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Electricity Demand of Pakistan in the Context of Cooling Degree Days: 1972-2022

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ABSTRACT

Objective: The study analyzes the complex electricity demand function revolving around the bottom of overall consumption to frame climate change inclusive, efficient electricity planning and policies for a country mired in darkness and vulnerable to climate change.
Research Gap: Pakistan faces consistently deficient policy and planning frameworks for its electricity sector, a prerequisite for its socio-economic development as well as achieving sustainable energy goals. Pakistan has become an epicenter of climate change which affects its electricity sectors in multiple ways. Therefore, robust electricity demand investigation requires climate change inclusive electricity demand by capturing the impact of cooling degree days along with other crucial factors i.e., income, number of consumers, and use of capital on the country’s electricity demand.
Design/Methodology/Approach: This study avails ARDL cointegrating bounds approach to assess the long-run effects for the case of Pakistan between 1972 and 2022. The study uses a BSTS technique to forecast Pakistan’s future electricity demand.
The Main Findings: The results showed that the cooling degree have a significant positive effect on electricity demand. Income had an inverted U-shaped effect, while the number of consumers was also positively and significantly affected. The analysis to forecast Pakistan’s electricity consumption demand by considering cooling degree days, along with other factors, shows that the demand is likely to grow around 6-8% per annum, which is twice the size of current estimates.
Theoretical / Practical Implications of the Findings: It is recommended to revisit Pakistan’s electricity planning to take cooling degree days into account to develop a climate change inclusive electricity sector, a prerequisite for the country's sustainable development.
Originality/Value: This study is instrumental in exploring the demand for electricity using cooling degree days indicator for Pakistan.

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1. Introduction

Electricity is integral for economic development. No economy can exploit any development revolutions from the invention of the wheel to the Industrial and Green Revolutions.

From fueling factories, transportation, upgrading and augmenting agriculture and related industries, viable services sector, emerging information technology, and decent living standards to lighting streets; electricity has become a nucleus of socio-economic development. Availability and access to electricity is core to achieving several sustainable Development Goals (SDGs). SDG seven, in particular, seeks to set the seal for universal access to cost-effective and sustainable energy sources, including electricity, by 2030.

Electricity is the foremost energy fount in Pakistan for all of its major and minor sectors including industry, agriculture, services, household etc. (Table 1). Apart from other challenges to its sustainable development, Pakistan faces inadequate electricity supply. Long-run electricity insufficiency also indicates the deficiency in measuring, analyzing and forecasting electricity demand to frame efficient electricity supply policies for the stakeholders.

Majority of any economic activity is determined by the smooth provision of electricity. Since Pakistan experiences major changes in weather between summer and winter it leads to a wide deviation in demand for electricity. This variation necessitates developing a model of electricity demand for which government can plan to develop infrastructure and smoothen its production.

Table 1 shows the sector-wise share of Pakistan's total electricity consumption. The dominant clientele of electricity is the household sector followed by the commercial, industrial and agricultural sectors as registered in the Economic Survey of Pakistan, 2022-2023.

Table 1: Energy Consumption Sector-wise

Sector	Consumption (GWh)	Share (%)
Household	39,200	46.6
Commercial	6575	7.8
Industry	23687	28.2
Agriculture	6906	8.2
Others	7664	9.1
Total	84034	

Source: Pakistan Economic Survey, 2022-2023

Electricity demand is complex and dynamic; it varies with variations in technology and its uses, demographics, climate change, and lifestyle. Viewed in complex electricity demand measurement and forecasting context is a challenge. Countering this challenge is becoming increasingly difficult even without climate change. Climate Change affects electricity consumption in various ways, in particular in electricity's role to mitigate the adverse effect of Climate Change. Pakistan has become an epicenter of climate change, facing multifaceted effects of climate change, including recurring floods, heatwaves, and spatiotemporal changes in rainfall and snowfall patterns, cyclones, windstorms and persistent increases in cooling degree days. Cooling degree day (CDD) is an average yearly numerical measure of the number of degrees where the average temperature of a day exceeds 18°C (65°F)[1]. Deficient electricity policies indicate probable missing factors i.e., increasing cooling degree days in electricity demand measurement. Therefore, it is imperative to revisit electricity demand gauging to recommend evidence-based policies for the stakeholders.

1.2. Research Question

The study addresses the question: Do cooling degree days along with electricity consumer numbers, per capita income, and import of capital goods influence electricity demand in the long run?

[1] https://www.ceicdata.com/en/pakistan/environmental-climate-risk/cooling-degree-days

1.3. Study Objectives

The study is designed to unfold the complex demand for electricity in the face of climate change revolving around the bottom of overall consumption to frame evidence-based, efficient electricity planning and policies for the country mired in darkness and vulnerable to climate change.

2. Literature Review

The import of capital goods plays an indispensable role in the development of developing countries, deficient in the production of capital goods in their home countries. The import of capital goods stimulates the use of efficient and advanced technologies, uplifts production capacities and possibilities, and uplifts economic efficiency. Further, the integration of capital goods would lead to human capital development through the spillover effect. The impact of capital goods boosts economic activities, thus paving the way towards higher consumption of electricity in developing countries in the long run (Parikh, 1986).

Gokten and Karatepe (2016) confirmed Granger causality arriving from capital goods imports to electricity consumption for Türkiye. Liu et al. (2023) assessed 20 countries between 2000-2018 and showed that when developing countries use capital goods imports to spur growth, they also tend to increase in demand for energy.

Import of advanced technologies i.e., capital goods promotes the in-house production of inputs in developing countries. Though advanced technologies pull down the energy intensity, aggregate energy consumption increases. Developing countries often experience an economy-wide sectoral shift from agriculture to an energy-intensive industrial sector, thus increasing the composite demand for energy (Nasreen & Anwar, 2014; Shahbaz et al., 2014).

Electricity demand is significantly affected by income, time, and also by weather patterns (Deaton & Muellbauer, 1980). Parkpoom & Harrison (2008) analyzed the future impacts of climate change on electricity demand for Thailand by conducting a situation analysis of the current status of electricity demand influenced by cooling degree days (CDD) along with cooling degree hours (CDH), a short-run genre of CDD along with socio-economic scenarios. The study has provided in-depth descriptions of a temperature-demand relationship, temperature demand sensitivity, and long-term socio-economic security simulated with climate change. The Global Circular Model (GCM) has been applied for climate temperature projections to find log-run electricity demand projections influenced by the above-mentioned factors. The study also carried out the projections of variations in electricity demand with changes in different temperature scenarios. It is projected that with certain climate changes paired with socio-economic scenarios, the yearly average temperature in Thailand will go up by “1.74-to-3.34-degree Celsius by 2080” and in response, the electricity demand is forecasted to increase by 6.6%-15.3% in 2080”.

Scoccimarro et al. (2023) applied a novel approach to analyze the impact of cooling-degree days on energy demand worldwide for twenty-one years starting from 2001. The study envelopes cooling degree days, humidity-weighted cooling degree days, and population-weighted degree days to explore the extent and spatial-temporal distribution of these changes. The study is done for all the regions of the world, including Pakistan and has highlighted the increasing tendency of energy demand due to a general increasing tendency in cooling degree days, humidity weight, and population weighting degree days.

Li et al. (2018) investigated the social electricity consumption in Nanjing city of China affected by cooling degree days (CDD) and Heating degree days (HDD). The study integrated metrological data with societal electricity consumption. It is found that society electricity consumption has increased due to an increase in CDD while it is found that HDD society electricity consumption has been reduced due to HDD in winter. The study deduced the results by applying OLS regression analysis. The correlation coefficient has also been deduced to show a high correlation between increasing electricity demand and increasing degree days whilst, because of the complexity and diversity of heating practices, the correlation between HDD and society's electricity consumption is not obvious.

Khosla et al. (2021) have analyzed the increase in electricity consumption in urban India due to an increase in cooling degree days to mitigate its sweltering effects and further explored the answer and policy solution to complex questions of "(1) what cooling appliances are purchasing? (2) How are people buying their ACs? And (3) how are people using their ACs? (4) Who has energy efficient ACs? (5) Is cooling consumption gendered? "Primary data have been collected by conducting a door-to-door survey in Delhi, India's highest electricity consumption region.

Jamil and Ahmad (2010) confirmed the unidirectional causality from real GDP to electricity consumption in Pakistan. But this relationship is not linear; a consistent increase in income would show an initial increase in electricity demand and then a fall its demand. This is because higher-income nations can adopt energy-efficient technologies (Dong & Hao, 2018; Fouquet, 2014; Richmond & Kaufmann, 2006). Liu et al. (2016) assessed 30 provinces in China between 1995-2012, the piecewise regression showed that with the increase brackets, the positive effect is diminishing but in the current sample the coefficient does not reach a negative value. This means that with the increase in income there is no constant proportional increase in electricity demand.

Uddin et al. (2011) investigated the energy consumption and economic growth relationship for Bangladesh from 1971 to 2007. The study has taken GDP/per capita as well as real GDP for analysis. By applying the autoregressive distributing lag (ARDL) bounds testing method, the study has found the unidirectional causality between energy consumption and economic growth, captured by per capita and real GDP).

Chaudhry (2010) investigated the countrywide electricity demand for the panel of 63 countries for the period of 1998-2008, including Pakistan, for income per capita. The study also took the firm level of electricity demand for Pakistan at the same time. By using the fixed effect model, the study unfolds the fact that a 1% addition in per capita income will pave the way forward for an increase of 0.69% in electricity demand countrywide.

Nawaz et al. (2013) investigated a linear as well as a nonlinear trend for the Pakistan's electricity demand by employing time series data for 1971-2012. By employing the logistic smooth transition regression technique, the study has found that electricity demand is primarily affected by economic development measured by per capita GDP for both the short run and long run. Whereas, in the long run, electricity demand is also influenced by its respective price, however, in the short run, electricity prices have a negligible effect on electricity demand.

A causal unidirectional relationship has been found by enveloping per capita electricity consumption and GDP per capita by using annual data for 1950-51 and 1996-97. The study has applied the Granger Causality method for the analysis (Ghosh, 2002). Shi et al. (2016) carried out an in-depth study of the increasing consumption of electricity in Chinese households due to certain factors e.g. income, household size, education, and consumers from different backgrounds along with the price of electricity substitutes/complementary goods. The data have been obtained from China Family Panel Studies (CFPS) of 2375 households in 2008 and were followed by 1940 households in 2019. Whereas it is found that residential electricity consumption is highly affected by household income along with other variables.

Electricity has become an indispensable necessity in every society, powering every aspect of daily life. As Pakistan's population continues to grow, the electricity demand also rises in tandem with the increasing number of consumers. Ali et al. (2020) researched Malaysia to explore a nexus of population growth, GDP growth, electricity consumption and generation and CO_2 emissions for the period of 1970-2014. They brought forth the fact that there is a strong positive relationship between population growth and electricity consumption in Malaysia.

Hlongwane & Daw (2023) found that increasing population along with increasing GDP is highly significant and positively related to electricity consumption in South Africa from 2022 through 2021 by applying seemingly unrelated regression analysis.

Dokas et al. (2022) carried out an intensive research study by taking the panel data of 109 developed and developing countries for the period of 2010-2018 to explore the determinants of electricity as well as overall energy consumption. By applying casualty tests, error correction methods, and dynamic cointegration methodologies among others population growth rates share a significant positive relationship for energy and electricity consumption in both developed and developing countries.

Empirical studies have commonly used the ARDL with a cointegrating bounds approach for time series analysis (Dergiades & Tsoulfidis, 2008; Nasir et al., 2008; Uddin et al., 2023) to estimate electricity demand. This model is suitable for assessing the long-run effect of variables even when they have a mixed order of integration (Pesaran et al., 2001).

Although there are several studies that have explored the determinants of electricity demand, but in the time series context there is dearth of studies which have explored the role of climate change in terms of cooling degree days in estimating changes in the electricity demand in Pakistan. This study will help policymakers to have a clear projection of increase in electricity demand in response to prevailing global warming.

3. Research Methods

This section details the methods relevant to the study.

3.1. Theoretical Framework

The conventional demand law governs the relationship that describes electricity demand's behaviour vis-à-vis income and price, beyond a certain basic level of consumption (below which electricity would be a necessity). Many studies unfold that electricity demand is price inelastic, show beyond doubt that electricity is a necessity (Shi et al., 2012, p. 44; Wahid et al., 2021). Therefore, the study in hand will proceed on the notion that electricity is a necessity in Pakistan.

3.2. Empirical Specification

The objective of the study is to estimate the causal relationship between electricity demand and Cooling Degree Days, to ensure robustness we control for the number of consumers, income, and the import of capital equipment into Pakistan. The relationship has been estimated using the following equation:

$$\mathrm{Demand}_t = \beta_0 + \beta_1 \mathrm{Cooling}_t + \beta_2 \mathrm{Income}_t + \beta_3 \mathrm{Income}_t^2 + \beta_4 \mathrm{Capital}_t + \beta_1 \mathrm{Consumers}_t + \beta_6 \mathrm{Dummy}_t + \varepsilon_t \quad (1)$$

The dependent variable in the study is Demand_t that measures the annual electricity consumption demand. The explanatory variables are $\mathrm{Consumers}_t$ (total number of electricity consumers), $\mathrm{Cooling}_t$ represents cooling degree days (Annual aggregate of difference between the daily temperature mean, and 65 Fahrenheit) from ERA5 Reanalysis2, Income_t (GDP per capita), Income_t^2 (square of GDP per capita to investigate whether income and electricity demand have a nonlinear relationship), $\mathrm{Capital}_t$ (import of capital into Pakistan), Dummy is a structural break variable accounting for significant regime change using Bai and Perron's (1998) method for the stability of the model. ε_t is the error term. As most variables vary in magnitude, we utilise the variables in log form to ensure comparability while maintaining scale.

The use of quadratic function of GDP per capita also denotes that the income elasticity of demand of electricity is dependent on the actual level of income. Thus, there would be different elasticity for rich and poor customers.

3.3. Data Sources

This study is based on secondary data obtained from the Pakistan Energy Yearbook, the World Bank's World Development Indicators and Climate Knowledge portal, the Pakistan Bureau of Statistics, and the electricity generation and distribution authority Pakistan.

[2] The fifth generation ECMWF atmospheric reanalysis of the global climate: https://www.ecmwf.int/en/forecasts/dataset/ecmwf-reanalysis-v5.

3.4. Forecasting

The forecasting model has been implemented based on ensemble prediction that averages over different combinations of predictors. Our system combines a structural time series model for Electricity Consumption Demand with a regression component capturing the contribution of Cooling Degree Days. The technique is based on the Bayesian Structural Time Series developed by Scott and Varian (2015). Specifically, the technique consists of three steps; the use of Kalman filter to de-trend and de-noise the time series (Harvey, 1991); Spike-and-Slab variable selection (George and McCulloch, 1997), and Bayesian Model Averaging (Volinsky, 2012).

Bayesian forecasting allows us to forecast the expected increase in Pakistan's electricity demand given the underlying trends in Cooling Degree Days. Our contributions include the inclusion of Cooling Degree Days into electricity demand analysis, which has not been done previously, and using said technique to forecast future electricity demand consumption.

4. Results

This section discusses the results of the study.

4.1. Unit Root Test

Most of our variables are time series, to test whether they are stationary, we employ the Augmented Dickey-Fuller Test (ADF) (Dickey & Fuller, 1981). As ADF takes into account the lagged difference term of the dependent variable as an independent variable, it also addresses serial correlation (Cheung & Lai, 1995), therefore is adequate for our purposes. As ARDL model is applicable irrespective to I(0) and I(1) nature of variables, hence any composition of the variables between these two categories would not change the course of estimation of this model. The calculations of time series unit root test reveal that the selected variables are integrated at I(1).

4.2 ARDL Results

As our variables are integrated at different orders, we use the ARDL technique (Auto Regressive Distributed Lag) as it models the short and long-run relationships between the variables irrespective of their orders of integration. Table(s) 1 and 2 summarise the results from the short and long-run relationships, respectively.

From table 1, the negative value of variable CointEq confirms the convergence in the model in long run. While the F bound test value of 15.87, which is significant at 1% I (1) bounds, confirm the presence of cointegration in the variables. The overall R Squared is 0.76 confirming that the selected independent variables explain 76% variation in the demand for electricity.

In the short run only two variables are shown as for other variable zero optimal lags were used by the ARDL model, further the structural break dummy has as positive significant coefficient showing that the unknown break had increased electricity demand in short run.

Table 2: Results from the short-run estimation for electricity consumption demand

Variable	Coefficient (Standard Errors)
$Cooling_t$	0.249***
	(0.059)
$Consumers_t$	-0.891**
	(0.284)
$Dummy_t$	0.016***
	(0.002)
$CointEq_{t-1}$	-0.427 ***
	(0.000)

Note: Significance levels; *0.1, **0.05, and ***0.01; (): standard errors

Table 3: Results from the Long run Estimation of Relationship with Electricity Consumption Demand

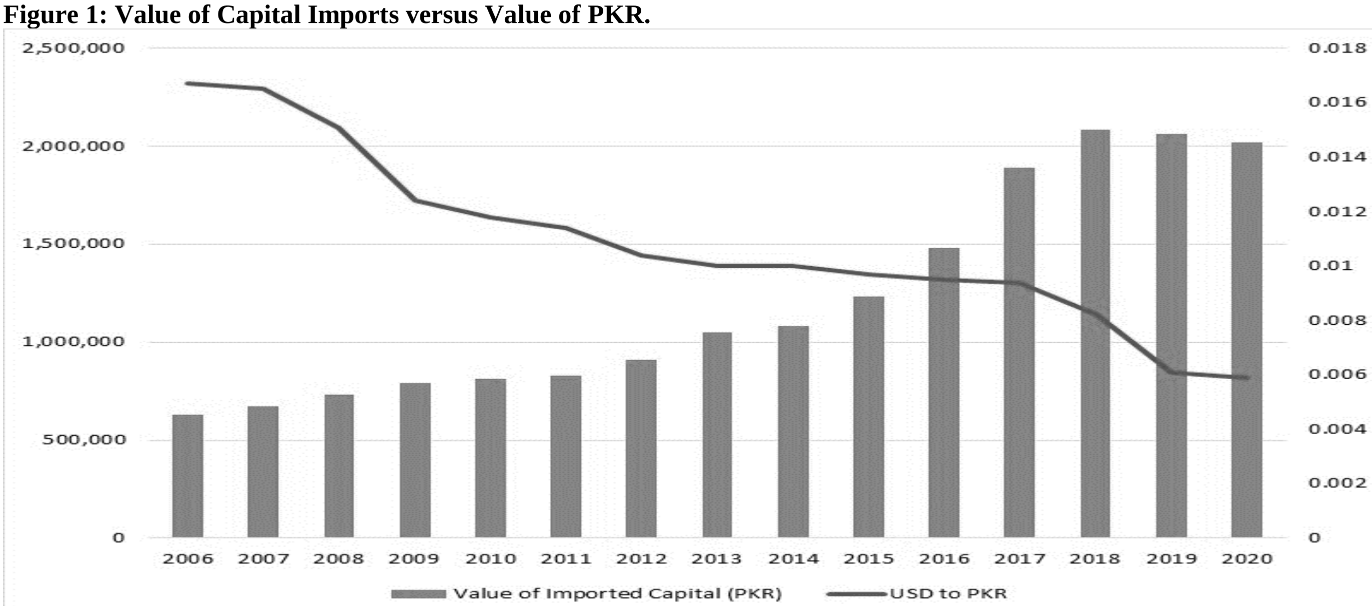
Variable	Coefficient (Standard Errors)
Cooling_t	1.027***
	(0.368)
$Consumers_t$	0.072
	(0.408)
$Income_t$	18.096***
	(4.766)
$Income_t^2$	-2.582***
	(0.784)
$Capital_t$	-0.010
	(0.060)

Note: Significance levels; *0.1, **0.05, and ***0.01; (): standard errors

We expect that with more consumers, electricity demand would increase; in the long run, the sign of the coefficient is positive (indicating that there is a positive relationship between electricity demand and the total number of consumers) (Kirschen, 2003). However, in the short run sign is negative, because the number of electricity consumers is measured by the number of electricity connections. Said connections are typically the first to be installed in new constructions; although that increases in the short run number of consumers, it does not equate to a similar increase in electricity consumption, because of two reasons: one, either the house is still under construction, or two, new homeowners may not be as well equipped with appliances, that is why we see the relationship play out in the long run differently (i.e., more consumers means more energy is consumed).

Capital, or the stock of capital machinery and equipment in Pakistan, has a negative and insignificant relationship with electricity demand consumption because of two reasons, first, machinery is becoming more energy efficient, especially as older fully depreciated units of capital are replaced, meaning that as more machinery is imported, it replaces older versions and consumes less electricity, resulting in a lowering of overall electricity demand. Second, many of Pakistan's industries have transitioned away from electricity-based consumption because of historical problems with electricity generation and load shedding (shifting towards gas). This is explained by the fact that the value of the stock of capital being imported into Pakistan has not kept pace with the falling value of the rupee. There should have been an exponential increase in the value of electric machinery, given the fast devaluation of the rupee, thus indicating that less electricity-based (or automated) capital is being imported into Pakistan (Figure 1).

Figure 1: Value of Capital Imports versus Value of PKR.

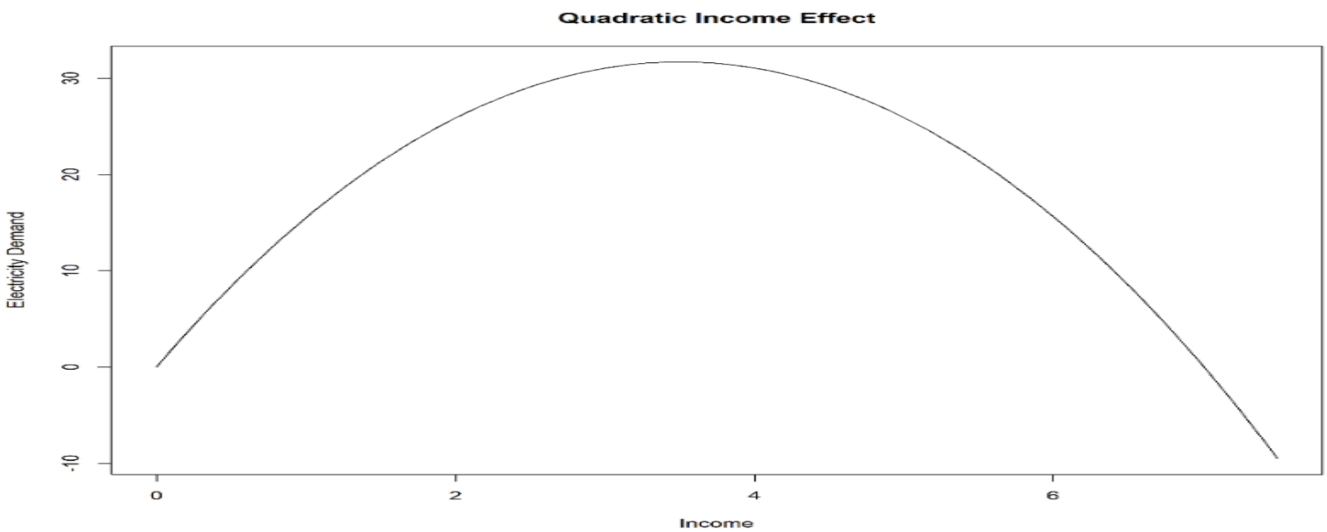


Source: Authors Compilation from Stata

Most importantly, we see that there is a positive and significant relationship between electricity demand and cooling degree days, both in the short and long run indicating that climate change is exerting stress on Pakistan's electricity infrastructure. Given that the effects of climate change are only going to worsen, modelling electricity demand on climate change is imperative.

Income has a positive relationship with electricity consumption, as people with more means will access more appliances; however, the square of income has a negative relationship, indicating that income has a nonlinear relationship with electricity consumption. This inverted U-shaped ∩ pattern is also shown in Figure 2.

Figure 2: Visualized Quadratic Effect of Income.



Source: Authors Compilation from Stata Analysis

Figure 2 also shows that for low income regimes, the increasing income had seen proportional increases in electricity demand making their income consumption curve positively sloped. While at higher income regime there is a fall in electricity consumption in response to increase in income.

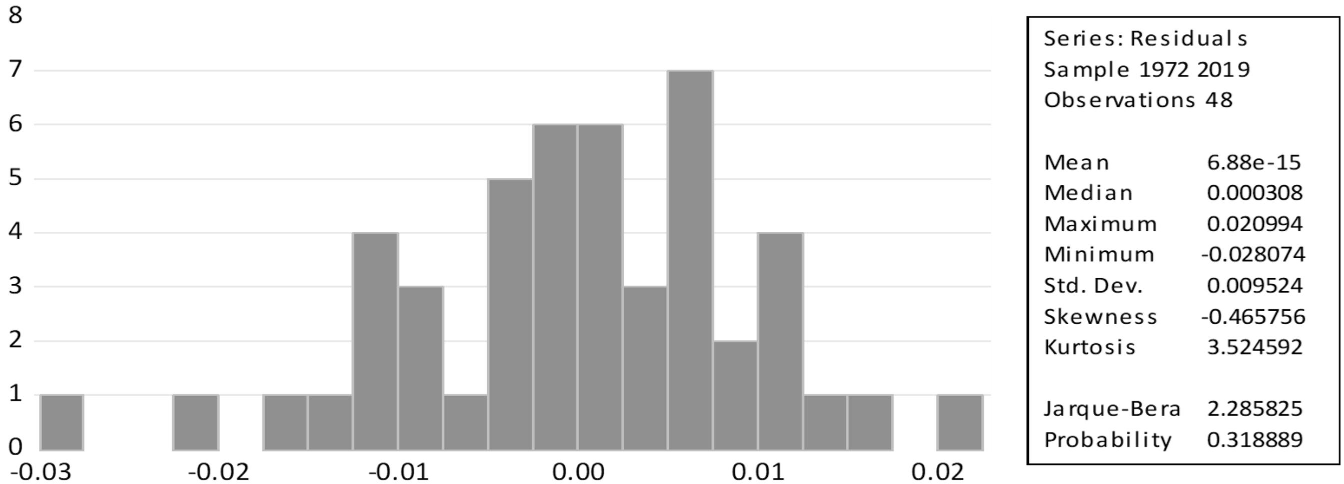
This may be because of the use of generators and renewable sources in Pakistan. As the electricity infrastructure continues to experience stress and use load-shedding as a method for dealing with the excess demand, many households choose to switch to installing solar panels. Furthermore, with more income households may switch over to less electricity-intensive alternatives, especially given the consistently increasing prices. Specifically, an increase of 3.504% in income results in the manifestation of these effects.

4.3 Robustness and Stability

To ensure the robustness of the model we check the normality of the residuals and compute the Breusch-Godfrey and Breusch-Pagan-Godfrey tests to check for Serial Correlation and Heteroskedasticity respectively. For stability, we use CUSUM and CUSUM square tests.

Figure 3 contains results from the normality test, showing that the model is normally distributed. Table(s) 3 and 4, show there is no autocorrelation or heteroscedasticity. Figures 4 and 5 show that the model is stable.

Figure 3: Normality Test.



Source: Authors Compilation from E-Views

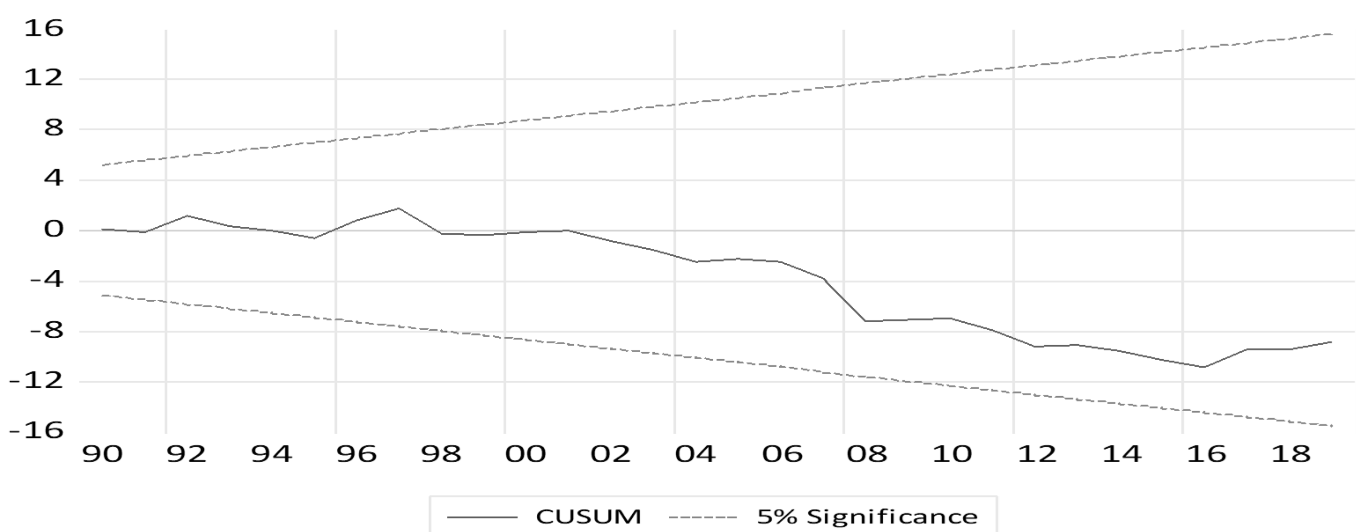
Table 4: Breusch-Godfrey Serial Correlation LM Test

Test	Test Statistic	Degree of Freedom	Probability
F	1.826	Prob. F (2, 36)	0.17
Obs*R-squared	4.422	Prob. Chi-Square (2)	0.109

Table 5: Breusch-Pagan-Godfrey Heteroscedasticity Test

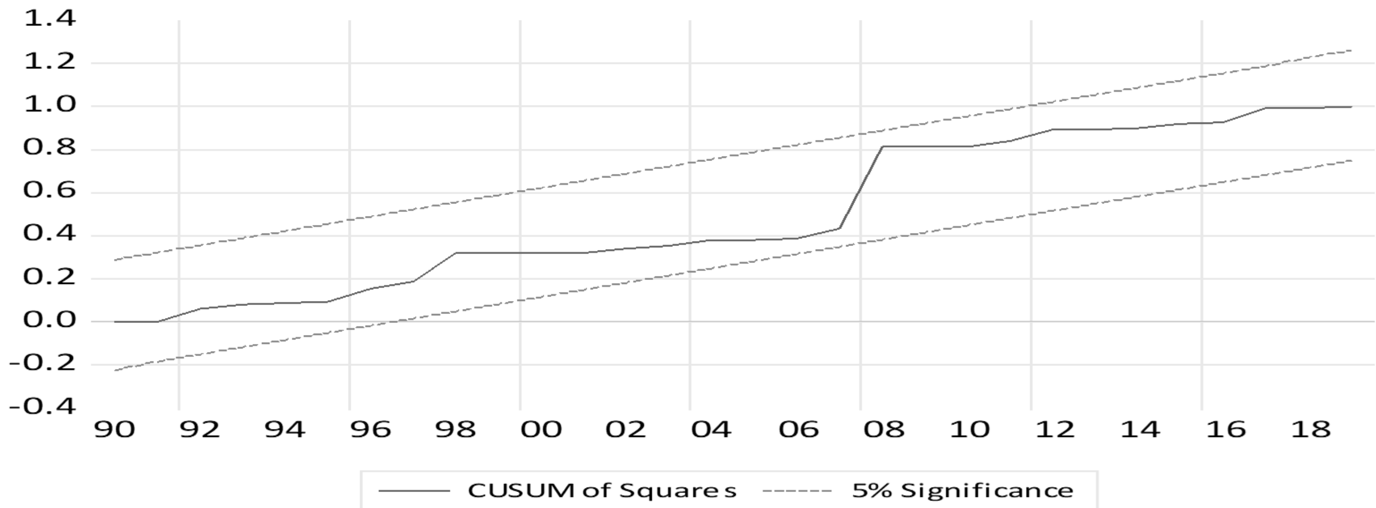
Test	Statistics	Degree of Freedom	Probability
F-statistic	0.603	Prob. F (9, 38)	0.786
Obs*R-squared	6.002	Prob. Chi-Square (9)	0.739
Scaled explained SS	4.749	Prob. Chi-Square (9)	0.855

Figure 4: CUSUM Graph



Source: Authors Compilation from E-Views

Figure 5: CUSUM Square Graph



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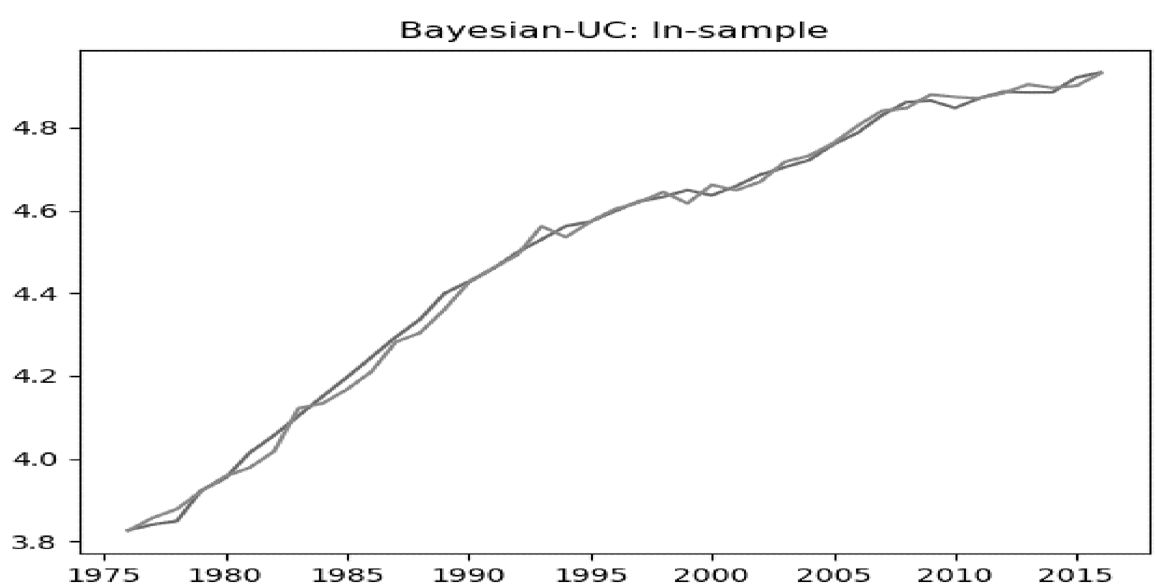
4.4 Forecasting

Using the Bayesian unobserved components technique mentioned above, we forecast the expected growth in electricity demand in the coming years. Existing predictions assume that Pakistan's electricity demand will grow by 4% on average per annum. Most expectations based on past data assume that the variables of interest are ergodic, meaning that their past averages will hold in the future. Furthermore, most models ignore the importance of climate change. As mentioned above, climate change is rarely taken into consideration when conducting the planning of future electricity demand growth. Given that Pakistan is among the top 10 countries to be impacted by climate change in terms of severity, the modelling is concerning. Using our technique, we can adequately fit past data (Figure 6).

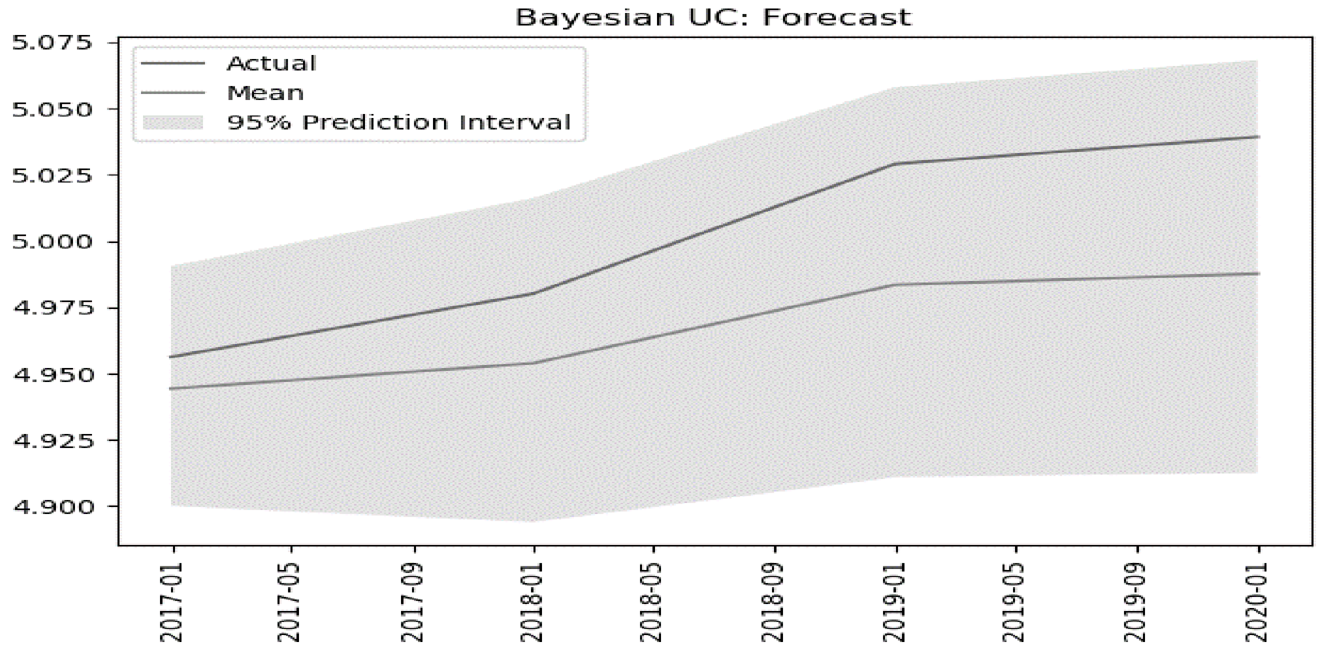
Figure 6: In Sample Estimation



Source: Authors Compilation from E-Views

Using back casting to assess the predictive power of our modelling, we show that our estimations are within the 95% confidence interval range (Figure 6).

Figure 6: Back Casting to Estimate Efficacy



Source: Authors Compilation from E-Views

Given our modelling, we forecast that Pakistan's electricity consumption demand is likely to grow around 6-8% per annum, which is twice the size of current estimates.

5. Policy Implications

Pakistan is considered a hotspot of heatwaves and barbarous prolonged summers due to climate change. The results of the study reveal that with an increase in cooling degree days, electricity demand is also increasing. Electricity demand is significantly and positively related to increasing cooling degree days. The forecasting analysis also shows that electricity demand will increase in coming years with more cooling-degree days. As mentioned earlier, electricity is an effective instrument to mitigate the adverse impacts of climate change. It is suggested to include cooling degree days when undertaking electricity supply analysis and planning policies.

The conventional determinant of demand i.e., income is revealing results based on the ground realities of Pakistan. Income has a significant positive relationship with electricity demand. Whereas the square of income has a negative, nonlinear, inverted u-shaped (∩) relationships with electricity demand. It shows that after a certain level, electricity demand decreases with an increase in income level. As electricity prices and load-shedding are skyrocketing in Pakistan, many electricity consumers, who can afford, are switching towards solar electricity use. Therefore, boosting per capita income would decrease the electricity consumers' reliance only on national grid electricity, an overall decrease in demand for grid electricity. With an increase in the number of electricity consumers, electricity demand would increase significantly in the long run, quite compatible with demand law.

Capital machinery or import of capital goods shares a negative and insignificant relationship with electricity demand in Pakistan. Pakistan imports capital machinery from technologically advanced countries, and almost all of the major capital goods manufacturing countries are signatories of international protocols to manufacture environmentally friendly and energy-efficient capital goods. Therefore, the import and use of capital goods is not affecting Pakistan's electricity demand. Also indicating that any resurgence of industrial activity in Pakistan will likely mean significant burden on our electricity infrastructure – something that should be given due consideration in policy planning.

The forecasting for Pakistan's electricity demand by taking past cooling degree days' data into account along with other factors, unfolds that Pakistan's electricity consumption demand is likely to grow around 6-8% per annum, which is twice the size of current estimates. The stakeholders must reframe Pakistan's electricity planning by considering climate change as an important ingredient to ensure a climate change inclusive electricity sector, key to the sustainable development of Pakistan.

Future studies can explore the advanced versions of ARDL models to estimate more robust estimates using QARDL or NARDL. This will help the researchers to assess if the distribution of relationship is continuous or discontinuous.

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