Solar Energy Applications in Agriculture with Special Reference to North Western Himalayan Region

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Authors’ contributions
This work was carried out in collaboration among all authors. Author NHM wrote the first draft of the manuscript. Authors FAB, SSM, BAA and MAB critically analysed and modified the manuscript. Authors AA, NH, SI and SF helped in literature searches. All authors read and approved the final manuscript.

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ABSTRACT
The UN Sustainability Goals emphasise on use of renewable sources of energy viz wind, solar, hydro power, biomass etc which are increasingly becoming important in the global energy mix. India with a 900 GW potential, aims to have 175 GW by 2022 and about 40% of total power production from renewable sources by 2030 with solar source contributing the most (83%). Solar energy is the most fundamental renewable energy resource with many agricultural applications. The abundance of solar energy makes it suitable for electricity and thermal applications and hence can be used in agriculture in photovoltaic electricity generation, powering irrigation, crop and grain drying, pesticide application, greenhouse heating and ventilation, cold storages etc. North western Himalayan regions are energy-poor with high energy requirements. Low ambient temperature, high Global
Horizontal Irradiance (GHI) and Direct Net Irradiance (DNI) of 4.8–6.43 kWh per square metre per day indicate huge solar potential, higher solar photovoltaic electricity and solar thermal production efficiency. Solar energy can replace or supplement conventional sources used for domestic and agricultural applications in the region. However, the use of solar energy is limited by policy and regulatory obstacles, financial obstacles, land availability constraints and low PV conversion efficiency. Hence a robust policy, financial measures and technological refinement are needed to remove the bottlenecks. In this paper, attempts have been made to discuss solar energy use in agriculture, scope in the north western Himalayan region of India and future recommended strategies.

Keywords: Agriculture; energy; solar; renewable; North Western Himalaya.

1. INTRODUCTION

Access to energy, water and food security is very imperative for human existence, poorness alleviation and sustainable development [1,2]. Factors like population growth, technological advancement, social and economic development, and climate change are set to increase the demand for clean water, energy and food significantly [3]. Globally 1.1 billion people lack modern, reliable energy supply and this might increase to 1.2 billion people by 2030 [4]. Agriculture sector consumes about 40% of worldwide energy use and involves, direct and indirect energy uses. Agriculture sector uses about 18.0% of electricity consumption [5], 7% of total petroleum products and 15% of total High Speed Diesel consumption in India. Direct energy is utilized in carrying out various field operations like land preparation, sowing, irrigation, harvesting and agricultural transportations. Indirect energy is used in the manufacturing, packing, transport and use of fertilizers, pesticides, seeds and agricultural machinery. Agriculture is an energy intensive activity with energy utilization in fertilization, irrigation, mechanisation, harvesting and processing, livestock and labour essential to the food production processes [6,7].

World’s primary energy to the tune of 85-90% is presently met from diminishing, hazardous, fossil fuels like coal which generates three-quarters of electricity in India. The India’s demand for energy like elsewhere will increase drastically, doubling by 2030 India's total energy with electricity demand tripling by the same time [8]. The current inefficient and subsidized/free electricity, usage pattern in Indian agriculture needs more sustained and focused measures [9]. The energy situation is variable across the regions with arid and hill regions, being the hotspots of energy poverty. Under the United Nations “Sustainable Energy for All” agenda, there is a goal to double the share of renewable energy globally by 2030 [10] and also to reduce the per capita consumption [11]. Renewable Energy Sources like solar, wind, hydro-power, geothermal, biomass, owing to their easy availability, environmental safety and inflation protection [12] are beneficial over conventional sources. Solar energy is beneficial over other renewable sources because of its modular nature, low costs, reliability or persistence, control of emissions, air, soil and water contamination from fossil fuels [13].

Global renewable energy consumption reached 171 GW in 2018 at a rate of 7.9 per cent increase from solar-wind energy [8]. India has about 900 GW renewable potential, with highest contributions from solar (83%) and wind (12%) followed by bio-energy (3%) and small hydro-power (2.2%) [14]. By 2030, India’s target is to have 40% renewable energy based power. The Indian Government has set a target of generating renewable energy to the tune of 175 gigawatts (GW) by 2022 [15] with wind energy comprising 60 GW and photovoltaic solar energy of 100 GW (including rooftop installed 40 GW) [16]. Renewable energy capacity in India in 2020 was 86.76 GW, with the production mostly from Karnataka, Tamil Nadu, and Gujarat states [8].

2. SOLAR ENERGY

Solar radiation is the most fundamental renewable energy source [17] and the conversion of solar into chemical energy is the foundation of all agricultural production processes [18]. Solar energy is a widely used resource in agricultural applications [19] and is expected to be the most important future renewable energy source (Table 1). The earth intercepts approximately 1.8 x 10^11 MW [20] which is over 20,000 times more than the energy consumed by humanity [21]. India is located in the equatorial belt and hence receives abundant
sun shine of about 5000 trillion kWh per year with a daily solar power potential of 0.25 kWh/m² on an average. The average solar insulation in India varies between 4-7 kWhm⁻² day⁻¹ with 250 -300 bright sunny days per year [22]. On the basis of solar availability, India is broadly divided into: Eastern, Himalayan, Northern, Southern -Middle and Western Zones with radiations of 3.5– 4.0 kwh/m², 4.0–4.6 kwh/m², 4.6–5.2 kwh/m², 5.2– 5.8 kwh/m² and 5.8–8.3 kwh/m², respectively [23].

Solar energy can be used either through photovoltaic technology which directly converts solar energy into electric energy or through solar thermal applications converting solar energy into heat [19]. Solar energy is a clean form of energy with no harm on climate, is inexhaustible, abundant and reduces cost and improves efficiency of farm operations [24]. Solar availability is more in countries with warm and sunny conditions and hence coinciding with the highest population and economic growth expected [23]. Flat plate collectors and concentrators are used for solar thermal applications whereas photovoltaic cells are used for electricity generation. Moreover electricity thus generated can be thermodynamically converted into mechanical energy. Of late simpler, well-designed, cost-effective and reliable solar systems have been developed and have been found to enhance productivity in the world agriculture [19].

3. APPLICATIONS OF SOLAR ENERGY IN AGRICULTURE

3.1 Photovoltaic Electricity Generation

As the agricultural electricity demand is set to increase many folds (Table 2), photovoltaic electricity could reduce the power deficits. Photovoltaics (PV), invented at Bell Labs, United States in 1954 [26], are mostly made of purified silicon and convert sun light into electricity. PV material, with many solar cells or one single thin layer, generated electricity varies in intensity according to the sunshine as more electricity is produced with more intense sunlight. Sunlight radiant on the material, dislodges electrons producing electric current which can be subsequently used. Photovoltaic (PV) systems are highly potential and might have higher efficiency than photosynthesis in solar energy capturing [27]. About 10 watt of electricity is generated per square feet of solar panel [21]. PV systems are cheaper, require less maintenance than diesel generators, wind turbines, or batteries alone and may be most suitable in areas with no power lines. Photovoltaic systems provide useful and economical electricity in far-off spots in agricultural farms, grazing lands, fruit orchards and for various agricultural activities [28]. On the basis of lifecycle, photovoltaic is more economical and favourable in small power applications wherever electricity is not available and fuel based machines are expensive to operate. The fall in the module prices of PV systems and removal of subsidies for fossil fuels, is believed to accelerate the use of PV systems further [13].

3.2 Solar Farming

Solar farming or solar energy farming (SEF) or agro photovoltaic (APV) generally means energy production from agricultural lands thereby raising the value of arable land further [13]. Solar panels can be set up at 15-20 feet and in proper configuration over farm fields for simultaneous crop and power harvesting without impacting the crop growth, particularly in horticultural crops. The shade of panels can also reduce irrigation crop growth, particularly in horticultural crops. The shade of panels can also reduce irrigation requirements [30]. The electricity thus generated can be used to meet the farm needs and the surplus power can be sold. Crop cultivation and renewable energy production is possible and efficient wherein solar power can be generated in a crop production system like grapes [31].

Agro photovoltaic (APV) can be most effectively used in developing countries facing high scarcity of water and agricultural land; and surplus energy can have many agricultural uses, like drying, heating, cooling, grinding and even power distribution [24]. APV can be highly profitable renewable energy system in densely populated and or mountain, island regions, with less land area [32] and arid/semi-arid regions where PV panels improve crop water use efficiencies [33]. APV enhances the overall profitability of farming by generating additional income through energy production and improves off-grid electrification as part of decentralized energy systems. In an Agro-electric Model about 250 tonnes/year CO₂ could be sequestered from 17.5 acres plantation besides economic and social impacts [34].

Solar plants worth 1.33 million MW capacity could be installed on 1% of India’s land area and about 2000 billion kWh electricity can be generated by using only 1% of India’s
wastelands. The expected annual land productivity of Rs 1 million per acre @ 4 Rs/kWh is manifolds higher than the irrigated, most productive agricultural lands [35].

3.3 Solar Water Pumping In Agriculture

Water pumping is a key energy demand in the agricultural sector and farmland irrigation uses about 15-20% of India’s total electricity [36]. In fact, water pumping was among the first applications of solar power in India that would replace 4-5 million diesel powered water pumps, with 3.5 kilowatts consumption per pump [35]. Modern irrigation systems like drippers, sprinklers etc. are vital in ‘more crop per drop’ mission, however, ensured and reliable power supply is essential to operate these systems. Photovoltaic (PV) water pumping systems may be the most suitable and least expensive irrigation option in off grid locations [24]. Solar powered pumps work most efficiently in the hot summer months when irrigation need is the highest. The size and cost of a solar water pumping system is determined by the solar energy available, the depth of pumping, installation costs and the water demand, and. PV systems are highly cost-effective for livestock water supply in remote locations, pond aeration, and sprinkler irrigation systems [37], ensure crop yield improvement and use of excess electricity for domestic needs and operating small farm machines. Solar radiation is available at the site of irrigation and hence does not need profuse transmission and distribution systems. Solar pumps will also reduce financial losses to Distribution Companies resulting due to subsidised power to farmers.

Consumption of one litre diesel produces about 2.6 Kg of CO₂. Diesel consumption exceeds 4 billion litres in India in addition to 85 million tons of coal per year to support irrigation water pumping. Replacing one million diesel pumps by solar pumps might save 9.4 billion litres diesel, Rs 8,400 crores and CO₂ emissions of 25.3 MT over the entire life cycle of solar pumps [38].

Replacing diesel with solar irrigation system would generate carbon credit equal to 5,48,548.76 generating revenue equal to USD 21,941,950.40 when sold at USD 40 and USD 382,98,676.80 when sold at USD 80 (Table 3) [39].

3.4 Cold Storage- Agriculture Value chains

Up to 90% of food loss in developing countries is lost in the supply chain resulting into poverty, hunger and ill health, as well as the environmental impacts. In India, despite sufficient and surplus production, rural poverty, undernutrition and hunger still prevail and cold-chains are an essential contributor to food security. India’s storage capacity is only 10 % (31 million metric tons) of the total production and hence great shortfall [30]. Conventional cooling technologies use fossil fuel based electricity and diesel for transport and refrigeration. The average operational energy for a conventional Vapor Compression Cycle (VCC) based cooling system is about 2 kWh/ Ton of Refrigeration [40]. The refrigerant industry faces various challenges due to the impact of refrigerants (Chlorofluoro carbons or CFCs) on the global environment [41].

Solar panel installations on roofs of storage units/warehouses can prove to be an important solution to post-harvest horticultural losses. Solar powered reefer vans and push carts can also minimize transportation and hence capital losses. Shelf life enhancement and extended storage is possible with solar shade of push carts and solar refrigerators particularly during warm and humid weather [30].

A privately-owned cold storage at Sonepat, Haryana handles about 11,000 MT of apple, kiwi, banana and other fruits sourced from Himachal Pradesh, Kashmir, and Assam and handles import-export trade with many countries. Conventional Freon based VCC refrigeration system is aided with a solar PV system which helps to reduce the energy bill by 10% [41]. A Farmer Producer Company (FPO) set up a solar powered cold storage and silo in Rampur, UP with storage capacity of 10 metric tonnes for cold storage and 100 metric tonnes for silo for storing organic vegetables ensuring fresh produce and better returns [42].

3.5 Solar Operated Farm Equipments

Solar sprayers, solar tractors, solar mowers and cutters, multipurpose machines, milking machines and even solar powered robots have been developed and tested for agricultural uses. Solar powered tractors and mowers are remotely operated, have high initial cost but low maintenance and are growing in demand [43].
Table 1. Estimated contribution of renewable energy sources to the total energy demand in India [25]

<table>
<thead>
<tr>
<th>Year</th>
<th>Installed capacity of renewable energy Sources (GW)</th>
<th>Expected Generation (Billion Unit)</th>
<th>Total energy requirement (Billion Unit)</th>
<th>% Contribution of renewable energy source</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Solar</td>
<td>Wind</td>
<td>Biomass</td>
</tr>
<tr>
<td>2021-22</td>
<td>175</td>
<td>162</td>
<td>122</td>
<td>38</td>
</tr>
<tr>
<td>2026-27</td>
<td>275</td>
<td>243</td>
<td>188</td>
<td>64</td>
</tr>
</tbody>
</table>

Table 2. Agricultural and total electricity demand (TWh) in India [29]

<table>
<thead>
<tr>
<th>Sector</th>
<th>2012</th>
<th>2022</th>
<th>2030</th>
<th>2047</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture</td>
<td>136</td>
<td>245</td>
<td>336</td>
<td>501</td>
</tr>
<tr>
<td>Total</td>
<td>762</td>
<td>1433</td>
<td>2239</td>
<td>4712</td>
</tr>
</tbody>
</table>

Table 3. Economic and environmental effects of diesel and solar pumps in Rajasthan, India [39]

<table>
<thead>
<tr>
<th>Crop</th>
<th>Diesel consumption per hectare (L/Ha)</th>
<th>Carbon emission (Kg/Ha)</th>
<th>Area irrigated by diesel pump (Ha)</th>
<th>Total diesel consumption in state (Million Litres)</th>
<th>CO₂ emission (tonnes)</th>
<th>Carbon credit*</th>
<th>Carbon price @ USD 40</th>
</tr>
</thead>
<tbody>
<tr>
<td>Groundnut</td>
<td>330</td>
<td>231.66</td>
<td>1,65,545.3</td>
<td>54.63</td>
<td>142,037.90</td>
<td>5,681,516.00</td>
<td></td>
</tr>
<tr>
<td>Bajra</td>
<td>82.5</td>
<td>57.91</td>
<td>54,620.1</td>
<td>4.51</td>
<td>11,716.00</td>
<td>4,68,640.00</td>
<td></td>
</tr>
<tr>
<td>Wheat</td>
<td>165</td>
<td>115.83</td>
<td>8,80,779.3</td>
<td>145.33</td>
<td>3,77,854.32</td>
<td>15,114,172.80</td>
<td></td>
</tr>
<tr>
<td>Barley</td>
<td>82.5</td>
<td>57.91</td>
<td>78,976.8</td>
<td>6.52</td>
<td>16,940.54</td>
<td>6,77,621.60</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>660</td>
<td>463.32</td>
<td>11,79,921.55</td>
<td>210.99</td>
<td>5,48,548.76</td>
<td>21,941,950.40</td>
<td></td>
</tr>
</tbody>
</table>
Bobde et al., [44] designed and developed a solar powered agri-cutter. It was based on the general principle of mowing and its performance was evaluated on different types of grasses showing 93% efficiency and a field capacity of $1.11 \times 10^{-4}$ ha/hr. Kumar and co-workers [45] designed and fabricated a solar powered multipurpose machine and reported that the machine can be practically used for sowing, levelling, weeding and fertilizing. Solar energy can be used in spraying pesticides, fungicides and fertilizers etc., through solar sprayers to reduce drudgery and environmental impacts.

Solar sprayers are efficient, save large quantities of fuel and reduce environmental pollution [46]. A solar operated sprayer uses a solar PV cell and mainly consists of a DC battery and DC motor. Solar photovoltaic sprayers with application rates of 84 litre h$^{-1}$, covering 0.21 ha h$^{-1}$ and solar photovoltaic duster have been successfully developed and tested [47]. A solar operated sprayer was developed consisting of a solar panel of 20 W capacity with operating speed of 2.5 km h$^{-1}$, theoretical field capacity of 0.6 ha h$^{-1}$, effective field capacity 0.5 ha h$^{-1}$ and field efficiency of 83.33 % [48]. Solar fencing and solar-powered animal deterrent lights are being used for protection of livestock, agricultural land and farm houses against animals like elephants and wild boars in Karnataka [49].

4. SOLAR THERMAL APPLICATIONS

4.1 Crop and Grain Drying

Sun drying of agricultural produce is one of the oldest and very widely used applications of solar energy. But the traditional open sun drying of farm produce is time consuming and less hygienic. Mechanized drying is faster and uses less land, but is costly. Considering the limitations of open sun drying, mechanical drying and also due to electricity shortages and rising fuel costs, solar drying seems the most potent alternative for food processing [23].

Solar dryers protect agricultural and horticultural products, dry uniformly at a rapid rate while improving product quality compared to open-air methods. Solar drying saves energy, time, occupies less area, improves product quality and protects the environment [18]. Solar dryers basically consist of an enclosed area, drying trays and a solar collector. A simple solar crop drying system may be a glazed box with a dark-colored interior to collect solar energy, which heats the air inside the box and heated air is moved by convection process or by a fan. Amount of material being dried, moisture content of the material, and availability of solar radiation determine the collector size and airflow rate. The advantages of solar drying include early and well planned harvest, long-term storage, better quality produce, less storage space, transport and distribution, better returns and maintain seed viability [24]. Solar food processing can generate energy for alternative uses and also reduces substantial food losses. Tunnel and Chimney type dryers can be used for drying various spices, fruits and vegetables and even meat. Cabinet type solar dryers have been found to produce cleaner and nutritious fruit bars compared to open drying and have a long shelf life [23]. The colour of solar dried grapes showed high acceptance as compared to the natural dried sample (medium acceptance) Gallalali et al. [50]. Higher degree of whiteness was found in solar dried rice than sun dried rice. Mehdiza et al., [51].
4.2 Space and Water Heating

Solar energy can be used to heat space and water in animal husbandry and other agricultural operations. Commercial dairy farms and poultry farms have high energy needs to heat water, equipment cleaning, udder stimulation of cows and for heating and ventilation requirements. A large amount of energy can be provided by solar air/space heaters [28], [52]. Water heating systems are either natural or forced convection forms and may be either direct where water in the current collector is heated and consumed, and indirect where water is used for heating a fluid such as a water-glycol antifreeze mixture in collectors [18].

Water heating needed for cleaning purposes etc [24] can account for 25% energy costs of a typical farm and water heating along with cooling milk accounts to about 40% of the total energy used. The efficiency of solar water heaters depends on the solar energy availability and temperature of incoming water. Single solar flat plate collector with a minimum heating capacity of 100 L of water to about 60 °C under winter conditions have been developed. A 100 L solar water heater can save up to 1500 units of electricity and 1.5 tonnes of Co₂ per year [53].

4.3 Greenhouse Heating

Photovoltaic renewable energy use is a must for sustainable greenhouse crop production [54]. Photovoltaic panels, in addition to electricity generation, can provide shade and reduce or limit excess solar radiation entering the greenhouse in high radiation areas and seasons [55]. Solar greenhouses store the trapped solar heat energy through solar thermal mass and retain this heat through insulation for use during the night and on cloudy days. In comparison to conventional greenhouses, solar greenhouses are equipped with heat-storing materials to retain solar heat; insulation in case of little or no direct sunlight; have glazing material to minimize heat loss and have natural ventilation system for summer cooling [24]. Photovoltaic heating systems for greenhouses are generally suitable for high-value crops.

Ezzaeri et al. in 2018 [55], in an experiment conducted in Morocco, reported that the mean plant height and yields of tomato was higher in a PV green house compared to that found in the control greenhouse, due to better conditions inside the PV greenhouse. Hence Photovoltaic panels can play a positive role in improving the tomato yield. Consequently, farmers of warm climates can install flexible solar panels on 10% of the roof of their tomato greenhouses to produce electricity, without harming their agricultural production in spring-summer crop cycles. Surprisingly, this study also revealed that the use of the photovoltaic panels on the roof of the greenhouse plays a positive role in term of reducing the development of T. absoluta (leaf miner).

5. SOLAR ENERGY- SCOPE AND INITIATIVES IN THE NORTH WESTERN HIMALAYAS

Himalayan regions are the hotspots of energy-poverty, whilst facing energy security and changing climate challenges. In Hindu Kush Himalayan countries vast majority (over 80%) of the rural population still are deprived of reliable, modern energy sources even for cooking [56]. Energy poverty in Himalayan regions is mostly due to inaccessibility, fragility, and marginality nature of such communities [57].

Mountain societies are highly dependent on natural resources, and hence more vulnerable to threats of climate change driven process. The interactions of climate change process with tectonic, geomorphic and ecological agents make the region prone to disasters. This vulnerability further exacerbates due to high dependency on agriculture and other natural resources for livelihoods [58]. The increased demand for irrigation due to more diversification and intensification of agricultural systems has lead to increased demand for electricity in Himalayas [56]. Due to its unique characteristics, energy usage dynamics is complex in the Himalayan states. Fuel wood continues to be major source of thermal energy, although inefficiently utilized. Due to fossil fuel based energy consumption, there has been increased pollution and glacial melting in the Himalayan terrain. With increasing population, commercialization and higher energy demands, grid extension for electricity supply has become an inevitable solution. However, this results in further ecological damages to an already fragile landscape. Sustainable locally available renewable energy sources are seen as the most potential energy demand mitigating options with biomass, hydro, solar, and wind forming the primary energy base in the region [59]. With rich forest (20 %), shrub lands (15 %) and grassland
(39 %) resources, the Hindu Kush Himalayas have a high hydroelectricity generation potential, i.e., over 500 GW [60], but sadly presently major part is diverted to the plains besides ecological implications. North Western Himalayan states have a high potential of renewable energy generation mainly solar energy (Table 4) that could have domestic, industrial and agricultural applications. With increasing fuel costs and contrarily declining PV costs worldwide, it is highly believed that by 2040 PV power will be competitive with coal-based power.

5.1 Jammu and Kashmir and Ladakh

Jammu and Kashmir is one of the energy-starved states in India resulting in poor development of all sectors in the region [61]. Agriculture consumes about 3.48 % of total electricity [62]. Even with huge estimated solar potential, the state has not made much progress in this direction [63]. Harnessing 10 % of solar radiation (1 kWh/m² surface) at 10 % conversion efficiency from only 0.01 % surface area of the state can potentially generate $2.22 \times 10^9$ MW energy, sufficiently meeting domestic energy requirements of the farming community [64]. Jammu and Kashmir has a solar potential of 111.05 GWp which is second highest after Rajasthan with 142.32 GWp [65].

The average annual GHI and DNI for all regions in J&K vary between 4.8-6.43 kWh per square metre per day [66]. Solar energy can effectively replace conventional sources used for domestic and agricultural applications. The Jammu and Kashmir ‘Solar Power Policy-2010 and several other policies were laid down by government to promote solar energy use [67].

The power requirement in Ladakh might increase to 140.5 MW by 2025. Currently, over 8000 litres of diesel are used per day to generate power in Ladakh [68]. Supplying power to isolated remote areas specifically during winter season, voltage fluctuations, higher fuel costs [69], massive deforestation and land degradation are the factors that demand and make solar energy the most viable renewable energy form in Ladakh. With over 320 days of sunshine in a year, high DNI and GHI, and about 23 GW potential [70] Ladakh is known as the solar capital of India.

Annual average solar radiation in Ladakh is about 5.54 kWh m² day⁻¹, with a maximum received during the month of September [68] and solar radiation of 2149 kW h/m² per year [71]. The low summer temperatures (< 27°C) ensure high PV module efficiency in producing electricity from sun.

A 50,000 crore mega solar power project in Ladakh was announced and promoted by Solar Energy Corporation of India (SECI) of MNRE in 2017 which aimed to develop two solar parks capable of generating 7500 MW solar energy by 2023. Of this 2500 MW in Kargil will transmit electricity into Kashmir valley and 5000 MW in Leh will have transmission lines up to Haryana and Delhi [70].

5.2 Himachal Pradesh

Renewable energy sources have high potential for lighting, cooking, water and space heating in the region [72] and as many initiatives have been taken by government for the renewable energy promotion with state being pioneer in using passive solar space heating of government and semi-government buildings. According to Artificial Neural Network (ANN) models, HP state is richly blessed with solar resource and low wind resource [73]. Himachal Pradesh receives an average insulation of 5.86 ± 1.02–5.99 ± 0.91 kWh/m²/day in the warm summer months and has an average GHI of 5.08 kWh/m²/day. Solar radiation above 4.5 kWh/m²/day is good for PV electricity generation, solar water heater and solar cooking [74]. Lahaul and Spiti have maximum average yearly solar energy production while as Shimla having the minimum [73].

Table 4. Estimated renewable power potential in NWH states (MW) [5]

<table>
<thead>
<tr>
<th>State/UT</th>
<th>Small Hydro power</th>
<th>Biomass power</th>
<th>Waste to Energy*</th>
<th>Solar Energy</th>
<th>Total</th>
<th>Distribution (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>J&amp;K</td>
<td>1707</td>
<td>43</td>
<td>-</td>
<td>111050</td>
<td>112800</td>
<td>10.28</td>
</tr>
<tr>
<td>HP</td>
<td>3460</td>
<td>142</td>
<td>2</td>
<td>33840</td>
<td>37444</td>
<td>3.41</td>
</tr>
<tr>
<td>UK</td>
<td>1664</td>
<td>24</td>
<td>5</td>
<td>16800</td>
<td>18493</td>
<td>1.69</td>
</tr>
<tr>
<td>India Total</td>
<td>21134</td>
<td>17536</td>
<td>2554</td>
<td>748990</td>
<td>1097465</td>
<td>-</td>
</tr>
</tbody>
</table>

* Industrial waste
Himachal Pradesh receives 99530395 MU of solar energy per annum and utilizing solar energy incident on 0.1% area of the state can generate 43324 MU annually. Further using only 0.1% land area of every district can generate 56206 MU of energy per year and this energy can be utilized along with other sources particularly in the higher altitude areas with sparse and isolated population [75]. HIMURJA, the nodal agency for promotion of renewable power in the state, had announced to generate and use 28 MW of solar energy in the state [76].

The Solar Irrigation Scheme or Saur Sinchayee Yojana was launched in HP in 2018 to make water accessible in every farmer's field and reduce the pressure on traditional energy sources. A budget provision of Rs. 200 crores was made for five years under which 5850 solar pumps are to be installed in the state. Presently 1189.71 hectare land has been brought under the scheme installing about 1210 solar pumps benefiting 2066 farmers. Under the Pradhan Mantri Kisan Urja Suraksha Evam Utthan Mahabhiyan Yojana (PMKUSUM), a provision of 85 % financial assistance for pumping machinery for the use of solar pumps to the farmers especially in remote areas lacking electricity and irrigation have been started in the state [77].

5.3 Uttarakhand

Uttarakhand state with its multiple microclimatic zones ranging from cold temperate to tropical zones, receives a good amount of solar insulation, about 4.5–5.5 kWh/m² with average solar radiation of 5.32 kwh/m²/day and average annual solar radiation of 1300 Kwh/Sq.m. Using 10% of total geographical area of the state can generate solar energy equivalent to solar power potential of about 4077 MW. A total cumulative capacity of 576.38 MW renewable energy has been deployed in the state in which solar energy has the highest share of 45.46% (262 MW) followed by small hydro-energy 34.31 % (197.78 MW) and bio energy 20.23% (116.60 MW). Solar Power Policy was issued in the state in 2013 aiming to install 500 MW solar power by 2018 [78].

In 2016, Uttarakhand Renewable Energy Development Agency (UREDA) launched a scheme in which 200 individuals from the state called as ‘Power Farmers’ were selected to set up solar plants (5 KV to 500 KV capacity) in villages to generate and supply solar power to state government at a fixed price of Rs. 4.35 per unit. It included installation of solar plants costing Rs. 70,000 per KV with net returns of 1500-2000 per individual per month [79]. UREDA in 2020 launched a special program providing employment opportunities to the youth and small and marginal farmers for enhancing their income through the sale of power to Uttarakhand Power Corporation Limited (UPCL). 1000 solar projects of 25 kW grid-connected solar projects totalling 250 MW were planned in the state for employment opportunities [80].

6. SOME SPECIFIC SOLAR ENERGY APPLICATIONS IN NWH REGION

6.1 Solar Water Pumping

The hill states of J&K (0.37 out of 0.9 m ha), Himachal (0.11 out of 1.0 m ha) and Uttarakhand (0.35 m ha out of 0.8 m ha), have very less area as the total crop area actually irrigated and is mostly canal and groundwater irrigated. Hence there exists a great scope of increasing irrigated area in the region. Solar pumps have immense potential in the region for lifting irrigation water from rivers and streams. For instance, in Kashmir valley rainfall decreases after May and except some showers of rain in July-August, most of the growing season remains dry. The problem of water shortage is severe in kandi areas and karewa lands where canals either cannot be dug or water supply cannot be conveyed. In this scenario lift irrigation by pumping to higher levels and then carrying through canals or digging wells and drawing out water by a lever system is a useful strategy. Solar water pumping can be a highly effective under such circumstances and also could be used for modern irrigation systems like sprinkler and drip irrigation in fruit orchards etc wherever farm electrification is not done and conventional fuels are costly. A 3 HP pumping system, costing Rs. 3.5-4.00 lakhs, is generally suitable for water pumping with a delivery head of about 75 m [68].

6.2 Solar Farming

As electricity supply in remote villages, tough terrains and agricultural fields is very challenging and land @2 ha MW⁻¹, is required for electricity generation through solar power plants, due to availability of abundant waste lands, fallow lands and fruit orchards, solar power can be generated in the region ensuring reliable power supply, income generation and safety in case of crop
failures. A 4 kW roof top PV system can generate about 6.66 MWh of electricity annually at Leh [68]. A 10 MW Agro-Photo-Voltaic (APV) project was recently announced by central government to be set over 100 ha at saffron fields of Pampore, J&K. The states of J&K, HP and Uttarakhand had 7.38, 2.25 and 1.28 million hectares of wastelands in 2010. Using only a small fraction (1 %) of these wastelands can generate enough solar power for the region. Under Mukhyamantri Kisan Aay Badhotari Yojana, the government of Delhi in 2019 approved the installation of solar panels on about one-third of the total land owned by a farmer. The farmers will be paid Rs 1 lakh per acre as rent with 6 % annual increase for 25 years and by 25th year the farmer will be getting Rs 4.04 lakh per acre from the companies. This model is supposed to increase the farmer’s income by 3-5 times besides receiving 1000 units of electricity every year for each acre of land. Such a model can also be adopted in the North western region for benefiting the farming community [81].

6.3 Solar Green Houses

Harsh winter conditions restrict crop production in the Himalayan regions, and as such cultivation under controlled environment of greenhouses is the only practical option [82]. Solar green houses are cost effective, eco-friendly and can maintain up to 20°C (±5°C) inside temperature while the outside temperature is extremely low (−40°C). Winter vegetable production under solar green houses is a promising area because of shortage of vegetables due to unfavourable growing conditions and transportation interruptions. There has been reported about 8 times more vegetable production and 30 % income rise by adopting solar green houses in Ladakh over conventional green houses.

6.4 Solar Dryers

Inclined type solar dryers of capacities varying from 10-100 kg, can be adopted in Himalayan regions for drying of fruits and vegetables, resulting in savings of about 290 to 300kWh/m² equivalent energy [68]. Solar drying has been tested in case of Saffron drying in which farmer’s practice i.e open shade drying (27-53 hours) was compared with hot air or solar drying which took only 4-7 hours and resulted in quality improvement by preventing enzymatic degradation of pigments, better texture, flavour etc. [83]. Shahi and co-workers [84] reported that drying under a Poly house type solar dryer was helpful in decreasing the time taken for dehydration by about 40–55 % in various vegetables and fruits under Kashmir conditions.

6.5 Cold Storages

Jammu and Kashmir has a controlled atmosphere storage requirement of 4 lakh mt whereas the availability is only 1.16 lakh mt. Photovoltaic energy can be used as a standalone system or can be used to supplement the existing electricity lines or diesel gen sets for agricultural/horticultural refrigeration. Solar thermal based cold storage can also be employed which is more efficient than PV system based cold storage units [85]. An On-farm green refrigeration system called Pusa-Farm Sun Fridge has been developed at ICAR-IARI, New Delhi. The cold storage facility is 100 % solar powered with a cold storage capacity of 2 tonnes. A 5000 mt storage plant project has been approved at Agriculture complex, Jammu having a solar power facility.

6.6 Solar Space and Water Heaters

Solar space and waters heaters can be used for domestic, dairy and poultry purposes. Space heaters can help retain warmth inside cattle sheds and poultry units thereby maintaining animal wellbeing and reducing bird mortality in the winter months. Interest Subsidy Solar Water Heating Systems (SWHSs) scheme was launched in J & K in March, 2015. The mountain areas face grave energy crisis and high dependence on fuel wood poses a potential threat to ecology, health of household inmates and involve drudgery in fuel wood collection. Water and space heating consume over 50 % of fuel wood/dung and causes indoor pollution, carbon emissions and forest degradation. Replacing conventional fuel wood by solar power can reduce about 4.9 MT carbon emissions per annum per household in mountainous cold regions besides saving in time and travelling [86]. These savings can indirectly benefit farming community in diverting the finances towards agricultural activities and raising income.

7. BARRIERS TO SOLAR ENERGY DEVELOPMENT

1. Renewable energy sector is faced with Policy and regulatory obstacles (lack of a comprehensive policy/regulations), institutional obstacles (insufficient and poor
inter-institutional Coordination), financial and fiscal obstacles (budgetary constraints and high initial unit capital costs), technological and educational obstacles (lack of market, skilled human resource) [25].

2. The shortage and rising cost of land is a serious constraint in reducing solar energy cost on per unit basis. Increased land costs (1 percent of total cost in 2011-12 to 4.7 percent in 2016-17) further increase the total cost of solar energy production [8].

3. Integration of solar PV to grid, intermittent nature of solar power and expensive battery storage in case of solar energy are the other issues.

4. The PV solar panels directly convert sunlight into electrical energy with an efficiency of about 12-15 % which reduces further due to heating losses, dust, and weather hence making solar power very expensive. The short life of storage batteries (5-6 years), replacement cost and disposal of batteries containing hazardous material are other challenges [21].

8. FUTURE RECOMMENDATIONS FOR SOLAR ENERGY DEVELOPMENT

1. Formulation of a comprehensive action plan or policy for the promotion of the renewable sector in the country.

2. Strong budgetary allowances should be provided for the clean energy development. Though investments have increased but are still not enough. China has about 128 times higher annual budget for renewable energy development compared to India. R&D should be strengthened in the country through policies and funds. Setting up of individual solar power plants, use of need based electricity, energy saving.

3. In order to reduce the cost and dependency on imports for cell and module requirements, strong manufacturing market needs to be developed indigenously.

4. The solar energy development and widespread use needs social awareness, human resource development and strong integration and idea sharing between the state, industry and academia.

5. Comprehensive educational and awareness modules need to be developed for renewable energy systems. Research to develop highly efficient, low cost, and long lasting photovoltaic cells and storage batteries.

6. The renewable energy application and performance can be made more effective through hybridization of two or more renewable systems (e.g solar + wind) along with the conventional sources.

7. The limitation of vast land availability can be largely overcome by using wastelands, surfaces of water bodies etc. The most practical approach may be to encourage and increase rooftop installations.

8. Renewable energy use in small and marginal farmer dominated Indian agriculture can be best achieved through small farmer groups and cooperatives. The best examples in India include the Solar Pump Irrigators Cooperative (SPICE), Gujarat, Community solar pumps under Oorja Development scheme in Uttar Pradesh etc.

9. CHAKHAJI, BIHAR- SOLAR IRRIGATION SERVICE PROVIDERS (SISP) - A SUCCESS STORY

With the support from CGIAR research programs on Climate Change, Agriculture and Food Security (CCAFS) and Water, Land and Ecosystems (WLE) and in partnership with Agha Khan Rural Support Program, India (AKRSP-I), the International Water Management Institute (IWMI) initiated field testing of an alternate model of solarising Bihar’s agriculture in Samastipur district of north Bihar through enterprising farmers. After one year, the experiment showed that the effective cost of irrigation declined by more than 50 %; almost all the diesel pumps operating in the area were crowded out; it contributed to reduced pollution; helped farmers to practice pre-monsoon sowing of kharif crops, and this also left more time for a third summer crop; increasing the gross cropped area significantly (3 % in kharif, 5 % in Rabi and 10.2 % in Summer/Zaid) and increasing the overall value of agricultural output (46 %) [87].
10. CONCLUSIONS

Due to global warming, fast depletion and rising fuel prices and non-reliable electricity supply, demand for energy alternatives has increased worldwide. As the energy needs of agriculture are increasing and there is an increased emphasis on renewable energy use, solar energy seems the most promising energy option worldwide. Solar energy can effectively replace or supplement diesel, fuel wood and hydro power, and has many agricultural applications like electricity generation for rural and farm requirements, farm produce drying, crop cultivation under controlled green house conditions, water pumping etc. India being a tropical country with high solar availability in general and North western Himalayan regions because of energy poverty, rising energy needs and high solar potential (GHI ≥5 kWh/m²/day and more than 250 sunny days) in particular are anticipated to be solar energy hotspots in the future. India has a renewable energy potential of about 900 GW with highest contributions from solar (83 %) and by 2022, India aims to have photovoltaic (PV) solar energy of 100 GW. However policy issues, land constraints, lower efficiency and intermittent nature of solar availability are the serious obstacles that mar the use of solar energy in agricultural applications. In order to generate and use solar energy most efficiently, strong policies, huge investments and technological refinement are immediately needed.

DISCLAIMER

The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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