Assessing Rooftop Solar Capacities for Green House Gas Mitigation Potential in India

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Abstract

Greenhouse gases (GHGs) emitted due to anthropogenic activities are the main cause of Global warming. Global warming is responsible for extreme disastrous activities like hurricanes, cyclones, floods, rising of temperatures and sea levels and tsunamis. So, it becomes imperative to understand and curtail GHGs emissions. In recent times it is noticed that energy sector is major contributor of GHGs. To cater the growing energy demand, it becomes vital to look for growth avenues which are non-polluting and are eco-friendly. India has set most ambitious renewables growth plan, amongst, 40000 MW is planned through rooftop and 60000 MW from utility based solar projects. This study is an attempt to understand the GHGs mitigated from rooftop solar. Based on prevailing solar insolation and rooftop solar capacity, the power produced is estimated.

Further the estimated power and the applicable gird emission factor are used for quantifying the GHGs mitigated. There is greater potential and scope for solar capacity addition through rooftop, only 4.7 % rooftop solar capacity is in operation of the total planned. The operational 1886 MW rooftop solar capacity has potential to produce 3456726.11 MWh of electricity with GHGs mitigation potential of 3238464.29 tonnes of CO_2 annually. Correspondingly, planned 40000 MW Rooftop solar capacity can produce 70080000 MWh annually and has potential to mitigate 58166400 tonnes of CO_2. On comparing 40000 MW GHGs emissions with countries total emission levels it is found that rooftop solar has potential to mitigate 2.36% of GHGs.

Keywords: Solar Energy, Rooftop Solar, Electricity, Greenhouse Gas Emission, India.

Introduction

Rising level of Green House gases (GHGs) in the atmosphere is a major threat to ecology. GHGs increase in the atmosphere is key contributor of Global warming. The impacts of global warming are disastrous creating greater imbalance in the ecology. Hurricanes, cyclones, floods, change in precipitation, coastal erosion, droughts, tsunamis, rising of temperatures and sea levels are extreme disastrous activities noticed due to global warming. To create the balance and to reduce the harmful impact of GHGs, it is essential to take proactive and effective steps[2,3]. Globally, most of the countries to reduce the disastrous effect of GHGs are switching on alternatives, which are helping to reduce GHG emissions[27].

India too devised its national framework for reduction of GHG emissions. India submitted its Intended Nationally Determined Contributions (INDCs) to United Nations Framework Convention on Climate Change (UNFCCC) and have shown its strong commitment for reduction of GHGs. The emissions reduction targets are 33 % to 35 % emission reductions by the year 2030 from that of 2005 emission levels[12, 13]. India set its National Mission of achieving 175000 MW capacity installation from Renewables i.e. through eco-friendly power generation sources[28]. Solar, wind, biomass, biogas, geothermal and small hydro are eco-friendly power generations sources.

Amongst National Mission 100 MW capacity is planned through solar development. Further the solar capacities split as 60000 MW utility based and 40000 MW through rooftop[11]. Rooftop solar panels are positioned on top of roofs of residential, commercial, or institutional structures. They make use of the light energy emitted by the sun and convert it into electrical energy[4]. The electricity is produced near to the consumption point catering the power requirement locally. Rooftop solar can be either grid connected or standalone[5,6]. The electricity generated by solar capacities is the cleanest form of energy which does not pollute environment[20,25].

Deploying rooftop capacity has unique advantage of setting up power station at doorstep and has the lowest transmission and distribution losses. In the journey of adding more solar capacities, India has effective enabling framework for rooftop solar installations. The leading states in rooftop solar are, Gujarat ranking first amongst, the total installed capacity as on February 2020 is 469 MW. Karnataka ranks second highest with 232.77 MW. Rajasthan ranks third highest with 224 MW. Maharashtra stands fourth highest with 219.56 MW.

Delhi stands at the fifth highest with 156.2 MW. Tamil Nadu houses the sixth largest with 155.99 MW. Uttar Pradesh houses the seventh largest with 146.1 MW. Haryana houses the eighth largest with 121.34 MW. Punjab stands at ninth largest with 118.52 MW and Telangana ranks tenth largest with 90.46 MW[7]. State Commissions in India notified

metering policies for the Rooftop solar. Up till now states like Assam, AP, Chhattisgarh, Goa, Gujarat, Delhi, Himachal Pradesh, Jammu, Kashmir, Kerala, Karnataka, Jharkhand, Punjab, Madhya Pradesh, Manipur, Odisha, Puducherry, Rajasthan, Uttar Pradesh, Tamil Nadu, Telangana, West Bengal and Uttarakhand have come out with Rooftop solar policy framework[13].

Rooftop solar too is identified and recognized for catering major power demand by the year 2022. Rooftop solar is uniquely placed apart from other renewable sources as the power is produced at the roof of the individual setups. It would be interesting to study the contribution of rooftop solar in reducing the disastrous GHGs catering electricity need with the help of alternative sources. The potential GHG reduction can trigger for devising policy and decision makers which would further increase the penetration rooftop installations.

The objectives of this study are:

i) Analysing state wise rooftop solar capacities and corresponding power generation,
ii) To understand the total power produced from the National Solar Mission targeted 40000 MW solar rooftop capacities,
iii) State wise Green House Gases Mitigated from rooftop solar capacities,
iv) Comparing emission reduction from 40000 MW rooftop solar capacities with that of the country's total emission.

Material and Methods

The data on rooftop solar installations, prevailing solar insolation, reference data on power generation, targeted rooftop solar capacities, grid emission factors and India's emission reductions are taken from the public domain[1,13,15,17].

i) To analyse state wise rooftop solar capacities and corresponding power generation

The total installed rooftop solar capacity in India is 1886.27 MW as of December 2019[13]. States like Maharashtra, Tamil Nadu, Gujarat, Rajasthan, Uttar Pradesh and Karnataka are leading in rooftop solar installations[7]. While the state wise rooftop solar capacities are identified, the prevailing solar insolations are collected from the nearest available source for quantifying the energy yield[17]. The reference 1 kW solar PV plant at insolation levels of 5 kWh/m^2/day produces 4.8 units on an annual basis[15]. Equation 1 shows the power output by 1 kW solar PV system, it is a representative empirical relation used for quantifying solar power output from different solar insolation levels. Table 1 shows the prevailing solar insolation level in the state and the corresponding power generated by 1 kW Solar PV system.

$$Power\ output\ from\ 1\ kW\ Solar\ PV = \frac{Site\ insolation * 4.8}{5} \quad (1)$$

The state wise solar insolation levels are studied and the nearest available solar insolation data is applied to the rooftop solar capacities for estimating solar power produced[13,17]. Equation 2 shows the number of units generated from the rooftop solar capacities for the locations where solar insolation data is not available. India's average insolation data of 5 kWh/m^2/day is considered for 1 kW energy estimate. Further energy produced by 1 kW system is used for energy estimating from the entire state rooftop capacity.

$$Solar\ Power\ Produced = Rooftop\ Solar\ PV\ Capacity\ x\ No.of\ units \quad (2)$$

Table 1 shows the state wise installed rooftop solar capacities and the corresponding solar power generated from the solar PV system. The cumulative clean and green power produced from all the rooftop solar capacities in India is 3456726 MWh on an annual basis.

ii) **To understand the total power produced from the National Solar Mission targeted 40000 MW solar rooftop capacities:**

National Mission of India planned for developing 40000 MW of solar from rooftop capacities. The commissioning of the stated capacity is by the year 2022[8]. Geographical location details for the entire planned capacity are yet not finalised. On an average India receives solar insolation of 5 kWh/m^2/day[16]. To quantify energy yield from 40000 MW, average solar insolation is considered. The power produced by insolation levels of 5 kWh/m^2/day is 4.8 kWh per kW[15]. Equation 3 shows the total power produced by the 40000 MW Capacity.

$$Solar\ Power\ Produced = Total\ Planned\ Solar\ Capacity\ in\ MWh\ x\ No\ of\ units \quad (3)$$

$$Solar\ Power\ Produced = 40000\ x\ 4.8$$

The total power produced by the 40000 MW Solar Capacity is 192000 MWh of electricity on daily basis and 70080000 MWh on annual basis.

iii) **State wise Green House Gases Mitigated from rooftop solar capacities:** State wise total installed rooftop solar capacities as of December 2019 is 1836.27 MW[13]. India has 5 grid zones: Eastern, Northern, North Eastern, Western and Southern Grids. The grid emission factor notified by the Central Electricity Authority of India (CEA) for year 2019 is Northern: 0.95, Eastern: 1.05, Western: 0.91, North eastern: 0.68 and Southern:0.92 tonnes of CO_2 [1]. The grid-based emission factors are applied to the Rooftop solar power based on the region the capacities are and considered for estimating the emission reductions. Equation 4 gives the GHG mitigated from the Rooftop solar Power produced in different states and table 2 shows the total solar power produced and the GHGs being mitigated from the solar capacities.

$$Green\ House\ Gas\ Mitigated = Total\ Power\ Produced\ in\ MWh\ x\ Regional\ Emission\ Factor \quad (4)$$

Table 1
Solar insolation and Power Produced by Rooftop solar capacities[13,15,17]

S.N.	State / UTs	Total Capacity	Solar Insolation	Units / kW	Power Produced in MWh
1	Andaman & Nicobar Island	4.59	4.80	4.60	21.11
2	Andhra Pradesh	88.03	5.40	5.18	456.00
3	Arunachal Pradesh	4.34	4.00	3.84	16.67
4	Assam	30.56	4.00	3.84	117.35
5	Bihar	6.94	5.00	4.80	33.31
6	Chandigarh	29.98	5.00	4.80	143.90
7	Chhattisgarh	10.39	5.00	4.80	49.87
8	Dadra and Nagar Haveli	0.48	5.00	4.80	2.30
9	Daman and Diu	0.39	5.00	4.80	1.87
10	Goa	3.83	5.00	4.80	18.38
11	Gujarat	301.71	5.60	5.37	1620.18
12	Haryana	118.47	5.00	4.80	568.66
13	Himachal Pradesh	15.46	5.00	4.80	74.21
14	Jammu and Kashmir	10.81	5.00	4.80	51.89
15	Jharkhand	13.57	5.00	4.80	65.14
16	Karnataka	131.83	5.47	5.25	692.11
17	Kerala	41.75	5.40	5.18	216.27
18	Madhya Pradesh	49.40	5.18	4.97	245.52
19	Maharashtra	216.11	5.19	4.98	1076.23
20	Manipur	4.55	5.00	4.80	21.84
21	Meghalaya	0.12	4.52	4.33	0.52
22	Mizoram	1.43	5.00	4.80	6.86
23	NCT of Delhi	109.80	5.00	4.80	527.04
24	Orissa	14.27	5.25	5.04	71.92
25	Puducherry	1.92	5.00	4.80	9.22
26	Punjab	67.85	5.00	4.80	325.68
27	Rajasthan	119.50	5.47	5.25	627.38
28	Sikkim	0.07	5.00	4.80	0.34
29	Tamil Nadu	155.78	5.37	5.15	802.27
30	Telangana	72.64	5.65	5.42	393.71
31	Uttar Pradesh	140.87	4.91	4.71	663.50
32	Uttarakhand	75.71	5.01	4.80	363.41
33	West Bengal	43.12	4.49	4.31	185.85
Total Power Produced & GHG Mitigated on daily basis					9470.48
Total Power Produced on annual basis in MWh					3456726.11

India's weighted average grid emission factor for the year 2019 is 0.83 tonne of CO_2 / MWh[1]. The same is being used for quantifying the total GHGs mitigated from the entire 40000 MW planned rooftop solar capacity. It is observed the 40000 MW solar capacity when applied to average solar insolation levels of 5 kWh/m^2/day produces 70080000 MWh on annual basis and has potential to mitigate 58166400 tonnes of CO_2 on an annual basis[15,16].

iv) Comparing emission reduction from 40000 MW rooftop solar capacities with that of the country's total emission: Understanding the implications of Rooftop solar installations on India's total emission gives the percentage rooftop solar capacities are contributing for mitigating of GHGs. In 2017, the global GHGs emissions were 10028 $MtCO_2$. India alone contributed around 6.8 % to global GHGs emissions. Country's total GHG emissions in 2017 were 2467 $MtCO_2$[21]. Comparing the potential, GHGs mitigated by 40000 MW rooftop solar power capacity with that of the country's emission levels. Equation 4 shows the percentage GHG mitigated from the Rooftop solar capacities.

$$GHGs\ Mitigated\ by\ Rooftop\ Solar\ Capacity = Esitmated\ GHGs\ Mitigated / Emissions\ of\ the\ Country \quad (4)$$

$$GHGs\ Mitigated\ by\ Rooftop\ Solar\ Capacity = 58166400 / 2467000000$$

The assessment shows that the planned rooftop solar capacities have potential to mitigate 2.36 % of GHGs

emissions on annual basis which would certainly contribute to meeting the India's planned emissions targets.

Results and Discussion

Climate change and global warming are caused due to an increase in average global temperatures. Human activities are believed to be main contributors to such increase in global temperatures and melting of ice[26]. The climate change caused due to rising emissions of CO_2 from power stations, vehicles, industries, will not only affect the atmosphere and the sea but also will change the geology of the earth. Emissions of CO_2 due to use of fossil fuels will change the climate and the temperature is estimated to increase by 2 – 6 degree Celsius within year 2100, which is a tremendous increase from Intergovernmental Panel on Climate Change (IPCC) prediction of current average temperature of 1.7 degree Celsius[24]. This is going to trigger huge alterations to our civilization. Fig. 1 shows the various risks and impacts of climate change[19].

Table 2
Solar Power Produced and GHGs Mitigated[1,13,15,17]

S.N.	State / UTs	Total Capacity	Solar Insolation	Units / kW	Power Produced in MWh	Emission factor	GHG Mitigated Tonne of CO_2/ MWh
1	Andaman & Nicobar Island	4.59	4.80	4.60	21.11	1.05	22.17
2	Andhra Pradesh	88.03	5.40	5.18	456.00	0.92	419.52
3	Arunachal Pradesh	4.34	4.00	3.84	16.67	0.68	11.33
4	Assam	30.56	4.00	3.84	117.35	0.68	79.80
5	Bihar	6.94	5.00	4.80	33.31	1.05	34.98
6	Chandigarh	29.98	5.00	4.80	143.90	0.91	130.95
7	Chhattisgarh	10.39	5.00	4.80	49.87	0.91	45.38
8	Dadra and Nagar Haveli	0.48	5.00	4.80	2.30	0.91	2.10
9	Daman and Diu	0.39	5.00	4.80	1.87	0.91	1.70
10	Goa	3.83	5.00	4.80	18.38	0.91	16.73
11	Gujarat	301.71	5.60	5.37	1620.18	0.91	1474.37
12	Haryana	118.47	5.00	4.80	568.66	0.95	540.22
13	Himachal Pradesh	15.46	5.00	4.80	74.21	0.95	70.50
14	Jammu and Kashmir	10.81	5.00	4.80	51.89	0.95	49.29
15	Jharkhand	13.57	5.00	4.80	65.14	1.05	68.39
16	Karnataka	131.83	5.47	5.25	692.11	0.92	636.74
17	Kerala	41.75	5.40	5.18	216.27	0.92	198.96
18	Madhya Pradesh	49.40	5.18	4.97	245.52	0.91	223.42
19	Maharashtra	216.11	5.19	4.98	1076.23	0.91	979.37
20	Manipur	4.55	5.00	4.80	21.84	0.68	14.85
21	Meghalaya	0.12	4.52	4.33	0.52	0.68	0.35
22	Mizoram	1.43	5.00	4.80	6.86	0.68	4.67
23	NCT of Delhi	109.80	5.00	4.80	527.04	1.05	553.39
24	Orissa	14.27	5.25	5.04	71.92	1.05	75.52
25	Puducherry	1.92	5.00	4.80	9.22	0.92	8.48
26	Punjab	67.85	5.00	4.80	325.68	1.05	341.96
27	Rajasthan	119.50	5.47	5.25	627.38	0.95	596.01
28	Sikkim	0.07	5.00	4.80	0.34	1.05	0.35
29	Tamil Nadu	155.78	5.37	5.15	802.27	0.92	738.09
30	Telangana	72.64	5.65	5.42	393.71	0.92	362.21
31	Uttar Pradesh	140.87	4.91	4.71	663.50	0.95	630.32
32	Uttarakhand	75.71	5.01	4.80	363.41	0.95	345.24
33	West Bengal	43.12	4.49	4.31	185.85	1.05	195.14
Total Power Produced & GHG Mitigated on daily basis					9470.48		8872.50
Total Power Produced on annual basis in MWh					3456726.11		
Total GHG mitigated on annual basis in tonne of CO_2							3238464.29

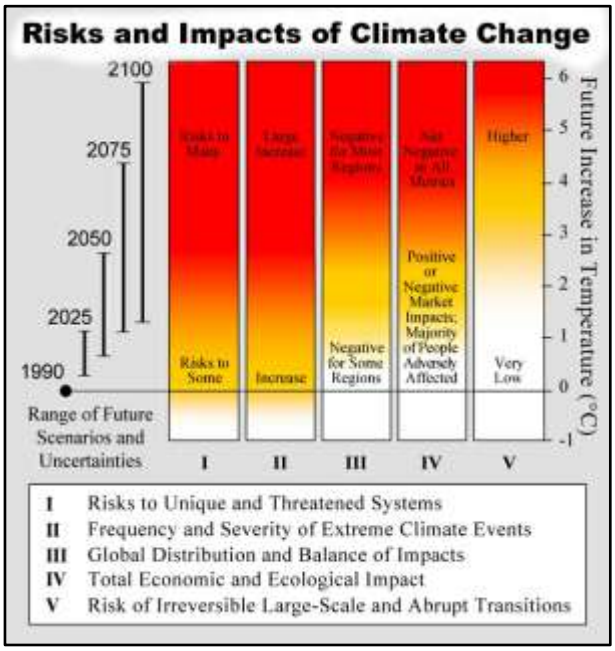

Fig. 1: Project Global Temperature rise from 1.1. to 6.4 degree Celsius[19].

In late 20th century, alterations have been observed in the trends of some extreme weather and climatic events. Human activities have, with varying degrees, contributed to these studied trends. Predictions for the 21st century indicate continuing changes in trends for several extreme events.

- Rise in the regions affected by drought
- Increased tropical cyclone activity and
- Increase of sea levels

Predictable changes in extreme events will have predominantly adverse impacts on environment and human beings[19]. It becomes imperative to understand on the various activities which can be taken up for the reduction of global warming which is ultimately reduction of GHG emissions. Increasing power generation base from that of renewables and reducing the use of fossil fuels to the larger extent would certainly help in reducing the GHG emissions. Renewables play significant role in mitigation of GHGs. Global call on mitigating GHGs and implementation of declared INDCs would help curtailing GHGs to the greater extent[22].

Countries who have submitted INDCs to UNFCCC post achievement of intended programs, would show significant improvement on GHG curtailment. India declared its National Mission in February 2016 and as part of the mission it was stated that country would achieve 175000 MW of renewable energy based installations by 2022[23].

Amongst the targets, 60000 MW is planned through utility base solar and 40000 MW solar through rooftop. The utility scale-based projects are closely monitored and developed by the Solar Energy Corporation of India. Be it utility based solar or rooftop based solar, it is eco-friendly mode of power generation and helps in mitigating GHGs. For capacity addition, to greater extent the rooftop solar is being promoted in India. All States in India have enabling framework for developing rooftop solar photovoltaic (PV) capacities.

Rooftop capacities have unique advantage, that power is generated and consumed near to the load centre. Bandwidth solar insolation levels received are in the range of 4 - 7 kWh/m^2/day[14]. The average solar insolation received is 5 kWh/m^2/day[16]. Applying average prevailing solar insolation levels to the 1 kW system, the energy yield realised is 4.8 units when exposed to 5 kWh/m^2/day solar insolation levels. Installed rooftop capacity of 1886 MW in different states is the result of existing policy framework and India's call on promotion of renewables.

The targeted rooftop solar capacity is 40000 MW that means only 4.7% of rooftop solar installations are in operation catering power demand and there is long way to go. Adding the planned solar rooftop capacities and bridging the gap between the capacities in operation versus targeted capacity addition would help in meeting the national targets more effectively. It becomes imperative to look for growth avenues and address the challenges being encountered by the rooftop capacity addition programme in the country.

Also, it is essential to adopt latest trends, techniques and the technologies emerging in the arena. States lacking in rooftop solar installations should review the policies, programs of the state's leading in installations and should adopt the lacking growth instruments for capacity additions more effectively through regulatory bodies. Solar insolation levels prevailing at the site locations play key role in power generation from the installed and planned solar capacities. Insolation levels measured by the nearest measurement station help in estimating the total power generated from the rooftop solar capacities.

The solar insolation in the higher range i.e. 5 kWh/m^2/day and above give better energy yield as compared to solar insolation levels of lower insolation zones. For having optimized energy yield from plant, it is advisable to choose favourable solar insolation zones. Fig. 2 shows the prevailing solar insolation in the different states in India on annual basis[18].

While entire country receives good solar insolation levels, States like Rajasthan, Tamil Nadu, Telangana, Gujarat, Maharashtra and Andhra Pradesh receive better insolation levels as compared to the other States in India. The large number of rooftop installations are also seen in the States which are blessed with good solar insolation levels[10]. Solar insolation plays pivotal role in generating power, better are the solar insolation levels, higher is the power generation[9]. From the data, it is found that operational rooftop solar PV capacities are producing 3456726.11 MWh of electricity when exposed to varying solar insolation levels and help in mitigating 3238464.29 tonnes of CO_2 on annual basis. Maharashtra, Gujarat, Haryana, Delhi, Karnataka, Tamil Nadu, Rajasthan and Uttar Pradesh are the leading rooftop solar installers.

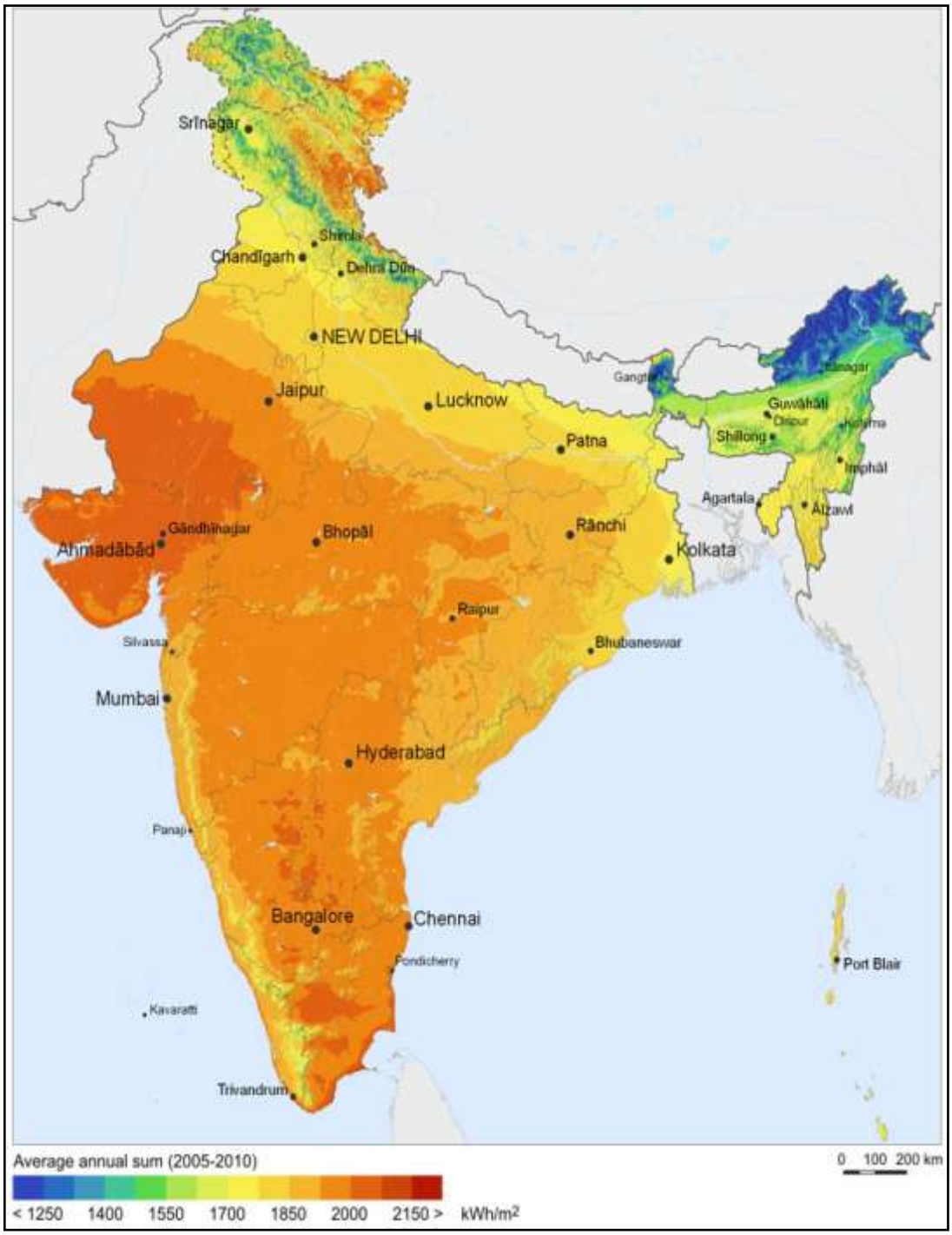

Fig. 2: Global Solar Insolation levels of India (Annually)[18].

Fig. 3 shows the rooftop solar capacities, solar varying insolation levels and power produced from the different Rooftop solar capacities in the states. For the States where higher power generation is seen along with insolation levels, the states too have good amount of rooftop solar installations.

The rooftop solar capacities are in different insolation zones and the grid regions. With application of prevailing insolation levels and the regional grid emission factors, the total GHG mitigated is calculated from the operational and planned rooftop solar capacities. Being leading rooftop installers, States like Gujarat, Haryana, Karnataka, Maharashtra, Delhi, Rajasthan, Tamil Nadu and Uttar Pradesh are also leading in mitigation of GHGs. The 1886 rooftop operational solar capacity has potential to mitigate 3238464.29 tonnes of CO_2 annually.

More are the rooftop capacities deployed, more would be the GHG mitigated. The operational rooftop solar capacities, total power produced and the GHGs mitigated from the rooftop solar capacities by the operating capacities in the states are shown in fig. 4.

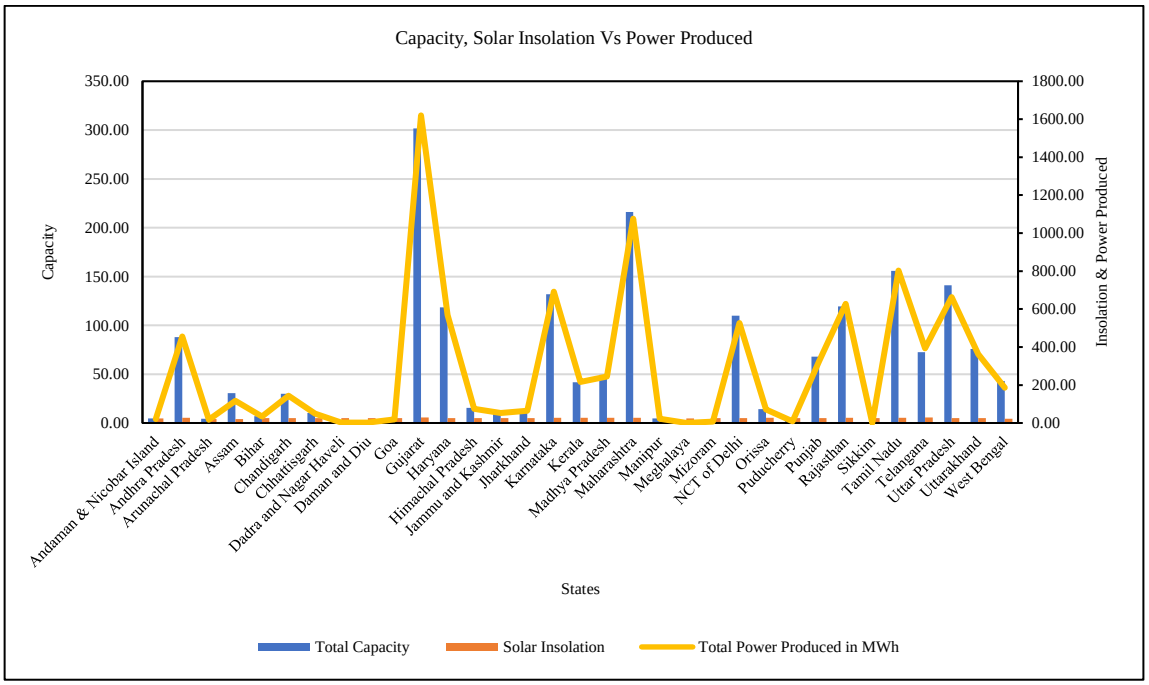

Fig. 3: Rooftop solar capacities, Insolation levels and Power Produced

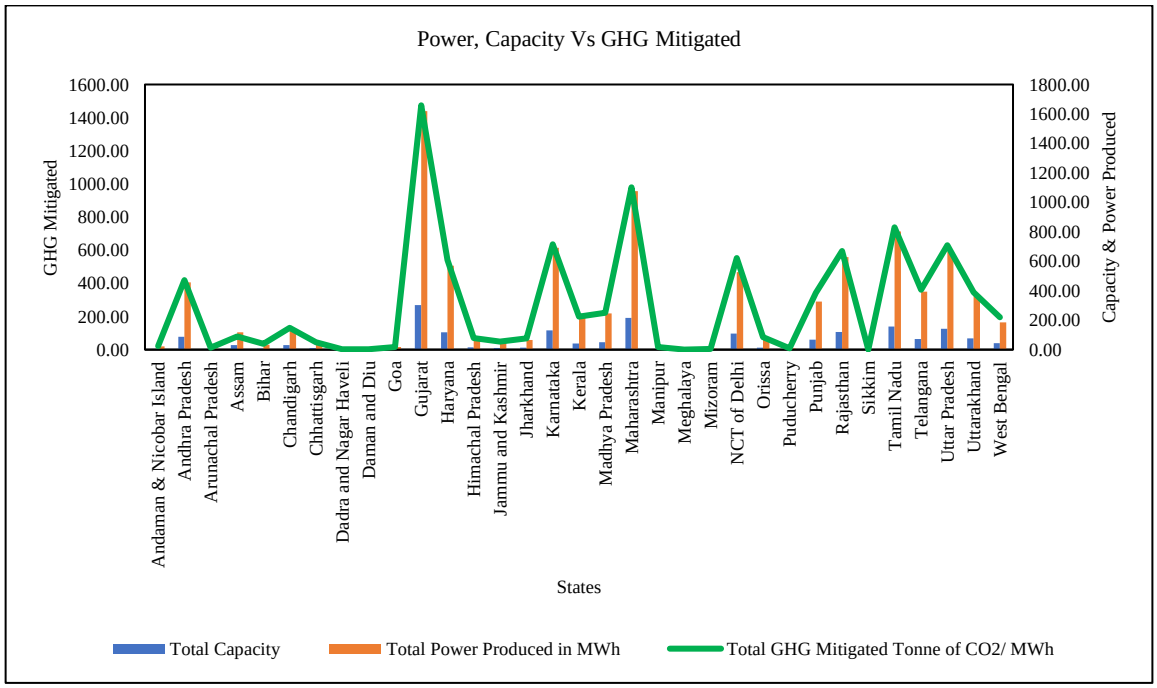

Fig. 4: Rooftop solar capacities, Power produced and the GHG mitigated from rooftop solar

Similarly, the planned 40000 MW Rooftop solar capacity can produce 70080000 MWh of energy on an annual basis and has potential to mitigate 58166400 tonnes of CO_2. In Conference of Parties (COP) 21, Paris Agreement, India stated its National intent is to mitigate 33% to 35% of GHGs emissions by the year 2030 as compared to 2005 emission levels. Every single MW capacity added from renewables would contribute for mitigation of GHGs and would help in meeting the national targets.

In 2017, India's total GHGs emission were 2467 $MtCO_2$. Comparing the 40000 MW mitigated emissions with that of the India's emission levels show that the National Mission planned Rooftop solar capacity alone can contribute for mitigation of 2.36 % of GHGs on an annual basis.

Conclusion

Increased CO_2 in the atmosphere would not only increase the global temperature but would also increase the frequency of disastrous activities. Global warming threatens the planet in unforeseen way by causing tsunamis, floods, volcanic eruptions and earthquakes. Many countries have come forward for reducing global warming impact by reduction of GHG emissions. In response to global GHG curtailment plan, India too gave its huge renewable capacity addition program of adding 175 GW by 2022.

In India, there is greater potential for solar capacity addition through rooftop, of the total planned capacities, only 4.7% rooftop solar installations are achieved. Adding more capacities through rooftop solar would help in meeting the 40000 MW National mission targeted capacity more effectively.

States like Rajasthan, Maharashtra, Gujarat, Tamil Nadu, Telangana, Uttar Pradesh and Karnataka have good Rooftop solar installations. States lacking in rooftop installations should revisit and review the instruments responsible for slow capacity addition and adopt the shortcomings for enabling the faster rooftop solar capacity addition. On an average, India receives solar insolation levels of 5 $kWh/m^2/day$. The operational 1886 MW rooftop solar capacity can produce 3456726 MWh and has potential to mitigate 3238464.29 tonnes of CO_2 annually. The planned 40000 MW Rooftop solar PV capacity can produce 70080000 MWh and has potential to mitigate 58166400 tonnes of CO_2 on annual basis. On comparing rooftop solar GHG mitigation potential with that of country's emission levels it shows, rooftop solar can help in mitigation of 2.36 % of GHGs on an annual basis.

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