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Impact of Climate Change on Electricity Demand: A Case Study of Pakistan

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The energy sector is sensitive to changing weather patterns and Pakistan is one of those countries where temperature rise induced by climate change is expected to be above the world average. In this backdrop the present study aims at finding the impact of climate change on electricity demand in Pakistan at the regional and national level. Using monthly data on temperatures to find heating and cooling degree days, the relationship between monthly electricity demand and temperature is explored which is then used to find the impact of projected climate change on electricity demand. The results suggest surging peak loads in summer season due to climatic effect which calls for capacity instalments over and above that needed to cater to rise in electricity demand attributable to economic growth.

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1. INTRODUCTION

The energy sector is one of those sectors which are sensitive to changing weather patterns; the latter affecting both the electricity supply and demand. Supply side concerns can be more pronounced in areas dependent upon hydropower plants whereas floods and other natural disasters can endanger the established generation plants as well. On the other hand, changing weathers have been found to be the most significant cause of short-term variation in electricity usage [Zachariadis (2010)]. Households and businesses use electricity for heating and air-conditioning and thus the express effect of changes in temperature is the change in the heating and cooling requirements. A long-term change in the weather pattern, such as that induced by the global climate change, therefore, may contribute to a shift in the electricity usage, which, if not foreseen in time, can cause imbalances in supply and demand of electricity.

Pakistan has been going through a severe energy crisis in the form of an acute shortage of electricity. Huge gaps between electricity demand and supply exist; during the year 2011 the electricity shortfall ranged between 5000MW to 7000MW [Malik (2012)]. On top of it, Pakistan lies in the world region where temperature rise induced by climate change is expected to be above the world average which, coupled by an overall warm climate, renders the country vulnerable to various impacts of global climate change [Rasul and Ahmad (2012)].[1] The rise in surface temperatures of South Asia region by the end of the century is projected around 3.3°C average annually (IPCC);[2] not only are the average temperatures rising but the range of extreme temperatures is also widening.

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[1] Pakistan Meteorological Department.

[2] Intergovernmental Panel on Climate Change.

With both the average and extreme temperatures rising across the globe, it is expected that cooling requirements of people will increase and heating requirements will decrease [Howden and Crimp (2001)]. These effects contribute in changing demand for electricity as the need for air-conditioning, refrigeration, and water temperature regulation change [Amato, *et al.* (2005); Rosenthal, *et al.* (1995)]. Though, reckoning the importance of this issue, a number of studies have been conducted analysing future demand conditions of different countries [e.g. Rosenthal, *et al.* (1995); Parkpoom and Harrison (2008); Howden and Crimp (2001), etc.] yet literature in Pakistan largely lacks in this dimension. Most of the studies estimating energy demand equation [Chaudhary (2010); Nasir, *et al.* (2008); Khan and Qayyum (2009)] do not take temperature as an explanatory variable and in case the relationship has been recognised [Jamil and Ahmed (2011)] further exploration of the subject, in terms of analysis of impact of climatic changes, has not been undertaken. A recent study [Ali, *et al.* (2013)] looks at impact of climate change on electricity demand considering the whole of Pakistan altogether. The nature of the problem, however, requires a more disaggregated analysis.

The estimation of such changes in electricity demand is imperative as they can have important consequences for electricity generation capacity building because meaningful planning to avoid supply bottlenecks in this sector hinges upon proper estimates of prospective demand. Given the electricity crisis that has, and continues to hit Pakistan economy, the study becomes even more relevant as it goes beyond the current demand conditions of the country and looks into the long run needs of the economy in the event of expected climatic changes and thus adds further insight into calculating prospective demand. As there is a protracted time lag between recognition of demand needs for electricity and its capacity building, the study will prove helpful for government regarding design of energy policy.

Increase in temperatures can affect human lives at every front but the present study focusses on examining the impact of climate change on demand for electricity in Pakistan. The broader objective of the study is the estimation of the impact of temperature changes on electricity demand in Pakistan and on the demand in residential and commercial sectors on regional level. This work also provides the projections of the changes in demand for electricity under different temperature rise scenarios expected as a result of climate change.[3] Rest of the study is structured as follows. Section 2 reviews the literature while Section 3 discusses data and variables used in the analysis. Section 4 details methodology and estimation technique while results and accompanied discussion is presented in Section 5 followed by sensitivity analysis in Section 6. Section 7concludes the paper.

2. LITERATURE REVIEW

Relationship between energy demand and climate change became the area of interest for researchers mainly in the late 1980s. Bhartendu and Cohen (1987) predicted the changes in residential electricity consumption in Ontario, Canada under the scenario of doubling up of carbon emissions. Using regression analysis by incorporating population weighted heating and cooling degree days, the study found carbon emissions

[3]A temperature rise scenario refers to the plausible rise in temperature as a result of climate change as predicted by various Global and Regional Climate Models.

to be positively related to cooling requirements of household while negatively related to per capita heating requirements.

United States of America has been a focus of much of research done in this area. Baxter and Calandri (1992) conducted a partial equilibrium analysis on California. Considering both the high and low climate change scenarios substantial rise both in the total electricity consumption and in peak demand for electricity were found. However, Rosenthal, *et al.* (1995) found a decrease in US heating and cooling energy requirements for residential and commercial sectors under global warming.

Use of two step method to estimate the impact of climate change in electricity demand is commonly found in literature. In the first step the sensitivity of electricity demand by household and commercial users to temperature changes is estimated and then these estimated sensitivities are used along with climate change projections to forecast future electricity demand. Sailor and Munoz (1997) addressed the effects of climate change on consumption of energy sources. Electricity consumption was regressed on temperature, in raw form as well as by first calculating the heating degree days (HDDs) and cooling degree days (CDDs). Least square estimates pointed towards a rise in electricity demand at higher temperatures. Amato, *et al.* (2005) estimated the impact of climate change on the Commonwealth of Massachusetts. Monthly per capita electricity consumption was regressed on annual trend, HDD, CDD, trends in HDD and CDD, price of electricity and hours of daylight and the results were suggestive of positive and significant impact of HDD and CDD on the demand for electricity. These results held for residential as well as commercial users of electricity. Using the calculated temperature sensitivities to electricity demand and the climate projections, future demand was also projected.

Hadley, *et al.* (2006) studied the fluctuations in energy demand in the US in response to climate change and the impact of changing energy needs on carbon emissions both under the low and high temperature rise scenarios from General Circulation Climate Models. The study suggest that irrespective of whether decrease in heating requirements outweigh the increase in cooling requirements or otherwise, the carbon emissions through electricity generation are likely to increase in response to climate change. Using the relationship between hourly electricity load and average daily temperatures for California over a year, Franco and Sandstad (2008) employed climate projections from three General Circulation Models (GCMs) to predict annual and peak rise in electricity demand from 2005 to 2099. The study found an expected annual increase in electricity demand to the tune of 3.1 percent in the period 2005 to 2034, 8.1 percent in 2035 to 2064 and 1.8 percent in 2065 to 2099 under worst case scenario. Miller, *et al.* (2008) use climate projections from General Circulation Models and predicts electricity shortfall of as high as 17 percent in California in peak demand conditions with the prevailing generation capacity.

In addition to United States, the climate change-energy demand nexus has been studied for other parts of the world as well. Conducting analysis on Hong Kong, both Lam (1998) and Yan (1998) found a strong correlation between electricity consumption and temperature wherein the temperature was introduced in the form of CDDs and mean temperatures respectively in the two studies. Howden and Crimp (2001) studied the impact of climate change in four regions of Australia using the climate change projections and showed that in case of 1^0 C increase in average temperatures, average demand would rise in two of the four regions they studied and decrease in the other two, while an increase of 7^o C would cause increased demand in all regions. Pardo, *et al.* (2002) estimated the influence of seasonality and temperature on electricity load of Spain using the degree day method and found that current and past HDDs influenced Spanish electricity consumption. Christenson, *et al.* (2006) found a decreasing trend in heating degree days in Switzerland from 1901 to 2003 and projected a further decline for future years whereas opposite trend was found for cooling degree days. Hor, *et al.* (2005) and Parkpoom and Harrison (2008) estimate the expected changes in Thailand's demand for electricity under different climate change scenarios. Both the studies concluded that increasing temperatures significantly increased the demand for electricity with the most profound impact on summer time peak demand thus calling for increased electricity generation and transmission capacity.

Pilli-Sihvola, *et al.* (2010) studied the impact of temperature on electricity demand of a panel of fifteen European countries using the degree day method, the HDDs in the said panel turned out to be significantly affecting the electricity consumption. Zachariadis (2010) and Zachariadis and Hadjinicolaou (2012) estimated the impact of climate change on electricity requirement of Cyprus by incorporating total annual degree days (Average of total annual degree days of two largest cities) along with income and price variables in the electricity demand equation. To estimate the elasticity of electricity demand to changes in the explanatory variables ARDL has been applied on annual time series of the period 1960–2007 of all the included variables. Furthermore, using the climate projections for Cyprus, the study forecasts the future electricity demand both under a no climate change scenario and in case of mean and peak temperature changes in the future, the difference between these projections gives the additional electricity requirement.

For Pakistan, however, the relationship between electricity demand and climate change remains an area yet to be explored; temperature has appeared as an explanatory variable in a few studies estimating the electricity demand functions [Jamil and Ahmed (2011)] but Ali, *et al.* (2013) is the only study which attempts to assess the impact of climate change on electricity demand. Ali, *et al.* (2013) has estimated the linear relationship between mean monthly maximum temperature and electricity generation to project changes in electricity demand for the country in response to change in future temperatures forecasted through ARIMA. The study finds that electricity demand owing to changes in temperatures may increase by 1.7 percent at maximum by the year 2020 while it may also show a decline in some months of the year.

Since Pakistan is a climatically diverse country the issue calls for a more disaggregated approach and the present study attempts to bridge this gap by analysing the historical relationship between electricity demand and temperature for Pakistan and for various regions of the country and then projecting the changes in demand in response to expected temperature changes as a result of climate change. In this respect based on the nature and scope of the analysis, the results of our study are more reliable and efficient in that not only potential non-linear relationship between temperature and electricity demand has been accounted for but some control variables are also added to arrive at a representative estimate of response of electricity demand to temperature change.

3. DATA DESCRIPTION AND VARIABLES

For country-level analysis, monthly data[4] on electricity generation in Pakistan has been obtained from Pakistan Bureau of Statistics (PBS).[5] The data refer to total electricity generated in Pakistan in each month spanning the period from June 1980 to June 2013. As electricity cannot be stored and the fraction of line losses has not changed substantially in this period, the data on electricity generation is used as a proxy for electricity demand [Ali, *et al.* (2013)].[6]

For regional analysis, monthly data on electricity consumption of residential and commercial sectors[7] have been used as a proxy for electricity demand. The data were requested from all the distribution companies in Pakistan[8] and provision of data by Karachi Electric Supply Corporation (KESC), Sukkur Electric Power Company (SEPCO), Gujranwala Electric Power Company (GEPCO), and Islamabad Electric Supply Company (IESCO) has allowed us to conduct analysis on the regions served by these companies.[9]

The data on average monthly temperatures[10] for this time period have been taken from Pakistan Meteorological Department (PMD)[11]while the record of district wise population is obtained from PBS. The data on electricity prices per kilowatt hour have been obtained from Water and Power Development Authority (WAPDA).[12]

A look at the data for Pakistan (Figure 1) shows that electricity generation has considerable seasonal fluctuations and an observable trend.[13]

[4]As a starting point the analysis was conducted on annual data on electricity consumption obtained from Pakistan Energy Yearbook (various issues). Because the order of integration was not the same for all the variables, bounds test was applied to check for long-term relationship and subsequent application of ARDL. However, bounds test rejected the presence of long-run relationship between annual electricity consumption and temperature plausibly because of dampening of seasonal effects in annual data. Thus, monthly data were found to be more suitable for analysing the response of electricity demand to changes in temperature.

[5]The authors are especially thankful to Mr. Haseebul Rehman, PBS for his co-operation in this regard.

[6]Use of electricity generation also helps us to account for the units of electricity that are illegally consumed and so do no not appear in consumption figures e.g. theft etc. However, non-availability of sector-wise monthly data does not allow us to analyse residential and commercial sectors separately.

[7]These sectors have been found in literature to be the most sensitive to changes in temperature as opposed to agriculture and industrial sectors [Rosenthal, *et al.* (1995)].

[8]We are especially thankful to Saad Hasan Latif, KESC, Waheed Akram, IESCO and Chief Executive Officers of SEPCO and GEPCO for their co-operation.

[9]The data from KESC span the period from July 1998 to June 2013 (180 observations), that from SEPCO and GEPCO span from July 2010 to June 2013 (36 observations), while the data obtained from IESCO range from July 2007 to June 2013 (72 observations).

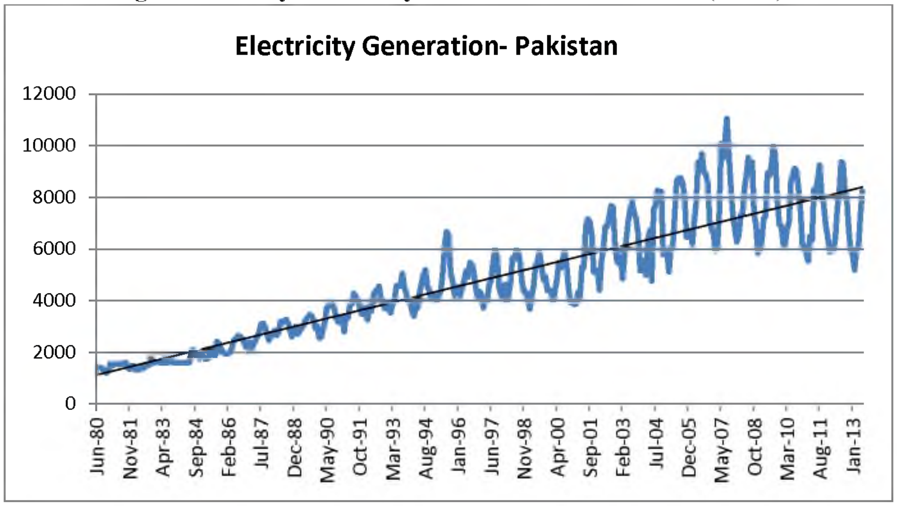
[10]Temperature stands out among the meteorological factors that affect electricity demandas reported by Parkpoom and Harrison (2008), Al-Hamadi and Soliman (2005), Hor, *et al.* (2005), Engle, *et al.* (1986), Filippini (1995), Henley and Peirson (1997,1998), Considine (2000), Johnsen (2001), Valor, *et al.* (2001) and Pardo, *et al.* (2002), among others.

[11]We owe gratitude to Numerical Modelling group of Research and Development Division, Pakistan Meteorological Department (PMD), Islamabad, International Development Research Centre (IDRC), Dr Munir Ahmed, PIDE, and Muhammad Nawaz and Hasan Siftain, PIDE for co-operating with us in this regard.

[12]Data on electricity prices is available in annual frequency which has been transformed in a rather crude way on monthly frequency by supposing that change in electricity price occurred on 1st January in each month.

[13]To substantiate the point that fluctuations in electricity demand are in a large part dependent on temperature variations, Hodrick-Prescott filter is used to separate growth in electricity consumption from fluctuations in electricity consumption and the latter is regressed on temperature variables. It is found that temperature variables significantly influence fluctuations in electricity consumption. For estimation output see Appendix A.

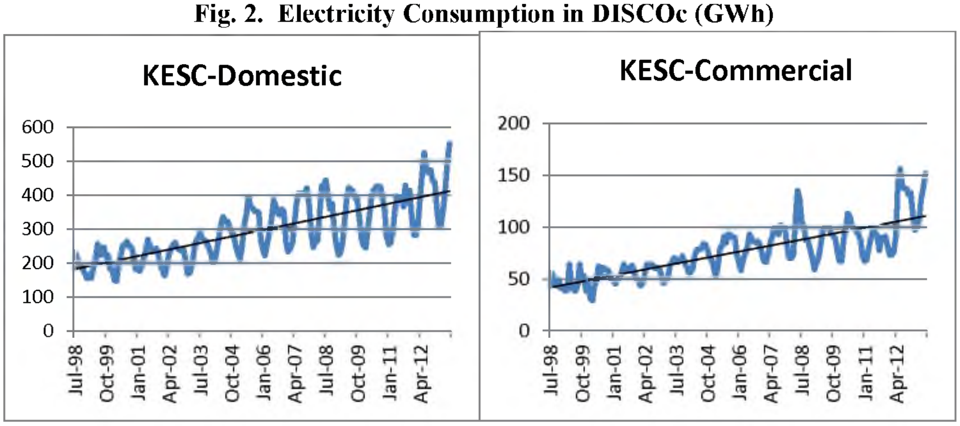
Fig. 1. Monthly Electricity Generation for Pakistan (GWh)

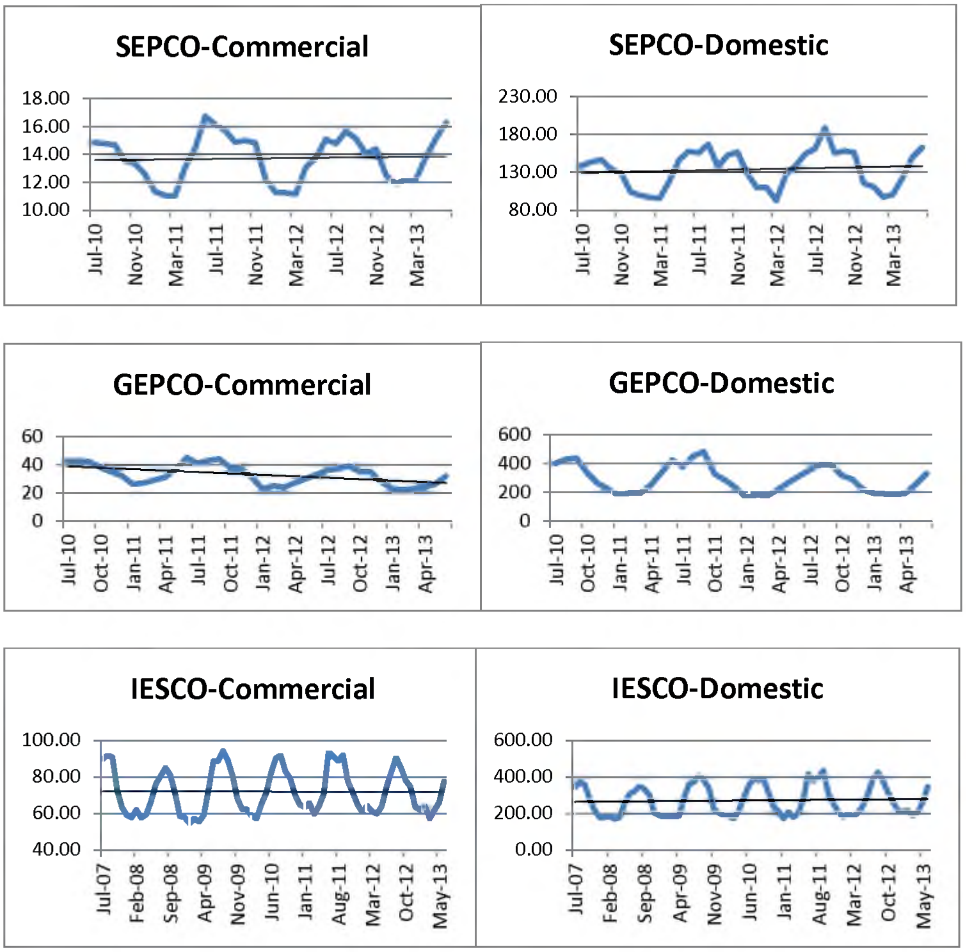


Sector-wise analysis on regional data (Figure 2) also suggests that electricity consumption has generally followed an increasing trend overtime. Fluctuations nonetheless are readily observable. The largest average consumption of electricity in residential sector is observed for Karachi district in the obtained data series followed by the regions served by GEPCO and IESCO while regions served by SEPCO show the lowest average residential electricity consumption in the period considered.

For commercial sector, the trend is a little different in that though area served by KESC registers highest electricity consumption on average, commercial sector in IESCO region shows larger consumption of electricity than that of GEPCO, SEPCO still remaining behind other regions in electricity consumption. In all the four regions served by their respective distribution companies, domestic consumption of electricity is significantly larger than commercial sector e.g. maximum electricity consumed in KESC and SEPCO domestic sector is 552 GWh and 189 GWh respectively as compared to that of commercial sectors of these regions which is just 156 GWh and 16.7 GWh in that order.

Fig. 2. Electricity Consumption in DISCOc (GWh)





Following Munoz and Sailor (1998), the present study employs the Degree Day method for incorporating temperature variations.[14] Degree days are a useful method to study energy requirements associated with different temperature conditions as it enables us to quantify the severity and duration of weather using a single index [Zachariadis (2010)]. A degree day is defined relative to a base temperature—the base being considered a comfortable temperature where neither heating nor cooling is required by individuals. A heating degree day (HDD) refers to a day when temperature is lower than the base by 1°C and heating is required to reach the base temperature and vice versa. Thus, at the temperature equivalent to base temperature, electricity demand is considered to reach the lowest level as the atmosphere itself facilitates the achievement of desired comfort level for individuals, suggesting a u-shaped relationship between electricity demand and temperature. Further following Yuan and Qian (2004), the study uses the definition of degree days as given below.

[14]The degree day method has been employed in literature to capture the non-linear relationship between temperature and electricity demand [Amato, *et al.* (2005); Ruth and Lin (2006)].

$$HDD_r = \gamma(T_b - T_r)m \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (1)$$

$$CDD_r = (1-\gamma)(T_r - T_b)m \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (2)$$

Where HDD_r and CDD_r are monthly heating degree days and cooling degree days respectively for region *r.* As we have conducted the analysis both at the regional level and at the national level the regions are defined accordingly; the region in the national level analysis is the country and at sub-national level, regions are defined as the areas served by the said distribution company.T_r is the monthly average temperature of region r calculated as a weighted average of temperatures of the districts being analysed where population share of the districts are used as weights [Bhartendu and Cohen (1987)], T_b is the base temperature, m is the number of days in the month under consideration, γ is a binary variable that equals 1 if $T_r < T_b$ and 0 otherwise.[15]The base temperature is taken at 26°C.[16]

4. METHODOLOGY AND ESTIMATION

The dependent variable in our model is the monthly demand for electricity[17]in Pakistan which is regressed on both the heating and cooling degree days to estimate relationship between the two. As electricity demand does not depend on temperature variables alone, control variables should also be included in the analysis such as GDP growth, population and price per unit of electricity [Jamil and Ahmed (2011)]. Thus, price index for electricity has been used as one of the explanatory variables[18] while due to unavailability of monthly data for the rest of the variables, the effect of time-varying variables is captured by using trend in the regression [Pilli-Sihvola, *et al.* (2010); Amato, *et al.* (2005)].

It is argued in literature that the relationship between electricity demand and temperature reflects two-way causality [Lee and Chiu (2011), Climate and Electricity Annual (2011)]. On one hand increase in temperature leads to rise in demand for electricity while on the other hand upsurge in power generation from thermal sources to satisfy increased demand may cause climatic effects such as higher average temperatures through Green House Gas Emissions [Climate and Electricity Annual 2011)]. In case of analysis on Pakistan as a whole, 33 years data on monthly electricity generation are used which is a period long enough to merit consideration of the climatic effect of electricity generation.[19] Thus, while regressing electricity generation data on temperature variables, we accounted for the problem of potential endogeneity by using Generalised Method of Moments (GMM) with internal instrumentation.[20] Initially to get a feel about the

[15]Ideally degree days should be calculated using daily data on temperature. However due to lack of access to such data we have used monthly temperatures in our analysis.

[16]In summers optimal room temperature is set at 26°C by Water and Power Development Authority (WAPDA), Pakistan.

[17]Proxied by electricity generation.

[18] Price index is used as a control variable in electricity demand equation because increase in prices of electricity can cause a change in demand for electricity by the consumers [Nasir, *et al.* (2008); Alter and Shabib (2011)].

[19]Engle-Granger test also pointed towards the existence of two-way causality.

[20]Lagged values of HDD and CDD have been used as instruments i.e. HDD(–12) and CDD(–12) which are justified because last year's temperature in a certain month have strong correlation with next year's temperature of that month but last year's temperature is not correlated with current year's electricity generation.

relationship between electricity demand and average monthly temperature, the following model is analysed.

$$E_t = \gamma_1 + \gamma_2 Temp_t + \gamma_3 Price_t + \gamma_4\, trend + \varsigma_t \quad \ldots \quad \ldots \quad \ldots \quad (3)$$

Where

E_t : Monthly electricity demand in GWh in period *t* in Pakistan,
$Temp_t$: Monthly average temperature (weighted by population shares[21]) of Pakistan,
$Price_t$: Price of electricity in period *t*,
trend : Trend variable used to capture the impact of all the time-varying factors, and
ς_t : Residual term.

Next, to take non-linearity of the relationship between temperature and electricity demand into account, the following equation has been employed.[22]

$$E_t = \beta_1 + \beta_2 HDD_t + \beta_3 CDD_t + \beta_4 Price_t + \beta_5 trend + \varepsilon_t \quad \ldots \quad \ldots \quad (4)$$

where

HDD_t : Monthly heating degree days in period *t*,
CDD_t : Monthly cooling degree days in period *t*, and
ε_t : Residual term.

Once we have quantified how electricity demand responds to changes in HDDs and CDDs, the next step is to project the changes in demand for electricity under different climate change scenarios, ranging from the one that predicts a 1°C rise in world average temperature by 2050 to the one that projects a grave 4°C rise in world average temperatures due to climate change [World Bank (2010)]. Following Parkpoom, *et al.* (2008), year 2012-13 is taken as a baseline scenario while projections are done for a rise in temperature by 1°C, 2°C, 3°C, and 4°C respectively to arrive at the estimates of change in electricity demand expected as a result of climate change.

In case of regional analysis, the dependent variable in our model is the monthly demand for electricity[23] in residential and commercial sectors of different distribution companies which is regressed on temperature variables, sector-wise prices and time trend. As the available data at regional level spans a shorter period of time (from 3-15 years), the problem of reverse causality in the relationship between electricity demand and temperature does not seem to be likely and temperature can be treated as exogenous variable. In addition upon testing with Granger Causality test, one way causality is found between temperature variables and electricity demand. The study uses Ordinary Least Squares (OLS) estimation procedure for regional analysis because if the assumptions required for proper functioning of OLS method hold, the estimators thus obtained have

[21]The temperatures are weighted by population shares because the focus of interest is electricity demand. If a relatively hot area is overly populated, the temperature of that region should be given more weightage than a relatively less hot area and vice versa.

[22]In contrast to the convention of using squared terms to capture non-linear relationships between variables, CDD and HDD are used that, by their construction, take non-linearity of relationship between temperature and electricity demand into account.

[23]Proxied by electricity consumption.

been proved to possess some ideal properties.[24] The estimators are linear and unbiased, and are efficient estimators in that they have minimum variance amongst a class of linear unbiased estimators. Given the desirability of properties of OLS estimators, the decisive factor in opting for OLS turns out to be whether or not the required assumptions for the procedure hold. In the present analysis, the underlying relationship between electricity demand and degree days calls for a linear model.[25] All the individual variables are tested for stationarity and are found to be stationary at I(0).[26] The problem of autocorrelation was observed which is dealt with by adding AR and MA terms in the regression after observing the correlogram [Prais and Winsten (1954); Pilli-Sihvola, *et al.* (2010)] while White Heteroscedasticity-consistent standard errors and covariances [White (1980)] were obtained to correct the issue of heteroscedasticity in the data. In addition, as the number of explanatory variables in our model is not large and the degrees of freedom are satisfactory, the application of OLS technique to the model is justified. Finally the obtained residuals from the regressions have been tested for stationarity and are found to be stationary reinforcing the appropriateness of the estimation technique used in our analysis [Box and Jenkins (1970)].

5. RESULTS AND DISCUSSION

As a first step towards establishing a relationship between electricity demand and changes in temperatures, monthly electricity demand for Pakistan has been regressed on monthly mean temperature, price of electricity and trend [Pilli-Sihvola, *et al.* (2010)]. Results are provided in Table 1.

Table 1

Regression of Electricity Demand (GWh) on Temperature (^0C) for Pakistan (GMM Estimation)

	Coefficients					
Dependent Variable	Average Monthly Temperature (S.E)	Trend (S.E.)	Price of Electricity (S.E.)	Constant (S.E.)	Adjusted R^2	J-Statistic (Prob.)
Electricity Demand (GWh)	76.87***	18.55***		–807.62***	0.864	0.0001
	(8.83)	(0.85)		(258.91)		(0.992)
	75.80***	63.94***	–20.10***	–3502.58***	0.578	0.187
	(15.18)	(15.50)	(6.50)	(1165.83)		(0.673)

***Significant at 1 percent.

The coefficient of temperature turns out significant at 1 percent and is positive corroborating the claims that demand for electricity increases with increase in temperatures.[27,28] Significantly negative co-efficient of price points towards the decrease

[24] Gauss-Markov Theorem attributed to Gauss (1821) and Markov (1900).

[25] Bartholomew, *et al.* (2002).

[26] In order to test for seasonal unit roots in monthly data, Osborn-Chui-Smith-Birchenhall (OCSB) and Canova-Hansen (CH) tests have been applied in R software.

[27] Findings are in corroboration with earlier literature, for example, Zachariadis (2010); Parkpoom and Harrison (2008); Amato, *et al.* (2005); Rosenthal, *et al.* (1995).

[28] It is possible that the electricity generation data may not be reflecting the true demand for electricity since the city experiences load-shedding due to electricity shortages.

in demand for electricity due to increase in its price. The positive and significant coefficient of trend means that electricity consumption surges with surges in its time varying determinants other than temperature.

In the next step the electricity demand was regressed on the monthly HDDs and CDDs and the results are reported in Table 2. A significant positive coefficient of the CDD variable implies that electricity consumption inflates as temperatures intensify; when temperatures rise above the threshold temperature of 26°C more electricity is used through the use of fans, air-conditioners etc. to bring temperatures at comfortable level. The significant but negative coefficient of the HDD entails that with declining temperatures, necessitating a need for heating to bring it to comfortable levels, electricity use declines.[29] One plausible explanation for this behaviour could be that space heating requirements are being fulfilled by the use of other energy sources like gas, firewood, coal etc. The price and trend coefficients enter again significantly negative and positive respectively suggesting that electricity usage decreases with rise in prices but generally increases over the time. As a sensitivity check, all the four models were also estimated using OLS technique and the coefficients maintained their signs and significance.[30]

Table 2

Regression of Electricity Demand (GWh) on CDDs and HDDs for Pakistan (GMM Estimation)

	Coefficients						
Dependent Variable	CDD (S.E.)	HDD (S.E.)	Trend (S.E.)	Price (S.E.)	Constant (S.E.)	Adjusted R^2	J-Statistic (Prob.)
Electricity Demand (GWh)	3.02***	-2.22***	18.54***		1112.10***	0.863	0.032
	(0.75)	(0.39)	(0.85)		(144.81)		(0.984)
	3.08***	-2.17***	28.94***	-5.02***	625.14***	0.895	0.053
	(0.68)	(3.60)	(1.99)	(0.89)	(164.59)		(0.973)

***Significant at 1 percent.

Regional Analysis

In case of regional analysis, electricity demand responds significantly positively to changes in temperatures in all the four DISCOs considered (Table 3) reinforcing our earlier findings. However, prices turn out to be insignificant in case of SEPCO while trend seems insignificant in explaining variations in electricity demand in GEPCO region. This insignificance of both the prices and trend may owe itself to the very short time span of data for these two regions which may not give us sufficiently representative results. The domestic sector in all of the DISCOs is found more responsive to temperature than commercial sector. A more detailed analysis at regional level incorporating HDD and CDD in the model suggests that generally electricity consumption rises with increase in cooling degree days and falls with increase in heating degree days (Table 4).

[29]Results are in corroboration with earlier literature [see Amato, *et al.* (2005)].
[30]Results are reported in Appendix B.

Table 3

Regression of Electricity Demand (GWh) on Temperature (^0C) for given DISCOs (OLS Estimation)

DISCO	Sector	Coefficients: Temp (S.E.)	Price (S.E.)	Trend (S.E.)	Adjusted R^2	F-Statistic (Prob.)	PP-test Statistic for residuals (Prob.)
KESC	Domestic	2.89***	–0.08	1.53***	0.909	345.11	–16.08
		(1.01)	(0.10)	(0.26)		(0.00)	(0.00)
	Commercial	0.83***	–0.01	0.45***	0.890	288.52	–13.42
		(0.26)	(0.02)	(0.08)		(0.00)	(0.00)
SEPCO	Domestic	1.72***	–0.60***	4.64***	0.510	13.16	–4.94
		(0.41)	(0.12)	(0.95)		(0.00)	(0.00)
	Commercial	0.14***	–0.02***	0.27***	0.554	15.53	–4.50
		(0.03)	(0.005)	(0.06)		(0.00)	(0.00)
GEPCO	Domestic	4.17**	–0.83*	3.92	0.698	17.20	–5.26
		(1.97)	(0.43)	(3.71)		(0.00)	(0.00)
	Commercial	0.22**	–0.06**	0.42	0.722	23.73	–4.86
		(0.11)	(0.02)	(0.28)		(0.00)	(0.00)
IESCO	Domestic	4.29***	–0.65***	4.57***	0.713	45.18	–6.90
		(1.03)	(0.20)	(1.43)		(0.00)	(0.00)
	Commercial	0.57***	–0.06***	0.67**	0.653	34.38	–6.76
		(0.16)	(0.02)	(0.26)		(0.00)	(0.00)

*** ** and * show significance at 1 percent, 5 percent and 10 percent respectively.

It must be noted, however, that the time span covered in this analysis is particularly shorter for the three DISCOs viz. SEPCO, GEPCO and IESCO where the whole period of analysis for these DISCOs consists of the years when electricity shortfall was particularly massive. Electricity shed is recorded around 36 percent of total energy sales in 2010 (NTDC, 2011) while the load shedding pattern marked significantly longer hours of power cuts in summers as compared to that in winter season. Given that we are using electricity consumption as a proxy for electricity demand in this analysis, energy shed may be the reason not only for smaller and in some cases, insignificant co-efficient of CDD but also for negative co-efficient of CDD in one case (GEPCO) which shows that people of the region actually consumed lesser electricity when the temperature got high. The coefficients, wherever significant, are found larger in case of domestic sector as compared to commercial sector corroborating our earlier findings in this regard.

Table 4

Regression of Electricity Demand (GWh) on CDD and HDD for given DISCOs (OLS Estimation)

DISCO	Sector	Coefficients: CDD (S.E.)	HDD (S.E.)	Price (S.E.)	Trend (S.E.)	Adjusted R^2	F-Statistic (Prob.)	PP-test Stat for Residuals (Prob.)
KESC	Dom	0.25***	–0.15***	–0.26***	2.06***	0.893	300.37	–10.49
		(0.04)	(0.03)	(0.10)	(0.33)		(0.00)	(0.00)
	Com	0.059***	–0.27***	–0.28	0.52***	0.884	273.85	–11.02
		(0.01)	(0.01)	(0.02)	(0.09)		(0.00)	(0.00)
SEPCO	Dom	0.07**	–0.04	–0.61***	4.72***	0.500	9.751	–4.92
		(0.12)	(0.03)	(0.124)	(0.97)		(0.00)	(0.00)
	Com	0.005**	–0.004**	–0.02***	0.27***	0.538	11.22	–4.55
		(0.002)	(0.002)	(0.005)	(0.06)		(0.00)	(0.00)
GEPCO	Dom	–0.44***	–0.23***	–1.64***	10.46***	0.702	21.66	–4.78
		(0.14)	(0.04)	(0.36)	(2.81)		(0.00)	(0.00)
	Com	–0.01	–0.003*	–0.03**	0.18	0.795	22.44	–6.82
		(0.10)	(0.002)	(0.02)	(0.26)		(0.00)	(0.00)
IESCO	Dom	0.06	–0.12***	–0.12	1.4	0.755	36.97	–7.82
		(0.06)	(0.06)	(0.29)	(2.16)		(0.00)	(0.00)
	Com	0.003	–0.02*	–0.005	0.12	0.726	31.93	–7.80
		(0.01)	(0.009)	(0.02)	(0.31)		(0.00)	(0.00)

*** ** and * show significance at 1 percent, 5 percent and 10 percent respectively.

A comparison of regional results with country-level analysis shows that though relationships among the key variables have generally maintained their signs, the coefficients are exceptionally larger in case of country wide analysis as compared to that of the DISCOs. This makes sense because, say, a unit increase in temperature is going to increase the units of electricity consumed for Pakistan much more than increase in consumption for any of the DISCOs given that number of consumers in any of the DISCOs is smaller than that in the country.[31] The last columns of Table 3 and 4 show that residuals were found stationary in all the estimations.

6. SENSITIVITY ANALYSIS[32]

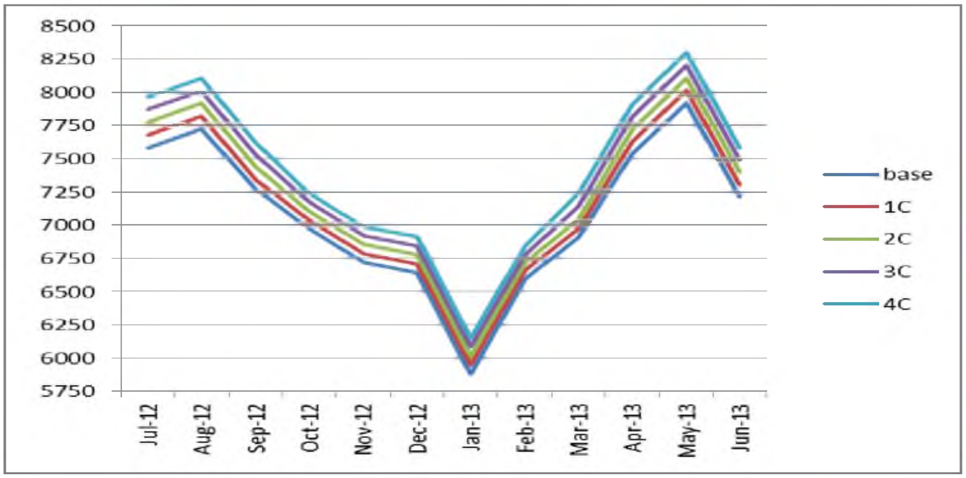
Based on the strength of the model in forecasting electricity demand, Equation 4 is chosen for projecting the changes in electricity demand under different climate scenarios. Results of the projection are presented in Figure 3 under 1^0C, 2^0C, 3^0C and 4^0C rise in temperature as compared to base year (2012-13).[33]

[31]To ensure that results sustain alternate specifications, log-linear specification is also estimated and the results are found generally consistent. Estimation outputs are available with the authors and can be provided on request.

[32]The name of the section has been adopted from conventional approaches towards the issue [Rosenthal, *et al.* (1995), Palmer and Burtraw (2004)] because the section deals with analysing sensitivity of electricity demand to temperatures under different climate scenarios. Specifically the analysis tells us that in case climatic changes cause temperatures to rise on average by a certain degree, by what percentage electricity demand will rise compared to the base year.

[33]Projections are being reported at national level rather than regional level because of the shorter span of data given by DISCOs and the consequent problems with their analysis. Only KESC had a relatively longer time-series (15 years) and projections for the corresponding region are presented in Appendix D.

Fig. 3. Projections of Electricity Demand for Pakistan under Different Climate Scenarios



It is found that generally the rise in electricity demand is more pronounced in the relatively hot months of the years as compared to relatively cold ones suggesting surging peak loads in summer season.

Under 1°C rise in temperature scenario, residential electricity consumption is expected to rise in the range of 0.92 percent to 1.8 percent, for a 2°C rise in temperature, the range is found to be 1.8 percent to 2.6 percent, for 3°C rise it lies between 2.7 percent to 3.8 percent while if the temperature increases by 4°C electricity demand may rise by 5.1 percent to 3.7 percent. The greater sensitivity of peak demand to temperatures suggest the need for capacity instalments over and above that needed to cater to rise in electricity demand attributable to economic growth.[34]

7. CONCLUSION

The study examines the impact of climate change reflected in rising global temperatures, on electricity demand in Pakistan. Employing heating and cooling degree days to capture the influence of temperature and controlling for other factors that affect electricity demand, regression analysis is used to arrive at estimates of relationship between temperature changes and electricity demand. The analysis suggests a significant positive response of electricity demand to rise in temperature and thus points towards increase in electricity demand in the country and its respective regions in future owing to climatic variations. The percentage increase in electricity demand as projected in this analysis (5.1 percent at most) should be carefully interpreted and two points should be given special attention while drawing any inferences in this regard. Firstly, the percentage increase in electricity demand found in the present study is the rise in demand attributable only to escalating temperatures disregarding changes in trends of all the other factors that affect increase in demand. It is expected that with growth in GDP and population as well as mechanisation, adaptation and other socio-economic factors, electricity demand will

[34]The results are found in line with literature available in this regard e.g., Howden and Crimp (2001).

increase in future over and above that which is induced by temperature [NTDC (2011)]. Secondly, electricity consumption or generation understates true demand for electricity owing to excessive load shedding in Pakistan which has grown more severe in recent years. If both of these factors are taken into account, the rise in electricity demand in response to climate change is expected to become more pronounced in magnitude and thus calls for more careful planning by the relevant authorities regarding capacity building and load management. In the end, given all the data limitations particularly that data on relevant control variables was not available on required frequency, analysis could be conducted only on a few regions where long time series could not be obtained at regional level, degree days could not be computed using daily temperatures and that monthly data on prices were constructed in a rather crude way, the study should be viewed as an effort to arrive at some meaningful estimates but there is ample room for more advanced and extensive research in this area. With all the caveats mentioned above, results of the study should be generalised carefully.

APPENDIX A

ANALYSIS OF FLUCTUATIONS IN ELECTRICITY DEMAND

Table A.1

Regression of Fluctuations in Electricity Demand (GWh) filtered through Hodrick-Prescott on CDDs and HDDs for Pakistan (GMM Estimation)

	Coefficients			
Estimation Technique	CDD (S.E.)	HDD (S.E.)	Adjusted R^2	Diagnostics
OLS Estimation	2.61***	–1.52***	0.653	F-Statistic (Prob.)
	(0.45)	(0.22)		249.12
				(0.00)
GMM Estimation	2.78***	–2.27***	0.395	J-Statistic (Prob.)
	(0.65)	(0.36)		0.019
				(0.990)

***Significant at 1 percent.

APPENDIX B

RESULTS OF OLS ESTIMATION ON MONTHLY DATA OF PAKISTAN

Table B.1

Regression of Electricity Demand (GWh) on Temperature (^0C) for Pakistan (OLS Estimation)

	Coefficients				
Dependent Variable	Average Monthly Temperature (S.E)	Trend (S.E.)	Price of Electricity (S.E.)	Adjusted R^2	F-Statistic (Prob.)
Electricity Demand	58.20***	18.34***		0.952	2640.40
(GWh)	(6.17)	(1.02)			(0.00)
	58.50***	25.82***	-3.73***	0.954	2035.2
	(6.01)	(2.17)	(1.01)		(0.00)

***Significant at 1 percent.

Table B.2

Regression of Electricity Demand (GWh) on CDDs and HDDs for Pakistan (OLS Estimation)

	Coefficients					
Dependent Variable	CDD (S.E.)	HDD (S.E.)	Trend (S.E.)	Price (S.E.)	Adjusted R^2	F-Statistic (Prob.)
Electricity Demand (GWh)	2.61***	–1.40***	18.35***		0.952	1969.66
	(0.38)	(0.26)	(1.04)			(0.00)
	2.61***	–1.42***	25.89***	–3.76***	0.953	1619.12
	(0.39)	(0.26)	(0.21)	(1.02)		(0.00)

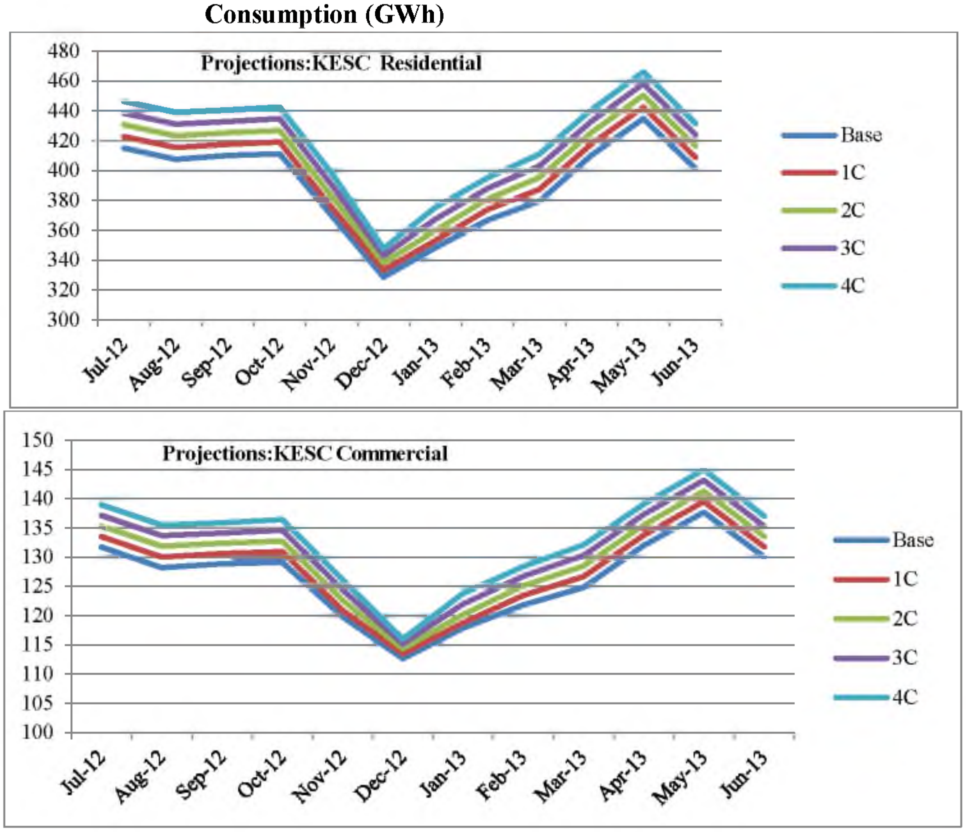
***Significant at 1 percent.

APPENDIX C

SENSITIVITY ANALYSIS FOR REGIONS SERVED BY KESC

In case of residential sector served by KESC, increase in temperature by 1°C increases electricity consumption in the range of 1.3 percent to 2 percent, a 2°C rise in temperature induces 2.8 percent to 4 percent increase, a 3°C increase in temperature causes 4.3 percent to 6.2 percent rise while in case temperature increases by 4°C, increase in electricity consumption is expected in the range of 5.8 percent to 8.3 percent.

Fig. D.1. Projections for KESC Residential and Commercial Sectors Consumption (GWh)



The surge in electricity consumption in commercial sector is relatively less pronounced ranging from 0.7 percent to 1.4 percent in case of 1°C rise to 3 to 5.8 percent under 4°C rise scenario. The results for Karachi region shows a higher percentage response to temperature changes in the projected electricity consumption as compared to the case of country-wide projections; the latter may be dampened because of region-wise and sector-wise aggregation of data.

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