Agrivoltaics in Himalayas: A Case Study from Tehri District of Uttarakhand, India

Sunil Singh[1*] • Atul Kumar[2] • Mahabir Singh Negi [3]

[1]*School of Liberal Arts and Sciences, Mody University of Science and Technology, Lakshmangarh-332311, Rajasthan, India; Present Address: Geography Department HNB Garhwal University Srinagar Garhwal*
[2]*Department of Geography, N.R.E.C. College Khurja, C.C.S. University, Uttar Pradesh, India*
[3]*Department of Geography, H.N.B. Garhwal University, Srinagar Garhwal, (A Central University), Uttarakhand, 246174, India*

[*]Corresponding Author Email Id: sunilgeo.hnbgu@gmail.com

Received: 10.04.2025; Revised: 01.05.2025; Accepted: 07.05.2025

Abstract: This study examines the integration of agrivoltaics in the study area, focusing on the coexistence of medicinal plants and agricultural crops under solar power systems. Through detailed field surveys, we identify various shade-loving species thriving in the unique microenvironments created by solar panels. The work highlights the medicinal and nutritional values of these plants and their adaptability to shaded conditions. Results demonstrate that solar energy infrastructure can support and enhance local biodiversity while promoting sustainable landuse practices. The study provides insights into how agrivoltaic systems can harmonize renewable energy development with the conservation of traditional botanical resources, offering a model for integrating solar energy initiatives with regional ecological and agricultural contexts. This approach underscores the potential for agrivoltaics to contribute to both energy sustainability and biodiversity conservation in mountainous regions.

Keywords: Land utilization Agrivoltaics • Shade-loving plants • Medicinal plants • Solar power plants

Introduction:

In the global context, climate change, energy demands and sustainable land use practices have become a critical focus for both environmental conservation and economic development (Singh et al 2022). Sustainable land use management has become a critical focus in addressing the dual challenges of food security and renewable energy production. Integrating agricultural practices with solar power generation, particularly by cultivating shade-tolerant medicinal plants and vegetables beneath solar panels, offers a promising solution. It often referred to as agrivoltaics which optimizes land use by combining photovoltaic energy production with agricultural activities. This integrated system can mitigate the adverse effects of land degradation, soil erosion and biodiversity loss, which are often associated with large-scale solar installations. Recent studies have shown that the microclimate created by solar panels can enhance the growth of certain crops, which not only thrive in shaded conditions but also contribute to biodiversity and soil health (Barron-Gafford et al 2019). Moreover, this practice can improve the economic viability of solar farms by providing an additional revenue stream from agricultural products (Dinesh & Pearce 2016, Singh et al., 2024). This synergy between solar energy and sustainable agricultural practices presents a novel approach to land management that can enhance energy production while promoting biodiversity and sustainable agriculture (Dupraz et al 2011; Chamberlain et al 2020). Moreover, the cultivation of medicinal plants, many of which are endangered or under threat, can support conservation efforts and provide economic benefits to local communities through the sale of high-value crops. The present work recorded the shade-loving medicinal plants and various vegetables growing beneath the solar modules in the mountainous region of Uttarakhand Himalaya. The findings of this work will contribute to the broader discourse on renewable energy, sustainable agriculture and environmental conservation, offering a model for synergistic land management practices that can be replicated globally.

Data and Methodology: The study is based on primary data (from 2021-23), collected through comprehensive field surveys, interviews with ground-mounted solar beneficiaries and site assessments. The data was collected by constructing a questionnaire cum schedule and the purposive sampling technique has been applied thereafter. There are 50 ground-mounted solar power plants surveyed in the study area and out of which 40% utilized for growing various crops and medicinal plants.

Study Area:

The study area is situated in the lap of the Uttarakhand Himalayas with an elevation ranging from 323m to 6717 m asl. (Fig 1). It is located between 30° 3' to 30° 15' N latitude and 78° 24' to 79° 23' E longitude and encompasses an area of 3911.51 km^2 (Fig 1). The area is bounded by Rudraprayag from the East, Haridwar in the West, Uttarkashi in the North and Pauri in the South. Administratively the area is bifurcated into 9 CD blocks, 7 tehsils, 2 communities and 4 towns (Census of India, 2011). The total population of the area is 610,931 persons with a population density of 170 p/km^2, sex ratio of 1077 females/1000 males and literacy rate of 7.4% (Census of India, 2011).

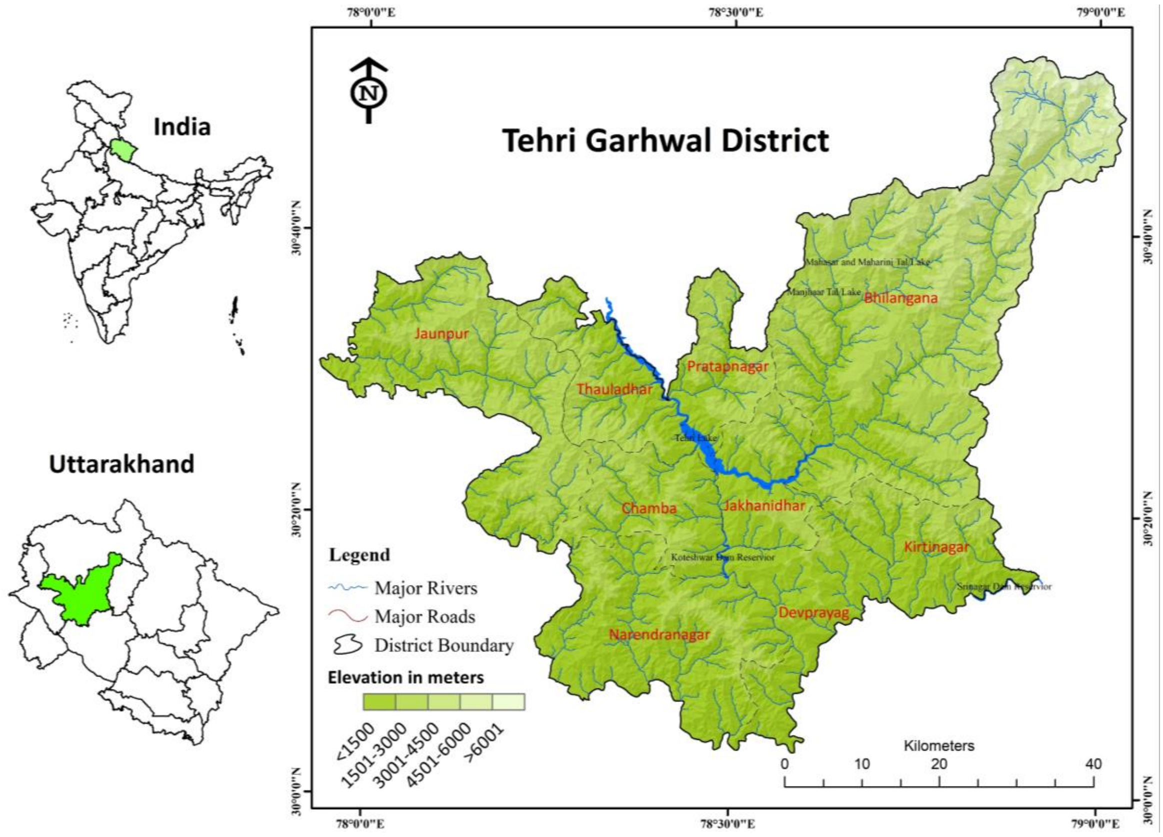

Fig 1. Location map of the study area

Land utilization beneath solar panels

Utilizing the land beneath ground-mounted solar plants for cultivating crops and medicinal plants presents a promising and sustainable strategy to maximize space efficiency. According to the primary data, out of 50 surveyed solar plants, 30 did not use the land beneath them for cropping. In contrast, 20 Solar plants (40%) effectively utilized this space for growing various crops and medicinal plants. The major crops cultivated beneath the panels include potato (*Solanum tuberosum*), ginger (*Zingiber officinale* Roscoe), coriander (*Coriandrum sativum L.*), tomatoes (*Solanum lycopersicum* L.), Sarso/mustard (*Brassica campestris* L.), beans (*Phaseolus vulgaris* L.), chili (*Capsicum frutescens* L.), cholai (*Amaranthus tricolor* L.), onion (*Allium cepa* L.), garlic (*Allium sativum* L.), methi (*Trigonella foenum-graecum* L.), cabbage (*Brassica oleracea var. capitata* L.), cauliflower (*Brassica oleracea var. botrytis* L.), carrot (*Daucus carota* L.) and radish (*Raphanus sativus* L.) (Figure 2). Additionally, the cultivation of medicinal plants such as arvi (*Colocasia esculenta* L.), amli (*Oxalis corniculata* L.), Bathua (*Chenopodium album* L.), makka (*Zea mays* L.) and turmeric (*Curcuma longa* L.) has been recorded in the area (Figure 2). This integration of solar infrastructure with agriculture not only promotes sustainable land use but also fosters diversified and eco-friendly farming practices. It highlights the potential for the coexistence of renewable energy projects and agricultural activities, underscoring the importance of strategic planning and land management for a more holistic and sustainable approach to energy production and food cultivation.

Fig 2. Showing various medicinal plants and vegetable crops growing beneath the ground-mounted solar panels.

Discussion

Growing shade-loving medicinal plants beneath solar panels, a practice known as agrivoltaics, offers a promising integration of renewable energy production and sustainable agriculture (Zainol et al 2021). Plants such as Arvi (*Colocasia esculenta*), Amri (*Oxalis corniculata*), Goosefoot (*Chenopodium spp.*), *Oxalis trifolium, Trigonella, Zea mays* (corn/Makka) and Turmeric (*Curcuma longa*) thrive in shaded environments, making them ideal candidates for cultivation under solar arrays. This synergy optimizes land use, creates a favourable microclimate by reducing excessive sunlight and retaining soil moisture and enhances biodiversity. These medicinal plants, known for their anti-inflammatory, antioxidant, and various other health benefits, can provide farmers with a diversified income source, balancing agricultural productivity with renewable energy goals. The *Colocasia esculenta* requires consistent moisture and thrives in shaded environments, making it suitable for growth beneath solar panels and traditionally used to treat inflammatory conditions and gastrointestinal issues due to its anti-inflammatory properties. The *Oxalis corniculata* (Amli) is known for its antiscorbutic and diuretic properties, Amri is used in traditional medicine for treating skin diseases and wounds (Thakur et al 2016). It flourishes in shady areas, benefitting from the moderated temperature and humidity under solar panels. The *Chenopodium Album* (Bathua) have antiparasitic and anti-inflammatory properties, and are valued for their nutritional benefits (Suleman et al 2021). It can adapt to various light conditions, including partial shade, making them well-suited for agrivoltaics systems. The *Oxalis trifolium* is known for its high vitamin C content and possesses antioxidant and antimicrobial properties and is used in traditional medicine for pain relief. It prefers shaded environments for cultivation, thriving in the protective microclimate provided by solar panels. The *Trigonella* (Methi) has anti-diabetic, anti-inflammatory and antioxidant properties (Narapogu et al 2021). Its seeds are used to manage diabetes, enhance lactation, and improve digestive health. The leaves are also used in cooking and as a medicinal herb for their beneficial effects on blood sugar levels and cholesterol. It can grow in partial shade, making it a viable candidate for cultivation beneath solar panels where it receives filtered light and stable temperatures. The Corn silk from *Zea mays* is used as a diuretic and anti-inflammatory agent in traditional medicine (Hasanudin et al 2012). It typically requiring full sunlight, certain corn varieties can tolerate partial shade, making them adaptable to conditions beneath solar panels. The Turmeric (*Curcuma longa*) is widely known for its anti-inflammatory, antioxidant and antimicrobial properties, used in various traditional remedies (Verma et al 2018). Thrives in shaded and humid environments, making it excellent for agrivoltaics systems with the moderated microclimate provided by solar panels.

Conclusion:

The integration of shade-loving medicinal plants and vegetables beneath ground-mounted solar power plants (SPPs) in Tehri District of Uttarakhand Himalaya showcases an innovative and sustainable landuse optimization strategy. In the study of 50 solar power plants, 40% utilized the land beneath their panels for agriculture and cultivating variety of crops such as potato, ginger, coriander, tomatoes, sarso, beans, chili, cholai, onion, garlic, methi, cabbage, cauliflower, carrot and radish. Additionally, medicinal plants were also cultivated. This practice highlights the potential for synergy between renewable energy infrastructure and agricultural productivity. By fostering diversified and eco-friendly farming practices under solar panels, it is possible to achieve dual benefits which enhancing energy production while simultaneously supporting food cultivation. This approach promotes sustainable landuse, emphasizing the need for strategic planning and effective land management. This work underscores a holistic and sustainable pathway for the coexistence of energy projects and agricultural activities, providing a model that can be replicated in other regions to maximize land productivity and support environmental sustainability.

Acknowledgement
The authors would like to thank Indian council of social sciences (ICSSR) for doctoral fellowship to the first author.

References

Barron-Gafford G A, Pavao-Zuckerman M A, Minor R L, Sutter L F, Barnett-Moreno I, Blackett D T, ... & Nabhan G P (2019). Agrivoltaics provide mutual benefits across the food–energy–water nexus in drylands. *Nature Sustainability,* 2(9), 848-855.

Chamberlain D, Fuller R J, Bunce R G, Duckworth J C & Shrubb M (2020). Effects of land-use management on the production and potential of renewable energy from land. *Renewable and Sustainable Energy Reviews*, 133, 110365.

Dinesh H & Pearce J M (2016). The potential of agrivoltaic systems. *Renewable and Sustainable Energy Reviews*, 54, 299-308.

Dupraz C, Marrou H, Talbot G, Dufour L, Nogier A & Ferard Y (2011). Combining solar photovoltaic panels and food crops for optimising land use: Towards new agrivoltaic schemes. *Renewable Energy,* 36(10), 2725-2732.

Hasanudin K, Hashim P & Mustafa S (2012). Corn silk (Stigma maydis) in healthcare: a phytochemical and pharmacological review. *Molecules*, 17(8), 9697-9715.

Narapogu V, Swathi C, Polsani M R & Premendran J (2021). Evaluation of anti-diabetic and anti-inflammatory activities of Fenugreek (Trigonella foenum-graecum) seed extracts on Albino Wistar Rats. National Journal of Physiology, *Pharmacy and Pharmacology*, 11(11), 1277-1282. .

Singh S & Negi M S (2024). Sustainable Energy in Himalayas: A Case Study on Solar Power Development in Uttarakhand. *J Fundam Renewable Energy Appl*, *14*, 340.

Singh S, Kumar A & Negi M S (2022). An Assessment of Solar Power Potential and Prospects in India. *Int J Mech Eng*, *7*, 30-43.

Suleman M, Faiz A U H & Abbas F I (2021). Antibacterial, antiparasitic and phytochemical activities of Chenopodium album (Bathua) plant extract. *Bangladesh Journal of Botany*, 50(2), 417-421.

Thakur M, Asrani R K, Thakur S, Sharma P K, Patil R D, Lal B & Parkash O (2016). Observations on traditional usage of ethnomedicinal plants in humans and animals of Kangra and Chamba districts of Himachal Pradesh in North-Western Himalaya, India. *Journal of Ethnopharmacology,* 191, 280-300. .

Verma R K, Kumari P, Maurya R K, Kumar V, Verma R B & Singh R K (2018). Medicinal properties of turmeric (Curcuma longa L.): A review. *Int. J. Chem. Stud,* 6(4), 1354-1357.

Zainol Abidin M A, Mahyuddin M N & Mohd Zainuri M A A (2021). Solar photovoltaic architecture and agronomic management in agrivoltaic system: A review. *Sustainability*, 13(14), 7846.