High-Resolution Solar Energy Parameters under the Climate Change Scenario for Jammu and Kashmir and Ladakh Region

Saurabh Verma and Charu Singh*

Marine and Atmospheric Sciences Department, Indian Institute of Remote Sensing (IIRS), ISRO, Dehradun, India.
Email: saurabhverma@iirs.gov.in, charu@iirs.gov.in

KEY WORDS: GHI, RE, MERRA-2, ERA5, Jammu and Kashmir, and Ladakh.

ABSTRACT:

Solar technologies are viewed as feasible options for reducing greenhouse gas emissions and encouraging long-term adaptation in the context of climate change and rising energy demand. Solar energy is India's second-largest Renewable Energy (RE) source, and playing increasingly important role in the country's low-carbon energy portfolio. Jammu and Kashmir and Ladakh are the northernmost states of India, with elevations ranging from 205 to 8564 meters above the mean sea level. Both states are located just south of the Karakorum and have a subtropical and cold-arid environment with scarce renewable energy resources. This study is performed to identify the annual and monthly variation of solar energy potentials for the recent climatological future over the western Himalayan region. The long-term annual average demonstrated the high efficiency of GHI over Leh and Kargil and low over the Jammu and Kashmir region. The monthly variation shows greater GHI values between March and October, varying from 225 to 375 W m^{-2}, and lower from November to February, less than 220 W m^{-2}. The mean ambient 2-m temperature indicates December and January months are bad for solar energy installations, while June and July are excellent. Overall, the findings show that Ladakh has a remarkable solar energy potential and is recommendable for further investigation.

1. INTRODUCTION

In the context of rising energy demand, renewable energies are seen as feasible options for reducing greenhouse gas emissions and encouraging long-term adaptation. Carbon dioxide emissions from fossil fuels are dangerously accumulating in the lower layers of the atmosphere, causing dramatic climate change, floods, heavy storms, and droughts in many regions (Mostafaeipour et al., 2011). Pollution and environmental damages are no longer a problem with renewable energies as they are with fossil and nuclear energies. Furthermore, because these resources are limitless, they appear to be viable alternatives to fossil fuels and nuclear power. The technology to utilise these resources is still in its infancy, but it is fast evolving. Considering growing concerns for a sustainable future and energy security (Kar et al., 2014), clean energy sources are gaining significant importance across the globe (Sharma et al., 2012), including in India. Amongst all the clean technologies, solar energy is an effective renewable energy source that has attracted particular attention in large-scale electricity production and a variety of building applications, such as crop and grain drying, greenhouse heating and lighting, heating and cooling, remote electricity supply, water pumping, and many other macro and micro-level applications (Devabhaktuni et al., 2013). Perhaps, if only 0.1% of the solar energy incident on the earth would be converted to electrical energy at a 10% efficiency rate, 3000 GW of power may be generated yearly, which is four times more than the energy consumed globally (Thirugnanasambandam et al., 2010). In addition to the previously listed advantages of renewable energies, solar energy has the following additional advantages: 1. Land reclamation; 2. Less dependency on the national power grid network; 3. Better water quality across the country; and 4. Rural electrification (Tsoutsos et al., 2005). Moreover, India has immense solar energy potential (Muneer et al., 2005; Ramachandra et al., 2011). Nearly 58% of the country receives yearly average Global insolation of 5 kWh m^{-2} day^{-1}, which could aid in meeting the country's rising power needs in a decentralised, efficient, and long-term manner (Ramachandra et al., 2011). In India, solar PV has a potential of up to 6000 GW, while CSP has a potential of up to 2500 GW (Mahtta et al., 2014). As a result, solar energy has the potential to improve energy supply and accessibility in even the most remote parts of the country.

This study mainly focuses on Jammu and Kashmir (J & K) and Ladakh. Both states have enormous potential for the application of renewable energy initiatives. However, there is a wide gap between the estimated potential and the cumulative achievements made so far (Chandrasekar and Kandpal, 2007). According to India's 2011 census, J&K and Ladakh have experienced rapid population growth of 23.71% and 25.48%, respectively. As a result, both states have significant energy demands that are increasingly difficult to supply through traditional power-producing methods. The main objective of this study is to identify the potential sites for solar energy and understand its variation over the western Himalayan region. The description of solar potential in India, including the study area, is discussed in Sect. 2. Data and methodology in Sect.3. The simulated results are discussed in Sect. 4, followed by summaries of the findings in the last section.

1.1 Solar Energy Potential in India

India has tremendous potential for generating clean electricity through Renewable Energy Sources (RES) such as hydro, wind and solar. This potential has been duly recognised and demonstrates India's awareness of the need to reduce its carbon footprint as a developing country (Kapoor et al., 2014). The government of India, intending to promote clean energy, inaugurated the Jawaharlal Nehru National Solar Mission (JNNSM) on 11th January 2010 (Sharma et al., 2015), which is

*Corresponding Address:
Dr. Charu Singh, Marine and Atmospheric Sciences Department,
Indian Institute of Remote Sensing (IIRS),
Indian Space of Research Organization (ISRO),
Dehradun, India, 278001.
Email: charu@iirs.gov.in

one of the eight missions under the National Action Plan on Climate Change (NAPCC–2008). This mission's vision is to install 22,000 MW power plants both on and off-grid. The solar radiation incident on India is 4–7 KWh per square metre per day, with an annual radiation range of 1200–2300 KWh per square metre (Kumar et al., 2010; MNRE (2006)). It has on an average of 250–300 bright sunny days and 2300–3200 hours of sunshine per year (Kumar et al., 2010; Sharma et al., 2012).

Figure 1a depicts the evolution of net energy generation from solar power from 1981 to 2020. Initially, from 1981 to 1994, India has not participated in generating electricity from solar power. However, after they started focusing and began with 1 MWh from 1995 onwards, it rose to 6134 MWh by the end of the financial year 2020. The growth rate in the last decade has been roughly fortyfold, and by 2030, it is expected to reach 746 GW (Gould, 2015). India's demographics make it a solar-power-abundant country, with an estimated capacity of 750 GW (MNRE (2017)). As a result, solar energy will meet the country's overall energy needs.

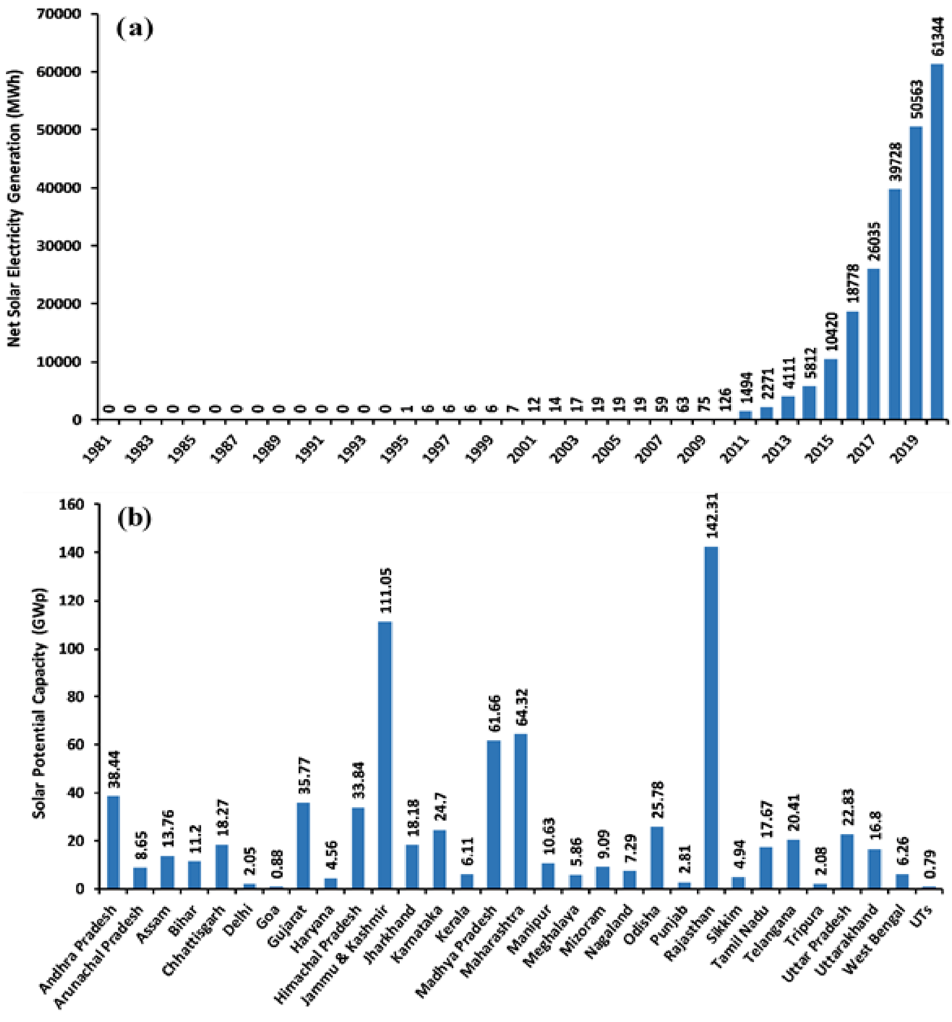

Figure 1. (a) Time series plot for net electricity generation growth from solar energy in India and (b) state-wise estimated solar potential capacity according to MNRE annual report 2020-21.

Figure 1b illustrates the state-wise estimated solar potential in India. The states with more than 30 GWp solar power potential include Andhra Pradesh, Gujrat, Himachal Pradesh, Jammu and Kashmir, Madhya Pradesh, Maharashtra, and Rajasthan. Besides all the other states, Jammu and Kashmir and Rajasthan have the largest capacity with 412.31 and 111.05 GWp, respectively. Goa and the UTs, on the other hand, have the lowest capacity with 0.88 and 0.79 GWp, respectively. In the early 1980s, India became the first government in the world to establish a Ministry of Non-Conventional Energy Resources (Kapoor et al., 2014). The Ministry of New and Renewable Energy (MNRE) has devised a plan to establish several solar parks across the country, each with a capacity for solar projects of at least 500 MW. The scheme proposes that the Government of India (GOI) will provide financial support to establish solar parks with the goal of facilitating the creation of infrastructure required for the establishment of new solar power projects in terms of land allocation, transmission and evacuation lines, access roads, water availability, and other factors in a targeted manner. The Solar Energy Corporation of India (SECI), a national public sector business under the MNRE, has been implementing different schemes to expand the country's solar sector (Akshay Urja. Newsletter MNRE (2010); MNRE (2015); Sharma et al., 2015). As per the policy, these solar parks will be constructed in partnership with State Governments. On behalf of the GOI, the Solar Energy Corporation of India (SECI) will be the implementation agency and manage the money made available under this scheme (Akshay Urja. Newsletter MNRE (2010)).

2. STUDY AREA

Jammu and Kashmir (J & K) and Ladakh are India's north–most states, with enormous potential for renewable energy

https://doi.org/10.5194/isprs-archives-XLIII-B4-2022-183-2022 |

development. The states are located just south of the Karakorum range, with latitudes of 33–37°N and longitudes of 72–80°E. The altitude varies from 205 to 8564 metres above mean sea level (amsl) (Fig. 2). The state covers approximately 2.22 lakh square kilometres, or 6.7% of the country's total geographical area, with about 30% under cultivation. The J & K state provides a diverse variety of agro-climatic conditions, allowing for the cultivation of subtropical (800 m amsl), sub-temperate (801–1500 m amsl), and temperate (> 1500 m amsl) crops. Ladakh, on the other hand, is mountains with scant vegetation

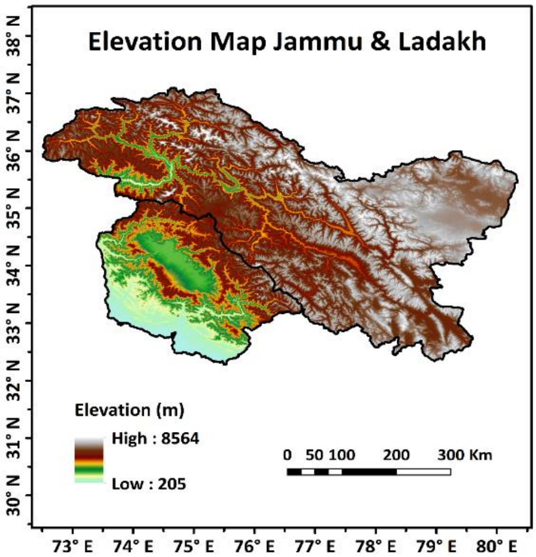

Figure 2. The elevation map of Jammu-Kashmir and Ladakh.

experiences high temperate and cold desert temperature. The states have a large amount of biomass by-products that can be used to generate electricity using solar energy, biogas, gasification technology, and other methods. The Ladakh region receives roughly 320 days of sunshine per year, making it one of the top solar cooking locations in the world. The technologies such as solar thermal systems, which include solar driers, solar water heaters, stream and dish colours, solar green houses, and other renewable energy technology, have been encouraged in the state.

2.1 Data and Methodology

The Global Horizontal Irradiance (GHI), also called surface incoming shortwave flux (SWGDN), and 2-m temperature datasets are used from MERRA-2 and ERA5-Land. MERRA version-2 reanalysis (MERRA-2) is released by NASA's Global Modelling and Assimilation Office (Gelaro et al., 2017). MERRA-2 is an upgraded version of MERRA, and is also the first long-term global reanalysis that can assimilate data from new microwave instruments and hyperspectral infrared radiation instruments. MERRA-2 includes various meteorological variables such as radiation, temperature, relative humidity, and wind speed. The data is available with a spatial resolution of 0.5°×0.625°, a temporal resolution of 1-hour, and 72 vertical layers. The European Centre for Medium-Range Weather forecasts (ECMWF) product ERA5-Land dataset provides a consistent view of the evolution of land variables over several decades at an enhanced resolution compared to ERA5. The dataset covers the globe at surface level with 0.1°×0.1° spatial resolution and 1-hour temporal resolution. The net electricity generation growth, estimated solar potential capacity, and installed solar power capacity dataset is taken from the U.S. Energy Information Administration (EIA) and MNRE annual report 2020-21. Both reanalysis datasets are considered on a surface level and interpolated at 0.05°×0.05° using the linear interpolation method to match the spatial resolution.

3. RESULTS AND DISCUSSION

Figure 3 shows the state-wise installed solar power capacity. Besides Rajasthan, Jammu and Kashmir have a tremendous amount of solar energy potential with 111.05 GWp (Fig. 1b). However, it is precisely less explored, with an installed capacity of only 46.87 MW. Therefore, this research aims to better identify possible sites for near-term climatological futures to understand solar energy variance in the western Himalayan region. In Jammu and Kashmir, the mean ambient 2-m temperature ranges from -6 to 15 °C, whereas in Ladakh, which receives the greatest GHI in India, the average ambient temperature ranges from -22 to 5 °C (Fig 4). Low ambient temperature necessitates a large amount of energy. The same amount energy is required for power generating (electricity) and heating, both powered by traditional electricity and provided mainly by coal, firewood, and LPG.

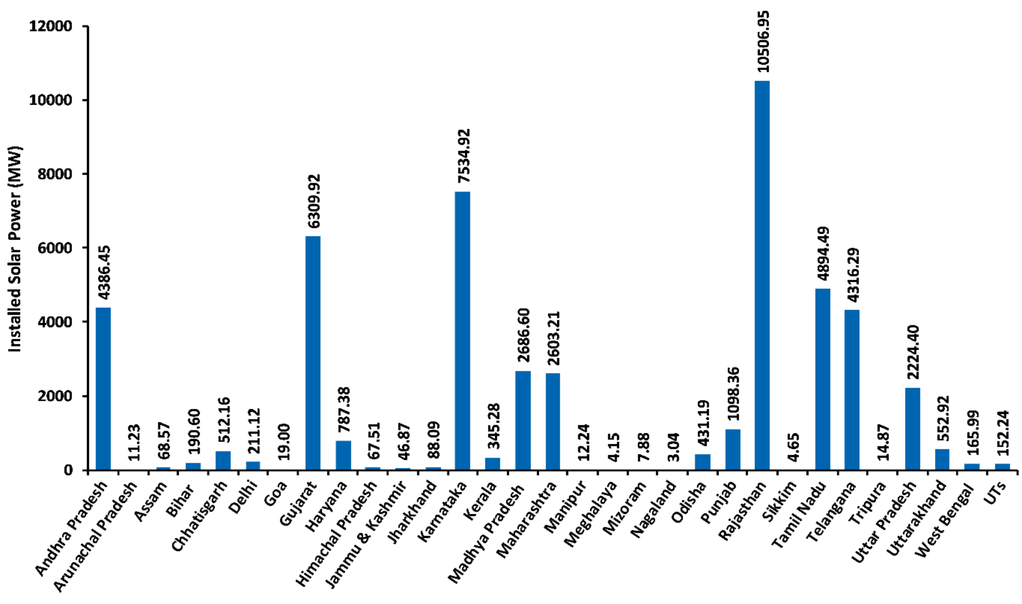

Figure 3. State wise installed solar power capacity by 31st January, 2022.

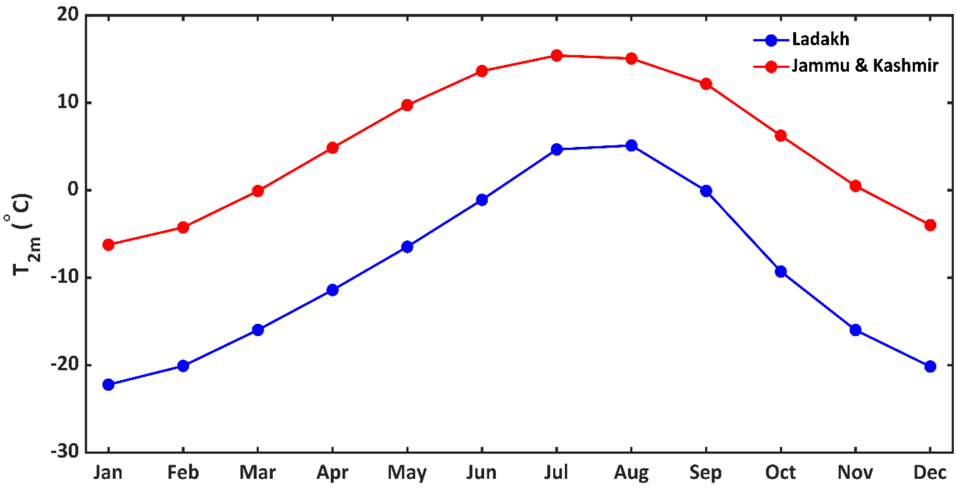

Figure 4. Monthly distribution of averaged 2m-temperature from 1981 to 2020.

On the other hand, the low ambient temperature is a crucial element in determining the efficiency of CST systems. Solar thermal generation can be most efficient when the ambient temperature is low, and the DNI is high. The Ladakh region has the most significant number of sunny days in the country, making it one of the best places for solar cooking, drying, and solar thermal power generation using trough collectors or CST technology. The same approaches can be utilised for the process of heat design to ensure heat flow through HVAC systems. Advanced DNI provides higher efficiency in solar cooking, solar water heating systems, and solar greenhouses.

Furthermore, solar radiation can be used to generate power and heat, either through photovoltaic or thermal systems. The availability of accurate solar radiation data is critical to the success of solar energy installations across the country. Solar radiation data in the form of GHI is a valuable factor in evaluating photovoltaics' efficiency for flat solar collectors. The GHI is the total amount of shortwave radiation received from above by a surface that is horizontal to the ground, and it comprises both Direct Normal Irradiance (DNI) and Diffuse Horizontal Irradiance (DHI). Figure 5 shows the averaged GHI for forty years from 1981 to 2020. The values are greater than 250 W m^{-2} in eastern and southern Ladakh. However, it is lower than 240 W m^{-2} in Jammu and Kashmir region. Ladakh's height ranges from 2550 to 7742 metres above mean sea level. It receives 300 days of sunshine every year, allowing it to provide 20% more energy due to a thinner atmosphere, lower solar zenith angle, which reflects less incoming solar radiation, and comparatively long duration of the day (Homadi, 2016.; Kapoor et al., 2014).

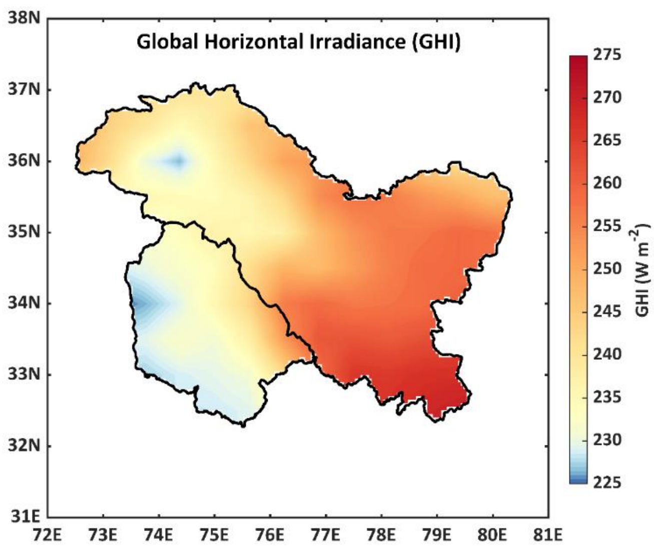

Figure 5. Spatial variation of yearly averaged GHI from 1981 to 2020.

Likewise, the monthly radiation analysis is also computed using hourly reanalysis estimations. MERRA-2 obtains the monthly values for the last four decades to compute the GHI radiation maps (Fig. 6). The lowest range (blue colour) of GHI is 115-215 W m-2, whereas the maximum range (red colour) is 295-375 W m^{-2}. December and January are weak months for solar

*Corresponding Address:
Dr. Charu Singh, Marine and Atmospheric Sciences Department,
Indian Institute of Remote Sensing (IIRS),
Indian Space of Research Organization (ISRO),
Dehradun, India, 278001.
Email: charu@iirs.gov.in

energy, whereas June is ideal. Solar radiation varies dramatically from season to season and month to month. Solar radiation is directly linked with day length (no of day hours) and the angle between sun radiation and surface. There is sound horizontal radiation in summer, which aids photovoltaic electricity generation. Low ambient temperature combined with

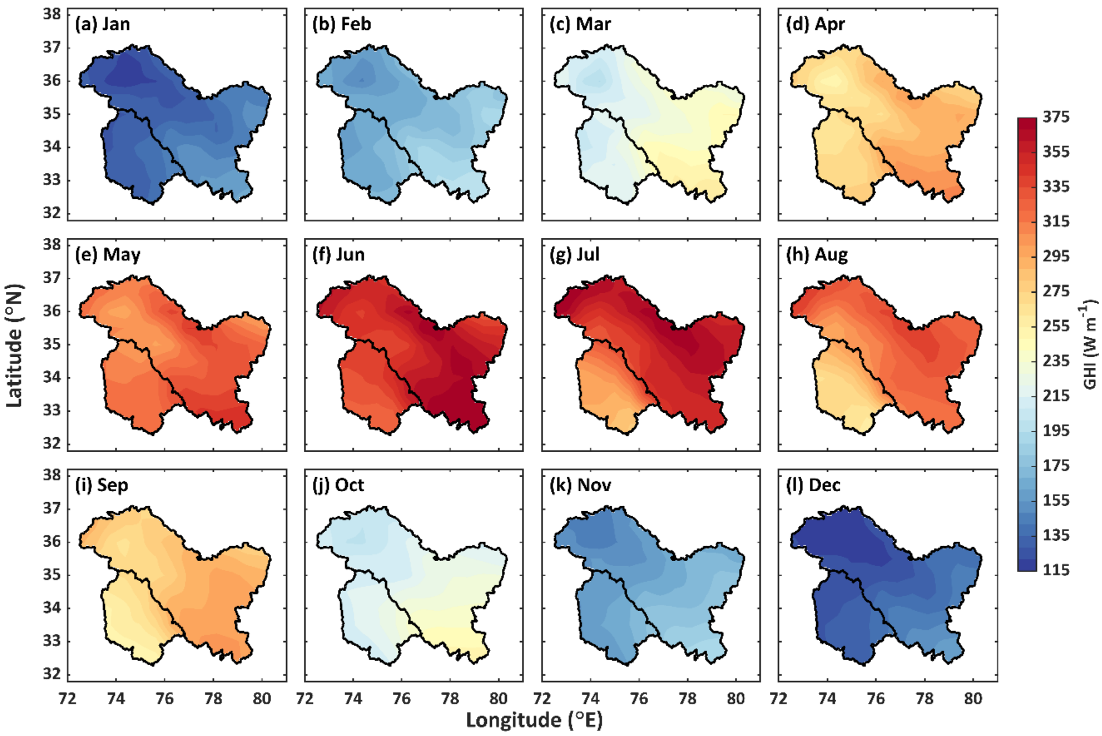

Figure 6. Spatial distribution of monthly averaged GHI from 1981 to 2020.

a high GHI ensures higher solar panel efficiency and, as a result, higher solar photovoltaic electricity generation. Solar radiation is generally good when demand is relatively high during the summer months. Electricity demand can be met during the winter months by combining solar photovoltaic and solar thermal technology. This would ensure that locations like Leh, Kargil, Kashmir, and parts of Jammu have inadequate energy solutions at present.

4. CONCLUSION

As concern about a sustainable future and energy security grows, clean energy sources are becoming increasingly important worldwide, particularly in India. Solar energy is an effective renewable energy source for large-scale electricity production among all the clean energy technologies. As a result, the primary goal of this research is to identify potential sites for solar energy in high mountain areas, particularly in Jammu and Kashmir and Ladakh. The annual and monthly variations in GHI are calculated using the MERRA-2 reanalysis dataset. In comparison to Jammu and Kashmir, Ladakh receives much more incoming solar radiation, particularly in the south and east, and has adequate potential for solar energy infrastructure. Furthermore, according to the site location, the months with the most solar radiation are June and July, while the months with the least are December and January. Finally, the annual average value of GHI in Leh and Kargil is more significant than 255 Wm^{-2}, indicating that they have the potential for photovoltaic applications and are recommendable for further investigation.

ACKNOWLEDGEMENTS

The authors would like to thank IIRS for computation resources, and the present work is a part of the project. We want to acknowledge the National Aeronautics and Space Administration (NASA) for providing monthly average short wave incoming solar irradiance from MERRA-2 reanalysis data (https://disc.gsfc.nasa.gov/daac-bin/FTPSubset2.pl), European Center for Medium-Range Weather Forecasts (ECMWF) for providing high resolution 2m-temperature dataset from ERA5-Land reanalysis (https://www.ecmwf.int/en/era5-land), U.S. Energy Information Administration (EIA) for providing solar electricity generation data (https://www.eia.gov), and Ministry of New and Renewable Energy (MNRE) for providing estimated and installed capacity of solar potential dataset (https://mnre.gov.in).

REFERENCES

Akshay Urja. Newsletter of the Ministry of New and Renewable Energy, Government of India 2010;4 (November–December (2–3)).

Chandrasekar, B., Kandpal, T.C., 2007. An opinion survey based assessment of renewable energy technology development in India. *Renewable and Sustainable Energy Reviews* 11, 688–701. doi.org/10.1016/J.RSER.2005.04.001

Devabhaktuni, V., Alam, M., Shekara Sreenadh Reddy Depuru, S., Green, R.C., Nims, D., Near, C., 2013. Solar energy: Trends and enabling technologies. *Renewable and Sustainable Energy Reviews* 19, 555–564. doi.org/10.1016/J.RSER.2012.11.024

Gelaro, R., McCarty, W., Suárez, M.J., Todling, R., Molod, A., Takacs, L., Randles, C.A., Darmenov, A., Bosilovich, M.G., Reichle, R., Wargan, K., Coy, L., Cullather, R., Draper, C., Akella, S., Buchard, V., Conaty, A., da Silva, A.M., Gu, W., Kim, G.K., Koster, R., Lucchesi, R., Merkova, D., Nielsen, J.E., Partyka, G., Pawson, S., Putman, W., Rienecker, M., Schubert, S.D., Sienkiewicz, M., Zhao, B., 2017. The Modern-Era Retrospective Analysis for Research and Applications, Version 2 (MERRA-2). *Journal of Climate* 30, 5419–5454. doi.org/10.1175/JCLI-D-16-0758.1

Gould, T., 2015. World energy outlook special report 2015. Paris. In: OECD/International Energy Agency. *International Energy Agency*, Paris, pp. 1–19. https://www.iea.org/reports/world-energy-outlook-2015

Homadi, A. M. (2016). Effect of elevation and wind direction on silicon solar panel efficiency. *International Scholarly and Scientific Research & Innovation*, 10(9), 1205-1212.

Kapoor, K., Pandey, K.K., Jain, A.K., Nandan, A., 2014. Evolution of solar energy in India: A review. *Renewable and Sustainable Energy Reviews* 40, 475–487. doi.org/10.1016/J.RSER.2014.07.118

Kar, S. K., & Sinha, P. K. (2014). Ensuring sustainable energy security: challenges and opportunities for India. *Oil, Gas & Energy Law*, 12(4).

Kumar, A., Kumar, K., Kaushik, N., Sharma, S., Mishra, S., 2010. Renewable energy in India: Current status and future potentials. *Renewable and Sustainable Energy Reviews* 14, 2434–2442. doi.org/10.1016/J.RSER.2010.04.003

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. doi.org/10.1016/J.RENENE.2014.05.037

MNRE (2006) Annual Report 2005–06, Ministry of New and Renewable Energy, New Delhi, India.

MNRE (2015) Annual Report 2015–16, Ministry of New and Renewable Energy, New Delhi, India

MNRE (2017) Annual Report 2017–18, Ministry of New and Renewable Energy, New Delhi, India.

Mostafaeipour, A., Sedaghat, A., Dehghan-Niri, A.A., Kalantar, V., 2011. Wind energy feasibility study for city of Shahrbabak in Iran. *Renewable and Sustainable Energy Reviews* 15, 2545–2556. doi.org/10.1016/J.RSER.2011.02.030

Muneer, T., Asif, M., Munawwar, S., 2005. Sustainable production of solar electricity with particular reference to the Indian economy. *Renewable and Sustainable Energy Reviews* 9, 444–473. doi.org/10.1016/J.RSER.2004.03.004

Ramachandra, T. v., Jain, R., Krishnadas, G., 2011. Hotspots of solar potential in India. *Renewable and Sustainable Energy Reviews* 15, 3178–3186. doi.org/10.1016/J.RSER.2011.04.007

Sharma, A., Srivastava, K., Kar, S.K., 2015. Jawaharlal Nehru National Solar Mission in India. *Green Energy and Technology* 201, 47–67. doi.org/10.1007/978-81-322-2337-53

Sharma, N.K., Tiwari, P.K., Sood, Y.R., 2012. Solar energy in India: Strategies, policies, perspectives and future potential. *Renewable and Sustainable Energy Reviews* 16, 933–941. doi.org/10.1016/J.RSER.2011.09.014

Thirugnanasambandam, M., Iniyan, S., Goic, R., 2010. A review of solar thermal technologies. *Renewable and Sustainable Energy Reviews* 14, 312–322. doi.org/10.1016/J.RSER.2009.07.014

Tsoutsos, T., Frantzeskaki, N., Gekas, V., 2005. Environmental impacts from the solar energy technologies. *Energy Policy* 33, 289–296. doi.org/10.1016/S0301-4215(03)00241-6