ASSESSMENT OF ROOF-TOP SOLAR ENERGY POTENTIAL IN PROPOSED SMART CITIES OF INDIA

Shashikant Sharma, Gaurav Jain, Shweta Mishra and Bimal Bhattacharya
Space Applications Centre, Jodhpur Tekra, Ahmedabad - 380 015

KEY WORDS: roof-top photovoltaic, solar insolation, smart energy, technical potential, renewable energy

ABSTRACT

Solar energy is one of the most sustainable form of renewable energy, both environmentally as well as economically, particularly so for developing countries. India, which accomplished a cumulative installed capacity of 9.23 GW of grid-connected solar power as on January 1, 2017, has set an ambitious target of attaining 100 GW of solar capacity by 2022, which includes 40 GW of grid-connected roof-top solar installations as well. Furthermore, in order to mitigate the ever increasing challenges of resource constrained urban areas in India, 98 cities have been identified under Smart Cities Mission to further their infrastructure development goals with the aid of information and communication technology. These proposed Indian Smart Cities have been encouraged to meet 10-15% of respective energy demand from renewable energy resources, wherein solar energy can contribute significantly. This study, therefore, attempts to estimate the rooftop photovoltaic (PV) potential of these 98 cities. The built-up area of these study cities is obtained from various spatial databases from legacy projects, subsequently updated from LISS-3 images acquired by Indian Remote Sensing satellites. The global (total) horizontal insolation, combining direct as well diffuse component of incident solar energy, is obtained from KALPANA-1 VHRR data for past years. The monthly as well as annual solar insolation over each study city was computed and total roof-top solar PV potential was thus estimated. The study estimates 10.02 GW of grid-connected roof-top PV potential with 103.51 TWh of energy annually in the proposed 98 smart cities of India. The results of the study were further published on a web-portal for wider dissemination and usage.

1.0 INTRODUCTION

Solar energy is one of the most sustainable forms of renewable energy, both environmentally as well as economically, particularly so for developing countries. India, which has a cumulative installed capacity of 9.23 GW of grid-connected solar power as on January 1, 2017 (MNRE, 2017), has set an ambitious target of attaining 100 GW of solar capacity by 2022, which includes 40 GW of grid-connected rooftop solar installations as well (MNRE, 2017). Photovoltaics (PV) or Solar cells convert sunlight directly into electricity. PV systems can be integrated in the building skin, i.e. roofs and facades (Gutschner et al., 2002). The electricity generated by the PV systems installed on the rooftops of residential, commercial, institutional and industrial buildings can be fed into power grid at regulated feed-in tariffs (referred as Grid-connected Rooftop Solar Installation), or can be used by building for self-consumption. In this context, Ministry of New and Renewable Energy (MNRE) initiated a programme on “Development of Solar Cities” and identified 60 cities to become ‘Renewable Energy Cities’ or ‘Solar Cities’, aiming to meet a minimum 10% of their projected demand of conventional energy at the end of five years, through a combination of augmentation in supply from renewable energy sources and energy efficiency measures like smart street lighting etc. Furthermore, in order to mitigate the ever increasing challenges of resource constrained urbanization in India, 98 cities have been identified under “Smart Cities Mission” to further their infrastructure development goals with the aid of information and communication technology (MoUD, 2015). 'Smart Energy' is considered one of the pillars of Smart Cities, wherein solar energy can contribute significantly towards reducing dependence on non-renewable energy. Several of the proposed smart cities in India like Pune have proposed to meet 15-20% of energy requirements from renewable sources (PMC, 2016), while the proposed guidelines for smart cities implementation also require that these smart cities ensure that at least 10% of their energy requirement is fulfilled from solar energy. However, it remains obscure that how much of the solar energy resource exists over these cities, which can be tapped for meeting their energy demand.

The amount of total energy resource that can actually be captured, under a given set of physical and technological constraints, irrespective of its economic feasibility and market acceptability, is referred to as “Technical potential”. The technical potential quantifies the power generation available from a particular technology, thereby providing an established reference point for a renewable energy technology. The estimation of technical potential at regional scale is needed particularly for policy-makers due to its wide-scale impact on the realization of a region’s energy-security goals. This has encouraged several research studies on national and regional scale world-over. Gutschner et al. (2002) proposed methodology based on thumb-rules for estimating the building-integrated PV potential (BIPV) taking into account the solar and architectural suitability. They recommended an assumption of 0.4 m^2 of roof area and 0.15 m^2 of façade area per one square meter of ground floor area as architecturally suitable building area for solar yield. Pelland and Poissant (2006) estimated BIPV potential in Canada on the basis of the approach recommended by Gutschner et al. (2002). The ground floor area of Canada for residential, commercial and institutional buildings were estimated from various secondary sources. This study estimated total technical potential of 73 GW installed capacity in Canada, capable of generating 73 TWh energy annually. Peng and Lu (2013) assessed the applicability of the approach proposed by Gutschner et al. (2002) on selected buildings in Hong Kong and observed that the measurement results were 10-15% larger than estimated results and accordingly revised the utilization factor of 0.4 to 0.6 in Hong Kong. The study concluded that the potential installation capacity of rooftop PV systems in Hong Kong is 5.97 GWp with an annual potential energy output corresponding to 5981 GWh. Siala and Stich (2016) estimated 430 TWh of annual generation capacity of solar PV in South East Asia considering availability 0.08% of total land area in the region for such installations. The study used a climate-based model for adjusting the solar radiation data provided by NASA, and applied topographic and land-use constraints in order to estimate the solar PV potential in South East Asia. It is thus apparent the most of the regional studies have relied on estimation of available roof-area from secondary sources like census and household surveys.

The solar energy incident upon a building in urban environment is also impacted by shadows from adjacent structures, tilt and orientation of the roof, sky obstruction due to urban canopy and reflections from multiple non-lambertian surfaces. The detailed analysis of these effects require large-scale 2D data, 3D city models, and analysis at individual building roof, which is not practical for regional-scale estimation. Ko et al. (2015) used large-scale GIS data (1:1000) of one local district in Taiwan to calculate the shadow areas on rooftops and estimated the installed ratio (ratio of solar PV installable area on worst daylight day to the total town planning area of the district). The study further assumed that 50% of roof area is available for solar PV installation while excluding the roofs less than 10 m^2 area. The installed ratio of 0.088 was subsequently applied to National Town Planning Area in Taiwan, thereby estimating the rooftop PV installation capacity in Taiwan at 12.43 GW with annual power generation capacity of 15.42 TWh. Gagnon et al. (2016) estimated the total technical potential of rooftop solar PV systems in United States of America, using light detection and ranging (LIDAR) data of 128 cities to devise models applicable for whole of the country. The LIDAR data comprised 26.9 million buildings accounting for 23% of total U.S. buildings. It was observed that small buildings (roof-area less than 465 m^2) accounted for 58% of total roof area in these 128 cities. The study used an empirical model relating secondary data viz. population, population density, land cover and detached houses count, to determine the total number of small, medium and large buildings in a region and further predicted the fraction of buildings with suitable rooftops. The study noted that 26% of small buildings could accommodate 731 GW of PV capacity, while 386 GW of installed capacity can be availed from the medium and large buildings. The study estimated the total technical potential of rooftop PV in United States as 1,118 GW installed capacity capable of 1,432 TWh of annual energy generation. The methodology proposed by Gagnon et al. (2016), though appears to be reasonable and more accurate as compared to other approaches as it considers the effect of shadow, tilt and orientation of roofs in computation of available solar insolation, the requirement of LIDAR data for developing model for estimating suitable PV roof areas is a major hindrance for its application in other regions.

It is apparent that the estimation of technical potential of solar energy has been done for several countries across the world. However very few studies have been conducted in India for regional estimation of solar energy, with focus largely on state-level assessments considering wasteland as primary source of land for PV installations. National Institute of Solar Energy (NISE) estimated state-wise solar potential in India using data from Census of India (2011) and the Wasteland Atlas of India (2010). The study assumed that 3% of wastelands in the country can be used for solar power projects. The total solar power in India was estimated at 748.98 GWp (MNRE, 2014). Yadav and Chandel (2015) estimated total potential of solar energy on the vacant wastelands in the Indian state of Himachal Pradesh as 40,000 kWh/day. Sharma et al. (2015) pegged the total potential of solar thermal energy in India at 756 GW considering wasteland with direct normal irradiation of over 1800 kWh/m^2/year. Singh et al. (2016) developed an approach for prioritization of states in India for developing solar energy resources on the basis of existing energy demand, available solar radiation, government policy, social acceptability, land availability and environmental issues. The study concluded that Rajasthan state has highest potential of solar energy amongst all the states in India, while states like Jharkhand, Jammu and Kashmir and Uttar Pradesh require greater effort to tap solar energy. Singh and Banerjee (2015) estimated the rooftop solar PV potential of Mumbai city in India. The study relied upon the building footprint ratio (ratio of actual area covered by the building to the plot area of the building) for different land uses in the city to estimate total rooftop available in the city. The effective building area available for installation of solar PV systems is further computed on the basis of PVA ratio (ratio of Photovoltaic-available roof area to building footprint area) of 0.28 (range of PVA ratio for Mumbai reported 0.28-0.40), for conservative estimates. The study concluded that the rooftop solar PV potential in Mumbai is 2190 MW. It is thus evident that information on total technical potential that can be generated in India from roof-top solar PV installations from the proposed smart cities of India remains a major gap area that this paper attempts to address. While the methodology for estimation of technical potential at regional scale show some uniformity in approach for ascertaining this information, the data availability itself is difficult to achieve. This study, therefore, attempts to estimate the total roof-top area available in these 98 cities using datasets organised in the Natural Resources Database (NRDB) of the National Natural Resources Management System (NNRMS), a project funded and supported by the Department of Space (Government of India).

The paper is structured in seven sections. Section 1 elaborates on various approaches used for regional level solar energy resource estimations globally and in India, while highlighting the need for such estimates. Section 2 provides an overview of the cities selected for the study. The details of data used in the study are provided in section 3. Methodology used for estimation of technical potential in 98 cities is discussed in the section 4. Section 5 presents the results of study and city-wise estimated solar energy potential. The limitations of this study and future work to further improve the estimates are provided in section 6, which is followed by conclusions of the study in section 7.

2.0 STUDY AREA

The study area consists of 98 cities in India as identified under the "Smart Cities Mission" of Government of India (MoUD, 2016). As these cities are also expected to promote use of renewable energy for meeting at least 10% of their energy demand, an estimate of available technical potential over these cities will be beneficial to their respective Urban Local Bodies (ULB). The areal extent of these cities will consider the actual spread of the city, irrespective of whether it is covered by the municipal limits of the city, while ignoring small scattered outgrowths and including the adjoining contiguous expansions. Greater Hyderabad and Greater Mumbai cities thus extend much beyond their municipal boundaries. It was further observed that 13 of the smart cities, viz. Bhopal, Bhubaneswar, Coimbatore, Guwahati, Indore, Jabalpur, Jaipur, Kakinada, Kochi, Ludhiana, New Delhi (NDMC area), Pune and Surat, have also been covered under the Solar Cities Mission.

3.0 DATA USED

The data on built-up area of cities is obtained from the various remote sensing application projects executed by Department of Space. The data is organized in NRDB and can be accessed using the national Natural Resources Repository (NRR) created as part of the NNRMS Programme through its portal (NNRMS Standards Committee, 2005). The data from National Resources Information System (NRIS), Natural Resources Census (NRC), Coastal Zone Information System (CZIS) and Large Scale Mapping (LSM) projects were used in this study. The land use theme of NRIS project includes the urban built-up area at 1: 50,000 scale, mapped using 23.0 m spatial resolution LISS-3 data acquired from Indian Remote Sensing (IRS) satellites for the period 2004-2005. The land cover at 1: 50,000 and 1: 250,000 scale were mapped under NRC project using LISS-3 and AWiFS (56.0 m spatial resolution) for the year 2005-06 and 2007-08 timeframes respectively. NRC data at 1: 50,000 scale was available for 32 cities whereas for 18 cities only 1: 250,000 scale data was available. CZIS data comprised 1:25,000 scale coastal land use mapped using LISS-4 (5.8 m spatial resolution) of 2004-06 timeframe. Habitation mapped in coastal land use theme of CZIS was used for two coastal cities (Diu and Kavaratti). Thus the built-up area of 82 cities are at 1:50,000 scale or larger, whereas the data for 16 cities is at 1: 250,000 scale. Furthermore, in order to estimate the ground floor area of buildings, which is important for estimating available roof-top for PV installation, the large scale mapping project data was used. LSM data mapped building footprints at 1:10,000 scale for 35 cities using high resolution satellite data of year 2009. The data of seven study cities, viz. Coimbatore, Jabalpur, Surat, New Delhi Municipal Corporation, Amritsar, Dehradun and Hyderabad, were used from LSM project for building footprint analysis. Table 1 summaries the NRDB data used in this study.

Table 1: NRDB Datasets Used

Sr. No.	Project	Scale	Themes	Time-frame	No. of Cities
1	Natural Resources Information System (NRIS)	1:50,000	Land use	2004-05	48
2	Natural Resource Census (NRC)	1:250,000	Land cover	2007-08	32
3	Natural Resource Census (NRC)	1:50,000	Land cover	2005-06	18
4	Coastal Zone Information System	1:25,000	Land use	2004-06	2
5	Large Scale Mapping	1:10,000	Base Map	2009	7

The global (total) horizontal insolation, combining direct as well diffuse component of incident solar energy, is obtained from the half-hourly observations at 8 km spatial resolution in optical and thermal infrared bands from the Indian geostationary satellite KALPANA-1 Very High Resolution Radiometer (VHRR) for three years, viz. 2013, 2014 and 2015. The data is available on MOSDAC (www.mosdac.gov.in) web portal of ISRO. The detailed methodology along with validation results, which includes spectrally integrated clear-sky and three-layer cloudy-sky models to determine the atmospheric transmittances and instantaneous surface insolation, is discussed in detail by Bhattacharya et al. (2013). The average of global normal irradiance of 2013, 2014 and 2015 was used to estimate the annual global horizontal irradiation (GHI).

4.0 METHODOLOGY

The built-up area of 98 study cities as obtained from different sources and NNRMS projects were organized into a common reference system and an integrated database. The thematic accuracy of 1: 50,000 scale data is reported to be 90/90. The built-up areas of all the cities were further verified using LISS-3 images, and necessary corrections for classification errors were applied, particularly for the coarse resolution data of NRC.

Distribution of building footprints of seven study cities obtained from LSM data is shown in figure 1. The small buildings have area less than 500 m^2, medium buildings area ranges between 500 - 2000 m^2, and large buildings have areas more than 2000 m^2. The buildings with area less than 10 m^2, which are considered very small for solar PV potential (Ko et al., 2015), account for less than 1%. It is apparent that the small buildings account more than 70% of buildings in most of the study cities, except the mega-cities, i.e. city with population of more than 10 million. The larger the population of a city, more is the proportion of medium and large buildings. The medium and large buildings usually have flat roofs with sufficient area for solar PV installation, whereas small buildings can occasionally have pitched roof. The data of these seven cities were used for estimating the fraction of built-up area covered by building footprint. As the area of interest for large scale mapping and the area as mapped under other projects of coarse-scale are different, direct comparison of city's mapping extent of LSM and other projects may provide misleading information. Thus, the areal extents of both, the LSM and NRIS/NRC data are to be standardized to enable the comparison. The procedure to estimate the ratio of building footprint area to the built-up area for Surat city is illustrated in figure 2. The feature envelop of LSM data is computed from building footprint. This is used to clip the built-up area of the city. The built-up area thus clipped is further used to select overlapping buildings from LSM building footprints. The ratio of geographical area of these buildings to the built-up area clipped by the LSM feature envelop, provides the ground floor area proportion. The average fraction of built-up area covered by building footprint is thus computed and is applied to estimate roof-top area in all 98 cities.

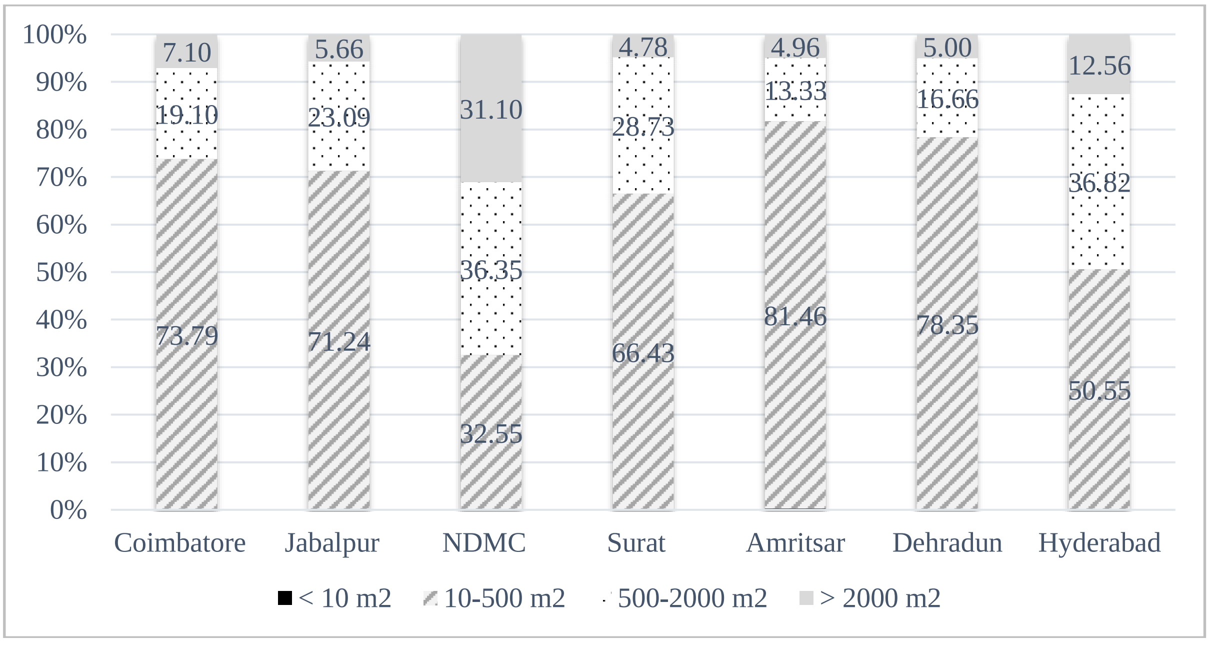

Figure 1: Proportion of Small, Medium and Large Buildings in Selected Indian Cities

The estimation of roof-top area suitable for PV installations is based on constant-ratio approach, where by a certain percentage of building rooftop area is considered suitable for hosting PV (Gagnon et al., 2016). Padipatti et al. (2008) estimated that 27% of total roof areas in residential buildings in warmer climate is available for PV systems. However, most of the buildings in USA, particularly the small buildings having area less than 500 m^2 have pitched roofs (92%). Gagnon et al. (2016) referred several studies adopting the constant proportion method for estimation of technical potential, reporting 22% -27% of residential rooftop area and 60% - 65% of commercial rooftop area as suitable for PV. Singh and Banerjee (2015) considered 28% of built-up area as effective roof area in Mumbai city

(India). In this study, it is assumed that roof-top area suitable for PV is equivalent to the 25% of the ground floor area. Thus, the available rooftop area for PV systems in each city is computed.

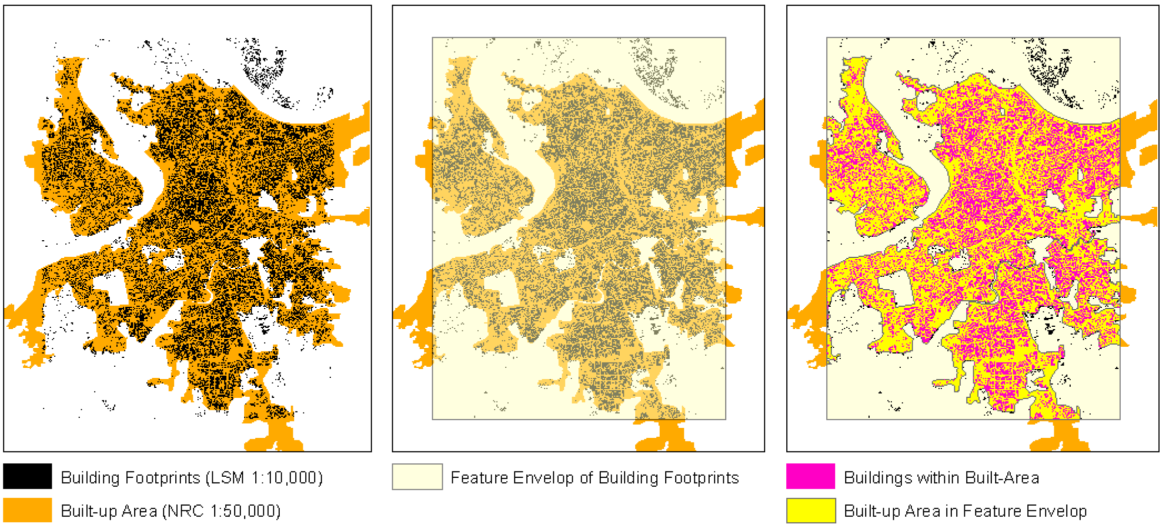

Figure 2: Estimation of Fraction of Building Footprint Area to Built-up Area in Surat City

The global (total) horizontal insolation, combining direct as well diffuse component of incident solar energy, as obtained from KALPANA-1 VHRR data for past three years, is then used to estimate the incident solar resource potential. The monthly as well as annual solar insolation over each study city was computed and total roof-top solar PV potential was thus estimated as product of suitable roof-top area and annual solar irradiation.

5.0 RESULTS AND DISCUSSION

The total built-up area of the proposed 98 smart cities was estimated at 6,360.92 km^2. Namchi city in Sikkim is the smallest city with built-up area of 92.84 ha while Greater Hyderabad is the largest urban area spread over 90,479.23 ha area. The proportion of building area in built-up area of selected cities is shown in figure 3. The average fraction of building footprint area to built-up area is 0.25, and therefore it was assumed that 25% of built-up area is covered by buildings. The total ground floor area occupied by buildings is thus calculated as 1590.24 km^2. The total suitable roof area (assuming 25% of roof area as suitable for PV) is therefore estimated at 397.56 km^2.

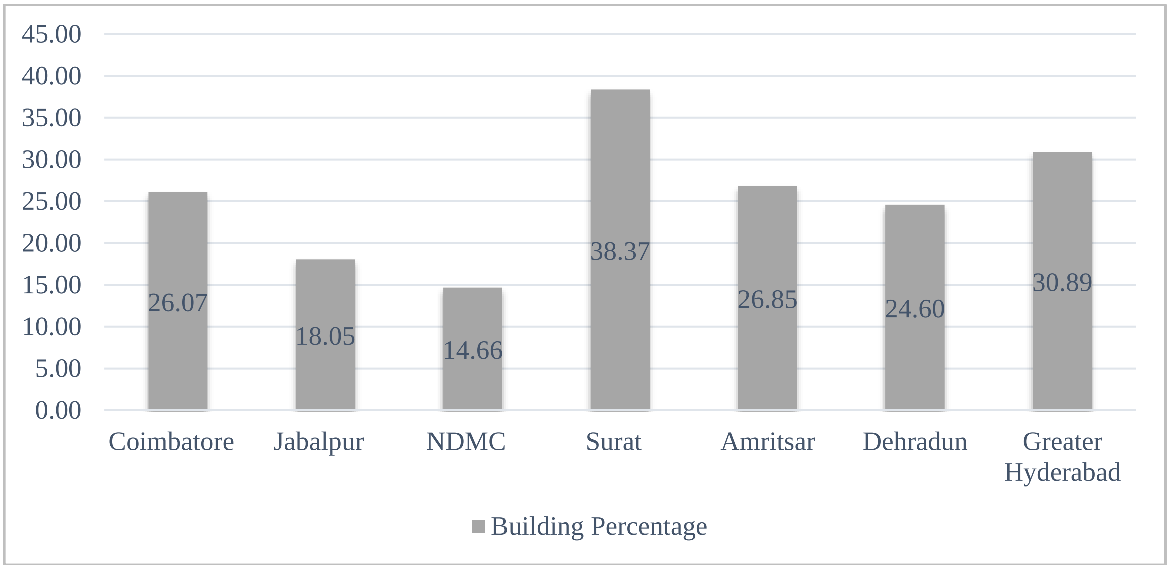

Figure 3: Fraction of Building Footprint Area to Built-up Area in Selected Cities

The power output of a photovoltaic cell is directly proportional to incident solar irradiation on the cell. The higher the solar irradiation, the higher the power output of a photovoltaic cell. GHI over each city is, therefore, estimated using the average annual global solar insolation of years 2013, 2014 and 2015. Figure 4 shows solar insolation over India during the year 2015. The weighted area average over the areal extent of each city is estimated. Tiruppur and Thoothukudi cities in Tamil Nadu state have annual GHI more than 1900 kWh/m^2/year. Dharmshala city in Himachal Pradesh and Namchi city in Sikkim have GHI less than 1200 kWh/m^2/year. The average GHI of all 98 smart cities is around 1597 kWh/m^2/year. Figure 5 shows the distribution of cities with respect to their corresponding annual GHI. It is apparent that 42 cities have GHI ranging between 1600-1800 kWh/m^2/y.

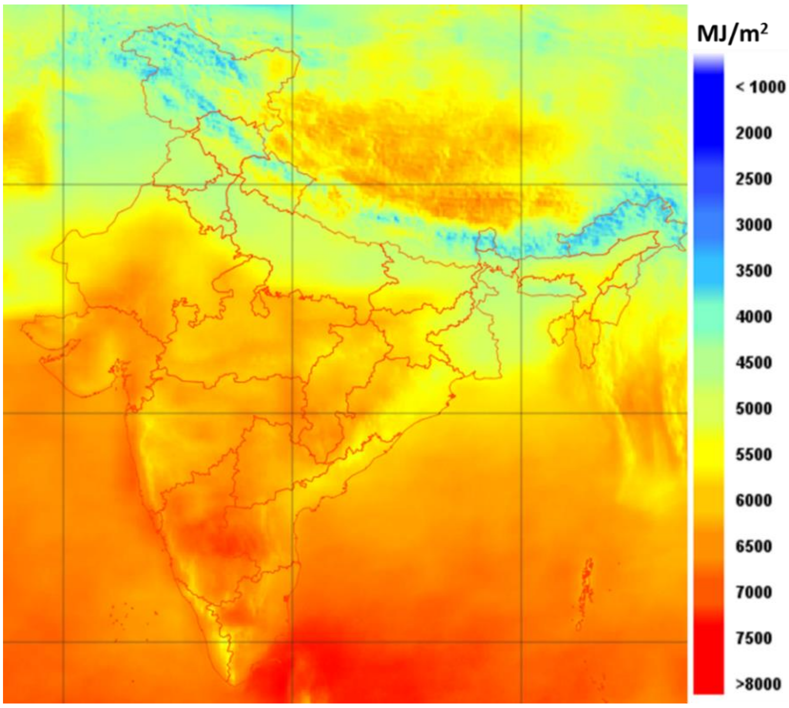

Figure 4: Global Horizontal Irradiation (GHI in MJ/m^2) in Year 2015 over India

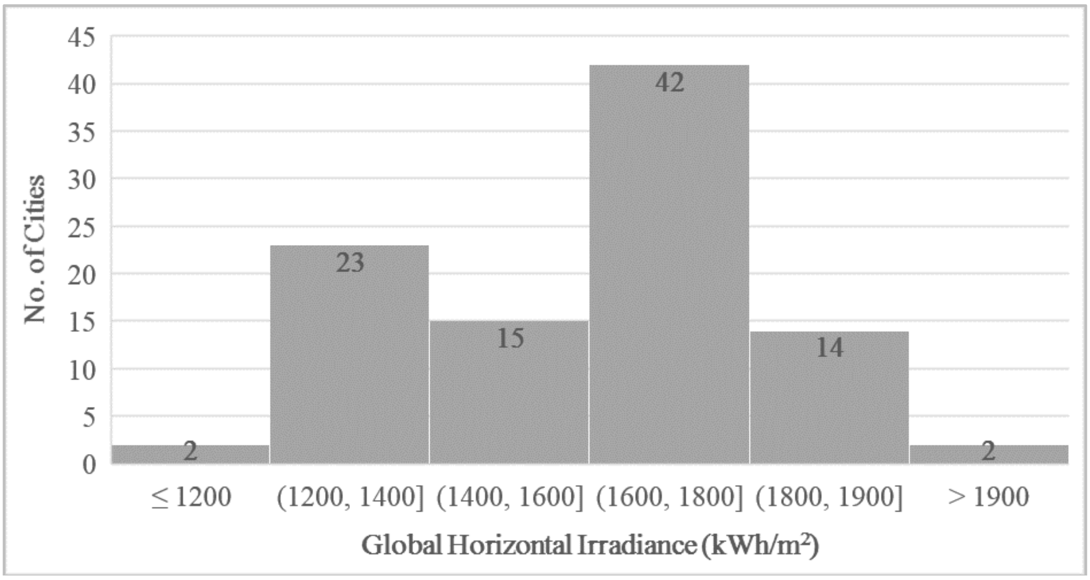

Figure 5: Distribution of Cities by Global Horizontal Irradiation (kWh/m^2/y)

The total solar energy input on suitable roof area is estimated as the product of suitable roof area (in m^2) and the total annual GHI in kWh/m^2. The efficiency of solar cells ranges from 10-20% (Hodge 2010). Gagnon et al. (2016) assumed module efficiency of 16% for estimating technical potential over USA. Assuming achievable efficiency of 16%, the total technical potential over 98 cities is estimated as 103.51 TWh per year. While the study assumed horizontal installation of solar panel, in practice an optimum tilt-angle is computed for each location and accordingly the solar panels are placed. The actual incident radiation will be therefore higher than the GHI used in this computation. Furthermore, assuming that a typical solar PV installation panels requires an area of 10 m^2 per kW and the system performance ratio of solar panels as 80% (Ko et al., 2015), the potential installed capacity available from roof top solar PV in these 98 cities is computed as 10.02 GW. The performance ratio is the ratio of actual to the theoretical energy output from the PV module. High performance PV plants can attain 80% of performance ratio. The city-wise total built-up area, average annual GHI, total roof area estimate, available roof area for PV, total annual energy potential and power generation potential is thus estimated.

The results of the study were further published on the VEDAS (Visualisation of Earth Observation Data and Archival System) web-portal (www.vedas.sac.gov.in) of ISRO for wider dissemination and usage as shown in figure 6. The website provides the total built-up area, annual maximum and minimum temperatures, optimum tilt angle, annual global insolation, annual generation potential, and monthly average of maximum temperature, minimum temperature and insolation, for each of the 98 smart cities. Map of built-up area of the city is also made available along with overlay of LISS-3 image and administrative boundaries, besides the charts showing monthly variation in temperature and insolation. The results of analysis can also be downloaded from the website in PDF file format.

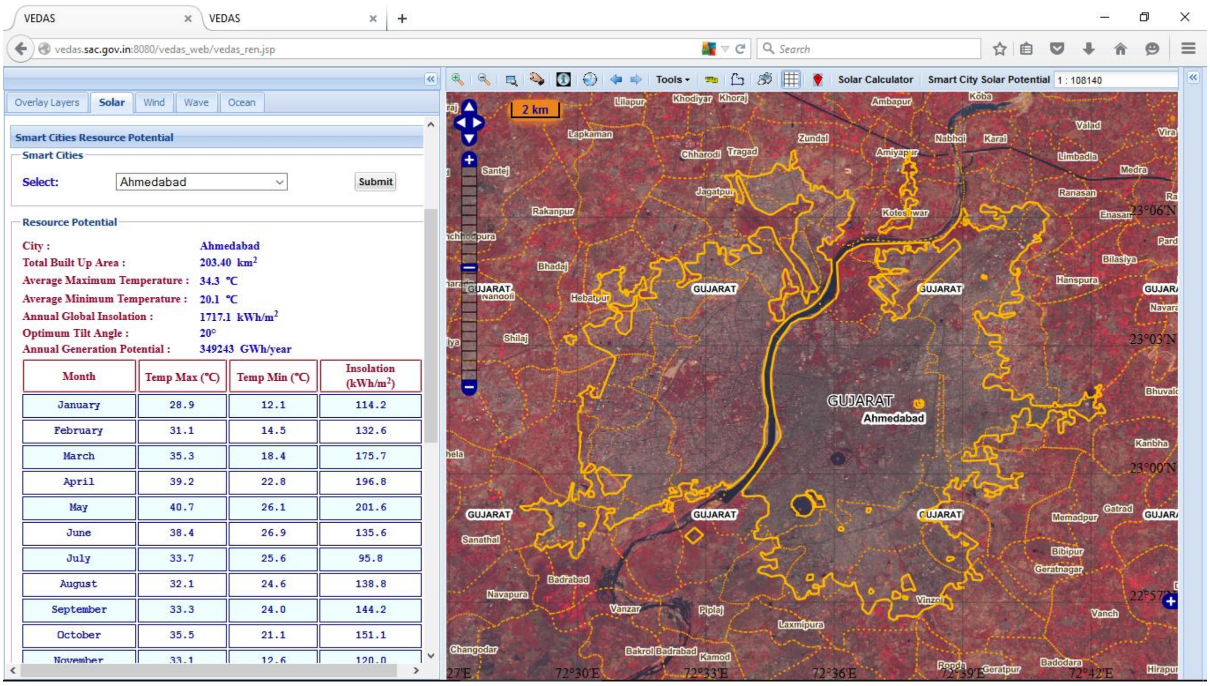

Figure 6: Web-based Information System for Dissemination of Solar Energy Potential of Smart Cities (www.vedas.sac.gov.in:8080/vedas_web/vedas_ren.jsp)

6.0 FUTURE WORK

The study has several limitations, which will be subsequently addressed in future work. The results can be improved considerably with the availability of large-scale built-up area maps, high vertical accuracy digital elevation model, high-spatial and temporal resolution insolation, and long-term day-time temperature average. Moreover, studies analysing buildings in Indian cities may be required to determine the proportion of rooftops suitable for solar PV deployment, which in this study has been assumed at 25%.

The scale of 1: 50,000 is considered to be coarse for analysis of urban areas. This coarse scale not only results into omission of several peripheral scattered developments (accounting for almost 15-25% of built-up areas), but also over-estimates built-up area by including several open-spaces, slums, transport surfaces etc. However, past studies on estimation of technical potential at regional scale have relied on data sourced from census records, household surveys, municipal office records etc. The availability of built-up area at 1: 10,000 scale may significantly improve the results, whereby 2.5 m Cartosat-1 data can be used. The effect of local topography on sky visibility is another area for improvement of the estimates, requiring detailed digital elevation model. This is different from the local level shadow, tilt & orientation, sky visibility and reflection effects which are required at larger scale 3D city models, that are needed at the time of implementation of solar PV systems.

The estimation of GHI in this study is based on average for three years only, and that too is available at 8.0 km spatial resolution. In order to improve upon the estimates on GHI, long term data is required. With the launch of INSAT 3D and 3DR, Higher spatio-temporal variability of atmosphere can be taken into account, providing inputs at 15-minute interval at 4.0 km spatial resolution. The algorithm, which currently provides total GHI, will in future be modified to provide direct and diffuse components of irradiation, which will improve the estimates. The study also does not take into account the effect of temperature. Higher temperature may lead to reduced efficiency of solar panels, and therefore better day-time average temperature is required to improve the estimates. PV panels are much more effective in hazy and partly cloudy conditions (Sen, 2008), and thus greater understanding of atmosphere is required.

7.0 CONCLUSIONS

The study attempted to provide an assessment of total rooftop solar PV resource potential for the 98 proposed smart cities of India. Solar energy can lead to installation of 10.02 GW, generating 103.51 TWh annually, which can aid India in realizing its goal of attaining 40 GW of grid-connected roof-top solar installations by 2022. The study has attempted to make a very conservative estimate with regard to available suitable rooftop areas. This analysis provides a baseline for policy-makers in promoting urban local bodies in effective implementation of achieving at least 10% of projected power demand in next five years from the roof-top solar power potential. While the study has several limitations, it is one of the first attempts at providing an assessment of the solar PV potential in 98 Indian cities, aimed at providing support to policy-makers and urban local bodies in realizing the vision of developing “smart energy”.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the support and guidance of the Ministry of New and Renewable Energy (MNRE), Government of India. We are thankful to Shri Tapan Misra, Director SAC, for his encouragement. Thanks are also due to Dr. Rajkumar, Deputy Director, EPSA and Dr Markand Oza, Head, CGDD for thoughtful comments and suggestions from time to time. We would also like to thank Shri Jalaj Garg for fruitful discussions.

REFERENCES

Bhattacharya, B. K., Padmanabhan, N., Mahammed, S., Ramakrishnan, R., and Parihar, J. S., 2013. Assessing solar energy potential using diurnal remote-sensing observations from Kalpana-1 VHRR and validation over the Indian landmass. International Journal of Remote Sensing, 34(20), pp. 7069-7090.

Gagnon, P., Margolis, R., Melius, J., Phillips, C. and Elmore, R., 2016. Rooftop Solar Photovoltaic Technical Potential in the United States: A Detailed Assessment. Technical Report No. NREL/TP-6A20-65298. National Renewable Energy Laboratory (NREL), USA.

Gutschner, M., Nowak, S., Ruoss, D., Toggweiler, P., Schoen, T., 2002. Potential for building integrated photovoltaics. Report No. IEA-PVPS T7-4. International Energy Agency.

Hodge, B. K., 2010. Alternative Energy Systems and Applications. John Wiley & Sons, Inc. New Jersey, USA.

Ko, L., Wang, J.-C., Chen, C.-Y. and Tsai, H.-Y., 2015). Evaluation of the development potential of rooftop solar photovoltaic in Taiwan. Renewable Energy, 76, pp. 582-595.

MNRE, 2014. State wise Estimated Solar Power Potential in the Country. No. 22/02/2014-15/Solar-R&D (Misc.). Ministry of New & Renewable Energy (MNRE), Government of India, New Delhi.

MNRE, 2017. Ministry of New and Renewable Energy (MNRE), Government of India, New Delhi. Retrieved August 01, 2017 from www.mnre.gov.in.

MoUD, 2015. Smart Cities, Mission Statement & Guidelines. Ministry of Urban Development (MoUD), Government of India, New Delhi.

MoUD, 2016. Ministry of Urban Development (MoUD), Government of India, New Delhi. Retrieved November 22, 2016 from www.smartcities.gov.in.

NNRMS Standards Committee, 2005. NNRMS standards: A national standard for EO images, thematic & cartographic maps, GIS databases and spatial outputs. Report No. ISRO: NNRMS: TR: 112: 2005, Committee Report. National Natural Resources Management System (NNRMS).

Paidipati, J., L. Frantzis, H. Sawyer, and A. Kurrasch. 2008. Rooftop Photovoltaics Market Penetration Scenarios. Subcontract Report No. NREL/SR-581-42306. National Renewable Energy Laboratory, Colorado, USA.

Pelland, S. and Poissant, Y., 2006. An evaluation of the potential of building integrated photovoltaics in Canada. In proc. of 31st Annual Conference of the Solar Energy Society of Canada (SESCI). Aug. 20-24th 2006, Montréal, Canada.

Peng, J. and Lu, L., 2013. Investigation on the development potential of rooftop PV system in Hong Kong and its environmental benefits. Renewable and Sustainable Energy Reviews, 27, pp. 149-162.

PMC, 2016. Reimagining Pune: Mission Smart City, Detailed plan to transform Pune into a world-class Smart City. Pune Municipal Corporation (PMC), Pune.

Sen, Z., 2016. Solar Energy Fundamentals and Modelling Techniques. Springer-Verlag London Limited, London.

Sharma, S., Sharma, A. K., Mullick, S. C. and Kandpal, T. C., 2015. Assessment of solar thermal power generation potential in India. Renewable and Sustainable Energy Reviews, 42, pp. 902-912.

Siala, K. and Stich, J., 2016. Estimation of the PV potential in ASEAN with a high spatial and temporal resolution. Renewable Energy, 88, pp. 445-456.

Singh, R. and Banerjee, R., 2015. Estimation of rooftop solar photovoltaic potential of a city. Solar Energy, 115, pp. 589-602.

Yadav, A. K. and Chandel, S. S., 2015. Solar energy potential assessment of western Himalayan Indian state of Himachal Pradesh using J48 algorithm of WEKA in ANN based prediction model. Renewable Energy, 75, pp. 675-698.