Solar Energy for Electricity Generation – A Comparative Study of Three States in India

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***Abstract*—Climate change and global warming are the major issues of environmental concern of this century and require serious actions by all the countries in the globe in building good atmosphere for the renewable energy technologies penetration. This study investigated the potential of solar electricity generation in three states in India i.e. Kerala, Tamil Nadu and Karnataka using Photovoltaic Geographical Information System (PVGIS) insolation data this will help to establish the solar electricity generation in the study sites. From this study, the complimentary relationship between solar insolation in solar electricity generation was established. However the study revealed that, when the advantage of higher population density and building style in India are coupled in solar electricity generation, Indian government solar energy target of 2022 can be achieved especially with storage option, which is already a matured technology in India. Therefore this study gives hope of using solar electricity as ultimate solution to the erratic power supply in the country island wide as well as hope for achieving the Indian government National Solar Energy Mission 2022 under National Action Plan on Climate Change.**

Keywords- PVGIS, Solar Insolation, National Action Plan on Climate Change, Solar Electricity, India

I. INTRODUCTION

Increased development of renewable energy technologies is the key factor in determining the development of any nation across the globe. This is because, renewable energy resources analysis, has revealed huge potential of renewable energy resources across all the regions of the globe which can be use to address the effect of climate change and global warming especially in electricity generation and transportation sectors [1]. Electricity being the inevitable parameter in determining the development of any country, has contributed immensely to the detrimental effect of global warming and climate change which are the major environmental challenges of this century [2, 3, 4].

India the second most populous country in the globe has very good innovative and enabling policies for the penetration of renewable energy technologies. The Indian renewable energy policy is helping in making India among the top 5 global nations in terms of installed renewable electricity mainly wind electricity [5]. However despite this renewable energy achievement, Indian government has a long way to go in shifting from fossil fuel based energy system to low carbon technologies in electricity generation. Until April 2017, the total installed electricity in India is supplied by about 67.1% fossil fuel making the country the 4th largest GHG's emitter in the globe [6].

Solar power is a universal resource because solar irradiance is distributed fairly consistently across the Earth's surface. The insolation received even at northern latitudes, is sufficient to provide a significant fraction of energy need even in the case of high population density areas of the globe [7]. The tremendous increased in installed solar electricity generation across the globe gives us idea about the unlimited potential available in solar energy in electricity generation [8]. The solar energy reaching the earth surface far exceeds the total human energy needs and several researches in the literatures, has establish the viability of using solar electricity generation in the supply of sufficient electricity needed for daily life for both on-grid and off-grid application [9]. Solar energy is more adaptable and predictable than other renewable energy sources. This is because there is no solar power in the night as such; the only unpredicted factor associated with solar energy in electricity generation each day is the cloud cover [7].

In this research, we investigated the potential of solar PV electricity generation technology in Kasaragod (Kerala), Mangaluru (Karnataka) and Chennai (Tamil Nadu) states of India, to create awareness as strategy for the penetration of solar PV technology for micro electricity generation in achieving the Indian Government National Solar Energy Mission 2022 under National Action Plan on Climate Change.

II. THE CONCEPT OF SOLAR ELECTRICITY GENERATION

Among the major developments in converting solar energy into useful energy form includes thermoelectric conversion to electricity using photoelectric effect [10]. However, another widely and easiest application of solar energy conversion is the production of heat mainly in the form of solar thermal which is widely used in heating water for domestic and industrial applications.

Photovoltaic is a form of solar energy conversion that converts light energy directly to electricity as a result of continuous excitation of electrons across p-n junction when solar energy (insolation) falls on the surface of solar module [11]. This technology has been proofed to supply adequate and sustainable energy required by humans at all times in most cases using storage option. The used of solar PV technology in supplying total energy required for significant number of population living completely off-grid has being established in several locations in the globe among which includes, Pulau Perhentian Besar Island in Malaysia [12], Sandwip, an Island in the south eastern coast of Bangladesh [13], Haiman Island China, Caribbean Island etc. [14, 15].

Solar photovoltaic cell production and installation has increased immensely worldwide [16]. Emerging solar photovoltaic technologies such as organic solar cells (organic synthesized Photovoltaic and dye-sensitized cells), advanced organic thin-film technologies, quantum and excitonic structures are showing great potential in the penetration of solar PV technology in electricity generation as well as huge cost reduction in addition to efficiency improvement [17]. Current status in solar PV application is competitive to all other energy sources across the globe efficiency wise. Recently solar PV converting efficiency has reached 44.7% efficiency using Concentrating PVs (CPVs). This means, solar PV power generation is competitive to many thermal power plants in India and other countries across the globe [11]. This achievement is showing that in near future, solar energy in electricity generation will be the key technological option in decarbonizing Indian energy sector from current level of fossil fuel electricity based generation to green and sustainable energy sources.

The general formulation for photovoltaic system electricity generation is adopted for this research in solar PV system simulation. Equation (1) is widely adopted for solar PV power output calculation and is used successfully by different authors in the different researches conducted in the literature [18, 19].

$$E = A * r * H * PR \quad (1)$$

Where,

E = Energy Output (W, kW, kWh) depending on the formulation

A = Total solar panel Area (m²)

r = Efficiency of the solar panel (%)

H = Solar insolation on the tilted panel

PR = Performance ratio, coefficient for all losses

A. Indian Solar Energy Potential

Indian energy demand is increasing and is expected to increase even more in near future especially with continuous penetration of electric vehicles in transportation sector. India is a tropical country that lays in the upper most part of the world and upper most locations have great potential of solar energy [20]. The solar insolation incident over India is equal to 4-7 kWh per square meter per day for 250-300 sunny days, which account for 748 GW solar potential [21]. With this great solar energy potential, higher population density and building style in India, the country can become global leader in renewable electricity generation in near future.

However, the current level of dependence on fossil fuels in electricity and heat generation is hindering the success of achieving the Indian government's renewable energy target of year 2022 [21]. Despite the higher penetration of wind electricity in the mix of installed electricity capacity, the potential is likely to deliver significantly low considering the facts that, the wind turbines are mostly far away from the national grid transmission stations and perhaps this can lead to power transmission lost because of long distance electricity transmission [22].

Solar energy can be seen as ultimate solution to long distance electricity transmission lost as it is almost all over just on top of our building [23]. Fig 1 illustrated the Indian technical, economical and market potential of Rooftop Solar Photovoltaic system as well as the position of India in the list solar installed power across the globe. It is surprising a country with this huge solar energy potential is still in the list of countries with low solar electricity installed power in the mix of energy supply despite the attractive government plans and policies in renewable energy electricity generation.

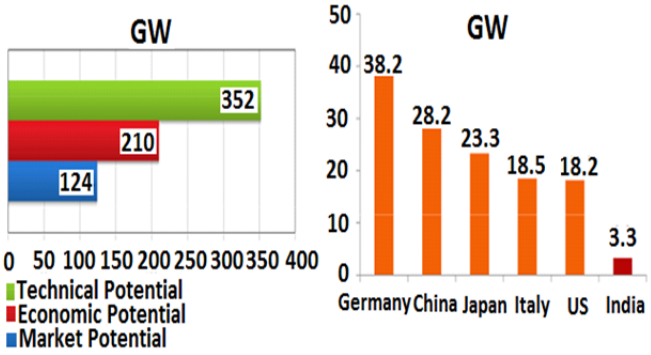

Figure 1: Indian rooftop solar PV potential and country wise solar installed electricity (GW)

Source: [24].

III. MATERIALS AND METHOD

The research utilized solar climatological data sets obtained from PVGIS to investigate the potential of solar electricity generation in 3 locations across three states in India Kasaragod (Kerala), Mangaluru (Karnataka) and Chennai (Tamil Nadu). The key details of the study sites are illustrated in Fig 2.

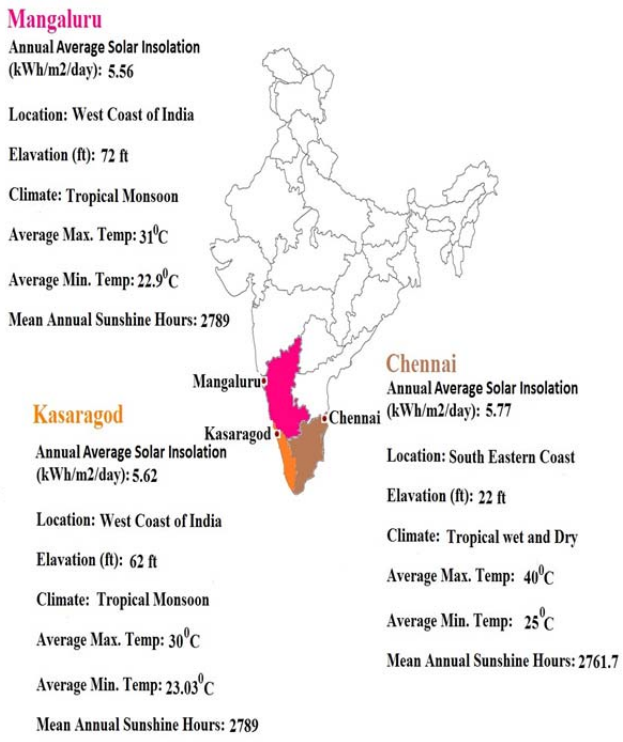

Figure 2: The key details of the study sites

Data extracted from: [25, 26, 27]

A. *Solar Irradiation Data*

Solar radiation dataset is the key parameter for the determination of solar PV output at all time and location. Several solar radiation data sources exist across the globe but none of such source is perfect. Ground level measurements or calculations are the most common data source used in solar electricity potential analysis. However, ground solar radiation measurements is prone to several problems, the most common being failure of the measuring device itself, covering of the sensor by dirt, frost, snow, shadow by the buildings and tree across the year.

To avoid error to minimal level, this research utilised satellite based measurement from PVGIS tool. PVGIS is proofed to be among the top accurate solar insolation data sources for solar energy electricity generation potential studies across the literatures. The method adopted in this research has been successfully used by several researches in different locations for the analysis of solar electricity generation potential [28-31].

B. *Electricity Demand Data*

The most important factor in designing a new electricity generation system is the knowledge of electricity demand profile of the power the system is expected to generate to meet the electricity demand of the end user. India is a country that has been a witness of chronic energy poverty with almost one fifth of the population with out access to electricity. Even the grid connected costumers, are faced with erratic supply of electricity mainly limited to few hours during the day [32]. Due to lack of electricity, it is very difficult to have an authentic power consumption profile that can be used as typical household electricity demand in India.

The electricity demand data adopted for this research is based on demand data available on the PVGIS. The energy consumption profile assumes that, the daily consumption is distributed in a manner over the hours of the day with most of higher consumption during evening time. The electricity demand profile used in this research is realistically far better than demand profiles produce based on interpolation. Interpolation demand profile usually comes with higher electricity demand values since it is based on estimates. The trend of the demand data used for this study is similar to the trend observed by Mohammad *et al.,* [33], Gado *et al.,* [3], Orhan and Banu [34].

C. *Solar PV Sysytem*

Different solar PV technologies are available for electricity generation across the globe, however it is important to know that, their utilization for power generation depend on their application as building integrated (roofing materials, substrates for used in curved surfaces in the building), ground mounted or coupled with solar tracking devices in the form of Concentrating solar power (CSP). This research utilises indigenous solar panel manufactured in India on leading edge module production line using world-class processes. The choice of the indigenous solar panel is to ensure higher tolerance and reliability to hash weather condition that can have negative effects to the solar PV power output. Table 1 presented the parameters of the chosen solar PV panel for the research.

Table 1: Electrical specification of PV module used for the research (at STC).

Parameter	Value
Nominal power (P_{max})	260 Wp
Panel Area (m^2)	1.67m^2
Open-circuit voltage (V_{OC})	37.9V
Short circuit current (I_{SC})	8.80A
Voltage at maximum power (V_{mpp})	30.6 V
Maximum power current (Impp)	8.49A
Module efficiency (η%)	15.60%
Power tolerance (W)	0 ~ +5

STC: Standard Test Conditions

Data Extracted from: Tatapower [35]

IV. RESULTS AND DISCUSSIONS

Diurnal solar insolation analysis provides better understanding of renewable resources in renewable electricity generation. The insolation data collected from PVGIS, is sorted, analysed and scaled to seasons of the year across the study sites. For this study, the hourly insolation data scaled to typical Monsoon season is used to establish the findings of the research. Although, Monsoon has lowest insolation as observed during data sorting and analysis, but it is utilised for this research to provide clear understanding of the role of solar electricity generation in achieving Indian government solar energy target of 2022. The output of the research is established based on the parameters in (1) in the text.

Fig. 3 presented the diurnal solar insolation scaled to typical day in Monsoon season across the study sites. The trend on the figure shows increase in solar insolation with hours of the day until a peak value is reached at noon hours before it starts declining to zero value during evening hours. It can be observed from the figure that, solar insolation incident on Chennai is considerably higher compared to Kasaragod and Mangaluru. The higher insolation observed in Chennai can be attached to the fact that, Chennai (Tamil Nadu) study site is located in the southern eastern coast of India with typical dry and wet climate according to Koppen climate classification compared to Kasaragod and Mangaluru which has typical Monsoon climates according to the same classification.

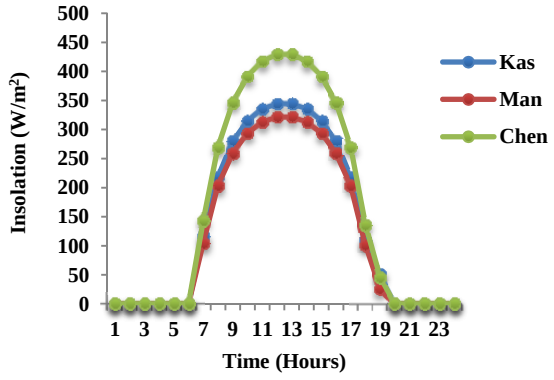

Fig 3: Solar Insolation of typical Monsoon day across the study sites.

Fig. 4 represents the solar PV power output of 260Wp solar panel across the study sites. It can be observed from the trend that, Chennai study site has highest power output than Kasaragod and Mangaluru. Although it is clear that, Kasaragod has considerably higher power output in comparison to Mangaluru. Despite Monsoon season having lowest solar insolation compared to other seasons of the year, but reasonable amount of electricity can be generated using solar PV generation technology.

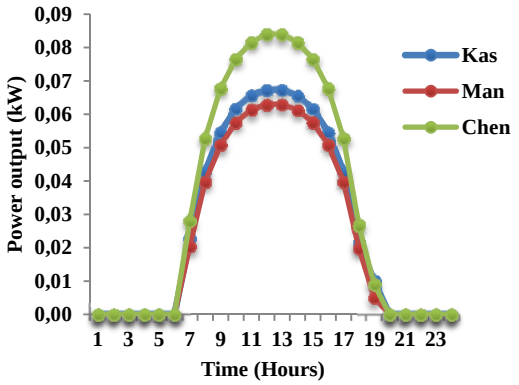

Fig 4: Power output of 260Wp solar Panel across the study sites

Fig 5 represents the relationship between solar resources and corresponding solar electricity production of the chosen solar panel for the research. It is evident from the figure that, at all points there is direct correlation between solar insolation and solar power output since the peak power output was observed during the peak sunshine hours of the typical day in Monsoon season. The trend also shows close values of solar insolation as well solar power output between Kasaragod and Mangaluru with can be attached to the facts that, the study sites are relatively at closer distance compared to Chennai study site. The trend observed between solar insolation and solar power output is similar to the trend observed by Ganesh and Ramachandra [36], Fatih *et al.*, [9].

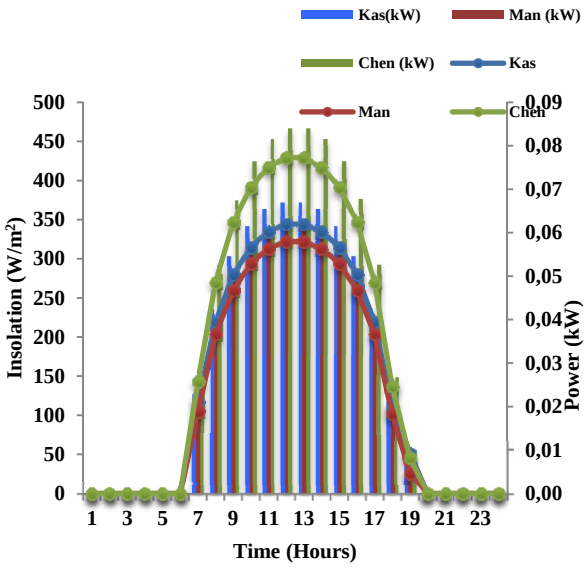

Fig 5: Solar Insolation and corresponding solar electricity production of 260Wp solar panel.

Fig 6 represents the hourly electricity demand of typical household as well as the hourly power output during typical day in the Monsoon season across the study sites.

Evidence from the figure shows that during sunny hours, the solar PV system generation exceeds the typical household electricity demand greatly. Although, there is higher gap between the generation and demand during non-sunshine hours, if storage system is coupled into the design during excess generation, the battery system can greatly cover part of the demand gap during higher electricity demand in the night hours. The analysis of t he results shows that even with storage option, there is demand deficit of 0.3kW, 0.41kW and 0.21kW across Kasaragod, Mangaluru and Chennai respectively. However, since all the study sites are connected to national grid, the demand deficit can be imported from the grid or by using other energy options.

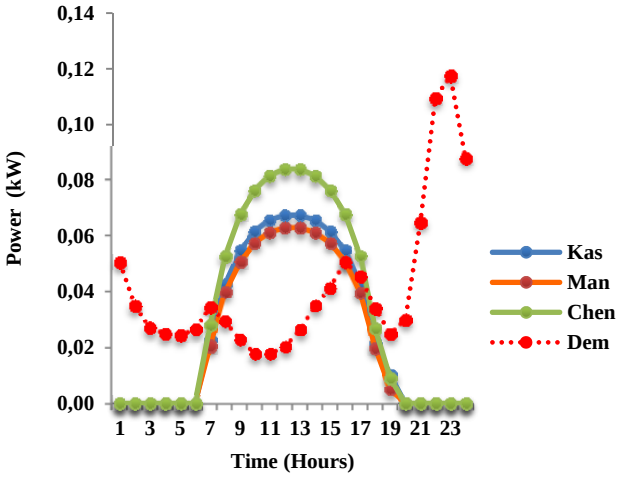

Fig 6: 260Wp Power output against the typical household electricity demand across the study sites.

V. CONCLUSION

In this study, we analysed the relationship between solar insolation and solar PV power output using diurnal solar insolation data scaled to typical Monsoon day obtained from PVGIS, to identify the potential of solar PV electricity generation across Kasaragod (Kerala), Mangaluru (Karnataka) and Chennai (TamilNadu) states of India.

The findings of the research reveled that all the study sites are considerably good atmospheres for harnessing solar power. The results shows that, solar PV technology performance even in the Monsoon season which has lowest solar resource compared to other seasons of the year can contribute significantly in supplying the electricity demand of typical household across the study sites. However, the findings reveled that, Chennai study site (TamilNadu) has highest solar PV potential due to higher solar resource in comparison to Kasaragod study site (Kerala) which has slightly higher solar resources compared to Mangaluru study site (Karnataka).

It can be concluded from the finding of the research that, with the advantage of higher population density which can help in reducing the per capita electricity demand, building style which plays very vital role in solar PV installation and abundant solar resources across the states of India, the Indian Government solar Energy mission of 2022 can be achieve in near future with higher penetration of government incentive and massive awareness on solar energy potential and its role in alleviating climate change and global warming which are the major issues of environmental concern of this century.

VI. ACKNOWLEDGEMENT

The authors wish to thank Indian Council for Cultural Relations (ICCR) for the financial support in the success of this research. The effort of PVGIS management team can never be ignored for making available the data used in the conduct of this research your efforts are gratefully acknowledged.

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