Need of Solar Energy in Indian Climate Load to Balance Energy Ecosystem

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***Abstract*— *In this article we have made a realistic assessment of utilization potential of solar energy as a parallel competitor of other source of thermal energy. Energy demand in India will increase by a factor of 1.5 to 2.5 by 2030 and minimum energy consumption of 2.3 toe/year/capita is needed today to achieve Human Development Index (HDI) of 0.9 where Less than 10% of the potential solar energy is utilized till date, and as per estimates, the demand for air-conditioning units has increased from about 25 million units (MU) in 1998 to more than 40 MU in 2006 and about 115370 GWh of electricity was used in India to meet the air-condition and cooling demand in the country in 2010-2011 and it is projected to increase by 40% in urban India and 21% in rural India by the year 2017. This is causing tremendous pressure on energy security and environment. The demand for energy to meet the weather component of load can be addressed by harvesting the clean energy, the solar energy which in turn can mitigate the climate change and carbon emission issues. A realistic assessment of utilization potential of solar energy has been carried out in the city of Kolkata, India where it has been found that consumption of electricity is proportional to the ambient temperature. As the mean average temperature is increasing as per climatology data of last 100 years therefore the cooling demand is also rocketing high day by day. The energy required to meet this cooling demand can be adjusted by the potential solar energy generation capacity of the city. A comprehensive study on weather load component of electricity consumption in an urban city (like Kolkata, India) concludes the requirement of alternative sustainable energy source. On study we concentrate on requirement of solar energy based on DNI and availability of rooftop open space for solar irradiance in the city area, gives better result in terms of energy security and sustainability.*

The present paper introduces the concept of estimating the cooling demand viz-a-viz PV generation using 'feel like' temperature and ambient temperature as independent variables respectively using an algorithm. Again as 'feel like' temperature and ambient temperature are related through relative humidity and ambient temperature has positive correlation coefficient with both cooling demand and SPV generation, the result shows and help measurement of stability of large scale grid integration in certain geographical areas.

This paper also presents the results of a detailed analysis for estimating the potential of solar thermal power generation in India considering (i) appropriate open space (ii) Direct Normal Irradiance (DNI) (iii) weather data (iv) electricity consumption (commercial and domestic). The prediction model developed based on special, weather and, electricity data of Kolkata can also be applicable to any other cities.

Keywords - weatherload component, cooling need, energy mix, solar energy, carbon free energy.

I. INTRODUCTION

Entropy of a system is always non-negative and the entropy of the world is increasing as we see the average increase in global temperature which results in global warming. On this context the increase in the Earth"s mean temperature stimulates various possible impacts of such changes on different economic sectors. As major geographical portion of India is having a tropical weather condition and our focus of study Kolkata is one of the most populated city in India where yearly temperature varies from 11^{o}C to 42^{0}C and the monthly average Cooling Degree Days (CDD) is more than 260 therefore here is a growing demand of cooling need. To fulfill this HVAC need people consume more power i.e., electricity and as such this study focus on how temperature as part of weather condition affect the demand for electricity at Kolkata. During summer and wet rainy seasons temperature and humidity are very high and uncomfortable for people and as such cooling degree days increases so demand for electricity increases. We explore the effect of climate variable on energy demand by analyzing the direct impact of temperature on the electricity consumption in Kolkata. This choice is motivated by the important share of energy to HVAC purpose and as per BEE (Bureau of Energy Efficiency) about 45% of peak load is shared by the Air-Conditioning load. Therefore temperature is a major determinant of electricity consumption. Global warming has already made the world 0.6^{o}C warmer. Investigating the relationship between electricity consumption and temperature is important to assess the impact of climate change on energy demand. This study is compiled by the non-linear pattern of the relationship between electricity consumption and temperature, daily solar radiation data, load components of the grid load etc.. An increase in temperature leads to a higher use of air-conditioners and other cooling devices. Taking this into consideration the non-linearity requires a specific treatment in statistical analysis for establishing the relationship. In analyzing the effect of temperature on electricity demand we extend the method used by Moral-Carcedo and Vicens-Otero (2005) a logistic smooth threshold regression model (LSTR) with temperature as threshold variable and also use winter model for forecasting the future load. As the peak load demand is during the day time and the said load is majorly governed by the Air conditioning load and the solar radiation and ambient temperature are in line of the same proportion, therefore, solar energy generation potential is important in the climate load consideration of Energy ecosystem in India.

II. LITERATURE REVIEW

Angel Pardoa, Vicente Meneua, Enric Valorb(2002) in their paper „Temperature and seasonality influences on Spanish electricity load‟ they found the influence of weather and seasonality was proved, and was significant even when the autoregressive effects and the dynamic specification of the temperature were taken into account. The estimated general model showed a high predictive power.

Marie Bessec and Julien Fouquau(2007) investigated the threshold panel approach to the non-linear link between electricity and temperature in European Union on 15 EU countries.

Moral- Carcedo and Vicens-Otero(2005) worked on effect of temperature on electricity demand in Spain using logistic smooth threshold regression model (LSTR).

O. Hyde and P.F. Hodnett (1997) worked on „An Adaptable Automated Procedure for Short Term Electricity Load Forecasting‟ where they indicated four component of electricity demand – Basic load, Weather load, Normal load, Specific event based load.

Eshita Gupta 2011, in her working paper "Climate Change and the Demand for Electricity: A Non-Linear Time Varying Approach" studied the Electricity demand in Delhi as a U-shaped function of temperature.

And many literatures were studied but no such work has been found which focus on this area of solar energy requirement into the Indian energy ecosystem.

III. Basic Model for load component

The total electricity load on the grid can be divided into different component.

The basic model can be written as

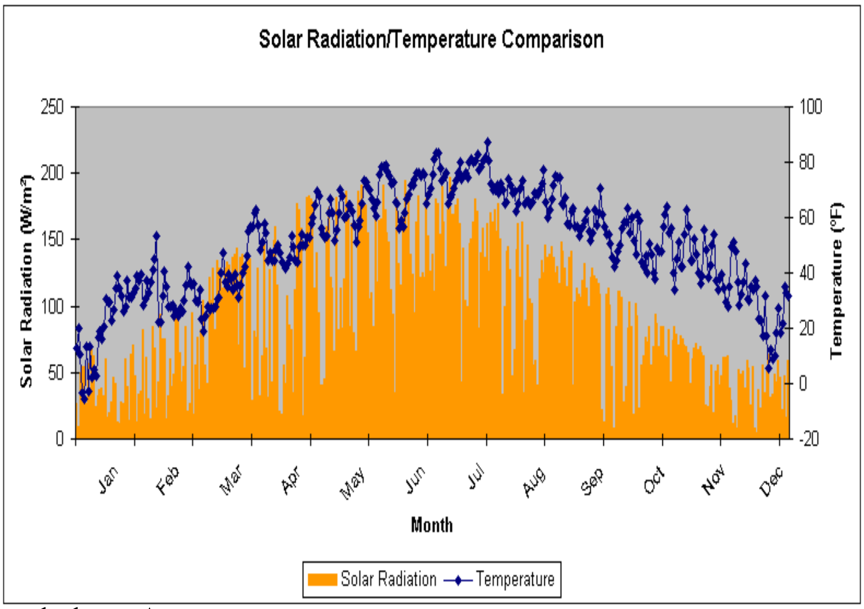
$$Y(t) = N(t) + W(t) + S(t) + r(t)$$

Where,

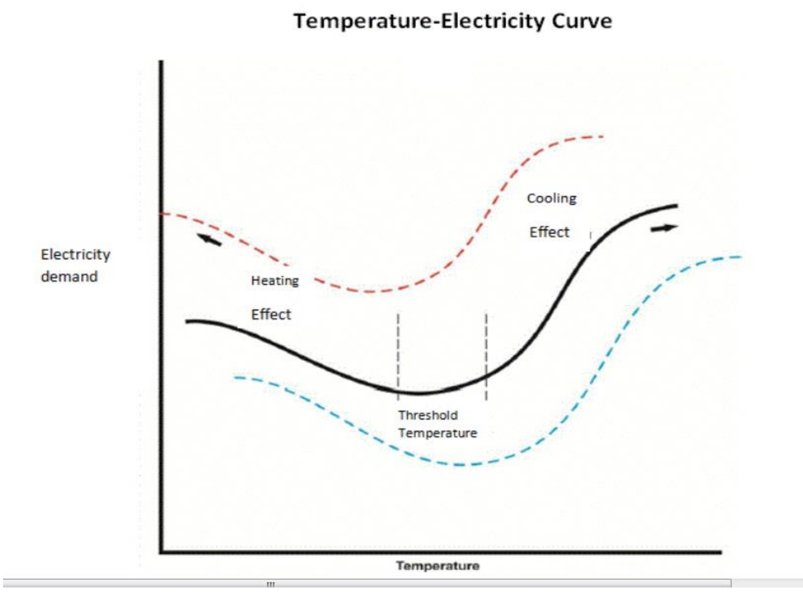
Y(t) – Total load,
N(t) – Normal load component,
W(t) – weather dependant load component,
S(t) – load due to special events,
R(t) – random load component,

The weather load component is dependent on ambient temperature, humidity, rain fall, wind speed etc.

Angle of Solar Radiation and Temperature are very closely related. When the sun's rays strike Earth's surface near the equator, the incoming solar radiation is more direct (nearly perpendicular or closer to a 90˚ angle). Therefore, the solar radiation is concentrated over a smaller surface area, causing warmer temperatures. The NASA RET



screen data as well as weather data including solar radiation of 67 cities for the Indian locations were collected and analyzed which revealed that solar



radiation is directly proportional to ambient temperature.
The relationship holds daily and yearly also. During daytime in the peak hours i.e. from 9AM to 6PM the energy consumption become maximum and during mid day hours the solar radiation also become maximum which if utilized to run air conditioning and cooling devices a large amount of grid load will be saved. The temperature – electricity curve indicate that electricity consumption increases at the very low temperature and after a certain high temperature. In India major geographical areas there is cooling need. The climatological data of last 100 years from India Meteorological Department clearly indicate that the average temperature is gradually increasing and as such cooling need also increases which in turns creates more pressure on the grid load. Whereas if the untapped solar energy be harvested the load can be reduced to a sizable amount.

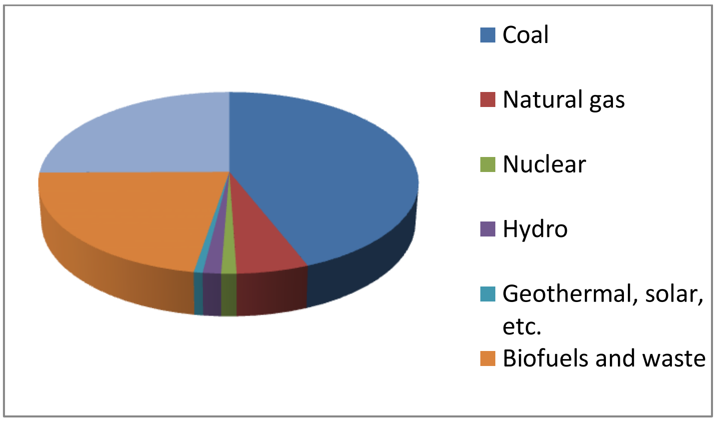


Fig: The total Energy Mix

It is evident that the primary source of energy is majorly coal, natural gas, bio fuel & waste etc.

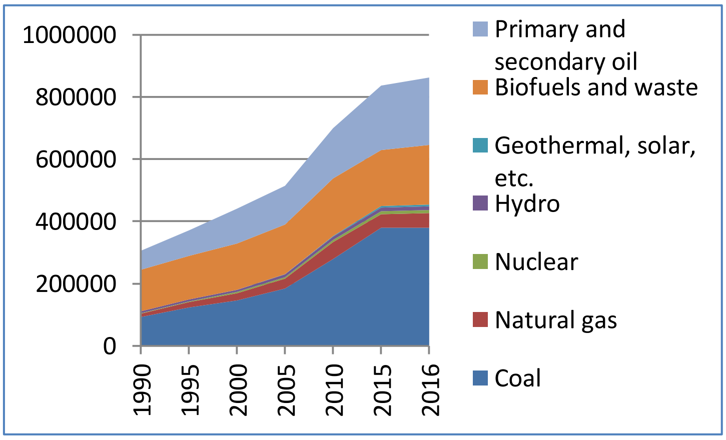


Fig: Share of primary source of energy in India

IV. TOTAL PRIMARY ENERGY SUPPLY BY SOURCE IN INDIA

The total primary source of energy in India is as follows:

Total Primary Energy Supply (TPES) by source - India

Units: ktoe

Year	Coal	Natural gas	Nuclear	Hydro	Geothermal, solar, etc.	Biofuels and waste	Primary and secondary oil
1990	92697	10571	1600	6161	10	133484	61099
1995	123303	17332	2080	6242	67	140030	82044
2000	145924	23069	4404	6403	180	148852	111985
2005	184224	31810	4514	9279	631	159344	124586
2010	279027	54402	6844	10669	1992	185109	161548
2015	379673	43222	9749	11660	5146	179765	207309
2016	379557	47034	9879	11826	5780	191612	216795

Source: IEA World Energy Balances 2018

but since 2010 the share of renewable energy basically solar PV and bit of geothermal increases. The production of solar energy is more than 2.5 times in 5 years between 2010 and 2015. And the rate of generation is faster day by day as more and more companies are coming into this business with the ease of doing business policy and national solar mission of Govt. of India.

V. RENEWABLE ELECTRICITY GENERATION

Less than 10% of the potential solar energy is utilized till date, and as per estimates, the demand for air-conditioning units has increased from about 25 million units (MU) in 1998 to more than 40 MU in 2006 and about 115370 GWh of electricity was used in India to meet the air-condition and cooling demand in the country in 2010-2011 and it is projected to increase by 40% in urban India and 21% in rural India by the year 2017. This is causing tremendous pressure on energy security and environment. The demand for energy to meet the weather component of load can be addressed by harvesting the clean energy, the solar energy which in turn can mitigate the climate change and carbon emission issues. Since 2010 the solar PV generation is rocketing high which can be seen in the following table.

Electricity generation from renewables by source – India is as follows:

Units: GWh

Year	Geothermal	Solar thermal	Hydro	Solar PV	Tide, wave, ocean	Wind
1990	0	0	71656	0	0	32
1995	0	0	72596	1	0	529
2000	0	0	74462	2	0	1684
2005	0	0	107910	3	0	6211
2010	0	0	124077	113	0	19657
2015	0	0	135609	10478	0	41663
2016	0	0	137533	14130	0	44856

Source: IEA World Energy Balances 2018

This is less than 10% of the potential solar energy which can be utilized into the energy mix of the country.

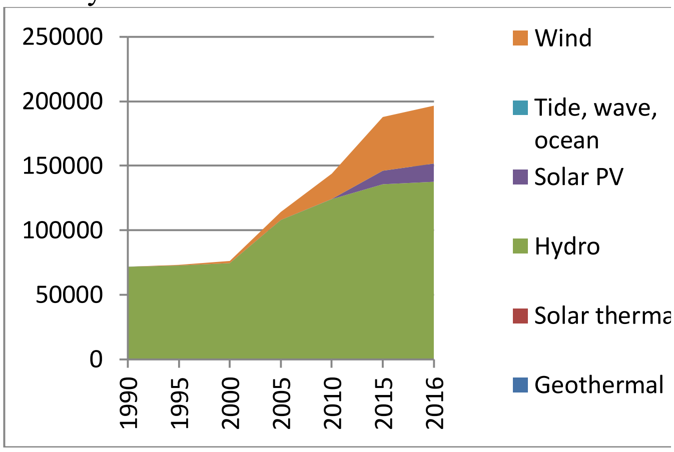


Figure: Generation of Solar Thermal w.r.t. energy mix

VI. CASE STUDY IN KOLATA

In Kolkata electricity consumption data from CESC 2010 to 2016 and weather date from IMD, Kolkata were taken.

- In an average a family consumes around **15%** of the **power** to meet their **cooling needs** (mainly fans and air coolers - except air-conditioners)[as per NSSO].
- Every year about **50,000**-odd consumers in Kolkata have **purchased ACs** in the summer.
- Big chunk of them have no intention of purchasing an AC but were hurried into the decision by the merciless weather. Such is the demand that shops are unable to commit delivery in a week.
- CESC generated 1,241 MW on a normal day of may, exceeding its combined generation capacity of 1,225 MW. State utility WBSEDCL supplied 735 MW to CESC and it bought the rest from the grid to meet the demand.
- The total number of fans used in Kolkata for domestic purpose is (1225 MW x 15%)/75 = 2.45 x 10^6 numbers of fans.
- Total population of Kolkata **(N_{POP})** is 14.96 million (as of census 2011)
- So, the approximate per capita cooling need is **(N_{FAN} / N_{POP})** = (2.45/14.96) = 0.1638 number of fans.
- Total number of installed A.C. machines **(N_{AC})** in Kolkata = 500 MW / 1000 W = 5 lakhs.
- Total number of families **(N_{FAMILY})** in Kolkata = 14.96 million / 5 = 2.992 million (approx)
- So, the approximate per family Air-Conditioning machine distribution in Kolkata is = 5 lakhs / 2.992 million = 0.167 number of A.C. machines.
- For Kolkata air temperature varies between 10°C-40°C.
- Different locations have different temperature, humidity, wind speed & radiation and as such varying cooling need.
- We calculate cooling needs in terms of usage of energy for cooling and no. of devices used for the purpose.
- The approximate per capita cooling need is **(N_{FAN}/ N_{POP})** = (2.45/14.96) = **0.1638 number of fans**.
- The approximate **per family A.C.distribution in Kolkata** is = 5 lakhs / 2.992 **million = 0.167 number of A.C.s**
- For Kolkata air temperature varies between **10^0c-40 ^{0}c**
- **300 days/year** are **hot & sunny** days and **solar radiation** varies between **3.5 -8.2 kWh/m^2/d**. Different locations have different temperature, humidity, wind speed & radiation and as such varying cooling need
- We use NASA ret screen data for Indian cities and analyze the Solar Radiation/yr
- We calculate cooling needs in terms of usage of energy for cooling and no. of devices used for the purpose

VII. Data and Methodology

The data on daily electricity consumption at Kolkata has been collected at 15 minutes interval and the corresponding ambient temperature of Kolkata has been collected from the Regional Meteorological Centre, Kolkata of the India Meteorological Department for the period from 01.04.2011 to 31.03.2015. To study the impact of Temperature on the consumption of electricity we take care of the daytime and nighttime as well as weekdays and holidays effect. We assume that power consumption due to lighting and ventilation remain the same devoid of temperature as HVAC effect is due to temperature and humidity.

The logistic smooth regression model allows the relationship between consumption and temperature to depend on the level of the threshold variable i.e., temperature. This approach has various advantages. Like it allows smooth transition from cold regime to the warm regime which is very relevant because there is a neutral zone for mild temperature where the demand is inelastic to the temperature. Moreover the impact of temperature can be assessed easily as the variable is treated as an explanatory variable in the model.

Here we use the statistical software package „R" to analyze the various regression models like exponential smoothing and winter"s model to investigate the relationship between the electricity consumption and the ambient temperature.

The model can be simulated to other cities with NIWE data.

VIII. Empirical Result and Discussion

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	1	17995562	17995562	648.25	0.000
Temp	1	17995562	17995562	648.25	0.000
Error	718	19931832	27760		
Lack-of-Fit	127	6161458	48515	2.08	0.000
Pure Error	591	13770374	23300		
Total	719	37927394			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
166.614	47.45%	47.37%	47.16%

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	-241.1	54.3	-4.44	0.000	
Temp	47.14	1.85	25.46	0.000	1.00

Regression Equation

Electricity Consumption = -241.1 + 47.14 Temp

Fits and Diagnostics for Unusual 668 Observations were made for Electricity with fields like;
Obs, Consumption, Fit Resid Std Resid,

Week_avg_temp	Fri_day	Sat_day	Sun_day	Mon_day	Tue_day	Wed_day	Thur_day
25.5	956.3139	956.8462	986.951	913.7047	821.0583	843.4051	927.3362
25.38571	888.0862	886.0268	897.3639	843.9475	767.4695	785.5099	863.1151
25.27143	843.0927	847.2416	852.1404	799.4538	736.5298	751.3086	819.7936
25.05714	827.5667	836.3044	831.6356	785.8873	721.5462	724.8978	799.0139
24.9	807.5418	820.0911	817.0618	785.1974	713.2133	724.6729	788.5741
24.6	781.3234	792.1207	785.3399	763.1581	702.636	693.0334	757.8994
24.64286	803.2578	837.4666	794.5551	796.2721	767.8994	747.1172	800.4436
25.32857	882.4002	928.2985	831.2882	869.5335	859.5785	830.041	887.7638
27.24286	992.0423	1008.678	848.6888	969.8254	929.1483	930.0006	992.0248
28.82857	1119.205	1120.517	865.3595	1119.547	1049.273	1065.721	1136.715
30.48571	1260.401	1244.908	897.8462	1268.617	1183.106	1210.089	1264.373
31.84286	1346.245	1303.658	942.7723	1366.534	1270.121	1297.264	1347.254
32.48571	1357.034	1313.28	967.8634	1387.162	1290.731	1314.838	1374.09
32.7	1315.95	1250.524	960.3503	1342.668	1229.629	1272.023	1337.077
33.01429	1343.895	1226.897	975.7839	1367.309	1243.428	1290.804	1364.01
32.52857	1367.412	1201.396	978.0308	1395.107	1274.333	1318.542	1393.705
31.67143	1366.837	1167.827	972.0623	1400.758	1286.52	1310.356	1404.217
30.35714	1364.047	1156.398	1009.785	1436.464	1338.407	1341.131	1400.898
28.58571	1451.44	1282.003	1188.247	1515.149	1456.874	1468.671	1452.09
27.75714	1427.901	1264.678	1196.45	1326.057	1400.733	1403.38	1420.073
27.08571	1338.037	1233.238	1180.039	1210.072	1271.928	1319.049	1353.078
26.71429	1255.69	1178.767	1170.169	1132.429	1184.591	1244.568	1278.002
26.41429	1176.568	1101.469	1138.42	1044.256	1095.913	1143.661	1185.365
25.72857	1090.75	1046.688	1048.068	935.8341	966.0439	1032.257	1087.795

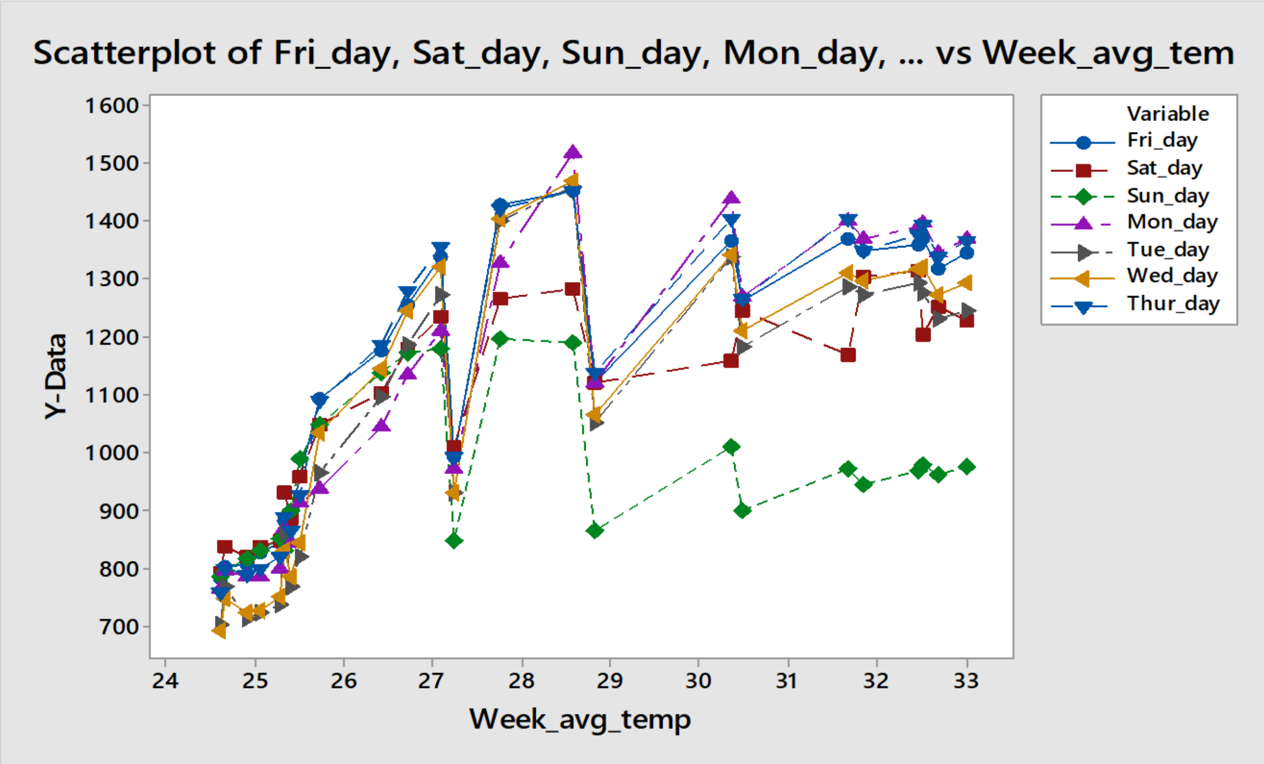


Fig: Scatter plot of days of week vs. weekly average temperature

Single Exponential Smoothing for Electricity Consumption

Data Electricity Consumption

Length 720

Smoothing Constant

α 1.64405

Accuracy Measures

MAPE 3.78

MAD 42.73

MSD 2866.01

Forecasts

Period	Forecast	Lower	Upper
721	1166.48	1061.79	1271.16
722	1166.48	1061.79	1271.16
723	1166.48	1061.79	1271.16
724	1166.48	1061.79	1271.16

we have investigated the relationship between electricity consumption and temperature in Kolkata, India. With the help of NIWE weather data this model can be simulated to other cities in India. It is evident from the result that the non-linear pattern of this relationship exists in all the days of the week in Kolkata. So it can be assumed that the same result will happen in other cities too.

This paper shows that temperature is a major determining factor of electricity consumption in cities like Kolkata and the relationship between the two variables is modified by the climate change. In line with the concern about global warming, these findings support the interests in energy related issues like, renewable energy, building integrated photo-voltaic(BIPV), solar air-conditioning systems, renewable energy policy and framework implementation at the state level etc.

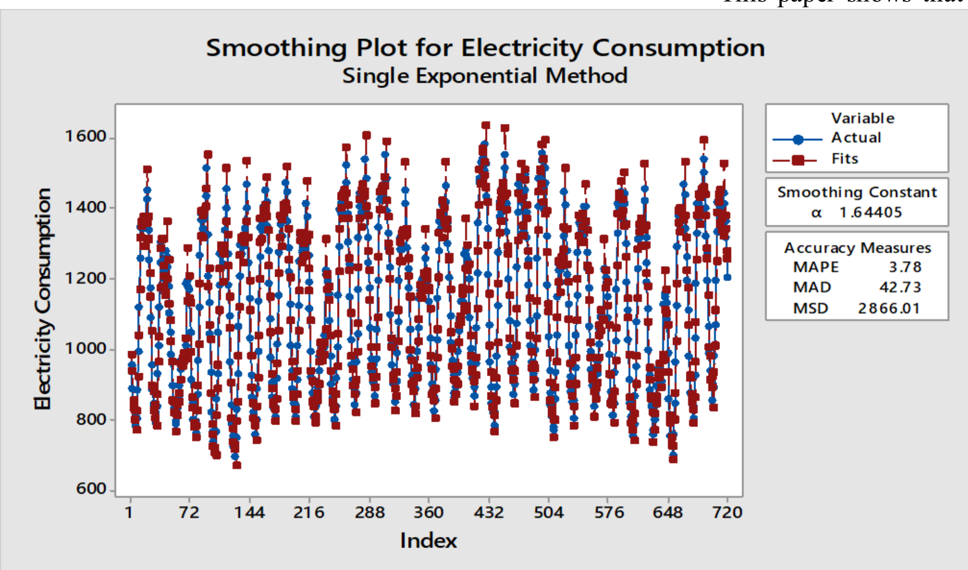


Figure: Smoothing Plot for Electricity Consumption (through Single Exponential Method)

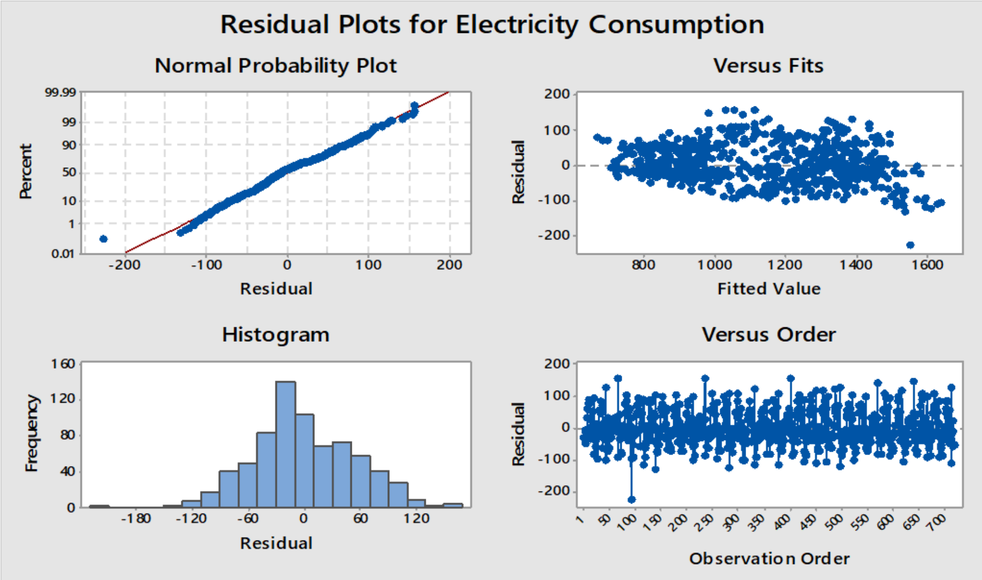


Figure : Residual Plot for electricity consumption

IX. THE SOLAR ENERGY POTENTIAL IN INDIA

The potential of solar energy in India is huge and if through Govt. policy and regulations the potential opportunity be utilized the energy security of the country can be aptly addressed and per capita energy consumption needed for

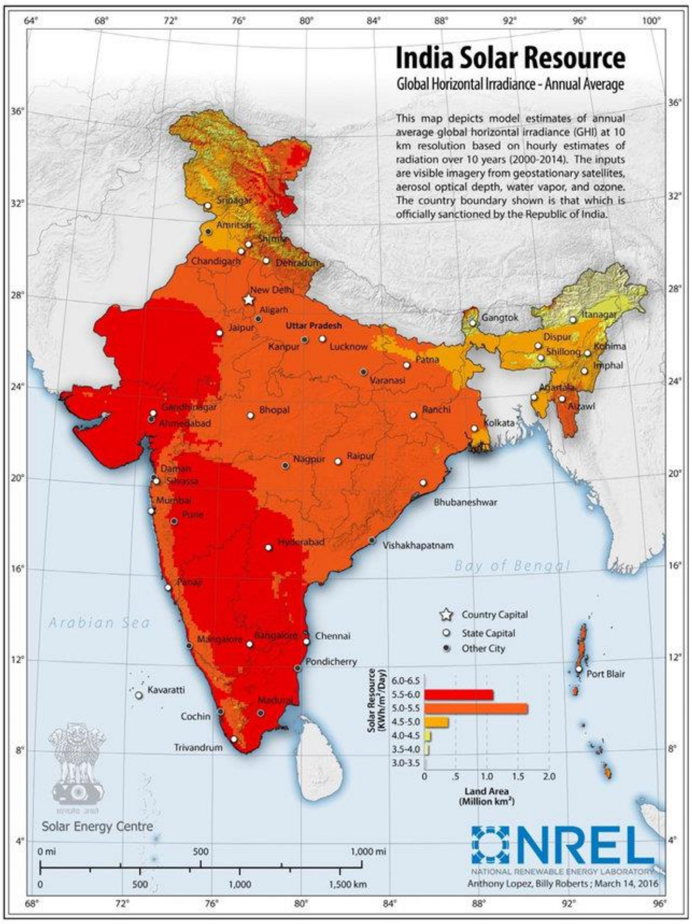


Figure : The Potential Solar Energy in India

desired Human Development Index (0.9) can also be attained.

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BIOGRAPHICAL INFORMATION

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Mr N. S. Manna, a National Scholar, is multidimensional person with varying interests and activities. He has 8 years of industry experience and 9 years of teaching & research experience. His research is in emerging Solar Energy Application, Building Integrated photo Voltaic, (BIPV), Market Potential mapping for solar driven devices, climate change etc. and in the field of education he serves as management faculty to reputed Technology and Management Institute and Universities including Vidyasagar University, Kalyani University and Calcutta University, Kolkata, West Bengal.
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Current Teaching & Research Interest:

a. Renewable Energy Applications, Energy Efficiency, Audit and Management, Sustainable Energy Use – prioritization of recommendns. Enhancement of Output of Solar Photovoltaic or hybrid systems through Tracking and Concentration;

b. Renewable Energy (RE) Systems, particularly, RE Driven Vapor Absorption Cooling Systems" Market Potential Studies;

c. Enhancement of Output of Solar Photovoltaic or hybrid Systems through Tracking and Concentration;

d. End-use integration of applied RE and energy efficiency (EE) in specific areas, viz. RE driven vapour absorption cooling system

Binoy K Choudhury, a Mechanical Engineering Graduate, Ph D from the Indian Institute of Technology (IIT) Kharagpur, Fellow of Institution of Engineers (India), Association of Engineers (India) & Indian Water Works Association - is currently Professor in the Energy Management stream of Public Systems Management (PSM) programme. He has over 24 years of teaching/professional experience which includes more than 21 years in the present Institute. He served as Principal Investigator/Coordinator in more than fifteen renewable energy and energy efficiency projects. He is Asst. Director International Member Development Asia Sub-continent in Association of Energy Engineers USA; member in Energy & Environment Standing Committee, the Bengal National Chamber of Commerce & Industry and also The Bengal Chamber; JICA Alumni Association of India; Energy; Low Carbon Energy for Development Network (UK). He is founder editor of Energy Window, on the editorial board of REASON- A Technical Journal and reviewer of ACTA Press, Energy for Sustainable Development, etc.

He has contributed/published, more than 50 in numbers, in books, journals, international and national seminars, workshops, etc. He is the founder secretary of AEE India Chapter and Energy Club and is life member of Solar Energy Society of India, AEE, Indian Society for Technical Education, Ramakrishna Mission Institute of Culture and Institution of Engineers (India) and Indian Water-Works Association (IWWA).Mob: +91-9433153009 ***Emails:*** *bkchoudhury@iiswbm.edu*