Journal of Applied and Natural Science
13(2): 512 - 519 (2021)
Published online: May 22, 2021
ISSN : 0974-9411 (Print), 2231-5209 (Online)
journals.ansfoundation.org

Research Article

A Geo-spatial approach for quantifying rooftop photovoltaic energy potential in Karnal smart city, Haryana - A case study

Meenakshi
Center of Excellence for Energy and Environmental Studies (CEEES), Deenbandhu Chhotu Ram University of Science and Technology (DCRUST), Sonipat-131039 (Haryana), India
Mothi Kumar K. E.*
Haryana Space Applications Centre (HARSAC), Citizen Resources Information Department, Govt. of Haryana (CRID), Hisar-125004 (Haryana), India
Nisha Kumari
Center of Excellence for Energy and Environmental Studies (CEEES), Deenbandhu Chhotu Ram University of Science and Technology (DCRUST), Sonipat-131039 (Haryana), India

*Corresponding author. Email: kemk@rediffmail.com

Article Info
https://doi.org/10.31018/jans.v13i2.2665
Received: April 3, 2021
Revised: May 10, 2021
Accepted: May 17, 2021

How to Cite
Meenakshi, *et al.* (2021). A Geo-spatial approach for quantifying rooftop photovoltaic energy potential in Karnal smart city Haryana - A case study. *Journal of Applied and Natural Science*, 13(2), 512 - 519. https://doi.org/10.31018/jans.v13i2.2665

Abstract
Solar energy is one of the best sustainable forms of renewable energy. India has a cumulative installed capacity of 9.23 GW of grid-connected solar power and set an ambitious target of attaining 100 GW of solar capacity by 2022, including 40 GW of grid-connected rooftop solar installations well. The present study demonstrates the Geospatial technology to estimate the potential of solar photovoltaic on the rooftops of Karnal city. The satellite data of Sentinel -2 and World View-II data was interpreted so as to extract the building footprints. Digital Elevation Model (DEM) data derived from ALOS (Advanced Land Observing Satellite) PALSAR (2019) data was used to calculate the Global Horizontal Irradiance (GHI). It was calculated that the average annual GHI varied between 0.79-5.9 kWh/m^2/day. The study revealed maximum GHI (462 kWh/m^2) was recorded during the monsoon season. It was estimated that the seasonal energy generation capacity in urban area was minimum (268.4MWh) in the winter season, while the maximum (2632.4MWh) energy generation capacity was observed during the monsoon season. In the case of the industrial area, the minimum seasonal energy generation capacity was found to be 23.9 MWh in winter while the maximum of 234.8 MWh during the monsoon season. If solar panels installed on the proposed rooftops, an estimated energy potential of 5.9 GWh would be generated in the study area.

Keywords: Geospatial Technology, Global Horizontal Irradiance, Photovoltaic, Rooftop

INTRODUCTION

Urban Population growth is rapidly increasing in India and after china India has second largest populated country in the world. In 2019 approximately 4% growth in power generation against 8% in electricity. With the increasing population, energy consumption growth rate will be 4.2% by the year 2035 (Mishra *et al.,* 2020)
In India electricity generating from the coal 74.0%, hydro 9.3%, natural gas 4.6%, wind 3.3%, bioenergy and waste 3.0%, nuclear 2.5%, solar 1.7%, oil 1.6% (IEA). Therefore, to ensure energy security sustainably, it is crucial to escalating investments in alternative sustainable, clean, and pollution-free energy (Mann *et al.,* 2015). To reduce the dependency on coal, government focused on sustainable source of energy. Mostly developed and developing countries generating electricity with renewable sources such as bio-energy, geothermal and solar energy in the recent years. In the year 2019, 26% of global electricity generated from renewable resources (Firozjaei *et al.*, 2019).
Jawaharlal Nehru National Solar Mission (JNNSM) had an initial target of 20 GW by 2022 and then increased this target up to 28.18 GW in March 2019 (Ministry of New and Renewable Energy, 2019). For the year 2021–22 the target has been fixed for 6.5% of renewable energy consumption (Central Electricity Authority, 2019). As a developing nation, India has honoured its commitment towards consciousness for reducing the country's carbon footprint with Karnataka, Rajasthan,

Andhra Pradesh, Tamil Nadu, and Gujarat are the leading solar energy-producing states. About 92% of solar energy in India is produced at utility-scale sites while only 8% is contributed by solar rooftop. The area utility data for solar power identifies rooftop as future potential sites to install new solar power plants (Kapoor *et al.,* 2014).

Residential buildings energy consumptions is one of the key aspect for the energy management of urban areas (Mattoni *et al.,* 2015), considering the primary energy consumption (PEC) and the renewable energy fraction (Noussan and Nastasi , 2018). Among renewables, solar energy is commonly the first energy source used in buildings to improve their energy sustainability and to reduce their consumptions of fossil fuels.

Singh and Banerjee (2015) estimated the roof top photovoltaic potential for Mumbai city using the available Land Use data. Comparison with sample daily load profiles shows that large scale deployment of Rooftop Solar Photovoltaic Systems can provide 12.8–20% of the average daily demand and 31–60% of the morning peak demand for different months, even with median conversion efficiency panels. Brito *et al.,* (2019) also estimated urban solar energy potential by using LiDAR data and 3D models from 2D geometries was created in CityEngine. Nelson, and Grubesic,(2020) also found PVGIS, NERL and UAV data are used for the estimation of solar energy irradiance. Cheng et al., (2020) calculated solar energy potential for 10 cities and found annual solar irradiation ranges from 41.39 to 772.94 TWh, with an electric capacity of 6.21–115.94 TWh.

In recent years, due to an emphasis on alternative energy sources, the assessment of solar energy potential has become an intensive area of research. Geographic Information System (GIS) has become an important and powerful tool to analyse regional renewable energy potential. Many researchers have specifically used GIS in the study of rooftop solar PV potential. A case study was carried out by Meenakshi *et al.,* (2019) to estimate the solar energy potential on roof top of Government buildings in Karnal city using the geo spatial techniques. It was estimated that an amount of 264782.7 kg of Carbon dioxide (CO_2) is emitted during the production of 267457.2 kWh electricity by the coal based power plant, and suggested to implement the installation of Solar PV systems on the digitized roof tops, so as to reduce the release of CO_2.

Need of the hour to Undertake the Study

The Government of India has identified about 98 cities in the country to mitigate the increasing resources constrained urban areas under Smart Cities Mission to develop the infrastructure facilities with the help of information and communication technology. These Smart Cities have been encouraged to meet about 10□15% of respective energy demand from renewable energy resources, wherein solar energy can contribute significantly (Sharma *et al.,* 2018).

The main focus of this study was to assess solar energy potential and electricity generation capacity in Karnal city by using the satellite data and geospatial technology.

MATERIALS AND METHODS

Study area

The Karnal city area situated in between 29°36'32.031 to 29°41'8.947" N latitude and 76°58'14.516" to 7659'19.176" E longitude with a geographical area of 90.40 km^2 and comprises of 20 administrative wards (Fig. 1). The Karnal city is a warm city, least topographic variability and has a high potential for PV energy generation. The city receives an average temperature ranges (38.8 °C) high to (7.5 °C) minimum, (CLIMATE-DATA.org) and the city is suitable for PV installations due to the least topographic variability.

Data use and methodology

The base map of Karnal city area with ward boundary was obtained from Municipal Corporation, Karnal, was digitised and given a proper projection system. In the present investigation, Sentinel-2 Satellite data (2019) having spatial resolution of 10 m were used for mapping the built-up areas after following the standard Geo referencing protocols using the ArcGIS 10.1 version. Apart from the Sentinel-2 data, World View-II satellite data, having a spatial resolution of 0.5 m, were also used to extract the roads, vacant land, railway lines, canals etc., so as to eliminate the unwanted areas from the built up land. ALOS PALSAR DEM with 12.5 m resolution for the year 2019 used as an input for the estimation of GHI in the study area. ALOS PALSAR DEM used as input file and this is freely available at the USGS Earth Explorer portal.

Basically, the methodology involves the interpreting the satellite data for the building footprints, followed by the calculation of GHI, the Geographic and Technical solar PV potential for Karnal city. The detailed process of methodology involved as described below:

Spatio -temporal variation in global solar radiation

The Ministry of New and Renewable Energy (MNRE) has been estimated in Indian 5000 trillion kWh of annual solar energy incident. Approximate 56% of the total Indian land area receives more than 5 kWh/m^2/day annual global radiations (Mahtta *et al.,* 2014). The present study focused on assessment of solar energy potential on rooftop in urban area and to achieve this target estimates the monthly variation in GHI received in Karnal city.

For the estimation of the GHI, the Solar Radiation tool

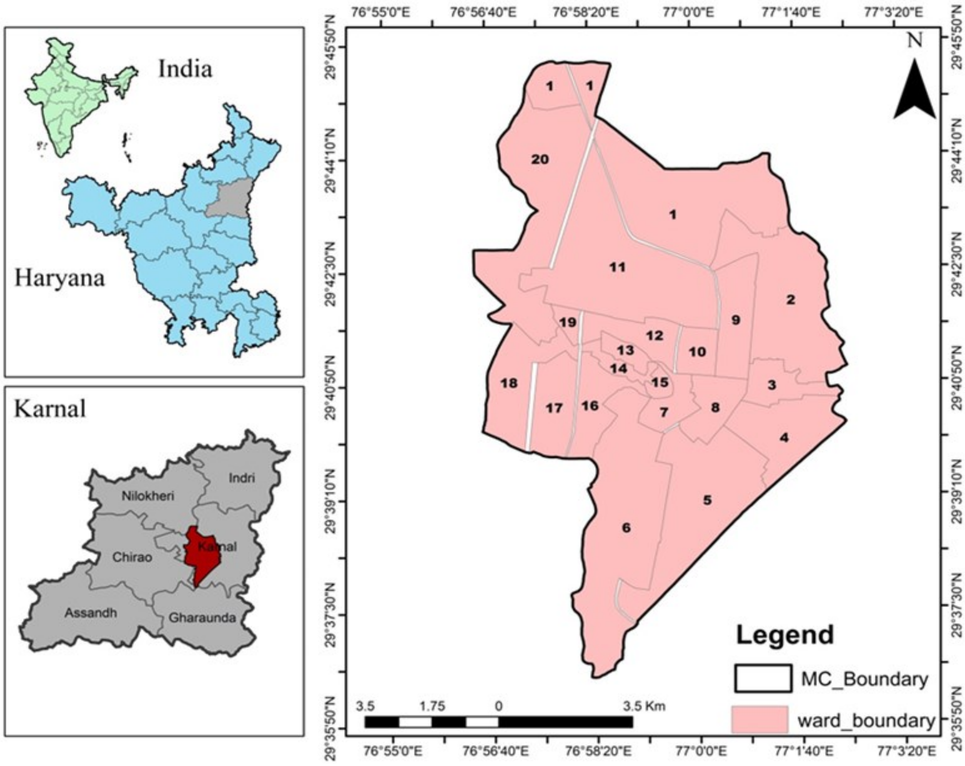

Fig. 1. *Location map of study area with ward boundary.*

set in ArcGIS software is used. This tool takes care of slope, elevation, orientation and atmospheric transmission as the most relevant inputs. The DEM of ALOS PALSAR, having all these parameters and was used as input raster, with a 200 sky size value as a default value (Kausika and Sark, 2021).

Calculation of the geographical potential area for solar (G)

Physical potential of rooftop area was calculated from the Sentinel 2 (resolution 10m) satellite data by supervised classification in ERDAS IMAGINE software. Built-up area was extracted by supervised classification. Rooftop area was estimated from the built-up area with the help of high resolution World View-II satellite data. Roads, Parks and vacant plot in urban area were removed.

Rooftop area calculated from the remote sensing may not always suitable for the installation of the PV panel. Some invariable factors like chimney, stairway and water tank on rooftop and shaded area not received direct solar radiation. Geographical potential area was estimated by using the following equation (Mishra *et al.,* 2020).

$$G = A.I.H \qquad \text{Eq.1}$$

Where

G= Geographical potential area

A= Total rooftop area (m^2)

I = Average solar radiation kWh/m^2/day

H= Average sunshine hours is 8 in a day in study area. (https://www.worlddata.info/asia/india/climate-haryana.php)

Calculation of the technical energy output potential (E)

Estimated electricity generation potential from the installed solar PV system is term as technical potential of the rooftop area. The equation used to calculate the estimated energy generation potential from PV system in the study area. This equation has been used by many other researchers also (Mahtta *et al.,* 2014; Gastli and Charabi, 2010).

$$E = G \times r \times PR \times \eta\mathrm{TH} \qquad \text{Eq.2}$$

Where

E= Energy (kWh)

r = solar panel efficiency (range between 15 and 18% default value used = 15%, (Charfi *et al.,* 2018; Gholami *et al.,* 2018)

PR = Performance ratio it ranges between 0.5 and 0.9 (default value used = 0.75)

ηTH = Temperature and irradiance losses (default value used = 0.9) (Bergamasco and Asinari , 2011)

RESULTS

Distribution of solar radiation

Monthly and seasonal variation in solar radiation was calculated to estimate the solar energy potential in smart city Karnal is given in figure 2. A close perusal of this figure revealed that, the maximum radiation occurred in June and July months of the 2019 and while the minimum radiation occurs in December month. It was observed that the range of the solar radiation during 2019 was found to be 24-177 kWh/m^2.

The solar insolation was observed as per the Indian seasons in Indian context, i.e., winter season (December to February), summer (March to May), monsoon (June to August) and post-monsoon (September to November) and shown as fig. 3. Further, it was observed that, maximum radiation was found during the monsoon season. During the winter season very less radiation reached to the surface because of high smog in the atmosphere.

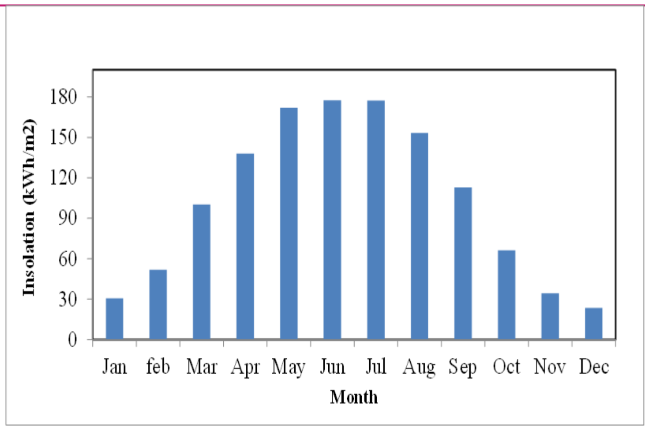

Fig. 2. *Monthly variation in solar insolation in Karnal city (GHI).*

Estimation of geographical potential

An attempt was made to map the ward-wise rooftop area of the study area (Fig. 4). The actual built-up area was calculated after eliminating the road network, riverbed area, and other features such as parks, stairs-cases and this feature eliminating work were done on the high-resolution world view-II satellite data. Table 1 depicts the identified urban and industrial areas. It was estimated that an area of 40.5 km^2 (45% of TGA) was found to be under the built-up land category while an area of 3.33 km^2 identified under Industrial and 37.2km^2 identified was under Urban. The ward numbers 1, 4, 5,6, 11, 18 and 20 were under the mixed category, which comprised both urban and industrial, while the rest of the wards were purely urban and devoid of any industrial units.

During the ground truth verification it was observed that all the built-up rooftop area was not available for panel installation, because of the fact that it was being utilized for other purposes such as construction of water tank, stairs-cases, room, chimneys etc. apart from the parameter of shadow, so that (12.2 km^2) 30% area of total built-up are considered as an available area for solar

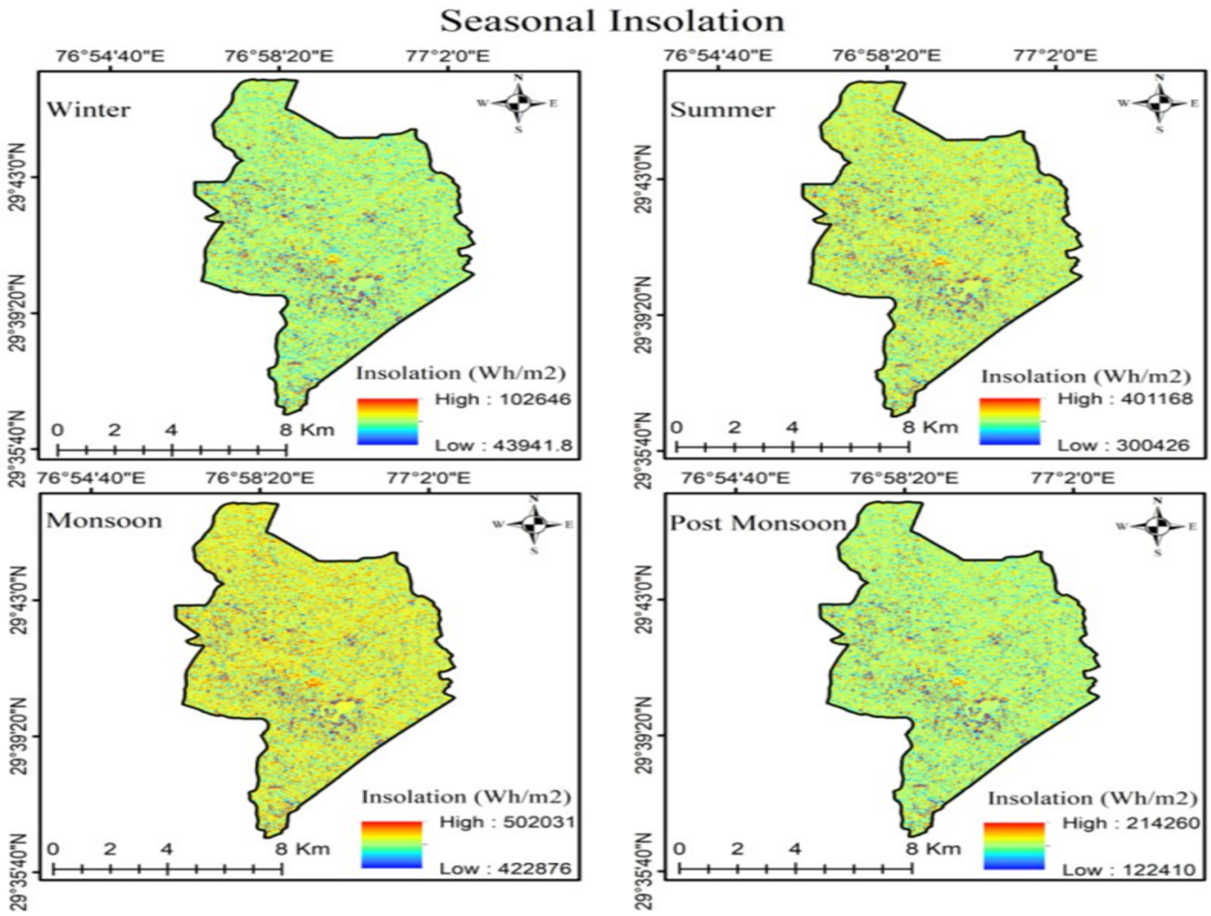

Fig. 3. *Seasonal variation in solar insolation in the Karnal city.*

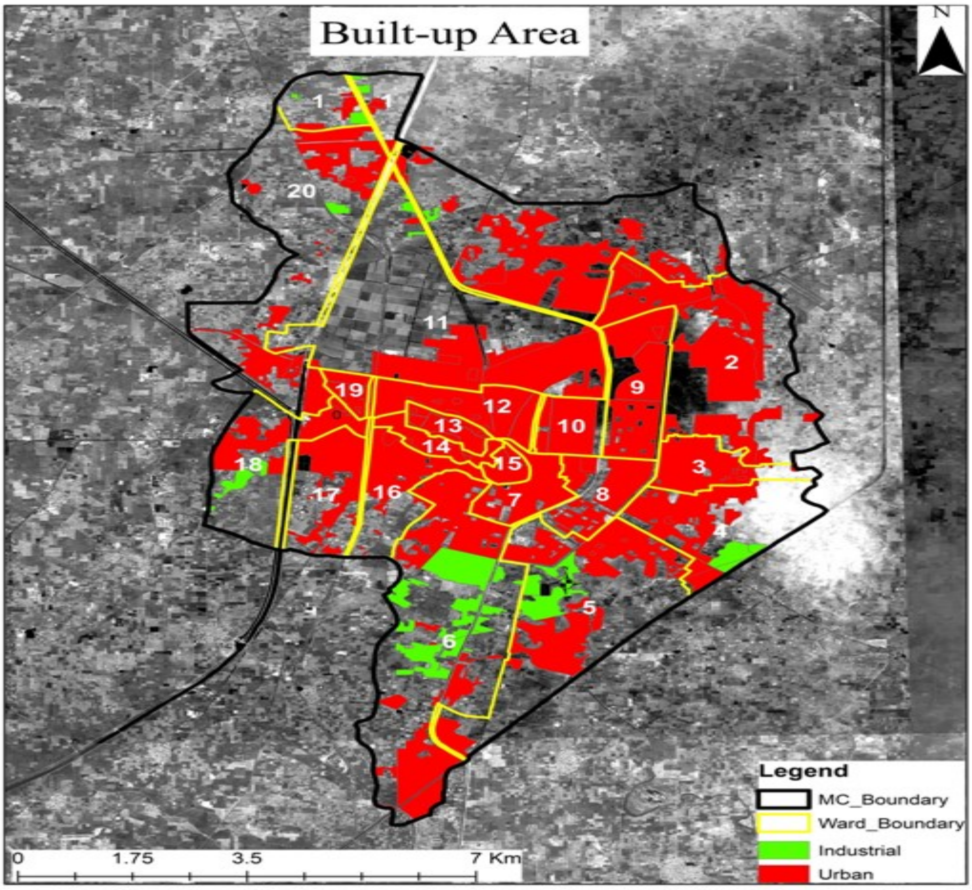

Fig. 4. *Urban and Industrial built up areas of Karnal city as viewed by WV*-II.

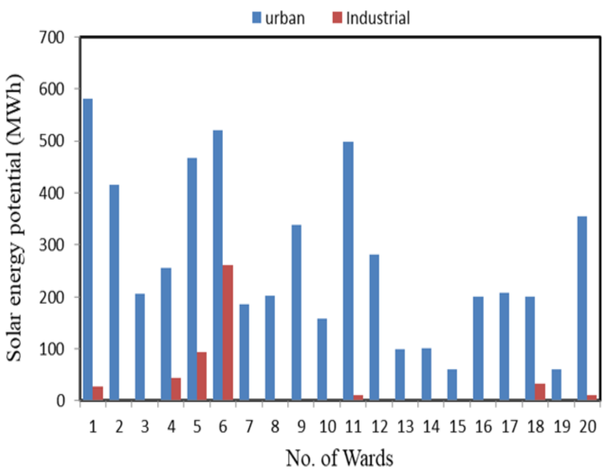

Fig.5 *Ward wise solar energy potential in urban and industrial area.*

panel installation. With the help of the remotely sensed data, and the DEM, we have calculated the average solar insolation for Karnal city and found to be 3.5 kWh/m^2/day, out of which the minimum was found to be 0.79 kWh/m^2/day, while the maximum was found to be 5.9 kWh/m^2/day.

Karnal city had high energy demands because this is developing city of Haryana State. Utilization of the rooftop area for generating electricity by PV system can reduce the burden on energy generated from fossil fuel. Extra energy produced in the study area can also be economically fed to the grid to maintain buffer energy pool, to be utilized during power shortage.

Estimation of technical potential

The Solar panel efficiency (15%), Performance ratio or the Conversion efficiency (75%) and temperature and irradiance losses (0.9) are non-variable factors, whereas the rooftop area and GHI of in the study area are the variable factors. As the study area is very small, and topographically being flat in nature, the variations in the GHI is found to be very negligible, so that solar energy generation potential is directly proportional to area of rooftop.

Seasonal (average) variation in potential of generating solar energy was shown in Table 2 and Fig.5. We have taken 30% of built-up area in the study area amounting to be 12.16 km^2 eliminating the areas under parks, stairs-cases, road network, river bed area etc.

It was estimated that the urban area has energy generation potential of 5393.3 MWh (92%) and while the Industrial area had 481 MWh (8%) potential. Further, a close perusal of table 4 had revealed that during, the (seasonal) energy generation capacity in urban area was found to be 268.4 MWh (winter), and for summer

Table 1. Total Built-up and available rooftop area for panel installation (Urban and Industrial built up area) in Karnal city (area in sq. kms).

Ward No.	Total area	Built-up Area	Built-up area			
			Urban		Industrial	
			Total Area	Available area for panel installation	Total area	Available area for panel installation
1	12.41	4.21	4.01	1.20	0.20	0.06
2	8.48	2.87	2.87	0.86	Nil	Nil
3	1.79	1.42	1.42	0.43	Nil	Nil
4	4.21	2.06	1.76	0.53	0.30	0.09
5	8.63	3.87	3.22	0.97	0.65	0.20
6	11.33	5.39	3.59	1.08	1.80	0.54
7	1.42	1.28	1.28	0.38	Nil	Nil
8	1.99	1.39	1.39	0.42	Nil	Nil
9	2.95	2.33	2.33	0.70	Nil	Nil
10	1.30	1.08	1.08	0.32	Nil	Nil
11	11.13	3.51	3.43	1.03	0.08	0.02
12	2.03	1.94	1.94	0.58	Nil	Nil
13	0.71	0.68	0.68	0.20	Nil	Nil
14	0.77	0.70	0.7	0.21	Nil	Nil
15	0.44	0.42	0.42	0.13	Nil	Nil
16	2.48	1.38	1.38	0.41	Nil	Nil
17	2.81	1.43	1.43	0.43	Nil	Nil
18	3.82	1.62	1.38	0.41	0.23	0.07
19	0.51	0.42	0.42	0.13	Nil	Nil
20	9.66	2.52	2.45	0.74	0.07	0.02

Table 2. Seasonal Solar Energy potential (Urban and Industrial rooftops) in Karnal city.

Ward No.	Urban potential (MWh)				Industrial potential (MWh)			
	Winter	Summer	Monsoon	Post monsoon	Winter	Summer	Monsoon	Post monsoon
1	28.94	193.55	283.76	75.12	1.41	9.43	13.82	3.66
2	20.69	138.39	202.89	53.71	Nil	Nil	Nil	Nil
3	10.22	68.39	100.26	26.54	Nil	Nil	Nil	Nil
4	12.72	85.11	124.77	33.03	2.15	14.39	21.10	5.59
5	23.26	155.58	228.09	60.38	4.69	31.39	46.02	12.18
6	25.92	173.39	254.19	67.29	12.95	86.63	127.01	33.62
7	9.23	61.71	90.47	23.95	Nil	Nil	Nil	Nil
8	10.05	67.20	98.53	26.08	Nil	Nil	Nil	Nil
9	16.81	112.42	164.81	43.63	Nil	Nil	Nil	Nil
10	7.82	52.34	76.73	20.31	Nil	Nil	Nil	Nil
11	24.78	165.74	242.98	64.32	0.54	3.63	5.32	1.41
12	13.97	93.42	136.96	36.26	Nil	Nil	Nil	Nil
13	4.90	32.79	48.07	12.72	Nil	Nil	Nil	Nil
14	5.05	33.76	49.49	13.10	Nil	Nil	Nil	Nil
15	3.05	20.37	29.87	7.91	Nil	Nil	Nil	Nil
16	9.95	66.53	97.53	25.82	Nil	Nil	Nil	Nil
17	10.35	69.22	101.49	26.87	Nil	Nil	Nil	Nil
18	9.99	66.79	97.91	25.92	1.68	11.24	16.48	4.36
19	3.06	20.44	29.97	7.93	Nil	Nil	Nil	Nil
20	17.71	118.43	173.62	45.96	0.51	3.41	4.99	1.32

season it was about 1756MWh followed by 2632.4 MWh (monsoon) and 696.9MWh (post monsoon). In case of industrial area the seasonal energy generation capacity was found to be 24 MWh (winter), 160.1 MWh (summer), 234.6 MWh (monsoon), 62.1MWh (post monsoon).

A close perusal of table 2 had revealed that the highest capacity of generation energy from solar panel during the monsoon and summer season and at the same period of year electricity demand is also high so this sustainable energy fill the gap in energy consumption and demand. In urban area highest potential found in Ward number 1 during complete year and in industrial area highest potential found in ward number 6 during all seasons.

DISCUSSION

The present research was carried to identify the potential solar of solar energy for the Karnal city (Haryana). The findings of the present study are with the conformal that of the others researchers.

Luqman *et al.* (2015) conducted a study to find out the solar energy potential (as an alternative source of energy) from the rooftops of residential areas in Lahore district of Pakistan, using the satellite data and GIS techniques and potential estimated was about 39,613,072 kWh/year. The estimated energy was found to be 9 times than the energy demand of the society, extra energy can be used in local /national electricity transmission grid. Solar PV energy would be supplement to compensate energy shortfall in local area. Assouline *et al.* (2017), carried out a study to estimate the rooftop solar PV potential for the urban areas at the commune level (the smallest administrative division) in Switzerland using the Support Vector Machines (SVMs) and Geographic Information System (GIS). The rooftop solar PV potential for a total 1901 out of 2477 communes in Switzerland was estimated. The results showed that, on an average, 81% of the total ground floor area of each building corresponds to the available roof area for the PV installation; the annual potential PV electricity production for the urban areas in Switzerland is estimated to be at 17.86 TW h (assumed 17% efficiency and 80% performance ratio). This amount corresponds to 28% of Switzerland's electricity consumption in 2015. Sharma *et al*. (2018) used the IRS LISS satellite data and Very High Radiometer Resolution Radiometer (VHRR) data (KALPANA) in mapping the Rooftop area at 1:50,00 scale. They successfully estimated 10.02 GW of grid connected rooftops PV potential with 103.51 TWh of energy annually in the proposed 98 smart cities of India.

Though the present study confirms with these findings, we successfully attempted to identify the potential solar of solar energy at ward level in a Karnal city suing Sentinel 2 data, and augmented with World View-II panchromatic data. CO_2 Emission Reduction Carbon contributes about 80% of all greenhouse gases which causes global warming (Lashof and Ahuja, 1990). As the Carbon emissions are increasing day by day, because of the increasing demand of energy, the alternate renewable energy technologies will definitely help to reduce Carbon emission as these technologies reduce less amount of CO_2 than fossil fuels. The outputs of the study in the form of raster data (radiations output) and the vector data (building foot print) along with the estimated energy values will provide a baseline information for future studies to be undertaken in the field of solar energy estimations. Thus, the data generated in the present research will help in future study for the potentiality of carbon sequestration and mitigation of climate change at regional or at micro level. If all the roof areas utilized for solar PV panels installations, the energy generated would be huge 5.9 GWh which can be used for the future requirements.

Conclusion

Geospatial technology plays an important role in estimation of solar energy potential on rooftop in the study area. The total geographical area of the municipal boundary of Karnal city was 90.4 Km^2. 45% (40.5 Km^2) of the total area covered by urban (41%) and industrial (4%) built-up during 2019. The total build-up area could not be available for solar panel installation because it might be utilized for water tank, stairs and other construction so that 30% area of the total built-up was considered a suitable area for panel installation. On the available area, solar insolation lied under 0.79-5.92 $kWh/m^2/day$ in a complete year and means solar insolation is 3.5 $kWh/m^2/day$. The total capacity of energy generation in the study area is 5.9 GWh and out of this 8% potential had Industrial area and 92 % urban area energy generation capacity from the solar photovoltaic system. Maximum potential of electricity generation is in monsoon and summer season. This work also helped to reduce CO_2 production in the environment because coal based power plant has main source CO_2 emission.

ACKNOWLEDGEMENTS

The first author (Meenakshi) is thankful to the Chairperson, Centre of Excellence for Energy and Environmental Studies, (CEEES) Deenbandhu Chhotu Ram University of Science and Technology, (DCRUST) for allowing to undertake the Ph. D program at CEEES Department. The author also would like to thank the Director, Haryana Space Applications Centre (HARSAC), CCS HAU Campus, Hisar for providing the satellite data and infrastructure facilities to carry out the research program.

Conflict of interest

The authors declare that they have no conflict of interest.

REFERENCES

1. Assouline, D., Mohajeri, N., & Scartezzini, J. L. (2017). Quantifying rooftop photovoltaic solar energy potential: A machine learning approach. *Solar Energy*, *141*, 278-296. http://dx.doi.org/10.1016/j.solener.2016.11.045
2. Bergamasco, L & Asinari, P., (2011). Scalable methodology for the photovoltaic solar energy potential assessment based on available roof surface area: further improvements by ortho-image analysis and application to Turin (Italy). *Sol. Energy*, 85 (11), 2741–2756. https://doi.org/10.1016/j.solener.2011.08.010
3. Brito, M. C., Redweik, P., Catita, C., Freitas, S., & Santos, M. (2019). 3D solar potential in the urban environment: A case study in lisbon. *Energies*, 12 (18), 3457. https://doi.org/10.3390/en12183457
4. Central Electricity Authority (2019), Central Electricity Authority Government of India Ministry of Power. https://cea.nic.in/old/reports/annual/annualreports /annual_report -2020.pdf
5. Charfi, W., Chaabane, M., Mhiri, H., Bournot, P., (2018). Performance evaluation of a solar photovoltaic system. *Energy Rep.,* 4, 400–406. https://doi.org/10.1016/j. egyr.2 018.06.004.
6. Cheng, L., Zhang, F., Li, S., Mao, J., Xu, H., Ju, W. & Li, M. (2020). Solar energy potential of urban buildings in 10 cities of China. *Energy*, *196*, 117038. https://doi.org/1 0.1016/j.energy.2020.117038
7. Firozjaei, M.K., Nematollahi, O., Mijani, N., Shorabeh, S.N., Firozjaei, H.K., & Toomanian, A. (2019). An integrated GIS-based Ordered Weighted averaging analysis for solar energy evaluation in Iran: current conditions and future planning. *Renew. Energy* 136, 1130–1146. https://doi.org/10.1016/j.renene.2018.09.090.
8. Gastli, A., & Charabi, Y. (2010). Solar electricity prospects in Oman using GIS-based solar radiation maps. *Renewable and Sustainable Energy Reviews*, 14 (2), 790-797. doi:10.1016/j.rser.2009.08.018
9. Gholami, A., Khazaee, I., Eslami, S., Zandi, M., & Akrami, E., (2018). Experimental investigation of dust deposition effects on photo-voltaic output performance. *Sol. Energy* 159, 346–352. https://doi.org/10.1016/j.solener.20 17.11.0 10.
10. Kausika, B. B., & van Sark, W. G. (2021). Calibration and Validation of ArcGIS Solar Radiation Tool for Photovoltaic Potential Determination in the Netherlands. *Energies*, 14 (7), 1865. doi.org/10.3390/en14071865
11. Kapoor, K., Pandey, K.K., Jain, A.K., & Nandan, A. (2014). Evolution of solar energy in India: a review. *Renew. Sustain. Energy Rev.,* 40, 475–487. https://doi.org/10.1016/j. rser.2014.07.118.
12. Lashof, D.A. & Ahuja, D.R. (1990) Relative Contributions of Greenhouse Gas Emissions to Global Warming. *Nature*, 344, 529-531. http://dx.doi.org/10.1038/344529a0
13. Luqman, M., Ahmad, S. R., Khan, S., Ahmad, U., Raza, A., & Akmal, F. (2015). Estimation of solar energy potential from rooftop of Punjab government servants cooperative housing society Lahore using GIS. *Smart Grid and Renewable Energy*, *6*(05), 128. http://www.scirp.org/journal/sgre http://dx.doi.org/10.4236/sgre.2015.65012
14. Mahtta, R., Joshi, P. K., & Jindal, A. K. (2014). Solar power potential mapping in India using remote sensing inputs and environmental parameters. *Renewable Energy*, 71, 255-262. https://doi.org/10.1016/j.renene.2014.05.037
15. Mann, C.C., (2015). Solar or Coal? the Energy India Picks May Decide Earth's Fate. Wired. Retrieved from. https://www.wired.com/2015/11/climate-cha nge-in-india/.
16. Mattoni, B., Pagliaro, F., Gugliermetti, L., Bisegna, F., & Cellucci, L. (2015). A territorial based strategy for the distribution of sensor networks in smart cities. IEEE 15th International Conference on *Environment and Electrical Engineering (EEEIC)*, 653–658. https://doi.org/10.1109/EEEIC.2015.7165242
17. Meenakshi, Kumar, K. E., & Kumari, N. (2019). Estimation of Photovoltaic Energy Potential and Reduced Carbon Emission through Geo-Spatial Technology–A Case Study of Karnal City, Haryana (India).In Proceedings of International Conference on *Sustainable Computing in Science, Technology and Management (SUSCOM),* Amity University Rajasthan, Jaipur-India, 2213-2219.
18. Mishra, T., Rabha, A., Kumar, U., Arunachalam, K., & Sridhar, V. (2020). Assessment of solar power potential in a hill state of India using Remote Sensing and Geographic Information System. *Remote Sensing Applications: Society and Environment*, 19, 100370. https://doi.org/10.1016/j.rsase.2020.100370
19. Ministry of New and Renewable Energy (2017). Ministry of New and Renewable Energy (MNRE), Government of India, New Delhi. www.mnre.gov.in.
20. Nelson, J. R., & Grubesic, T. H. (2020). The use of LiDAR versus unmanned aerial systems (UAS) to assess rooftop solar energy potential. *Sustainable Cities and Society*, *61*, 102353. https://doi.org/10.1016/j.scs.2020.102353
21. Noussan, M., & Nastasi, B. (2018). Data analysis of heating systems for buildings - A tool for energy planning, policies and systems simulation. *Energies*, 11(1), 233. https://doi.org/10.3390/en11010233
22. Sharma, S., Jain, G., Mishra, S., & Bhattacharya, B., (2018). Assessment of roof-top solar energy potential in proposed smart cities of india. Conference*: Asian Conference of Remote Sensing*, New Delhi, India.(PDF) Assessment of Roof-Top Solar Energy Potential In Proposed Smart Cities Of India (researchgate.net)
23. Singh, R., & Banerjee, R. (2015). Estimation of rooftop solar photovoltaic potential of a city. *Solar Energy*, 115, 589-602. https://doi.org/10.1016/j.solener.2015.03.016