Assessment of Solar Energy Adoption in Himalayan Region: A Primary Survey-Based Study of Pauri Garhwal, Uttarakhand

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Abstract: The transition towards renewable energy has significantly increased the adoption of solar power in recent years, particularly in geographically diverse regions. This study examines the existing scenario of solar energy installations in Pauri Garhwal, based on both primary and secondary data collected through a structured field survey (conducted between April 2025 to March 2026) and state government portals. A total of 60 ground-mounted (GM) and 1,746 rooftop (RT) solar plants were analysed to understand their spatial distribution, temporal growth, subsidy patterns and technological characteristics. The results indicate a clear dominance of rooftop solar installations, with a rapid increase observed after 2023, largely influenced by government subsidy schemes and ease of installation. In contrast GM systems remain limited due to factors such as land constraints, higher investment requirements and lack of awareness regarding their economic potential. The study also identifies several challenges, including maintenance-related issues, dependency on vendors, delays in subsidy disbursement, and shortage of skilled manpower for large-scale systems. Despite these constraints, solar energy has shown strong potential in improving energy access and generating local employment. The findings highlight the need for better awareness, technical support, and efficient policy implementation to ensure sustainable solar energy adoption in the region.

Keywords: Solar Energy • Rooftop • Ground-Mounted Solar • Solar Subsidy • Pauri Garhwal • Renewable Energy

Introduction

The global transition toward renewable energy has gained momentum in response to growing concerns over climate change, energy security, and sustainable development (Yang et al 2024). This transition aligns closely with the United Nations Sustainable Development Goals, particularly SDG 7, which emphasizes universal access to affordable, reliable, sustainable, and modern energy (Singh et al 2025). Over the past decade, renewable energy capacity has expanded significantly worldwide, supported by technological innovations, declining costs, and favorable policy interventions (Marzouk 2025).

In India, the government has actively promoted the adoption of renewable energy through various policies and ambitious capacity expansion targets. According to reports from the Ministry of New and Renewable Energy and the Central Electricity Authority, solar power has emerged as the leading contributor to the country's growing renewable energy portfolio (Rajkhowa et al 2026). Among renewable sources, solar energy offers distinct advantages due to its widespread availability, scalability, and ease of installation (Singh et al 2025). Unlike hydropower and wind energy, which often require specific geographic conditions and substantial infrastructure, solar systems can be deployed across diverse settings. Rooftop solar installations have gained particular importance as they facilitate decentralized electricity generation, reduce transmission losses, lower dependence on grid electricity, and provide a cost-effective, low-maintenance energy solution for both urban and rural households

(Rathore et al 2018; Singh et al 2022; Marzouk 2025).

The Himalayan state of Uttarakhand possesses significant potential for solar energy development owing to its favorable solar radiation and abundant renewable energy resources (Singh et al 2024). However, the region's rugged topography, dispersed settlements, and limited accessibility to conventional energy infrastructure present substantial challenges to ensuring reliable energy supply, particularly in remote mountainous areas (Ukoba et al.2024). Consequently, decentralized renewable energy systems have emerged as a viable solution for meeting local energy demands (Katsoulakos & Kaliampakos 2016). Among these, small-scale and rooftop solar installations have proven effective in enhancing energy access, reducing dependence on conventional fuels, and improving the quality of life in isolated communities (Terrapon et al 2014).

Recognizing the importance of solar energy, both the Government of India and the Government of Uttarakhand have introduced various initiatives to promote its adoption. National programs, including the Rooftop Solar Scheme of the Ministry of New and Renewable Energy and PM Surya Ghar: Muft-Bijli Yojana, provide financial incentives and subsidies to encourage residential solar installations. Complementing these efforts, state-level policies support solar deployment across urban and rural areas. By reducing installation costs and increasing public awareness, these initiatives contribute to sustainable energy development. The present study evaluates the status of solar energy adoption in the study area and highlights the need for localized technical training, streamlined financing mechanisms, and targeted community outreach to fully harness its potential.

Study Area

The study area is located in the western part of the state and constitutes a substantial segment of the Garhwal Himalayan region. Geographically, it extends between approximately 29°26′N to 30°19′N latitude and 78°10′E to 79°23′E longitude, covering a total area of about 5,280.36 km² (Fig 1). The physical landscape of the district is predominantly mountainous, characterized by steep slopes, deeply incised valleys, and highly dissected ridges, which are typical features of the lesser Himalayan terrain. Administratively, the district is organized into several tehsils and development blocks, containing a vast network of rural villages alongside a handful of urban hubs. The Census of India (2011) recorded Pauri Garhwal's population at 687,271, with the overwhelming majority of residents living in rural communities. Because of the rugged mountain terrain and limited transport links, communities are highly fragmented. This dispersed layout complicates the rollout of traditional power grids, underscoring the absolute necessity for off-grid alternatives like solar energy. Climatic conditions across the district vary from subtropical to temperate, driven almost entirely by shifts in altitude and slope direction. Low-lying zones face warmer temperatures, while the upper ridges stay cool year-round. Rainfall is moderate to heavy, concentrated mostly during the southwest monsoon from June to September, with occasional winter snowfall capping the highest peaks. With elevations swinging dramatically from 196 m to 3,068 m above sea level, the local environment is incredibly diverse. These localized shifts in cloud cover, temperature, and direct sunlight ultimately dictate where solar infrastructure is most viable and effective.

Data and Methodology

The present study has been done based on both primary and secondary data collected through field-based investigation (from April 2025 to March 2026) and state government portals (such as Uttarakhand Renewable Energy Development Agency & Uttarakhand Power Corporation Limited).

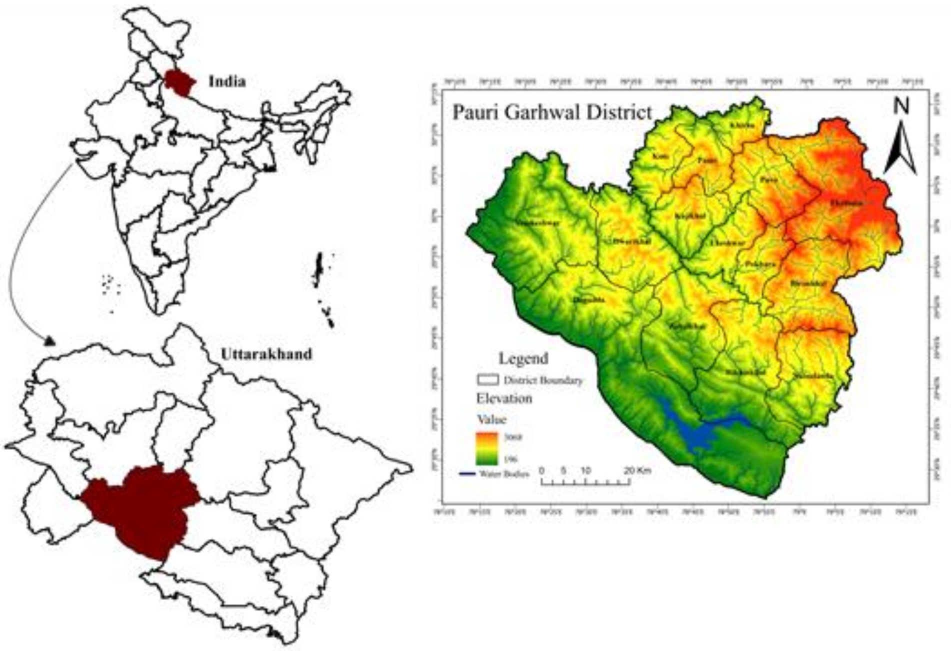

Fig 1. Location of the study area

Prior to the field survey, the locations of both ground-mounted and rooftop solar installations were identified with the help of Google Earth Pro. This initial step helped in planning the survey and locating existing installations. During the field visits, additional data were collected for installations that were not visible or updated in Google Earth Pro, particularly newly installed systems. A structured questionnaire was prepared to collect detailed information on aspects such as type of solar panel, year of installation, subsidy status, ownership details, and problems faced by users. The survey was conducted through direct interaction with respondents across different parts of Pauri Garhwal, along with field observations. In total, 60 GM solar power plants and 1,746 rooftop solar systems were surveyed during the period from April 2025 to April 2026. The collected data include both qualitative and quantitative information, which were further organized and analyzed to understand the current status of solar power installations and the challenges associated with their adoption in the study area.

Result and Discussion:

Distribution of Solar Installations:

The analysis of primary survey data collected from Pauri Garhwal indicates that ground-mounted solar installations are relatively limited in number but spatially distributed across several parts of the district. A total of approximately 60 ground-mounted solar power plants were recorded during the survey period from 2025 to 2026. These installations are concentrated across nearly 10 development blocks, including Khirsu, Pauri, Pabo, Kote, Dwarikhal, Yamkeshwar, Dugadda, Ekeshwar, Kajikhal, and Thalisain. Among these, Pauri, Kote, and Ekeshwar blocks exhibit a comparatively higher concentration of ground-mounted systems (Fig 2). This pattern can be attributed to favorable geographical and climatic conditions, such as suitable slope, better solar exposure, and availability of relatively open land, which make these areas more suitable for such installations.

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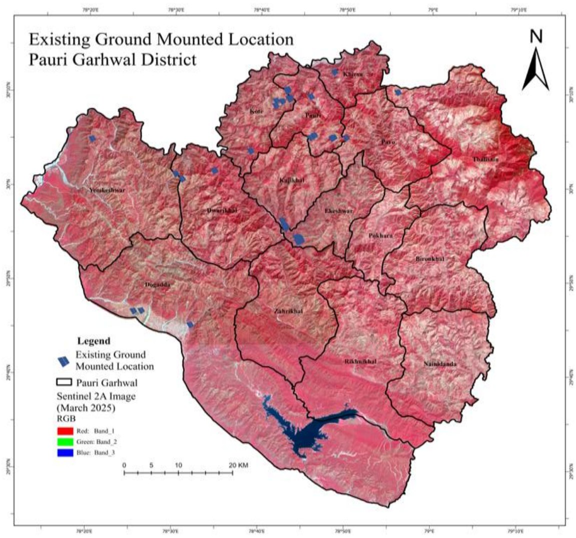

Figure 2. Existing Ground Mounted Solar Power Plants Location in Pauri Garhwal District

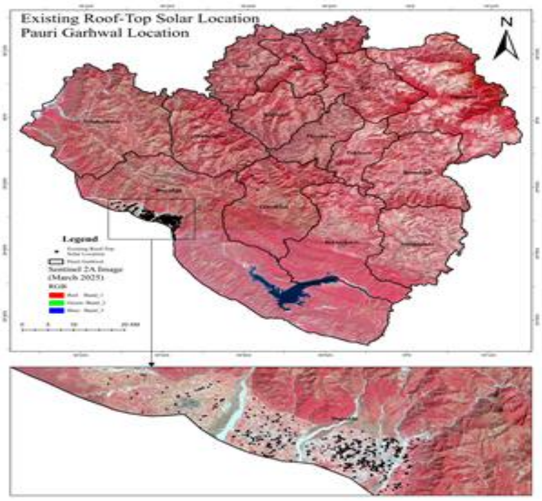

Fig 3. Existing roof top solar power plant's location in Pauri Garhwal District

In contrast, rooftop solar installations show a much wider and denser distribution across the district. The survey recorded approximately 1,746 rooftop systems, with a significant concentration observed in a few key blocks. Dugadda block, particularly in the Kotdwar region, accounts for nearly half of the surveyed rooftop installations, indicating a high level of adoption in this area. This is followed by Khirsu block, especially in Srinagar and Srikot, where a large number of installations have been observed (Fig 3). Notably, many of these systems in Srinagar and Srikot appear to be recently installed within the last two years, reflecting a rapid increase in adoption. Additional clusters of rooftop installations are found in Pauri block (around Pauri town), as well as in Zahrikhal and Dwarikhal blocks, suggesting a growing trend of decentralized solar energy use across both urban and semi-urban areas. A comparative assessment of ground-mounted and rooftop solar systems clearly indicates that rooftop installations are more widely adopted, primarily due to their suitability for household-level energy needs and ease of installation (Fig 4). Rooftop systems require less space, lower initial investment (especially with subsidy support), and are more accessible for individual users. On the other hand, the relatively lower number of ground-mounted installations can be linked to factors such as limited awareness, constraints related to land availability, and the need for higher initial resources and investment. However, it was also observed during the field survey that users who have already benefited from solar installations (particularly ground-mounted systems) show a greater willingness to expand or reinvest in additional capacity. This reflects a positive perception of solar energy and highlights its long-term potential in the region.

Fig 4. Showing the ground mounted SPP in the study area (Collected during field survey)

Temporal Trend of Installation:

In the case of ground-mounted solar power plants, installations remained very limited in the initial years, with only a few systems recorded before 2020. A noticeable increase is observed around 2021, which marks the peak period with the highest number of installations. After this phase, the growth appears relatively moderate, with a small number of new installations continuing up to 2025 (Fig 5).

This trend suggests that ground-mounted systems experienced an initial phase of adoption driven possibly by early policy support and pilot implementations, but their expansion remained constrained in subsequent years. In contrast, rooftop solar installations exhibit a much more dynamic and rapidly increasing trend over time. While only a negligible number of installations were recorded before 2020, a gradual rise begins after 2021, followed by a sharp surge from 2023 onwards.

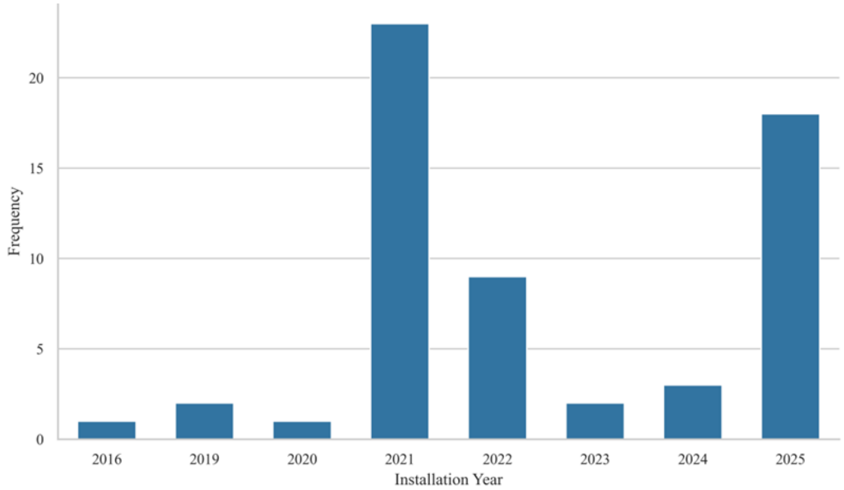

Figure 5. Existing ground mounted solar installation year with frequency.

The most significant growth is observed between 2024 and 2025, with 2025 alone accounting for the highest number of installations among all recorded years (Fig 6*)*. This steep increase clearly indicates a recent acceleration in rooftop solar adoption, likely influenced by enhanced government support, subsidy schemes, and growing public awareness. The continued installations into 2026 further reflect that rooftop solar is still expanding rapidly across the district. Overall, the temporal pattern highlights a clear shift in solar adoption trends from limited and relatively slower growth in ground-mounted systems to a rapid and large-scale expansion of rooftop installations in recent years. This transition emphasizes the increasing preference for decentralized, household-level energy solutions, which are easier to implement and more adaptable to the geographical and socio-economic conditions of the region.

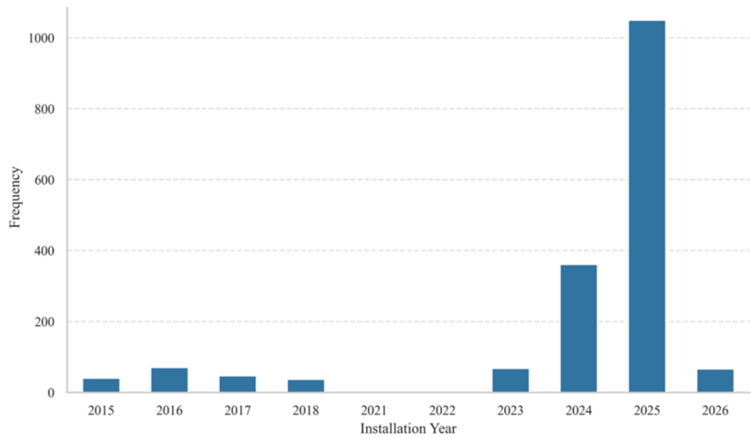

Fig 6. Existing Roof Top Solar Installation year with Frequency

Subsidy and Adoption Pattern: The analysis of primary data from Pauri Garhwal reveals that government subsidy has played a significant role in promoting the adoption of solar energy, particularly for rooftop systems. A majority of rooftop installations were supported under the central scheme PM Surya Ghar: Muft Bijli Yojana, launched in 2024 (Fig 7). Under this scheme, households receive Central Financial Assistance (CFA) of around Rs.30,000 per kw up to 2 kw and Rs.18,000 per kw for additional capacity, with a maximum subsidy of approximately Rs.78,000 for larger systems (MNRE, 2024).

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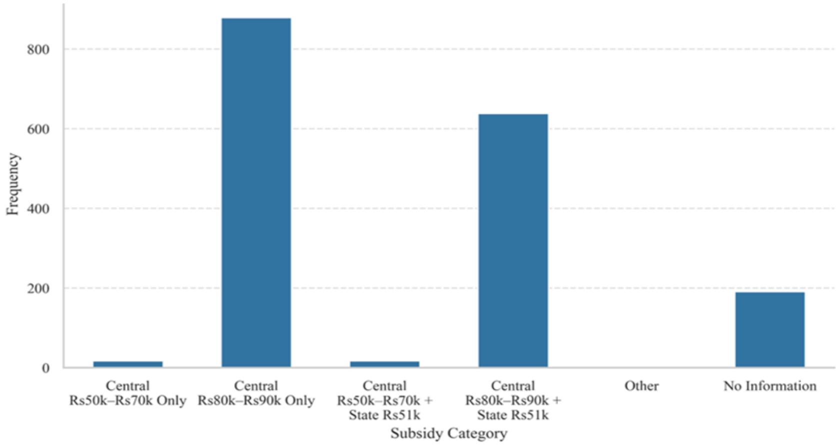

Figure 7. Subsidy category for the Roof Top Solar power plants

This financial support has significantly reduced the initial installation cost, encouraging widespread adoption, especially in residential areas. In addition to the central scheme, respondents reported receiving a state-level subsidy of around Rs.51,000 under solar promotion initiatives in Uttarakhand. However, it was observed during the field survey that this state subsidy was discontinued around March 2025, which may have influenced recent adoption trends.

While rooftop systems largely depend on such financial support, ground-mounted solar installations show relatively lower dependence on subsidies. Many of these systems are developed by users with higher investment capacity or specific energy needs, where subsidy acts as an additional benefit rather than a primary driving factor (Fig 8).

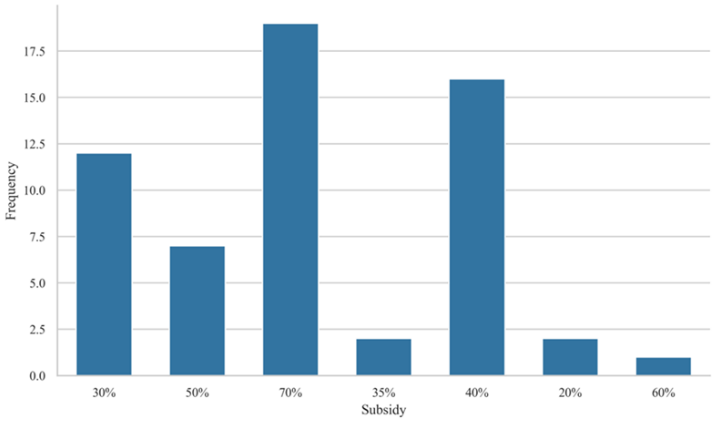

Figure 8. Subsidy category for the Ground Mounted Solar power plants

Overall, the findings suggest that subsidy mechanisms have been crucial in accelerating solar adoption, particularly at the household level. At the same time, the presence of several non-subsidy-based installations (especially in ground-mounted systems) indicates a growing confidence among users in solar energy as a reliable and long-term energy solution.

Comparison between Ground-Mounted and Rooftop Solar Systems:

A comparative analysis of solar installations in Pauri Garhwal clearly indicates that rooftop solar systems are more widely adopted than ground-mounted installations. One of the primary reasons for the limited number of ground-mounted systems is the constraint of land availability, especially in a mountainous

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region where flat and accessible land is scarce. In addition, lack of awareness regarding the potential of ground-mounted solar as a source of income further restricts its adoption. Many respondents were not fully aware that such installations could be utilized not only for energy generation but also as an economic opportunity. As a result, despite having suitable climatic conditions in certain areas, the expansion of ground-mounted systems remains relatively slow. On the other hand, rooftop solar systems have experienced rapid growth, particularly after 2023. This increase is largely influenced by the availability of subsidy schemes, especially at the state level, which significantly reduced the financial burden on households (Fig 9).

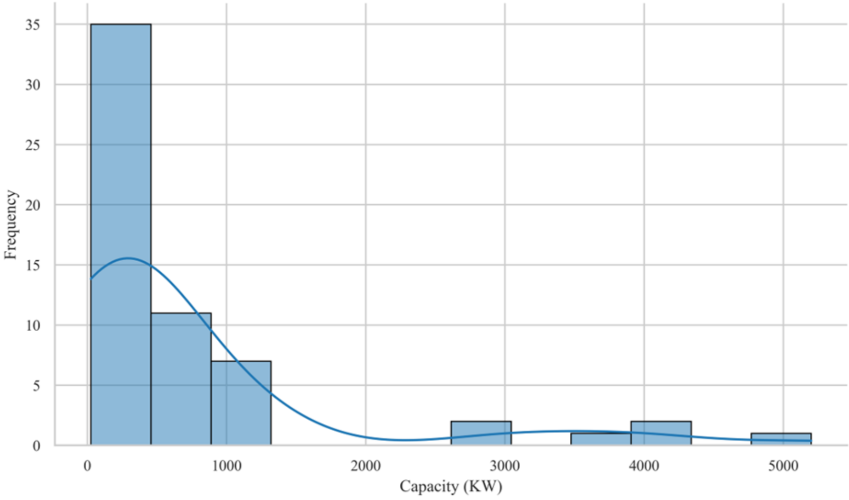

Fig 9. Capacity distribution among existing ground mounted solar power plants.

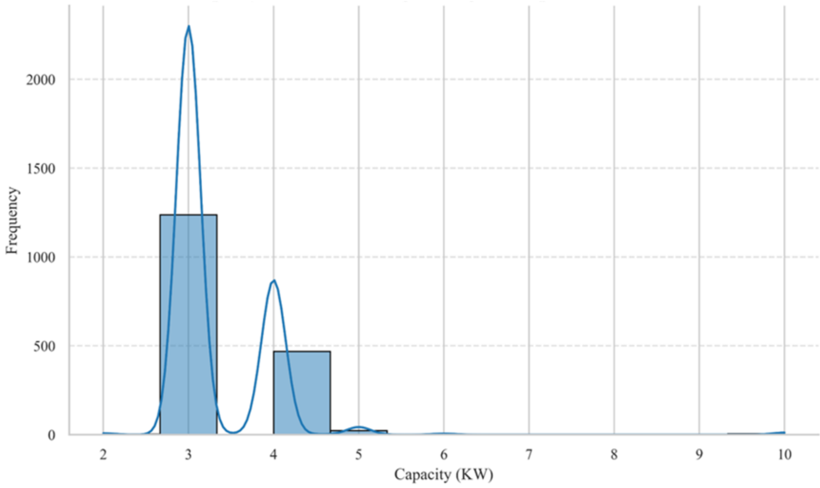

Fig 10. Capacity distribution among existing Roof Top solar power plants

Rooftop systems are easier to install, require less space, and can be conveniently set up on terraces or other available open spaces within residential premises. Moreover, they are relatively easier to maintain compared to large-scale ground-mounted systems, making them more suitable for individual users Fig 10). These advantages have contributed to their widespread acceptance and rapid adoption across the study area.

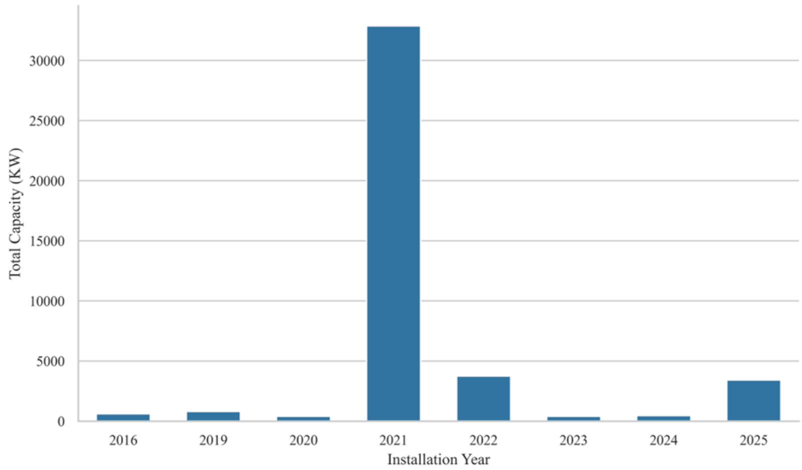

Fig. 11. Total capacity on the installation among existing Ground Mounted SPP.

However, while ground-mounted systems are fewer in number and comparatively difficult to manage due to their larger spatial extent, they offer certain socio-economic benefits (Fig 11). During field visits, it was observed that such installations generate local employment opportunities, particularly in maintenance and operational activities.

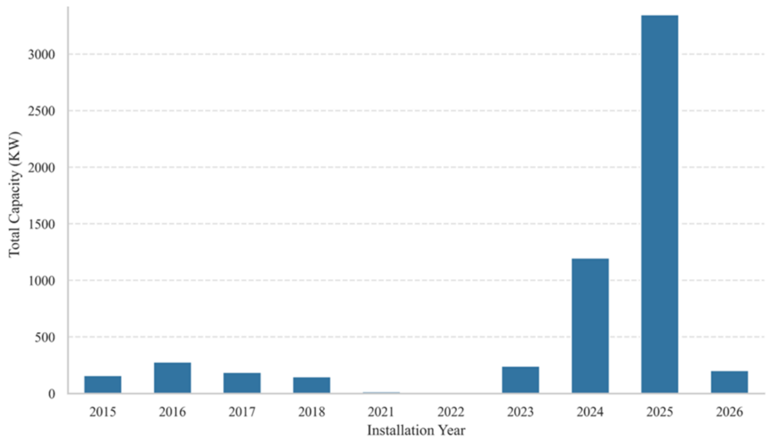

Fig 12. Total capacity on the installation among existing rooftop solar power plants.

Interactions with local residents revealed that several individuals, who had previously migrated to other states for work, returned to their villages after the COVID-19 pandemic and are now engaged in solar-related activities. These individuals are involved in maintaining solar plants and are able to earn a stable income. This highlights that, despite their limitations, ground-mounted solar systems have the potential to contribute to rural livelihoods and local economic development.

Problems and Challenges:

The insights derived from field visits across Pauri Garhwal reveal several practical challenges associated with the adoption and functioning of solar power systems. One of the major issues observed is the lack of awareness among users regarding proper maintenance practices. In many rooftop installations, users were found to have limited knowledge about routine cleaning, system monitoring, and minor troubleshooting, which directly affects the efficiency and overall performance of the systems. Another key concern is the high dependency of consumers on vendors, particularly in rooftop systems. Most users rely entirely on vendors for installation, documentation, and maintenance, with very little technical understanding of the system. Along with this, delays in receiving subsidies were frequently reported, where respondents mentioned that the disbursement process is often slow and lacks clarity, creating dissatisfaction among users. In the case of ground-mounted solar systems, additional challenges were observed during field visits. It was found that there is a shortage of trained manpower for maintaining these installations. Since ground-mounted systems cover larger areas and involve more complex technical components, their maintenance requires skilled personnel. However, in many locations, a limited number of workers are responsible for handling multiple plants, which increases the risk of technical faults not being addressed on time. This highlights the need for proper training and capacity building, so that employees can efficiently manage and resolve technical issues, ensuring better performance and sustainability of GM solar systems.

Conclusion

The present study provides a comprehensive assessment of the existing scenario of solar power installations in Pauri Garhwal based entirely on primary field data. The findings highlight a clear shift towards decentralized energy solutions, with rooftop solar systems emerging as the dominant form of adoption due to their ease of installation, lower maintenance requirements, and strong support from government subsidy schemes. In contrast, ground-mounted solar systems, although limited in number but play an important role in terms of higher capacity generation and local employment opportunities. The study also reveals that geographical and climatic suitability significantly influences the spatial distribution of installations, while policy interventions and financial incentives act as key drivers in accelerating adoption. At the same time, the research identifies several ground-level challenges, including lack of awareness regarding maintenance, dependency on vendors, delays in subsidy disbursement, and shortage of trained manpower for managing large-scale systems. These issues indicate that while policy frameworks are effective in promoting adoption, there remains a gap in implementation and post-installation support. Addressing these challenges through awareness programs, skill development, and streamlined administrative processes can further enhance the efficiency and sustainability of solar energy systems in the region.

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