Study on Impact of Climate and Weather Sensitivity on Electricity Demand in Chennai District

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Abstract

Most of the economic activities are subjected to the influence of weather and climatic fluctuations. The most sensitive among them is the electricity market where the demand for it is linked to many weather related variables, viz., air temperature, relative humidity, rainfall, wind speed etc. Since large amount of electricity cannot be stored, produced electricity should be instantly consumed. Hence a good modelling of forecasting electricity demand is therefore depend upon the sectoral consumption pattern of electricity that fluctuate in different seasons in a year. Moreover the influence of weather and climate on electricity demand in different sectors is not uniform throughout a year. Modelling of electricity consumption is multivariate exercise consisting in a mix between climate and other important economic factors. The constituents of economic factors are energy prices, income, energy demand index etc.

Keyword : Energy price, Income ,Demand Index etc.

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In the present paper, an attempt is made to analyse the relationship between electricity load and weather and climate related variables such as temperature, relative humidity etc., for Chennai City. Chennai City is located in the hot humid climate zone where the demand for electricity has been increasing rapidly for the weather and climate related end-uses. A bulk of the electricity consumption of households during the months of summer is for weather sensitive electrical appliances. The increased penetration of weather sensitive household appliances into urban households connotes an increased residential demand for electricity. Households cool indoor space in order to minimise the effect of extreme outdoor temperature and to achieve comfortable indoor living environment. The energy consumption for that purpose depends on the nature of the building envelope such as materials used air tightness and weather proof on the terrace. The indoor temperature lost or gained during the operation depends upon the level of insulation and the ventilation of the building envelope.

Initially the general trends that govern the energy demand in Chennai City have been identified on yearly, seasonal, monthly and daily basis, and then seek to determine the relationship between electricity demand and ambient monthly and daily air temperature. The empirical relationship between energy consumption of different sectors of the economy and climate related variables have been performed in order to assess the weather and climate sensitivity on electricity demand. The link between hot weather and increased electricity demand is useful for other cities worldwide where the use of air conditioners have increased. The study lays the base for climate and economic influences in the event of climate change on electricity consumption.

1. Introduction

Changes in weather conditions are anticipated to have geographically distinct impacts. For a large country with varying nature of geography

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like India, the ability to capture and interpret the impact variations in weather related variables on electricity demand is very difficult.

But studies of climate sensitivity on electricity demand in metropolitan cities may help the authorities to estimate the nearly exact demand for electricity in different seasons. The growth of electricity demand in Chennai City is primarily being determined by urbanisation, population growth and climate change. But these variables basically determine the long-term growth of electricity demand while short-term variations in electricity demand is largely being driven by changes in weather pattern.

There is an obvious link between weather and climate, and energy demand. Weather can be defined as the atmospheric conditions existing over a short period in a specific location. It is relatively difficult to predict weather change, however historical trajectory may continue in future. Climate, on the other hand, is the average weather conditions over a longer period. Weather is more important determinant for short-run demand forecasting of electricity. The long term demand forecasting requires varying values of climate variables based on seasons, annuities and decades.

The variability of short-term weather conditions influence generation, transmission and demand for electricity. The electricity demand is more sensitive to various weather related variables than generation and distribution. Moreover, the weather sensitiveness of electricity is not uniform everywhere. But its sensitivity depends on geography and topography. Therefore correlation for temporal and location differences in weather is crucial in forecasting the demand for electricity. The peculiarity of electricity is that a large quantity of electricity cannot be stored hence as and when electricity is produced, it must be instantly consumed. Moreover, investment in traditional supply sectors of power takes a long gestation period for production; therefore an unexpected demand for electricity cannot be supplied immediately. There lies the need for forecasting the demand for electricity where weather related variables adore more important position in impacting consumption. This fact must be taken into account while planning for the future energy development as well as devising demand side management policies. Weather and climate sensitivity of electricity is therefore essential for designing policies, aiming at reducing energy demand, improving energy efficiency and to switch over to carbon-free or clean energy production.

The national and international evidences have shown that the hottest years since 1900 appear in the recent years. The earth's five hottest years between 1890 and 2006 are in the order of 2005, 1998, 2002, 2003 and 2006. But in India 2009 is the hottest year ever recorded and almost one degree warmer than usual. Of the 12 hottest years since 1901, eight have been in the past decade. It clearly confirms that this part of the earth is getting warmer and warmer in the recent years. It shows the need for a study on weather sensitiveness of electricity demand for a city located in hot climatic zone such as Chennai City.

Weather and climate variation is an important driver of electricity demand. Regional specific demand forecasting of electricity based on sensitivity of weather and climate variables is useful for checking peak loads, changes in load curve and helpful for the State Electricity Boards to adjust the mix and stock of generating facilities in response to expected demand. The work presented in this paper forms a part of investigation into the potential of weather change to influence electricity demand in Chennai City. It assesses the influence of temperature variations on electricity demand. It also applies weather sensitivity model of electricity.

2. Temperature And Electricity Demand

Daily electricity demand throughout the world exhibits clear climate sensitivity. The variations in temperature could have strong impact on electricity demand. Outdoor temperature has the greatest short-run influence on electricity demand showing wide variations between cold and hot seasons. Temperature increase raises the evaporation rate which in turn increases the humidity. Temperature impact analysis on energy indicates that a rise in average temperature increases cooling space requirements necessitating higher power capacity build-up.

The weather sensitive electrical appliances like air conditioners, refrigerator and heater penetrate fast with the change in temperature on either side of the normal level. Changes in temperature alter electricity demand as well as energy consumption pattern. The link between climatic variables and energy consumption to assist short-term planning has been widely documented[1,2,3,4,5,6,7,8,9,10].

A unit change in temperature does not have the same impact on electricity consumption over different regions and time. A 1°C increase of temperature in different levels of temperature scale has varying impact on the electricity demand. In an estimate at national level in Israel[11] shows that an increase in temperature of 4°C is associated with a 10 per cent increase in average summer peak loads and decrease in energy consumption for heating by 10 per cent in winter. In another study, a 1°C increase in temperature will increase energy demand for cooling by 28 per cent; assuming a business as usual scenario[12].

3. Chennai City

Chennai City is the capital of Tamil Nadu and emerged as the fourth largest metropolitan city of India. Chennai is situated in the North-Eastern end of Tamil Nadu and it lies between 12⁰ 9ᴵ and 13⁰ 9ᴵ of the Northern latitude and 80⁰ 12ᴵ and 80⁰19ᴵ of the Eastern longitude. The climate is hot and humid. Chennai City has a long coast which stretches nearly 25.60 km. The topography of the city is almost flat and the ground level rises upto 22 feet above the mean sea level. The temperature of Chennai is always on the higher side with high humidity due to the proximity to coastal area. Chennai receives maximum rainfall during the period from October to December and the city receives heavy rainfall during cyclones and low pressure developments in the Bay of Bengal. Based on the rainfall and temperature, the Meteorological Department classified a calendar year into four seasons. They are:

(i) Cold Weather : January and February
(ii) Hot Weather : March, April, May, June
(iii) The South-West Monsoon : July, August, September
(iv) The North-East Monsoon :October, November, December.

Generally in steep weather fluctuating cities like Delhi, higher temperature reduce the demand for space heating in the winter and increase the demand for space cooling in the summer months. Moreover, an increase in temperature will lead to a higher average demand and peak load in summer months. Chennai City does not demand electricity for space heating because average daily temperature of the city does not decline below 18°C.

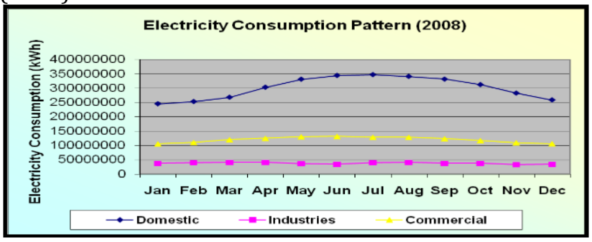
The residential and commercial demand for electricity is much more sensitive to temperature than the industrial uses in summer. The temperature sensitivity on electricity demand for residential, commercial and industrial sectors is not uniform but noticeably different. The overall upward trends of electricity consumption in both residential and commercial sectors are due to changes in the size of the local population combined with changes in household sizes, building stocks and increased proliferation of air-conditioning and the overall increase in the commercial activities of the region. Between economic sectors, there exists different energy use temperature relationship. In 2008, it is found that the residential sector demands 63.8 per cent of the total electricity consumption in Chennai City, while commercial and industrial sectors account for 25.3 and 7.9 percentages respectively.

The average daily electricity demand reaches peak during summer months caused by the wide upward variation in daily temperature from the balance point temperature. The seasonal pattern results from varying solar radiation and changing economic activity throughout the year. Winter peaks in electricity demand is largely attributed to increased lighting demand.

4. Pattern Of Electricity Consumption In Chennai City

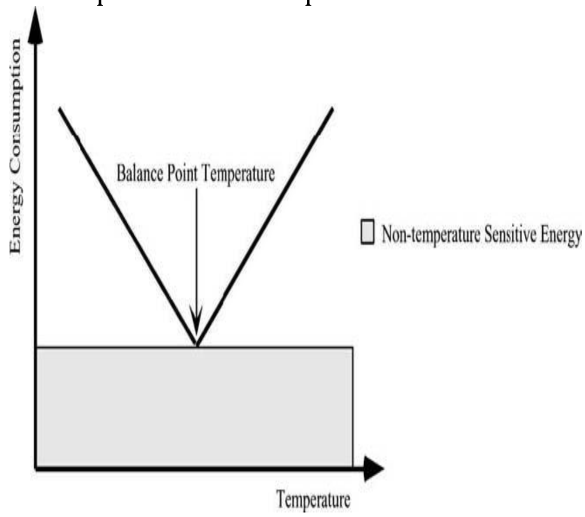
Different sectors display various levels of sensitivity to climate change because of autonomous adaptive capabilities and other inherent characteristics. In the figure 1, it is apparently evident that the consumption of electricity is tremendously high for domestic sector when compared to industries and commercial sectors. Electricity consumed by the domestic sector shows an upward trend from January and the same trend continues till June–July thereafter it gradually tappers down to December. The minimum consumption is recorded in December and January and the maximum consumption is in June and July. It indicates that domestic energy demand in Chennai City are sensitive to climate and that a range of scenarios of climate change may noticeably decrease during cold weather and north-east monsoon seasons. Domestic electricity consumption increases due to weather sensitivity in hot and south-west monsoon seasons. Such increases alone may prove significant enough to warrant changes in peak load capacity planning for the region.

Figure 1. Electricity Consumption Pattern in Chennai City (2008)



5. Theoretical Relationship Between Temperature And Energy Use

The use of degree days is a common energy accounting practice for forecasting electricity demand. The demand for electricity is a function of degree days. The degree day methodology shows a V–shaped temperature electricity consumption relationship[13].



The bottom of the V–shaped temperature energy consumption relationship depicts the balance point temperature. Any temperature difference from the balance point results in some temperature sensitive energy use. Temperature explaining the largest share of changes in energy use is objectively designated as the balance point temperature. Deviations from the balance point temperature are in the form of Cooling Degree Days (CDD) and Heating Degree Days (HDD). Each degree variation of average daily temperature from the balance point is taken as one degree day. If we take 24^{o}C as the balance point temperature and the day's average degree temperature is 30^{o}C, this would result in 6 CDDs for that day. Similarly if the average daily temperature is below the balance point temperature, the difference would result in number of HDDs. As outside temperature deviate below or above the balance point temperature, energy demand increases proportionately. HDDs can be used to estimate space heating demand for electricity and the CDDs can be employed to determine the cooling energy load for a household.

Energy analysis commonly use balance point temperature as 24^{o}C. It is the threshold in the relationship between space cooling or space heating and the temperature. However, the balance point temperature of an energy system depends upon the place specific characteristics such as building shell, humidity, precipitation, wind speed and household behaviour.

Usually for the residential sector and commercial sector, the balance point may not be the same. Commercial buildings typically have a lower balance point temperature than the residential buildings because the former type of buildings have higher internal heat gains from official machinery, lighting and equipments. It is possible for an area to have non-temperature sensitive energy use.

6. Modelling Weather Sensitivity

Modelling of weather sensitivity is expected to translate future projections of weather related variables like temperature into electricity demand. The model requires the actual changes in mean, maximum and minimum temperature, to be useful to indicate future changes in daily and seasonal load profiles with greater priority for peak demand levels.

The paper is of a preliminary nature of a simpler approach which is adopted to formulate regression models linking electricity demand with temperature on monthly and seasonal basis. This approach is useful for making projections with such a model assumes that such relationships will hold over time.

The weather sensitivity of electricity demand model is constructed by using multiple linear regression models to encode the daily, monthly and seasonal consumption pattern of electricity. The model is consistent with high quality regression which is based on cooling degree days derived from temperature and daily electricity demand. To understand the impact of temperature on daily electricity demand, regressions were performed for holidays, working days and different seasons in a year. The form of the regression equation is:

$$\mathbf{D = \beta_1 + \beta_{CDD}\,(CDD) + \varepsilon} \qquad \text{----------1}$$

Where: D is the demand for electricity in each time period; $\boldsymbol{\beta_1}$ is the intercept of the regression line on the demand axis, $\boldsymbol{\beta_{CDD}}$ is the slope of the

539

regression line giving the sensitivity of demand to cooling degree days (MW / CDD) and **ε** is the random error. **β_{CDD}** represents the relative sensitivity of each day to changes in CDD acting as proxy for temperature.

The use of CDDs is common in demand modelling of electricity based on weather sensitivity. The CDDs is given by

$$\mathbf{CDD}\ (T_h) = \{\sum_{h=1}^{N} (T_h - T_{bh})\ \text{for}\ T \geq T_b \qquad \text{---------------}2$$

Where: N = Number of cooling degree days in the period of interest

T = Average air temperature

T_b = The threshold temperature (24°C).

Data Description

A series of total daily consumption of electricity in Chennai City spanning a period from January 2001 through December 2008 has been used in the study. The data comprises electricity consumption in all economic sectors inclusive of residential, commercial and industrial. The climate data consist of daily maximum, minimum and average temperature from the Chennai Meteorological Service located in Nungambakkam.

Model Application

Figure 2. Average Daily Cooling Degree Days

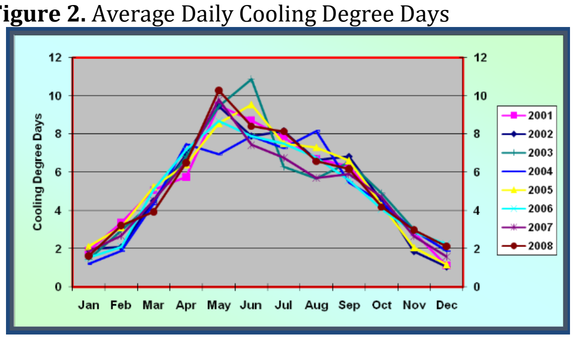


Figure 2 indicates the average daily cooling degree days in different months from 2001 to 2008. The cooling degree days are four to five times higher in the hot and south-west monsoon seasons when compared to the cold and north-east monsoon. However the hot season has the largest number of CDDs followed by south-west monsoon. Thus it is clear that seven out of the 12 months in a year record high temperature in Chennai City.

Figure 3. Average Daily Electricity Consumption 2001-2008 (MU)

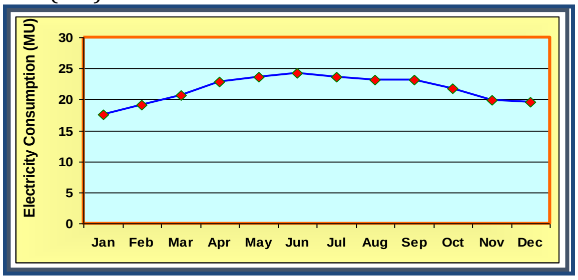


Figure 3 depicts the average daily electricity demand, spanning the period from 2001 to 2008. A comparison of figure 3 and figure 2 reveals those months with high CDDs show higher average daily electricity consumption. Moreover there exists a definite positive relationship between the CDDs and average daily electricity consumption. June records the peak CDDs and average daily electricity consumption.

The season-wise average daily cooling degree days and average daily electricity consumption is shown in Tables 1(a) and 1(b) respectively.

Table 1(a). Season Wise Daily Average Cooling Degree Day Variation(Threshold Level = 24 Degree C)

Seasons	2001	2002	2003	2004	2005	2006	2007	2008
Cold Season	2.6	2.0	2.1	1.5	2.6	1.8	2.2	2.4
Hot Season	7.3	7.2	7.9	6.6	7.4	7.2	7.1	7.3
South-West Monsoon	7.0	7.2	6.2	7.0	7.2	6.6	6.1	7.0
North-East Monsoon	2.8	2.5	3.3	3.1	2.5	3.1	3.0	3.1

Table 1(b). Season Wise Daily Average Electricity Consumption in Chennai City (MU)

Seasons	2001	2002	2003	2004	2005	2006	2007	2008
Cold Season	12	12	13	11	22	23	25	27
Hot Season	13	14	14	21	27	29	30	35
South-West Monsoon	13	14	13	24	28	29	29	36
North-East Monsoon	13	12	12	22	23	26	27	28

The pattern of average daily cooling degree days shows that hot season and south-west monsoon season record hot weather when compared to cold season and post monsoon season. The variation in the former two seasons is nearly three times in relation to latter two seasons. This variation clearly reflects in the average daily electricity consumption. In all the eight years hot season and south-west monsoon seasons consume more average daily electricity consumption as compared to cold season and post-monsoon season. The pattern of electricity consumption broadly reflects the temperature profile with consumption rises in the hot and south-west monsoon seasons.

The relative sensitivity of electricity demand is consistent with higher temperature during the hot seasons. The peak sensitivity tends to coincide with the highest level of electricity consumption.

7. Energy Demand Sensitivity Analysis

The regression analysis is conducted by taking the quantity of daily residential electricity consumption as the criterion variable and daily average temperature as the predictor variable. The regression results of the four seasons are presented in Table 2.

Table 2. Regression Results for Residential Sector

Seasons	R^2	Sig F	F Change
Cold	0.055	0.766	0.116
Hot	0.690	0.011	13.355
South-West Monsoon	0.518	0.107	4.307
North-East Monsoon	0.070	0.370	0.519

The values of coefficient of determination (R^2) clearly presents that the hot season shows the highest weather sensitivity on electricity demand followed by the South-West Monsoon while R^2 values are the lowest in cold and North-East Monsoon seasons with less F change and P values.

The outdoor temperature is the important short-term determinant of residential electricity consumption. Depending on the climate, weather affects the electricity consumption. Day-to-day changes in temperature affect electricity consumption for space heating and air conditioning.

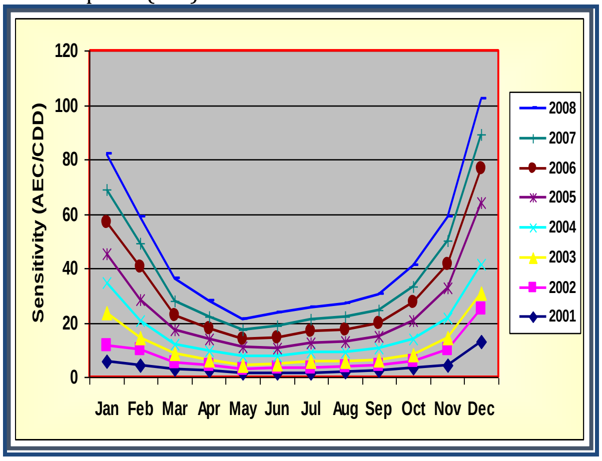
Table 3. Sensitivity of Weather and Electricity Consumption (MU)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2001	6	4	3	2	1	2	2	2	2	3	4	13
2002	6	6	3	2	2	2	2	2	2	3	6	12
2003	12	4	3	2	1	1	2	2	2	2	4	6
2004	11	6	3	3	3	3	4	3	5	6	7	11
2005	11	8	5	4	3	3	3	4	4	6	11	22
2006	11	12	5	4	3	4	4	4	5	7	8	13
2007	12	9	6	4	3	4	4	5	5	6	9	13
2008	13	10	8	6	4	5	5	5	6	8	9	13

Table 3 shows the sensitivity of temperature to electricity. Sensitivity can be estimated by dividing average daily electricity consumption to average cooling degree days:

Average Electricity Consumption
Sensitivity = ---
Cooling Degree Day

Figure 4. Sensitivity of Weather and Electricity Consumption (MU)



It is apparent that temperature increase will have a proportionally greater impact on electricity consumption. In figure 4 shows less values of sensitivity from March through October. The sensitivity values are high in January and February and November and December explains the lesser influence of temperature on electricity demand. The weather sensitivity of seven hotter months is shown by the lines close to the horizontal axis. Thus it is clear that greater the value of sensitivity, lesser the relationship between electricity consumption and temperature and vice versa.

8. CONCLUSION

The present study used a methodology for assessing the weather sensitiveness of electricity demand with the help of daily energy consumption and temperature data of Chennai City. Results indicate that the domestic demand for electricity is the most sensitive to temperature as compared to commercial and industrial demands. It is found that the electricity demand for industrial sector is the least sensitive to temperature. The impact of temperature change on electricity demand is the maximum during the hot season followed by South-West Monsoon, North-East Monsoon and cold season. It is interesting to note that in all the seasons the relationship between daily temperature and electricity demand is found positive in Chennai City.

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