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Impact of Climate Change on Electricity Demand: A Case Study of Karachi District

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1. INTRODUCTION

Out of the climatic variables such as temperature, humidity, precipitation, cloud cover, etc., electricity demand has been found most responsive to changes in temperature [Parkpoom and Harrison (2008); Al-Hamadi and Soliman (2005); Hor, *et al*. (2005)]. According to National Aeronautics and Space Administration, the decade from 2001 to 2010 was the warmest worldwide while the rise in surface temperatures of South Asia region by the end of the century is projected around 3.3°C average annually (IPCC);[1] not only are the average temperatures rising but the range of extreme temperatures is also widening. Increase in temperatures can affect human lives significantly; the present study focusses on examining the impact of climate change on demand for electricity in Pakistan.

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 to changing demand for electricity as the need for air-conditioning, refrigeration, water temperature regulation etc. change [Amato, *et al.* (2005); Rosenthal, *et al.* (1995)]. Though, recognising the importance of this issue, a number of studies have been conducted internationally on analysing future demand conditions of different countries [e.g. Rosenthal, *et al.* (1995); Parkpoom and Harrison (2008); Howden and Crimp (2001)] literature in Pakistan largely lacks in this dimension.[2] The estimation of such changes in demand is important as they can have important consequences for electricity generation capacity building. Given the electricity crisis that has 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 need of capacity generation. As there is a protracted time lag between recognition of

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[1]Intergovernmental Panel on Climate Change.

[2]Most of the papers that have estimated energy demand equation [Chaudhary (2010); Nasir, *et al*. (2008); Khan and Qayyum (2009)] do not take temperature as an explanatory variable [Jamil and Ahmed (2011)] further exploration of the subject 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.

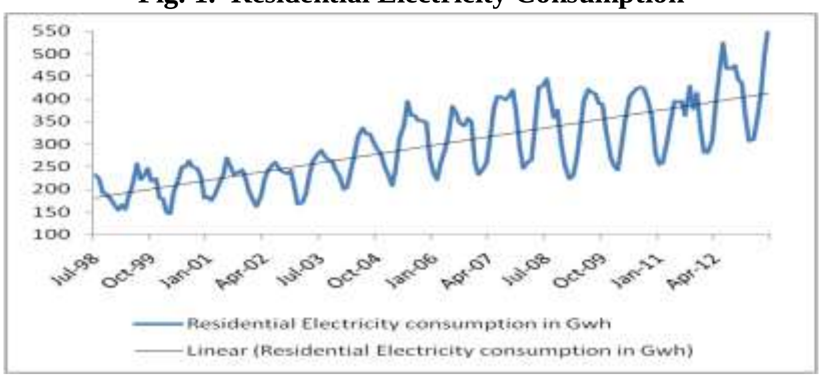
demand needs for electricity and its capacity building, the study will prove helpful for government regarding design of energy policy.

The objectives of the present study are (1) estimation of impact of temperature variation on electricity demand in Pakistan in residential and commercial sectors, and (2) projection of the changes in demand for electricity for the two sectors of the economy under different temperature rise scenarios. As the analysis is still in progress, we will share only the results for a single region i.e. Karachi and its suburbs. Section 2 discusses data and variables used in the analysis while Section 3 deals with methodology and estimation. Results and accompanied discussion is presented in Section 4 followed by sensitivity analysis in Section 5 while Section 6 concludes the paper.

1. DATA AND VARIABLES

Monthly data on electricity consumption of residential and commercial sectors,[3] from July 1998 to June 2013, have been obtained from Karachi Electric Supply Corporation (KESC).[4] The data on average monthly temperatures for this time period have been taken from Pakistan Meteorological Department (PMD).[5] A look at the data (Figures 1 and 2) shows that electricity consumption has considerable seasonal fluctuations and a time trend both in the residential and commercial sectors.[6] During the period the maximum monthly average temperature was 36°C and minimum 11.9°C. A simple graph of temperature reveals a slightly increasing time trend pointing to global warming impacts.[7] Consequently, a modest increase in cooling degree days and decrease in heating degree days can also be observed as shown in Figures 3 and 4.

Fig. 1. Residential Electricity Consumption



[3]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)].

[4]We are especially thankful to Saad Hasan Latif, KESC for his co-operation.

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

[6]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 I.

[7]Global Warming is a very gradual process and our dataset spanning only 15 years may be inadequate to capture it fully.

Fig. 2. Commercial Electricity Consumption

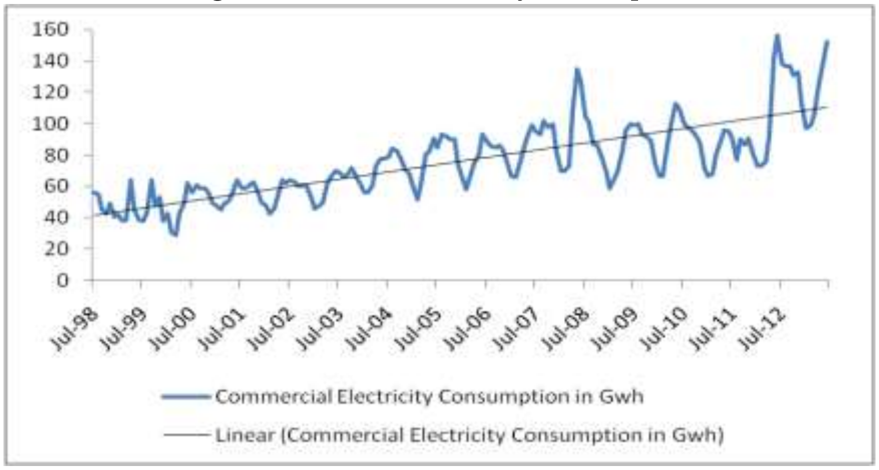


Fig. 3. Monthly CDDs

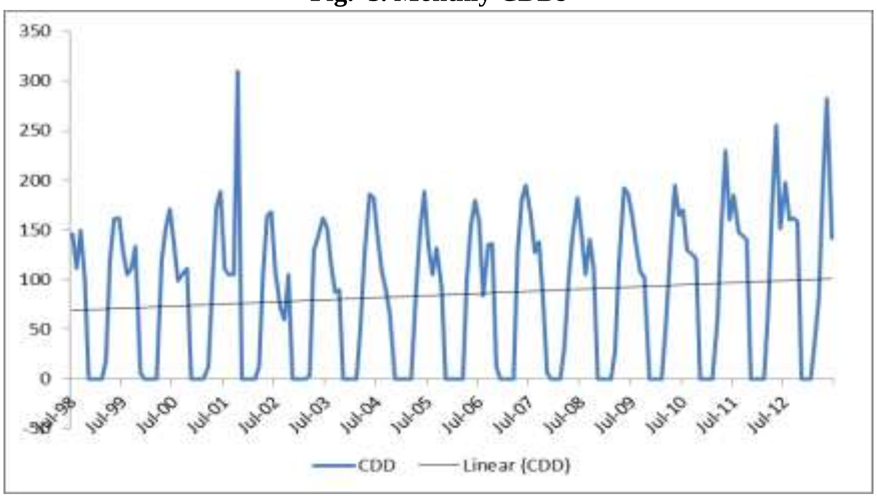
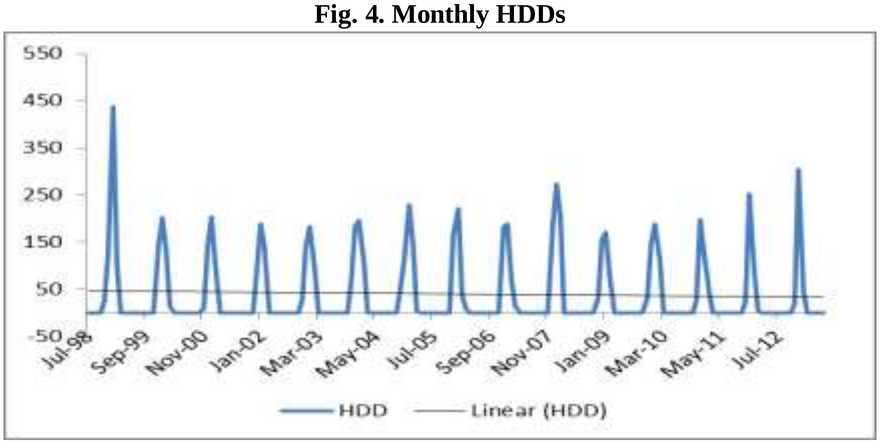


Fig. 4. Monthly HDDs



Following Munoz and Sailor (1998), the present study employs degree day method for incorporating temperature variations.[8] A degree day is defined relative to a base temperature wherein the heating degree day (HDD) refers to a day when temperature is lower than the base 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. In this way, without introducing squared term in the analysis, HDD and CDD are utilised to incorporate u-shaped relationship between temperature and electricity demand. Further, following Yuan and Qian (2004), the study uses the definition of degree days as given below.

$$HDD_i = \gamma(T_b - T_i)m \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad (1)$$

$$CDD_i = (1-\gamma)(T_i - T_b)m \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad (2)$$

Where HDD_i and CDD_i are monthly heating degree days and cooling degree days respectively for region *i* where regions are defined as the area served by a particular power distribution company, in this case, KESC, T_i is the monthly average temperature of region *i*, 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 $T_i < T_b$ and 0 otherwise.[9] The base temperature is taken at 26^{o}C.[10]

3. METHODOLOGY AND ESTIMATION

The dependent variable in our model is the monthly demand for electricity[11] in residential and commercial sectors of Karachi and its suburbs which is regressed on both the heating and cooling degree days to estimate the 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)]. Due to lack of data at regional level, the effect of time-varying variables is captured by using trend in the regression [Pilli-Sihvola, *et al.* (2010); Amato, *et al.* (2005)].

Initially the relationship between electricity consumption and average monthly temperature has been studied using the following equation.

$$E_{it} = \gamma_{1i} + \gamma_{2i}Temp_t + \gamma_{3i}trend + \varsigma_{it} \quad \dots \quad \dots. \quad \dots \quad \dots \quad (3)$$

where

E_{it} : Monthly electricity demand in GWh in sector *i*,
$Temp_t$: Monthly average temperature in the region,

[8]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)].

[9]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.

[10]In summers optimal room temperature is set at 26^{o}C by Water and Power Development Authority (WAPDA), Pakistan.

[11]Proxied by electricity consumption.

trend : The trend variable used to capture the impact of all the time-varying factors, and

ς_{it} : Residual term

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

$$E_{it} = \beta_{1i} + \beta_{2i}HDD_t + \beta_{3i}CDD_t + \beta_{4i}trend + \varepsilon_{it} \quad \ldots \quad \ldots \quad \ldots \quad (4)$$

where

HDD_t : Monthly heating degree days in region i,

CDD_t : Monthly cooling degree days in region i,

ε_{it} : Residual term

The study uses Ordinary Least Squares (OLS) estimation procedure for the analysis because if the assumptions required for proper functioning of OLS method hold, the estimators thus obtained have been proved to possess some ideal properties.[12] 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.[13] All the individual variables are tested for stationarity and are found to be stationary at I(0)[14] while testing with Granger Causality test, one way causality is found between temperature variables and electricity demand. The problem of autocorrelation was observed which is dealt with by adding AR and MA terms in the regression [Prais and Winsten (1954)] after observing the correlogram while White Heteroscedasticity-consistent standard errors and covariances [White (1980)] were obtained after correcting 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)].

4. RESULTS AND DISCUSSION

As a first step towards establishing a relationship between electricity consumption and changes in temperatures induced by climate change, residential electricity consumption has been regressed on monthly mean temperature and trend. Results are provided in Table 1. The coefficient of temperature turns out significant at 1 percent and is corroborating the theoretical claims that demand for electricity increases with increase in temperatures.[15,16] Similarly for the commercial sector of Karachi and its adjoining

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

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

[14] Results of Unit Root tests are given in Appendix II.

[15] Demand for electricity is derived demand which changes with the change in use of electrical appliances.

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

areas regressing electricity consumption on temperatures gives a significant positive coefficient to the temperature variable showing that in this sector too, electricity demand rises with rising temperatures (Table 1). The positive and significant coefficient of trend means that electricity consumption surges with surges in its time varying determinants other than temperature.

Table 1

Regression of Electricity Consumption on Temperature

Dependent Variable	Coefficients: Average Monthly Temperature (S.E.)	Coefficients: Trend (S.E.)	Adjusted R^2	F-Statistic (Prob.)
Residential Electricity Consumption (GWh)	2.673*** (1.01)	1.315*** (0.14)	0.907	431.27 (0.00)
Commercial Electricity Consumption(GWh)	0.78*** (0.26)	0.40*** (0.05)	0.890	361.04 (0.00)

***Significant at 1 percent.

In the next step the electricity consumption of the residential sector was regressed on the monthly HDDs and CDDs. Table 2 shows the regression results. A meaningful positive coefficient of the CDD variable implies that electricity consumption inflates as temperatures intensify; when temperatures rise above the threshold temperature of 26ºC 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 declining temperatures necessitate a need for heating to bring it to comfortable levels, leading to electricity use declines.[17] 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 trend coefficient enters again significantly positive meaning that electricity usage increases with time.

Table 2

Regression of Electricity Consumption on Monthly CDDs and HDDs

Dependent Variable	Coefficients: CDD (Prob.)	Coefficients: HDD (Prob.)	Coefficients: Trend (Prob.)	Adjusted R^2	F-Statistic (Prob.)
Residential Electricity Consumption (GWh)	0.172*** (0.05)	–0.146*** (0.05)	1.321*** (0.18)	0.896	307.01 (0.00)
Commercial Electricity Consumption (GWh)	0.044*** (0.013)	–0.025** (0.012)	0.398*** (0.057)	0.888	282.56 (0.00)

***Significant at 1 percent. **Significant at 5 percent.

Likewise, regressing the electricity consumption in the commercial sector on the monthly HDDs and CDDs along with trend provides a significant positive coefficient of the CDD reiterating that, the use of electricity expands with increase in the number of days requiring cooling and the negative but significant coefficient of the HDD variable

[17] Results are in corroboration with earlier literature, see Amato, *et al*. (2005).

denotes that rising need for heating contracts the electricity use. The trend coefficient is consistent with our previous results and has the similar explanation. [18,19]

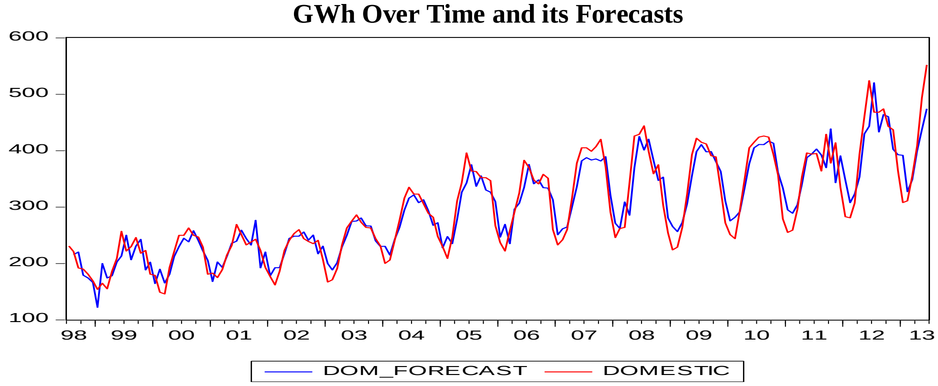
5. SENSITIVITY ANALYSIS

Figures 5 and 6 show the demand for electricity by residential and commercial sectors against their respective forecasts obtained by using Equation 4. Given the apparent success of forecasts in explaining the actual values, we use Equation 4 to test for sensitivity of electricity demand to temperatures under different global temperature scenarios. Following Parkpoom, *et al.* (2008), year 2012 is taken as a baseline scenario while projections are done for a rise in temperature by 1°C, 2°C, and 3°C respectively.[20] Thus sensitivity curves are obtained and compared for each scenario as presented in Figures 7 and 8.

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 1.14 percent to 1.27 percent, for a 2°C rise in temperature, the range is found to be 2.3 percent to 2.5 percent while if the temperature increases by 3°C electricity demand may rise by 3.5 percent to 3.8 percent. On similar trends, commercial electricity consumption is likely to rise by 2.3 percent to 3.6 percent under 3°C temperature rise scenario. The greater sensitivity of peak demand to temperatures suggest the need for capacity installation over and above that needed to cater to rise in electricity demand attributable to economic growth. [21]

Fig. 5. Residential Electricity Consumption in GWh Over Time and its Forecasts



[18]The coefficient of CDD is greater in magnitude than the coefficient of HDD which may also indicate that electricity demand is more sensitive to high temperatures. This result is in concurrence with available literature e.g. Sailor and Pavlova (2003).

[19]The coefficients of temperature variables have higher magnitudes in case of residential electricity demand as compared to commercial hinting at relatively larger sensitivity of the former to changes in temperature.

[20]A more sophisticated analysis could be conducted by using Climate Change Scenarios Data for Karachi. However due to lack of access to this data for years prior to 2071, we have adopted a rather generalised approach.

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

Fig. 6. Commercial Electricity Consumption in GWh and its Forecast

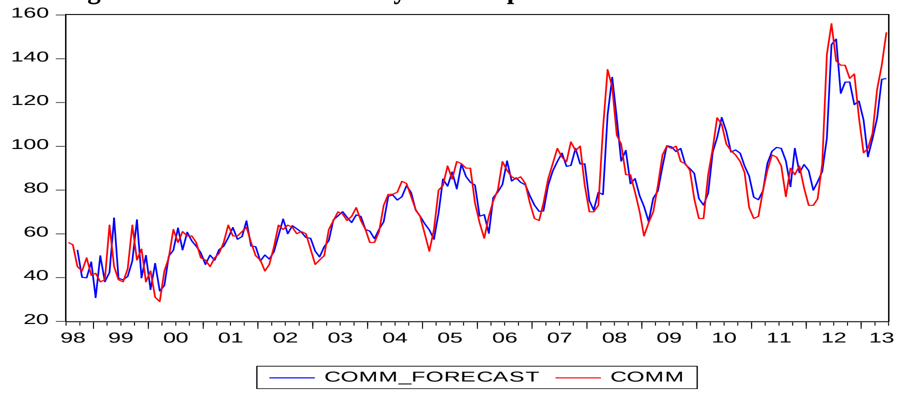


Fig. 7. Residential Base Consumption and Projected Consumption

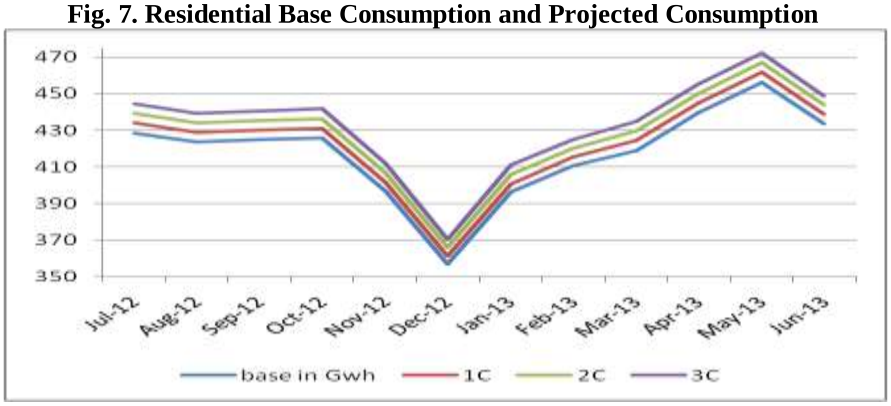
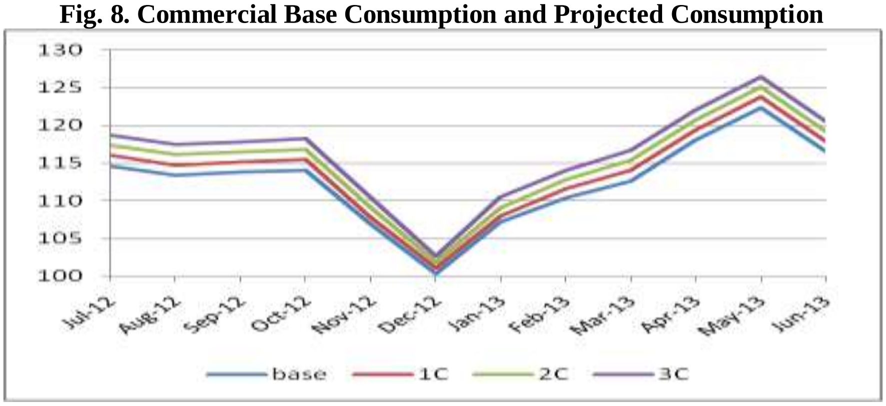


Fig. 8. Commercial Base Consumption and Projected Consumption



6. CONCLUSION

The study finds impact of climate change, proxied by rising temperatures, on electricity demand in Karachi and its suburbs. The analysis suggests a significant positive response of electricity demand to rise in temperature and thus points towards increase in electricity demand in the region in future owing to climatic variations. The percentage increase in electricity demand as projected in this analysis seems too small to be worried about (3.8 percent at most), possibly because of primitive nature of temperature regulation mechanisms used by the residents. Two points, however, should be kept in mind while drawing any inferences even for the case of Karachi region alone. 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 and other socio-economic factors, electricity demand will increase in future over and above that which is induced by temperature. Secondly, electricity consumption understates true demand for electricity owing to excessive load shedding in Pakistan in the period considered for analysis which holds true for Karachi as well. 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.

Appendix I

Impact of Temperature on Fluctuations in Electricity Consumption

Fluctuations	Coefficient: Average Monthly Temperature (Celsius)*	R^2	F-Statistic (Prob.)
Residential Electricity Consumption	5.157118 (0.000)	0.748996	174.0664 (0.000000)
Commercial Electricity Consumption	1.135120 (0.000)	0.660234	113.3533 (0.0000)

*Estimation done through OLS.

Fluctuations	Coefficients** CDD (Prob.)	HDD (Prob.)	R^2	F-Statistic (Prob.)
Residential Electricity Consumption	0.186857 (0.0003)	–0.152476 (0.0021)	0.746678	128.2180 (0.000000)
Commercial Electricity Consumption	0.049638 (0.0000)	–0.027119 (0.0052)	0.660815	84.74841 (0.000000)

**Estimation done through OLS.

Appendix II

Results of Unit Root Test

(i) Residential Electricity Consumption

		Adj. t-Stat	Prob.*
Phillips-Perron Test Statistic		–3.823886	0.0174
Test Critical Values:	1% Level	–4.010143	
	5% Level	–3.435125	
	10% Level	–3.141565	

(ii) Commercial Electricity Consumption

		Adj. t-Stat	Prob.*
Phillips-Perron Test Statistic		–4.526310	0.0018
Test Critical Values:	1% Level	–4.010143	
	5% Level	–3.435125	
	10% Level	–3.141565	

(iii) Average Monthly Temperature

		Adj. t-Stat	Prob.*
Phillips-Perron Test Statistic		–5.320169	0.0001
Test Critical Values:	1% Level	–4.010143	
	5% Level	–3.435125	
	10% Level	–3.141565	

(iv) Cooling Degree Days

		Adj. t-Stat	Prob.*
Phillips-Perron Test Statistic		–6.467832	0.0000
Test Critical Values:	1% level	–4.010143	
	5% level	–3.435125	
	10% level	–3.141565	

(v) Heating Degree Days

		Adj. t-Stat	Prob.*
Phillips-Perron Test Statistic		–6.467832	0.0000
Test Critical Values:	1% level	–4.010143	
	5% level	–3.435125	
	10% level	–3.141565	

REFERENCES

Al-Hamadi, H. M. and S. A. Soliman (2005) Long-term/Mid-term Electric Load Forecasting based on Short-term Correlation and Annual Growth. *Electric Power Systems Research* 74:3, 353–361.

Ali, M., M. J. Iqbal, and M. Sharif (2013) Relationship between Extreme Temperature and Electricity Demand in Pakistan. *International Journal of Energy and Environmental Engineering* 4:1.

Amato, A., M. Ruth, P. Kirshen and J. Horwitz (2005) Regional Energy Demand Responses to Climate Change: Methodology and Application to the Commonwealth of Massachusetts. *Climatic Change* 71, 175–201.

Bartholomew, E. S., R. Buskirk, and C. Marnay (2002) Conservation in California during the Summer of 2001. *LBNL*-51477, 22 pp.

Box, George and Gwilym Jenkins (1970) *Time Series Analysis: Forecasting and Control.* San Francisco: Holden-Day.

Chaudhry, A. (2001) A Panel Data Analysis of Electricity Demand in Pakistan. *Lahore Journal of Economics* 15 (Special Edition), 75–106.

Gauss, C. F. (1821) Theoria Combination is Observationum Erroribus Minimis Obnoxiae (Pars Prior). Presented 15.2.1821. Commentationes societatis regiae scientiarium Gottingensis recentiores, Werke, Vol. 4, Dieterichsche Universit ats-Druckerei, 1880, 1–108.

Hor, C. L., S. J. Watson, and S. Majithia (2005) Analysing the Impact of Weather Variables on Monthly Electricity Demand. *IEEE Transactions on Power Systems* 20:4, 2078–2085.

Howden, S. M. and S. Crimp (2001) Effect of Climate and Climate Change on Electricity Demand in Australia. In *Integrating Models for Natural Resources Management Across Disciplines, Issues and Scales. Proceedings of the International Congress on Modelling and Simulation* (pp. 655–660).

Jamil, F. and E. Ahmad (2011) Income and Price Elasticities of Electricity Demand: Aggregate and Sector-wise Analyses. *Energy Policy* 39:9, 5519–5527.

Khan, M. A. and A. Qayyum (2009) The Demand for Electricity in Pakistan. *OPEC Energy Review* 33: 1.

Markov, A. A. (1900) *Wahrscheinlichkeitsrechnung*. Telner, Leipzig.

Muñoz, J. R. and D. J. Sailor (1998) A Modelling Methodology for Assessing the Impact of Climate Variability and Climatic Change on Hydroelectric Generation. *Energy Conversion and Management* 39:14, 1459–1469.

Nasir, M., M. S. Tariq, and A. Arif (2008) Residential Demand for Electricity in Pakistan. *The Pakistan Development Review* 47:4, 457–467.

Parkpoom, S. J. and G. P. Harrison (2008) Analysng the Impact of Climate Change on Future Electricity Demand in Thailand. *IEEE Transactions on Power Systems* 23: 3, 1441–1448.

Parkpoom, S., G. Harrison, and J. Bialek (2008) *Climate Change Impacts on Electricity Demands*. Edinburgh, UK: Institute for Energy Systems.

Pilli-Sihvola, K., P. Aatola, M. Ollikainen, and H. Tuomenvirta (2010) Climate Change and Electricity Consumption—Witnessing Increasing or Decreasing Use and Costs? *Energy Policy* 385, 2409–2419.

Prais, S. J. and C. B. Winsten (1954) *Trend Estimators and Serial Correlation.* 383, Cowles Commission Discussion Paper.

Rosenthal, D., H. Gruenspecht, and E. Moran (1995) Effects of Global Warming on Energy Use for Space Heating and Cooling in the United States. *The Energy Journal* 16, 77–96.

Ruth, M. and A. C. Lin (2006) Regional Energy Demand and Adaptations to Climate Change: Methodology and Application to the State of Maryland, USA. *Energy Policy* 34, 2820–33.

Sailor, D. and A. Pavlova (2003) Air Conditioning Market Saturation and Long-term Response of Residential Cooling Energy Demand to Climate Change. *Energy* 28, 941–951.

White, H. (1980) A Heteroskedasticity-Consistent Covariance Matrix Estimator and a Direct Test for Heteroskedasticity. *Econometrica: Journal of the Econometric Society*, 817–838.

Yuan, S. Q. and H. S. Qian (2004) Indices and Models Assessing Climatic Impacts on Energy Consumption. *Resource Science* 26, 125–130.

Comments

This study is also part of the research projects being funded by the Pakistan Institute of Development Economics to promote innovative research ideas and novelty in techniques needed to explore burning issue of energy crises in Pakistan. First of all, I would like to appreciate authors of the study for identifying the variables of interest in this context. The study provides results and makes projections for electricity demand of residential and commercial sectors of Karachi under various temperature scenarios—the largest city of Pakistan—as detailed work on other affected areas still continues. The study used latest data on electricity consumption of industrial and residential sector of Karachi from 1998–2013 and also used average monthly temperature. The study employed degree day method of Munoz and Sailor (1998)[22] to incorporate temperature variations. The results suggest that rising temperature has effect on electricity demand of residential and commercial sectors of Karachi and its suburbs.

However this study has few weaknesses which are as follows:

- Authors have not mentioned objectives, source of data, sample covered and findings of the study in the abstract.
- Section on the Survey of related studies has not been included separately. Authors need to explore well in the issue of the impact of temperature variation on electricity demand and for that a comprehensive knowledge of earlier studies on the issue is needed.
- Ordinary least square technique has been used to test the hypothesis of impact of temperature variation on electricity demand of residential and commercial sectors of Karachi which may give spurious relationships in the presence of non-stationary variables. Since this study uses monthly time series data for which more appropriate techniques from time series could have been used.

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[22]Munoz, J. R. and Sailor, D. J. (1998) A Modelling Methodology for Assessing the Impact of Climate Variability and Climatic Change on Hydroelectric Generation. *Energy Conversion and Management* 39:14, 1459–1469.