***PAPER TITLE-***

***EFFECTS OF CLIMATE CHANGE ON ELECTRICITY DEMAND IN INDIA: CASE OF THREE DIFFERENT CLIMATE ZONES***

 Divya Jain, PhD Scholar,91+9790466435,divya.jain3@terisas.ac.in

 Gopal.K.Sarangi, Assistant Professor, +911171800222,gopal.sarangi@terisas.ac.in

 Sukanya Das, Associate Professor, +911171800222, sukanya.das@terisas.ac.in

**Overview**

Global warming poses a major concern for the various sectors of the economy. The energy sector is one amongst them which is closely interlinked with climate change as it is not only the primary source of greenhouse gas emissions but is also equally vulnerable to it. One of the reasons being the temperature variability that causes seasonal fluctuations in electricity consumption on the demand side, and consequently gives rise to heating and cooling energy needs. According to World Bank, it is expected that the average temperature in India will rise from 25°C to 29.1°C by the end of the century. With the increase in temperature, demand for cooling rises during the warmer season, and demand for heating falls during the winter season resulting in a V-shaped curve. However, the nature of non-linearity in the relationship differs across Indian geography due to its defining spatial features and temporal climate peculiarities. Electricity system operations include system planning, maintenance scheduling, and power management are weather dependent. Moreover, the electricity demand-supply gap that exists between different seasons results in frequent power outages. Thus, it becomes imperative to assess how climate change causes the variation in electricity demand growth. According to the National Building Code (2005), India is mainly divided into five climate zones; warm- humid, temperate, cold, composite, and hot-dry climate zone. However, warm-humid, composite and hot-dry climate zones comprise the states with large population sizes and cover almost 80% of India’s geography. Warm and humid climate zone constitutes states from southern India with tropical climate conditions where high relative humidity persists along with moderately high temperature during day and night. Similarly, composite climate zone comprises of states with high humidity and rainfall during wettest months; high temperatures during summers, and lower during winters. Additionally, a hot and dry climate zone signifies higher temperatures with lower humidity and rainfall. Against this backdrop, the paper proposes an application of a parametric and non-parametric time-series approach to empirically examine the long-term impact of climate change factors on daily per-capita electricity consumption in these three major climate zones. Two states are selected from each separate climate zone i.e. Tamil Nadu and Maharashtra (warm-humid); Punjab and Uttar Pradesh (composite); Madhya Pradesh and Rajasthan (hot-dry). The rationale of choosing the states is built around the fact that these are among the major power-consuming states of India with unique climatic and socio-economic characteristics. Studies in the Indian context that correlate the electricity demand with climate change are limited and have approached the problem at an aggregated level or micro-level that precludes several key dimensions (Gupta, 2012; Gupta, 2016, Harish et al., 2020). For instance, Gupta (2012) employs a semi-parametric variable coefficient approach for Delhi to show the leftward shifting of the temperature-electricity curve with the falling of the minimum threshold level over time. Similarly, for other countries like Europe, Bessec & Fouqau (2008) establishes the non-linear pattern for the group of 15 European countries and conclude that the non-linear pattern is more evident in the case of warm countries as compared to cold countries. Hence, the present paper bridges the gap by carrying out a regional level analysis and providing a detailed state-level assessment with explicitly capturing the seasonal differences and other climate facets. The study specifically aims to establish the nature of the long-term relationship between climatic change and per-capita electricity consumption, and secondly, shifts in the demand for heating and cooling across the states in different seasons. The climate change variables considered are daily average temperature (°C), daily relative humidity (%), daily wind speed (km/hr), and daily precipitation (mm) coupled with the socio-economic parameters like average yearly population (in millions) and per-capita NSDP (Rs.crore) from 2010-2019.

**Methods**

Two methods namely, piecewise-linear regression approach and multivariate adaptive regression splines (MARS) are deployed for capturing the climate-sensitive electricity consumption and seasonal effects. A piecewise regression model is a parametric technique that applies multiple linear functions across various ranges of the predictor variables. Thus, the non-linear relationship is approximated here through the quantification of linear temperature-derived predictors of Daily HDD and Daily CDD in the model. Heating Degree Days (HDD) is defined as an increase in electricity demand for heating at temperature levels below a threshold limit. Similarly, Cooling Degree Days (CDD) refers to the increase in electricity demand for cooling when the temperature crosses a base level. On the contrary, multivariate adaptive regression splines (MARS) is a non-parametric modeling technique that splits the data into piecewise basis functions to ascertain the non-linear association between the response variable and a set of predictors, regardless of assuming any particular functional form. It provides the relative importance of predictors in decreasing order of importance to predict the dependent variable in a clear and interpretable manner. The model is built based on a forward-backward stepwise algorithm. The forward pass adds all the basis functions in pairs but this process usually over-fits the data. Thus, a backward pass helps in selecting the smallest sub-model by removing the basis functions and selecting the ones with the largest decrease in the residual sum of squares (RSS).

**Results**

Modeling results demonstrate that the temperature is the most prominent variable which describes the positive impact on electricity consumption. Additionally, some part of the variation also arises due to the relative humidity and precipitation factors which have a negative impact on the electricity consumption in the majority of the states. The models formed through the multivariate adaptive regression splines technique provide a better fit to the data in terms of the goodness of fit diagnostics in comparison to the parametric method i.e. piecewise linear regression approach. Empirical results suggest that heterogeneity exists in the degree and magnitude of the heating and cooling effect across the different Indian states*.* The cooling effect dominates the heating effect in the warm and humid climate zone as well as composite climate zone. The rise in demand for cooling (10.65%) is greater than the fall in demand for heating (4.15%) for Maharashtra. Likewise, the corresponding figures for Tamil Nadu show that cooling demand rises by 3.6% and heating demand falls by 0.69%. In addition, the demand for cooling rises by 4.6% and exceeds the demand for heating which falls by 1.2% in Punjab. Similarly, cooling demand rises by 2.2% in Uttar Pradesh. However, the heating effect is more noticeable than the cooling effect in the hot and dry climate zone. The fall in heating demand (2.8%) outweighs the rise in demand (0.8%) for cooling in Rajasthan. Similarly, the fall in demand for heating (3.8%) is higher than the rise in demand for cooling (3%) in Madhya Pradesh. Seasonal variation is represented through the computation of the monthly seasonal variation index (MSVIij= Eij/$\overbar{E\_{j}}$; Eij is the monthly average electricity consumption for the month ‘i’ in the year ‘j’ and $\overbar{E\_{j}}$ is the monthly average electricity consumption in year ‘j’) for the different states. The states with tropical and composite climate show an almost similar seasonal pattern but this stands in sharp contrast to the states in hot and dry climate zone. Firstly, the maximum rise in demand is observed during July and August (monsoon season) in Punjab and during the summer season i.e. May and June in Uttar Pradesh. Similarly, the highest rise in demand is observed during April, May, June (summer season) in Maharashtra and Tamil Nadu. However, it can be noted that demand peaks during the winter season (December, January, and February) which can be possibly due to the larger demand for space-heating in Rajasthan and Madhya Pradesh.

**Conclusions**

The growing electricity demand solely on account of climate change raises serious concerns from an environmental standpoint to strengthen policies such as energy-efficient schemes and demand-side management i.e. seasonal time of day tariffs across various states. The state-level governments should ensure more compliance towards schemes such as Standard and labeling program to encourage energy-saving and reduce end-use energy consumption. Policy coherence is required with a focus on the cross-cutting issues of energy use, particularly cooling electricity demand, and climate change to be efficacious. The findings from the study could be of interest to the electricity demand companies and policymakers to bolster the demand-side management measures and managing seasonal peaks in demand in the future. The methods employed in the present study can be applied to derive the results for states in other countries as well with the similar climate features.