899369
FDI	1.90E-06	4.118528	1.638396
Trade	1.47E-07	140.0462	1.62653
C	0.077175	79429.28	NA

Table 4 indicates the VIF. The values of centered VIF demonstrate that the model of this research is not subject to multicollinearity as these values are less than 10 for all variables.

Table 5
Unit Root Results

Variables	Level		1st Difference	
	Intercept	Intercept and Trend	Trend	Intercept and Trend
HDI	0.9895	0.6582	0.0370	0.1775
Access	1.0000	1.0000	0.0674	0.016
Clean	1.0000	0.0467	0.0118	0.0029
Emply	0.9933	0.9913	0.0709	0.0378
FDI	0.1604	0.3561	0.0541	0.0041
Trade	0.2627	0.5426	0.001	0.0063

Table 5 reports the results of unit root test. This study used ADF test to verify the stationary of series. Values in Table 5 show that clean energy variable is stationary at level but all other variables are stationary at 1st difference. It can be seen that none of the variable is integrated of 2nd difference. So, these results support the application of ARDL on this data series.

Adding FDI, trade, and employment (emply) as control variables, the study aimed to examine the long- and short-run subtleties between

electricity accessibility and HDI during 1998 and 2020.

Table 6
Long-run Results

Variables	Coefficient	Std. Error	*t*-statistics	Prob.
Access	0.00941	0.00308	3.05169	0.011
Clean	0.00399	0.00019	21.6026	0
Emply	0.01032	0.00301	3.42346	0.0057
FDI	0.00637	0.00088	7.22724	0
Trade	-0.0005	0.0003	-1.6699	0.1231
C	-0.8035	0.33349	-2.4092	0.0347

The long-run results shown in Table 6 indicate that all independent variables of this study have positive relationship with HDI except trade (Martinez & Ebenhack, 2008; Wang et al., 2018). These coefficient values are significant at 5% level. A 1% upsurge in accessibility to energy directs to 0.0094% increase in HDI. These results are in harmony with Acheampong et al. (2021). Energy contributes a dynamic part in the present world. Access to energy opens new doors for earning opportunities. It ensures individuals to have jobs in many sectors. Having an earning source confirms human welfare, so is the case with human development. As far as the clean energy is concerned, it benefits women more. They can save their time while using clean fuel for cooking, and may spend this saved time to groom themselves or in earning. This study showed that a 1% increase in clean energy source can improve the HDI by 0.00399%.

As economy provides greater access to energy, its production sector grows. Expanded production sector means new employment opportunities would open. Human development results show that a 1% increase in employment leads towards 0.010% growth in HDI. FDI is also positively related with HDI. A 1% rise in FDI leads towards 0.0063% escalation in HDI. According to the current study, only trade has negative relationship with HDI but its coefficient value is not significant at 5%.

Table 7
ECM Results

Variables	Coefficient	Std. Error	t-statistics	Prob.
D(Access)	0.000288	0.000757	0.380961	0.7105
D(Employment)	-0.0036	0.001234	-2.91491	0.0141
D(FDI)	0.000354	0.000767	0.462266	0.6529

Variables	Coefficient	Std. Error	t-statistics	Prob.
D(Trade)	0.000174	0.000164	1.059512	0.3121
CointEq(-1)*	-0.53653	0.036425	-14.7299	0.0000
R^2	0.849208	Mean Dependent Var	0.006455	
Adjusted R^2	0.813728	S.D. Dependent Var	0.004459	
S.E. of Regression	0.001924	Akaike Info Criterion	-9.47181	
Sum squared resid	6.29E-05	Schwarz Criterion	-9.22385	
Log Likelihood	109.1899	Hannan-Quinn Criteria	9.4134	
Durbin-Watson Statistic	2.176295			

As the value of ECM in above table is between 0 to -1 and significant at 1%, it shows that model would converge towards equilibrium gradually. ECM coefficient value shows that deviation of HDI from equilibrium in the present period would be modified by 53% in the succeeding year. The short-run coefficient value of access to energy variable shows that it has a positive impact on HDI. However, its long-run value is greater than its short-run value and also significant in long-run. Access to electricity has positive and significant effect on HDI in short-run.

In time-series econometric analysis, guaranteeing the validity and dependability of derived models entails running many diagnostic tests. One of the essential assumptions in conventional regression analysis is that the residuals (error terms) of the model are normally disturbed. Although the ARDL framework is reasonably resilient to violations of several classical assumptions, evaluating the normality of residuals remains critical for statistical inference, hypotheses testing, and model reliability.

The error term has a bell-shaped distribution with a zero mean and constant variance if the residuals are normal. Since proper t-tests and f-tests depend on the assumptions that residuals are normally distributed, especially in small samples, this assumption is very crucial. The calculated standard errors and test statistics may be skewed if the residuals considerably vary from normality, which could result in erroneous conclusions about the importance of explanatory variables.

This study used the Jarque- Bera (JB) test, which is frequently employed in econometric research, to determine whether residuals are normal. The JB test determines whether the residuals' skewness and kurtosis are consistent with a normal distribution. The residuals' normal distribution is the test null hypothesis. The null hypotheses cannot be rejected when the probability value is greater than 0.5, indicating that the residuals have the normal distribution. On the other hand, a low *p*-value denotes the non-normality,

which could suggest the presence of outliers or model misspecification.

In addition to normality testing, further diagnostic tests are performed to assess the robustness of the ARDL model. Autocorrelation in residuals can be found using the Breusch-Godfrey serial correlation test. Error terms are frequently connected over time in time-series data, a phenomenon known as 'serial correlation'. It can result in biased standard errors and ineffective estimations if it is present. To determine if the variance of the residuals is constant over time, a heteroscedasticity test (such as the Breusch Pagan or the white test) is also performed. Heteroscedasticity may lead to false inference and wasteful estimations.

Additionally, the stability of the calculated coefficients during the sample period is evaluated using model stability tests, such as the CUSUM and CUSUMSQ in Pakistan, where the energy industry has undergone structural changes, governmental reforms, and foreign shocks. Stability tests make sure that structural failures or regime changes have no effect on the estimated associations between energy accessibility and human development.

Table 8

Diagnostic Tests

Tests	Approach	Probability Value	Remarks
Serial Correlation	Breusch-Godfrey Serial Correlation LM Test	0.0618	No serial correlation
Heteroscedasticity	Breusch-Pagan-Godfrey	0.5418	No hetro
Ramsey test	Ramsey RESET Test	0.1647	Correct model specification

Table 7 also shows the results of diagnostic tests. The Durbin Watson test and the LM test have been used in this work to evaluate the endogeneity, model's heteroscedasticity, and correlation. The Pesaran et al. (1991) proposals for CUSUM and CUSUM2 were approved out to evaluate the stability of the model. The adopted model is in good health, according to diagnostic tests. The blue lines of both CUSUM indicate that the estimated results are trustworthy for policy implications. Figure 1 and 2 depict the CUSUM2 sitting near the 5% threshold between the critical boundaries'

level of relevance. This supports the model's accuracy as well as the long-term and short-term variables.

Figure 1

Recursive Residual's Cumulative Total at 5% Significance

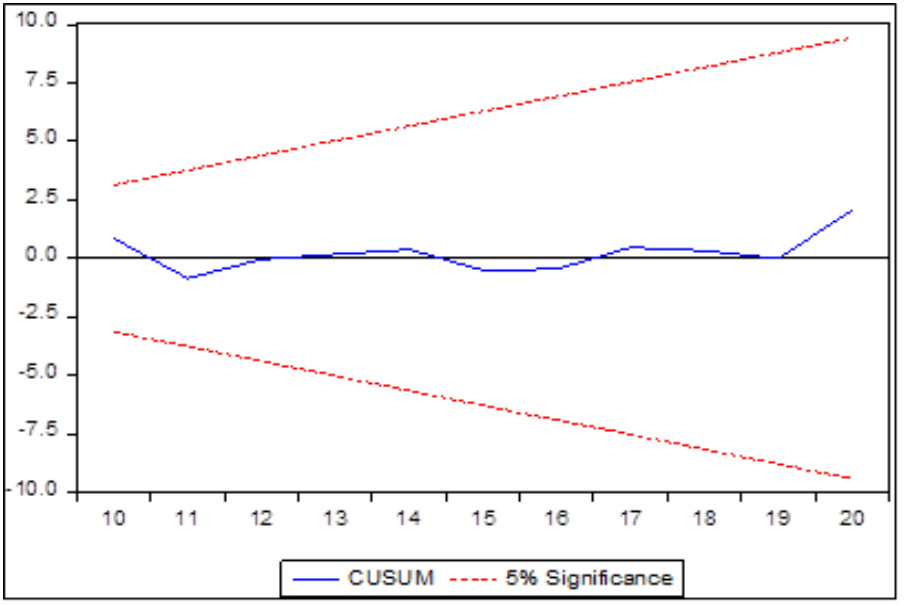
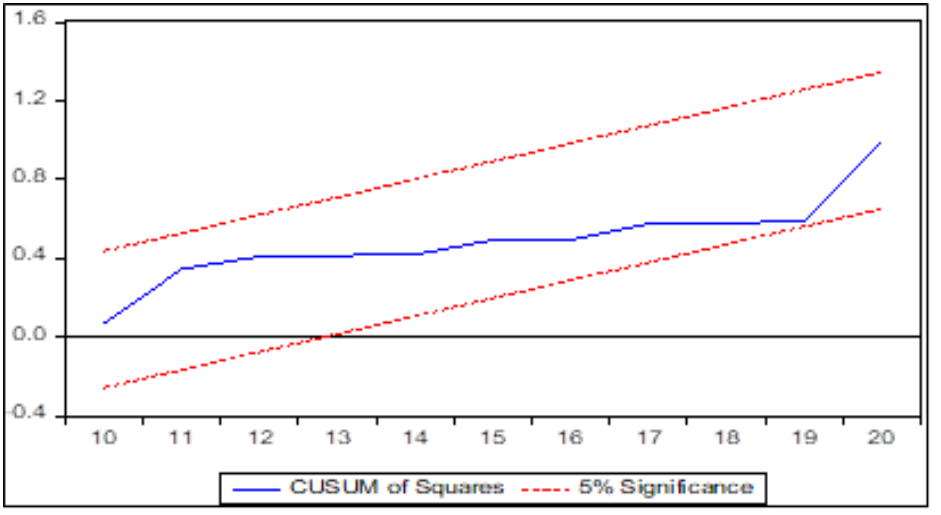


Figure 2

Cumulative Sum of the Square of the Recursive Residual



Policy Implications

The study's conclusion has a number of significant policy ramifications for Pakistan. Firstly, authorities should give energy infrastructure expenditures top priority, especially in neglected rural and remote areas, given the beneficial effects of power availability on human development. Modernizing and expanding the electrical infrastructure may provide access to healthcare, education, and employment possibilities, improving human well-being in general.

Secondly, the use of clean fuels has made a substantial contribution to human growth, which emphasizes the need to support sustainable and reasonably priced clean energy options. Initiatives by the government to expand access to natural gas, LPG, and renewable energy technology may lower reliance on conventional biomass fuels, enhance public health, and improve living conditions.

Thirdly, authorities should keep enacting policies that promote international commerce and draw investment in the energy sector since trade openness and FDI have a favorable impact on human development. These expenditures can promote the growth of contemporary energy infrastructure, increase energy efficiency, and encourage technological transfer.

Furthermore, as increased employment directly contributes to advancements in human development, creating jobs should continue to be a primary policy goal. Access to contemporary energy services can be improved and new economic possibilities could be created by integrating energy policy with labor market and industrial development initiatives.

Lastly, a comprehensive policy framework that concurrently addresses energy accessibility, economic growth, social welfare, and environmental sustainability is necessary to achieve sustainable human development goals. This would require bolstering renewable energy initiatives, enhancing energy governance, and guaranteeing fair access to contemporary energy services.

Conclusion

In the contemporary world of globalization, human development cannot be imagined without energy accessibility. Many studies have been conducted on energy importance for human development for different

regions and countries. However, there is a study gap in the case of Pakistan. So, the current research highlighted the long-run association between energy accessibility and HDI in the case of Pakistan during the time period 1998 to 2020, with ARDL approach to co-integration. The results confirmed that electricity accessibility can improve HDI in long-run.

Using the time-series ARDL framework, this study empirically investigated how energy accessibility contributes to human development in Pakistan. The results showed a strong long-term correlation between human development and energy accessibility. This suggests that better access to contemporary energy services enhances welfare outcomes. By promoting economic activity, healthcare, and education, energy accessibility raises living standards and strengthens the human growth as a whole.

The empirical findings also showed that short-run dynamics are important. This is because human development outcomes can be momentarily impacted by energy supply shocks before the system yields to its long-run equilibrium. The error correction mechanism emphasizes the significance of stable and consistent energy policies by confirming the derivations for equilibrium are corrected over time. Overall, the findings corroborated the concept that energy is not only an economic input but a vital social foundation for human progress.

From a policy standpoint, the findings indicated that increasing access to reasonably priced and dependable power ought to be a top priority for national development. To lessen regional differences in human development results, policymakers should concentrate on enhancing energy infrastructure, especially in disadvantaged and rural areas. Achieving equitable development can be greatly aided by investments in off-grid renewable energy systems, grid extension, and rural electrification initiatives. To guarantee long-term energy security and environmental sustainability, the government should support clean and sustainable energy sources. The energy industries' efficiency and financial sustainability can be improved by promoting private sector involvement, strengthening power sector governance, and enacting tariff reforms that strike a balance between affordability and cost recovery. The development advantages of increased energy availability can be further enhanced by integrating energy policy with planning for the health and education sectors.

Future Research Directions

Lastly, by utilizing disaggregated regional or household-level data, future research should examine how energy poverty, energy efficiency, and renewable energy accessibility influence human development outcomes. Such research would aid in the development of focused inventions and offer greater insights into the distributional effects of energy policies. In general, attaining Pakistan human's development objectives and pledges under the SDGs depends on providing universal and sustainable energy access.

Moreover, clean fuel usage improves the living standards of households, which, in turn, may improve their health and income. So, use of clean fuel also has a positive impact on HDI. Other independent variables, such as employment, FDI, and trade also treated HDI positively. To boost human development and expand access to energy, policymakers in Pakistan must prioritize energy sector investment and strengthen the institutional capacity of organizations that deal with energy in order to design and manage energy substructure projects. Additionally, expanding access to energy is necessary to guarantee improved socioeconomic outcomes. This calls for private sector involvement in the energy market. Policymakers must establish a favorable climate to draw prospective private investors to the energy sector by putting in place suitable regulatory frameworks and supplying incentives for these potential investors, such as tax breaks and subsidies.

Limitations of Study

When interpreting the results of this study, it is important to take into account a number of limitations. Firstly, the sample size was very limited because the research was based on annual time-series data for Pakistan ranging the time period 1998-2020. This restriction resulted from the consistency and accessibility of data on human development metrics and energy accessibility. Since comparable data for some variables was not available for previous years, it was not possible to extend the study period.

Secondly, the study used aggregate national-level statistics, which could obscure regional differences in human development and energy availability between provinces and between rural and urban areas. Due to a lack of consistent and thorough subnational data over the whole study period, analyses at the provincial or district level were not included. Thirdly, access to clean fuels and technologies, as well as electricity, was used to gauge energy accessibility. Despite their widespread use in the literature, these

metrics fall short of capturing other crucial aspects of energy access, including cost, dependability, supply quality, and power outage frequency. The lack of long-term, nationally representative datasets, and the restricted availability of data hampered the inclusion of these dimensions.

Lastly, the results are unique to the institutional and socioeconomics setting of Pakistan. As a result, the findings might not be immediately applicable to other industrialized or developing nations with distinct energy systems, regulatory framework, and development paths. By using data at the household or provincial level, adding more aspects of energy accessibility, and performing cross-national comparisons, future research may be able to overcome these constraints.

Author Contribution

Sania Ahmad: conceptualization, formal analysis, software, resources, methodology, investigation, writing-original draft **Sana Butt:** validation, supervision, writing - review &editing.

Conflict of Interest

The authors of the manuscript have no financial or non-financial conflict of interest in the subject matter or materials discussed in this manuscript.

Data Availability Statement

Data supporting the findings of this study will be made available by the corresponding author upon request.

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