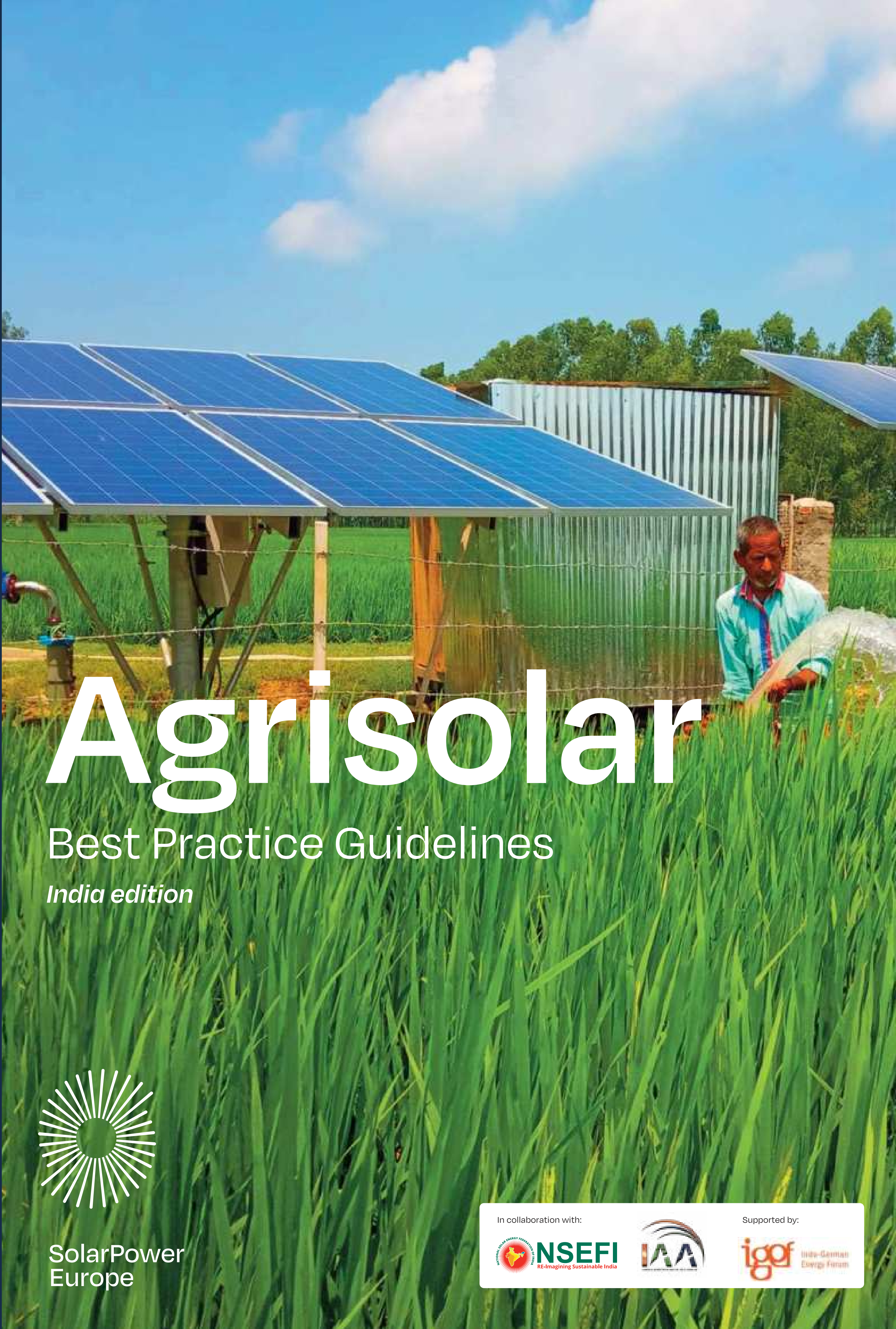


Agrisolar

Best Practice Guidelines

India edition

SolarPower Europe

In collaboration with:

NSEFI
RE-Imagining Sustainable India

Supported by:

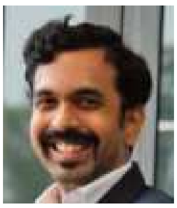
Foreword

Welcome to the India edition of the Agrisolar Best Practice Guidelines. India is currently the fourth biggest solar market globally, with its installed capacity standing at 73.32 GW at the end of 2023, representing roughly 7% of the global market share. The rapid growth of solar in the country has sharpened competition for land for new PV power plants. If India is to reach its target of 280 GW of solar by 2030 it will increasingly have to turn to innovative applications, such as Agrivoltaics, to overcome the pressures on available land.

The advantages for both industries of co-locating solar and agricultural are undeniable. One of the benefits is additional income for local farmers through higher crop yield as well as from power generation or from renting land. Agrivoltaics can also provide a useful adaptation measure to climate change, shading plants and helping farmers to exercise more control over growing seasons, or protecting crops from adverse weather conditions.

The India edition of the SolarPower Europe's Agrisolar Best Practice Guidelines reflects the experience and views of both European and Indian stakeholders from the industry. Supported by the Indo-German Energy Forum (IGEF), the document is based on the second edition of SolarPower Europe's Agrisolar Best Practice Guidelines, adjusted to the Indian context in a joint effort between SolarPower Europe, National Solar Energy Federation of India (NSEFI), and 68 Indian and European solar industry professionals.

We thank IGEF for their support, and NSEFI and SolarPower Europe members for their engagement, which reflects the importance of Agrisolar for the solar industry.



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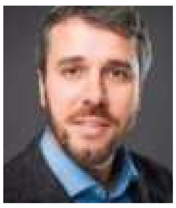

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Abbreviations

CAZRI	Central Arid-Zone Research Institute
CIAS	Composite Index of Agricultural Sustainability
DC	Direct current
EPC	Engineering, procurement, construction
GHG	Greenhouse gas
GWp	Gigawatt peak
IGEF	Indo-German Energy Forum
IPBES	Platform on Biodiversity and Ecosystem Services
IPCC	Intergovernmental Panel on Climate Change
LCA	Lifecycle Assessment
MFOT	Motion Free Optical Technology
Mha	Million hectares
MLPE	Module Level Power Electronics
MoU	Memorandum of Understanding
MWp	Megawatt peak
NSEFI	National Solar Energy Federation of India
O&M	Operation and maintenance
RCC	Reinforced Concrete Columns
SAC	Sustainable Agriculture Concept

1 Introduction

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Today, the world faces an unprecedented crisis – human-induced global warming, which is rapidly affecting the Earth's climate. In March 2023, the Intergovernmental Panel on Climate Change (IPCC) published the final part of its 6th Assessment report; it concluded that greenhouse gas (GHG) emissions due to human activities are warming the climate at an alarming rate: global surface temperature has risen by 1.1°C compared to the pre-industrial period. Under all emission scenarios, the IPCC estimates that global warming will reach 1.5°C by the early 2030s. The report also draws attention to the alarming effect that global warming has on food security, saying "about half of the global population currently contends with severe water scarcity for at least one month per year. Climate change has also slowed improvements in agricultural productivity in middle and low latitudes."[1]

The impacts of climate change in India have become strikingly evident; during the months of March and April 2022 temperatures soared to unprecedented levels, breaking both decadal and all-time records in various regions. Across the country, from the western Himalayas to the plains of Punjab, Haryana, Delhi, Rajasthan, and Uttar Pradesh, temperatures consistently hovered 3°C-8°C above the average for more than six consecutive days. This extended heatwave extended its reach to states like Odisha, Madhya Pradesh, Gujarat, Chhattisgarh, Telangana, and Jharkhand, where severe heatwaves with temperatures ranging from 40°C–44°C were reported by the end of March.[2]

In response to this, India has emerged as a global leader in the adoption of renewable energy, making significant strides in combating climate change. As of October 30th, 2023, the country has successfully installed 132.13 GW of renewable energy capacity, with solar power accounting for a substantial 72.02 GW of this total.[3] Underlining its commitment to a sustainable energy future, India has set an ambitious target of achieving 500 GW of renewable energy capacity by the year 2030.[4] In 2022, India achieved a remarkable milestone by adding 15 GW of renewable energy capacity. Building on this momentum, the country has set even more ambitious targets for the coming years. The plan is to increase the annual installation to 25 GW in 2023-24 and further elevate it to an impressive 40 GW in 2024-25.[5] These targets underscore India's determination to accelerate its transition towards a cleaner and more sustainable energy landscape. India estimates a massive USD 15 trillion investment will be required to fund the necessary infrastructure and initiatives to meet the ambitious goal of achieving Net Zero emissions by 2070.[6]

Despite these impressive advances, most of the country's power needs are served by coal-fired generation which poses significant challenges for India's agricultural sector and the nation's food security, both of which are heavily reliant on the monsoon season. Over the past century, the central belt from western Maharashtra State to the Bay of Bengal has experienced a threefold increase in extreme rainfall events, coupled with longer dry spells.[7]

1 Sophie Boehm and Clea Schumer (2023).
2 India Meteorological Department (2023).
3 Ministry of New and Renewable Energy (2023).
4 Ministry of Power.
5 Saurav Anand (2023).
6 The Economic Times – India Times (2023).
7 Roxy Koll et al. (2017).

The adverse effects on agriculture were particularly pronounced, with the heatwave disrupting critical stages of crop development. The grain filling process crucial for crop yield, especially for crops like wheat, was significantly hindered. These changes have posed challenges to a sector integral to India's economy and food security.

Moreover, the Himalayas, traditionally acting as a shield against drought, are now under threat. Predictions indicate that by 2100, at least one-third of the glaciers in the region will vanish. Glacial melting, a consequence of rising temperatures, has intensified both flooding and drought, particularly affecting agricultural mountain communities dependent on seasonal snowmelt.[8]

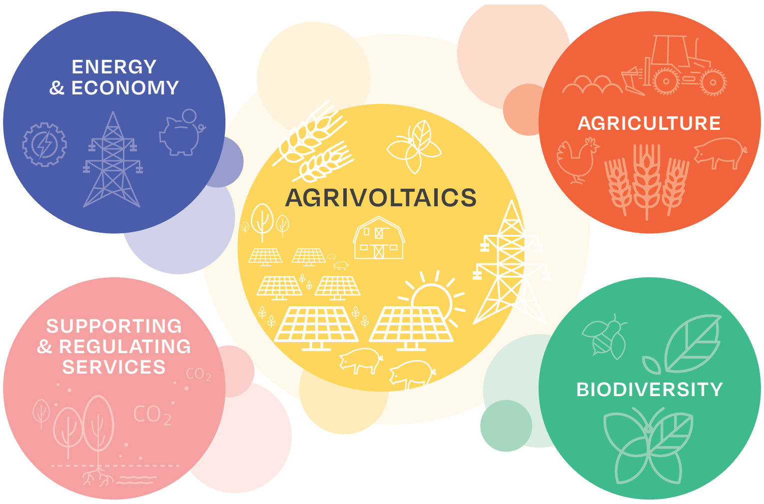
The Indian agricultural sector is navigating the complex terrain of sustainability, as highlighted by the Composite Index of Agricultural Sustainability (CIAS) developed by scientists at the Indian Council for Agricultural Research.[9] The index, comprising indicators categorised under soil health, water resources, biodiversity and ecology, and socio-economic factors, reveals a moderate level of sustainability at the all-India level, with an average CIAS of 0.50. Notably, Mizoram, Kerala, Andhra Pradesh, Madhya Pradesh, and West Bengal emerge as beacons of sustainable agriculture, showcasing significant strides in crop diversification, improved agricultural infrastructure, responsible farm credit practices, and sustainable input use. However, the arid landscape of Rajasthan stands as the least sustainable, signalling a need for targeted interventions to bolster sustainability in this critical sector. The Indo-Gangetic Plains, encompassing states like Uttar Pradesh, Punjab, Bihar, and Haryana, as well as rice-dominant regions such as Jharkhand and Assam, face heightened risks due to their agricultural practices putting food security at risk.

In parallel, global food insecurity has increased since 2016.[10] The increase in food commodity prices and the COVID-19 pandemic have all impacted the global food market, and reduced the availability of food on a global level. Global food prices increased by over 60% in March 2022, in comparison to the previous year.[11] Food insecurity has doubled in 2023 in comparison to 2020, with almost 345 million people at risk of not accessing sufficient food according to the World Food Programme.[12] The Russian invasion of Ukraine had a significant impact on global food markets as Ukraine has seen a large decline in exports causing food prices to increase further. High food prices can impact the affordability of products and threaten low-income and vulnerable groups globally. Solar irrigation, among the most mature applications, is being widely adopted to improve access to water, thus enabling multiple cropping cycles and increasing resilience to changing rainfall patterns. The use of solar irrigation pumps has raised farmers' incomes by 50% or more in India compared to rain-fed irrigation.[13] Cold storage and refrigeration are a necessity at every stage of the agri-food chain to increase shelf life, cut losses, and maintain the quality of products from crops, livestock, and fisheries.

As per the Land Use Statistics 2018-19, the total geographical area of India is 328.7 million hectares, of which 139.3 million hectares is the reported net sown area and 211.36 million hectares is the gross cropped area with a cropping intensity of 151.08%. The net sown area works out to be 42.4% of the total geographical area. The net irrigated area is 71.6 million hectares.[14] Soil health is inevitably linked to agricultural practices in India. Soil degradation is a significant environmental issue that poses severe threats to sustainable agricultural development and ecosystem health in India. It refers to the deterioration of soil quality, fertility, and functionality due to various natural and human-induced factors. According to the National Bureau of Soil Survey and Land Use Planning, soil degradation in India affects approximately 147 million hectares (Mha) of land. This degradation includes 94 Mha from water erosion, 16 Mha from acidification, 14 Mha from flooding, 9 Mha from wind erosion, 6 Mha from salinity, and 7 Mha from a combination of factors.[15] Some more important causes of soil degradation in India are land clearing, unsustainable agricultural practices, over-grazing, and urbanisation & industrialisation. Soil also plays a vital role in carbon sequestration. However, soil degradation leads to a loss of soil organic matter and affects the soil's capacity to store carbon. Consequently, it is crucial to ensure sustainable land practices because it will help to preserve soil ecosystems, guarantee food security, and safeguard climate adaptation measures.

8 Philippus Wester et al. (2019).
9 Chhabilendra Roul and Prem Chand and Suresh Pal (2020).
10 Food and Agriculture Organization of the United Nations, the World Bank Group and the World Trade Organization (2023).
11 FAO (2024),
12 World Food Programme (2023).
13 IRENA and FAO (2021).
14 Ministry of Agriculture and Farmers Welfare (2023).
15 Council of Agricultural Research (ICAR).

FIGURE 1 CO-BENEFITS OF AGRI-PV



Scarcity caused by the expansion of different economic sectors puts pressure on land resources and creates competition for land. Besides, additional pressure on land availability stems from an increase in global food production, which in turn is caused by the growing population on a global scale. On top of that, human-induced activities and climate change pose high risks to the natural world. According to the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES), at least one million animal and plant species are considered to be under threat of extinction.[16] Indian policymakers are also now prioritising environmental and biodiversity policies. With the National Biodiversity Action Plan (NBAP), the objectives are to conservation of biodiversity, sustainable use of its components, and fair and equitable sharing of benefits arising out of the use of these resources.[17] Healthy ecosystems are the foundation for human well-being, as they can provide food, fresh and clean water, and fuel.[18] More than 90% of our food comes from terrestrial ecosystems and provides humans with other services.

The development of renewable energies, particularly solar energy, on the one hand, and the maintenance of agricultural land use, on the other, could appear irreconcilable, leading to a conflict of use for the same land. However, there is a solution that makes it possible to maintain and enhance agricultural production, while producing PV energy: Agrivoltaics (hereinafter referred to as Agri-PV and defined in Chapter 2: Sustainability).

Agri-PV has gained attention worldwide due to the opportunities it presents to co-locate energy generation, while providing multiple ecosystem services. This application brings a range of benefits, including land efficiency or land productivity, while maximising synergies between energy, food, and environmental security (see Figure 1).

PV panels offer a buffering effect to agricultural production facing extreme climatic events and can provide favourable micro-climatic conditions with the right design. Numerous studies have shown that shading by PV panels offers multiple additive and synergistic benefits, including reduced drought stress on plants, increased food and biomass production, and reduced heat stress or protect the plants against severe weather events. Ultimately, the synergies between the agricultural world and the photovoltaic sector demonstrate the endless positive benefits of PV installations which do not harm agricultural activities.

16 IPBES (2019).
17 Ministry of Environment, Forest and Climate Change (2019).
18 Dr. Priyom Bose (2022).

The theoretical potential of Agri-PV in India is high: agricultural land accounts for 59.09%, where 45.52% is net sown area.[19] An estimate shows that solar PV production could offset global energy demand if less than 1% of cropland were converted to Agri-PV systems.

In a published study conducted by Fraunhofer ISE, it was estimated that total installed Agri-PV capacity in India could reach as much as 783 GW by 2040.

Another study says that India has an Agri-PV potential greater than 1.2 TW, emphasising the wide scope of this technology.[20] Such data highlights the potential of Agri-PV to contribute to decarbonisation targets, and secure renewable energy deployment.

In addition to environmental benefits, Agri-PV offers multidimensional opportunities by facilitating sustainable development in agricultural areas. Agri-PV can be beneficial to rural economies, by creating jobs, generating community income, and tax revenues, and by providing diverse income revenues to farmers and landowners. Agri-PV can play a crucial role, especially in rural areas with high droughts and arid landscapes, which desperately need sustainable agriculture and energy production practices. Job creation and improving economic prosperity by increased and diversified income streams in rural areas can, in turn, reduce rural-to-urban migration or so-called rural depopulation. In India the rural population of declined from 82.9 % (in 1915) to 67.2 % (in 2015).[21] The projections for 2050 suggest that the urban-rural segregation will be 52.8% and 47.2% respectively.[22] Agri-PV can boost the socio-economic welfare of rural areas, which is the foundation for a sustainable and prosperous future.

1.1 Goal and scope of the report

A dual land-use approach responds to renewable energy production needs, while simultaneously enhancing the value of agricultural production. Specifically, it facilitates climate adaptation measures and increases the agricultural sector's resilience towards climate crises, by providing optimal protection of crops in extreme weather conditions. Other benefits include improved efficiency in the use of land and other natural resources - including water - improved crop yields, soil health, and biodiversity enhancement. In parallel, Agri-PV can boost the local economy, and support rural development. To maximise these benefits, the Sustainable Agricultural Concept (SAC) needs to be followed. To ensure high quality Agri-PV projects, adequate planning, and project design need to be considered at an early stage, as well as throughout the project development and operation phase.

The aim of this report is, therefore, to review the best international practice for Agrisolar, and provide information on:

- Criteria for benchmarking the quality of Agri-PV installations through assessing their impact on agriculture, the environment and farmers, and the quality standards of the installation itself.
- Existing Agri-PV projects in India; these updates will include data on crop yield, water and soil efficiency, biodiversity enhancement, and socio-economic benefits.
- Information on innovation in Agri-PV; these updates will include an overview of new pilot projects and demonstrators, updates on new research projects, and innovation trends in the sector.
- Engineering, Procurement and Construction (EPC) and Operations and Maintenance (O&M) best practices.

This document provides guidance for the deployment of sustainable Agri-PV practices for solar industry stakeholders; it also addresses wider stakeholder groups and serves as an informative tool for the Agrisolar sector.

19 Ministry of Agriculture & Farmers Welfare (2023).
20 CSTEP (2023).
21 Akash Gulankar (2019).
22 Umesh Sah.

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2.1 Definition of Agrisolar and Agri-PV

In this report, Agrisolar is used as a general term to refer to a market sector where sustainable agriculture practices are combined with PV installations. Sustainable agricultural practices aim to improve environmental and socio-economic benefits for the farm and its land. Decarbonisation of a farm's energy supply provides a strong basis for the adoption of other practices aimed at improving overall sustainability, including agroecology, or local community engagement. The scope of Agrisolar includes, but is not limited to, the deployment of solar panels on barn roofs, or the use of solar electricity to power agricultural machinery.

Some other Agrisolar examples are:

- Integration of solar panels into irrigation systems: Some systems use floating solar panels or panels mounted on structures to generate energy, while supplying water to the crops. This solution enables more efficient water usage by combining irrigation and solar energy production.
- Agricultural sheds with solar roofs: Agricultural sheds are often used to store equipment, rear livestock, or for crop protection. Thanks to the installation of solar panels on the roof of these structures, solar energy can be generated without losing agricultural land. The solar panels can be mounted on fixed supports or designed to track the sun's movement.

Agri-PV is defined as a land-use concept that co-locates PV installations and energy generation, with agriculture and nature conservation, which are dependent on sunlight.

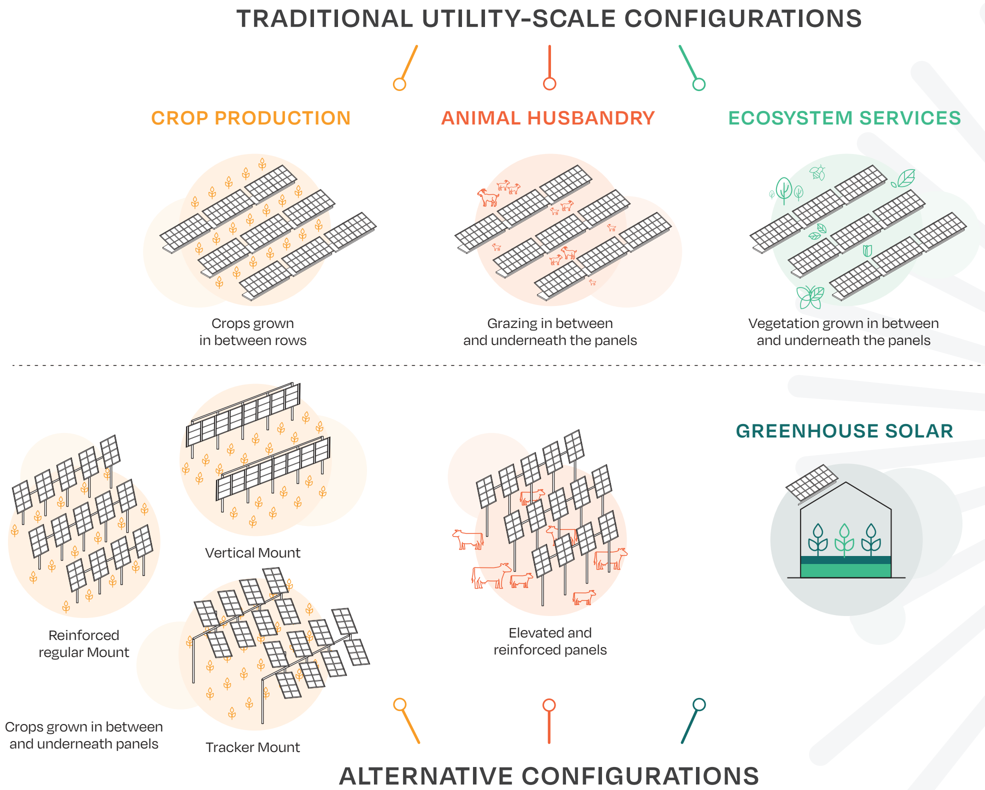
Agri-PV offers a wide range of applications, adaptable to each production site, and the local conditions (See Figure 2). Some of the most common applications can be seen in Table 1 on the following page.

Agri-PV installations should guarantee that agricultural activity is at least preserved, and ideally improved. An approach of PV implementation on farmland in harmony with agriculture and nature conservation needs to be at the core of Agri-PV development.

TABLE 1 COMMON EXAMPLES OF AGRI-PV APPLICATIONS

Combination of crops and solar farm	Cultivation of intercropped crops, or offering grazing areas for animals between rows and, in some cases, beneath solar panels. Preferred types of crops are those with leafy vegetables. These solutions help optimise land use and can increase land productivity.
Elevated solar panel installations, with or without dynamic	Solar panels are mounted on elevated structures above crops or animals. This allows crops to grow beneath the installations and benefit from partial shading provided by the panels. This provides a climate change adaptation solution, protection against adverse weather conditions, agronomic benefits, and/or improved animal welfare.
Solar greenhouse	Systems that are equipped with solar panels to simultaneously produce agricultural goods and energy. The panels provide shading to the crops and protect against adverse weather conditions.
Aviaries with solar shading structures	Poultry farms often require covered structures to protect birds from adverse weather conditions and predators. In this context, solar shading structures are used as the roof of aviaries, providing shelter to birds whilst generating electricity. The shading can be designed in order to allow optimal natural light penetration, ensuring animal welfare.
Vertical PV	Systems are designed to harness solar energy using vertically oriented PV panels. Unlike traditional horizontal panels, vertical PV systems are installed on vertical structures which help optimise the use of space, especially in rural areas. This configuration allows for increased energy generation and architectural integration, making it suitable for applications in Agrivoltaics, where horizontal space is limited.

FIGURE 2 DIFFERENT AGRI-PV APPLICATIONS



SOURCE: Cleantechnica.

2.2. Climate change effects on agriculture and food security of India

The pervasive effects of climate change on Indian food and agriculture underscore the imperative for sustainable practices and adaptive measures. According to the IPCC, projections indicate that certain regions may face a substantial decline in precipitation, potentially reaching up to 30% by the year 2100.[23] This anticipated decrease poses a formidable challenge to rain-fed agriculture, which constitutes 60% of India's agricultural landscape.[24]

The concurrent spread of pests and diseases has inflicted a toll on global crop yields, with estimates suggesting a reduction ranging from 10% to 25%.[25] This dual onslaught necessitates resilient and adaptive agricultural practices to mitigate losses.

The scenario compounds the challenges faced by low-lying coastal regions in India, demanding robust adaptation strategies to safeguard agricultural productivity. The ramifications of climate change in agriculture extend beyond immediate crop losses, with the World Bank projecting that the cumulative impact could force an additional 100 million people into extreme poverty by 2030.[26]

India, with a temperature rise of about 0.7°C over the last century, is experiencing altered climatic conditions that impact crop growth patterns. According to the Indian Agricultural Research Institute (IARI), wheat yields could witness a substantial decline of up to 23% by 2050, with a parallel decrease of up to 10% in rice yields - a staple crop essential to the nation's food security.[27]

The melting glaciers in the Himalayas pose a multifaceted challenge, affecting river flow and subsequently impacting water availability for irrigation. In a country where 60% of agriculture relies on rain-fed practices, the potential disruption to water sources underscores the urgency of sustainable water management and conservation measures.

The melting glaciers in the Himalayas pose a multifaceted challenge, affecting river flow and subsequently impacting water availability for irrigation. In a country where 60% of agriculture relies on rain-fed practices, the potential disruption to water sources underscores the urgency of sustainable water management and conservation measures.

Projection scenarios underscore the gravity of the situation, with rainfed rice yields in India anticipated to decrease by 20% in 2050 and a staggering 47% in 2080 in the absence of adaptation measures. Similarly, irrigated rice yields are projected to decline by 3.5% in 2050 and 5% in 2080 scenarios. Wheat, another agricultural cornerstone, faces a potential yield reduction of 19.3% in 2050 and a stark 40% in 2080 scenarios, introducing significant spatial and temporal variations.[28]

The outlook for kharif maize, a vital crop in the Indian agricultural portfolio, foresees yield reductions of 18% and 23% in 2050 and 2080 scenarios, respectively.[29] These projections necessitate a comprehensive re-evaluation of agricultural practices, emphasising sustainable, climate-resilient approaches to safeguard food security and mitigate the far-reaching impacts of climate change on Indian agriculture.

2.3. Indian agricultural sustainability policies

2.3.1. PM – KUSUM Scheme

The PM-KUSUM Scheme is a government initiative to provide clean energy to farmers by solarising their water pumps and allowing them to set up small solar power plants on their land. The Scheme has three components:

- Component A: Installation of 10,000 MW of decentralised ground- or stilt-mounted solar power plants on barren, fallow, pasture, marshy or cultivable land of farmers of capacities ranging from 500 kW to 2 MW. Such plants can be installed by individual farmers, solar power developers, cooperatives, village councils (panchayats), and farm producer organisations.
- Component B: Installation of 14 lakh (1.4 million) stand-alone solar-powered water pumps in off-grid areas.
- Component C: Solarisation of 35 lakh (3.5 million) grid connected water pumps through individual pump solarisation (C1) and feeder level solarisation. (C2)

23 Gerald A. Meehl et al. (2007).
24 Bioremediation and Bioeconomy (2016).
25 CABI.
26 Bramka Arga Jafino et al. (2020).
27 Ministry of Agriculture & Farmers Welfare (2023).
28 PIB Delhi (2023).
29 See 28.

The Scheme aims to achieve the following objectives:

- Decarbonisation of the agricultural sector, reducing dependence on fossil fuels and saving costs for farmers.
- Providing water and energy security to farmers, ensuring reliable irrigation and power supply.
- Increasing the income of farmers, enabling them to sell surplus solar power to the grid and earn extra revenue.
- Curbing environmental pollution, reducing greenhouse gas emissions, and enhancing soil health.
- Potential to generate direct employment among rural communities.

The PM-KUSUM Scheme is relevant to Agrivoltaics as it provides an opportunity for farmers to adopt this innovative approach and reap its advantages. For instance, under Component A, farmers can install solar power plants on their cultivable land and grow shade-tolerant crops or fodder under the panels. Under Component B and C, farmers can solarise their pumps and use the water for irrigation or livestock. Under Component C, farmers can also solarise their feeders and supply power to other agricultural activities, such as cold storage, processing units, etc.

The PM-KUSUM Scheme is one of the largest initiatives in the world to promote clean energy and Agrivoltaics in the farm sector. It has the potential to transform the rural economy and enhance the livelihoods of millions of farmers in India. As of November 2023, the installed capacity of KUSUM – A is 141.33 MW against the total sanctioned solar capacity of 4,766 MW.[30]

2.4. Role of Agri-PV in sustainable agricultural development

Agri-PV has a key role to play not only in producing renewable energy, but also by supporting rural areas, and ensuring sustainable agricultural practices. Agri-PV offers several opportunities to minimise environmental pressure, provide socio-economic benefits to farmers, and fight against climate change. Agri-PV provides solutions to minimise land scarcity issues driven by different competing sectors, and the growing global population. It also offers solutions to limit water scarcity issues; protect and increase crop growth; provide sustainable energy production; and support rural areas against severe weather conditions such as droughts and floods.

2.4.1. Environmental impacts

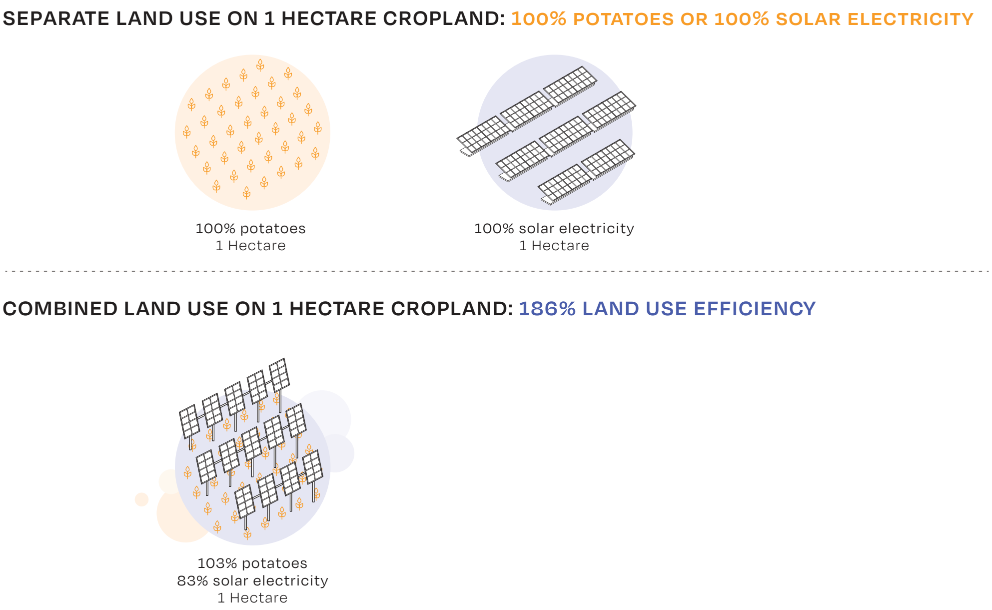
In a recent study conducted by M. Wagner et al., environmental impacts of single-use agriculture and overhead Agri-PV systems were compared using Lifecycle Assessment (LCA). The results illustrated the positive environmental benefits of Agri-PV systems installed on agricultural land. They showcase the positive environmental impacts in fifteen out of sixteen impact categories including land use, climate change and eutrophication. In addition, they indicate that, under certain conditions, Agri-PV systems can contribute to renewable energy production without decreasing food production resources.[31]

2.4.2. Land productivity

Various reports and studies have showcased the increase in land productivity, resulting from the co-sharing benefits of Agri-PV. According to a study conducted by A. Sarr et al., Agri-PV systems can improve land productivity by 35-73%, whereas other studies estimated the land productivity to increase by 60-70%.[32] Figure 3 (on the following page) showcases the increase in land efficiency by 186% where PV installations are co-located with potato cultivation. Similarly, an increase of more than 30% in the economic value of land has been estimated in a study conducted by Dinesh and Pearce.[33] This increase in the economic value was achieved by reducing crop yield loss as a result of PV panels providing shading to selected crops.

30 PM KUSUM Scheme, Ministry of New and Renewable Energy.
31 Moritz Wagner et al. (2023).
32 Aminata Sarr et al. (2023).
33 Harshavardhan Dinesh and Joshua Pearce (2016).

FIGURE 3 INCREASE IN LAND USE EFFICIENCY IN POTATO CULTIVATION WITH CO-LOCATION OF ENERGY PRODUCTION



2.4.3. Water efficiency

Agriculture irrigation or watering accounts for 70% of total global freshwater usage.[34] A rise in atmospheric temperature caused by global warming, and an increase in severe weather conditions will put additional stress on drought-prone regions. To adapt to these global challenges, water efficiency and sustainable water management will be essential. There is a high correlation between evapotranspiration and solar radiation. Agri-PV can help to reduce water usage for irrigation by decreasing evapotranspiration through PV module shading. This will reduce crop water demands, and increase water use efficiency. Moreover, less energy will be required to power irrigation systems, and improvements in microclimatic conditions, such as temperature and soil moisture, or water use efficiency for irrigation purposes, can positively impact crop cultivation in arid areas.

Studies have been conducted to assess soil moisture. The results showed an increase in soil moisture by 14.7% and 11.1%, in fixed and mobile installations respectively.[35] More efficient water use can be achieved by maintaining higher soil moisture. A study conducted by Adeh et al., estimated that water use efficiency improved by 328% - an increase resulting from the use of Agri-PV panels.[36] More specific results showcased the water use efficiency estimated at 157% for chili, 65% for tomatoes, and 12% for lettuce.[37] Furthermore, a reduction of approximately 20% in the water demand for lettuce was estimated in another study.[38]

2.4.4. Biodiversity enhancement

Agri-PV has significant potential to enhance biodiversity on solar sites. For instance, solar sites that establish pollinator habitats can benefit local flora and fauna and serve as an important conservation mechanism for endangered species. An increase in pollinator habitats can result in higher ecosystem restoration services such as crop pollination, and pest control in the vicinity of agricultural areas, which in turn can enhance crop yield for fruits like strawberries or

34 Tariq Khokhar (2017).
35 Shengjuan Yue et al. (2021).
36 Elnaz Hassanpour Adeh et al. (2018).
37 Mohd Ashraf Zainol Abidin (2021).
38 Yassin Elamri et al. (2018).

blueberries. In addition, appropriately designed and managed solar sites placed on degraded or low-value agricultural land can restore degraded land and even provide significant biodiversity net gains. These benefits include, but are not limited to, improved soil health, greater diversity of local flora and fauna and, more generally, support the restoration of ecosystems.

PV co-location with animal husbandry is another well-known concept and has shown great results in land productivity and compatibility. Several studies have shown the increase in land efficiency by co-sharing livestock grazing with energy production.

2.4.4. Plastic reduction and circularity

Another benefit of Agri-PV systems is the reduction of existing crop protection systems. Different methods such as plastic tunnels and shade nets are commonly used to protect high-value permanent crops. Agri-PV can work as a protection system and replace the use of plastic tunnels, the use of which can potentially increase toxicity in the environment. Therefore, a reduction in plastic use thanks to Agri-PV systems can have a positive impact on the environment and contribute to a circular economy.

2.4.6. Socio-economic

Socio-economic factors are key in supporting rural areas and their development. Agri-PV can play a role in contributing towards generating income, providing employment, and facilitating social support. Some of the socio-economic benefits of Agri-PV are listed below:

- Improved crop yield / food produce
- Avoiding losses and reducing some of the costs, for example, for irrigation
- Improved farmer income from higher yield
- Energy generation as a means of additional revenue
- Renewable energy communities
- Electrification of the agricultural sector
- Job creation and providing new qualifications in the agriculture sector
- Added value to agricultural sector by using the generated electricity to run facilities such as cold storage, food processing units, and climate controlled greenhouses.

Firstly, Agri-PV installations protect crops by mitigating the impacts of adverse weather conditions, and therefore guarantee economic performance in the context of climate hazards. Several studies[39] show that Agri-PV installations provide an opportunity to enhance economic performance and can increase farmers' income. There are two main economic models for farmers to enhance the value of their farms.

2.5. Agri-PV business models

1. A farmer installs an Agrivoltaic plant on their agricultural land and consumes the electricity produced, selling the excess to the grid via a PPA, signed under the PM-KUSUM – A Scheme or through open-access. This results in savings on electricity bills through self-consumption and improved economic gains through selling excess electricity and agricultural produce.
2. A farmer sells all the electricity produced by an Agrivoltaic installation on their land to the grid via a PPA, signed under the PM-KUSUM – A Scheme or through open-access. This results in two revenue streams, from the electricity and agricultural produce sold, but does not generate savings on electricity bills.
3. A solar developer leases agricultural land from farmers installing and running anAgrivoltaic power plant. The developer earns money through the sale of electricity to the grid via a PPA, signed under PM-KUSUM – A Scheme or through open-access, and the farmer receives revenue from the land lease and through the sale of agricultural produce.

The income from the sale of electricity from the plants or through land lease allows the farmers to receive a guaranteed annual rent for the entire life of the Agri-PV plant. This helps diversify and stabilise their income, and thus contributes to the development of their activity. Agri-PV is not only an affordable and economically profitable technology for farmers to use; it is also considered to be a safe investment.

In a context where the agricultural world is strongly subject to climatic hazards, Agri-PV guarantees a farm's financial security. By contributing to the revitalisation of the agricultural world, Agri-PV also plays a social role in regional development.

39 See 31.

2.6. Rural development and job creation

Agri-PV can also support rural development by creating additional jobs, generating additional revenues through energy production, and ensuring overall economic stability. However, certain skills and knowledge are needed to further accelerate the deployment of Agri-PV. These are outlined in Table 2.

The general approach of the Government of India to boosting skills development is to establish Centres of Excellence that work with relevant actors in the target industry.

TABLE 2 SKILLS AND KNOWLEDGE REQUIRED TO FURTHER ACCELERATE THE DEPLOYMENT OF AGRI-PV

Renewable Energy Engineering	Engineering is a key profession in the Agri-PV sector. From design to installation and maintenance of Agri-PV solutions, understanding of the PV technology, system sizing, and electrical design or grid integration is essential.
Agricultural knowledge	A solid understanding of agricultural practices is also an essential component of an Agri-PV project. Knowledge of crop cultivation, irrigation, soil management, and livestock farming allow for optimisd land use.
Project Management	Project Management: Effective project management skills are necessary for coordinating and overseeing Agrisolar installations to ensure timely execution, resource allocation, stakeholder coordination, and adherence to quality standards and regulatory requirements.
Electrical Skills	Electricians or electrical engineers with expertise in solar PV installations are required to handle the electrical components of Agrisolar systems. Their expertise can be used to ensure correct wiring, connections, and commissioning of solar panels, inverters, and electrical systems.
Construction and Installation	Construction workers such as technicians or installers are needed to install Agri-PV systems.
System Monitoring and Maintenance	Ongoing monitoring and maintenance are essential for ensuring the optimal performance and longevity of Agrisolar systems. Technicians or maintenance specialists are responsible for regular inspections, cleaning of panels, troubleshooting, and repairing any technical issues.
Environmental and Land Use Planning	Professionals with expertise in environmental impact assessment and land use planning play a crucial role in evaluating the environmental and social implications of Agri-PV projects. These professionals can ensure sustainability and regulatory requirements are adhered to.
Research and Development	Researchers and scientists are essential when it comes to the development of new technologies beneficial to the Agrisolar sector. Moreover, studies, data analysis and innovative solutions contribute to more productivity, and improved integration of Agri-PV solutions into agricultural lands and operations.
Policy and Regulatory Experts	Professionals with expertise in Indian renewable energy policies, regulations, and incentives can provide guidance to improve, understand and navigate the policy landscape.

Building on this, a Centre of Excellence for Agrivoltaics is being established at the Indian Agricultural Research Institute (IARI). The centre is supported by the Indo-German Energy Forum (IGEF) and the German Development Cooperation GIZ with the aim of advancing research and development at the intersection of solar energy and agriculture.

Another example of a remarkable initiative aiming at developing knowledge and skills is the India Agrivoltaics Alliance (IAA), spearheaded by NSEFI along with 10 like-minded organisations, which is dedicated to advancing the concept of Agrivoltaics in India, including the simultaneous use of land for both agriculture and solar energy generation. The objective of IAA is to foster cooperation among diverse stakeholders, including national and state policymakers, research institutions, academia, and industry players, to encourage collaboration for scaling Agrivoltaics in India and to support policymakers in elevating Agrivoltaics by leveraging comprehensive research, analysis, and actionable policy mapping to bolster momentum and ambition.

2.7. 3-star benchmark for Agrisolar projects: System evolution

The elements described above provide a good basis for the creation of a framework for benchmarking the quality of Agrisolar projects. This framework could take the form of a 3-star benchmark to be used in the initial design stage and throughout the lifecycle of a project. However, the attempted proposal developed in these guidelines should not be considered a fully-fledged quality assurance framework or a standard. Instead, these guidelines are meant to inspire the development of robust regulatory frameworks for Agrisolar.

A 3-star benchmark captures how well a specific Agrisolar project is designed and operated in terms of the agro-energetic synergies it creates, and its overall social and environmental sustainability. The agro-energetic synergies and its sustainability can be schematically represented, as seen in Table 3.

2.7.1 How to read the 3-star benchmark criteria

An Agrisolar project which respects the essential criteria of the SAC in these guidelines (minimum acceptable criteria), such as the preparation of the SAC itself, would qualify as an Agrisolar project with a one-star rating. If a project fulfills additional criteria (recommended criteria), such as demonstrating synergies between the PV system and the Agricultural activity, or whether the project contributes to socially or environmentally sustainable practices, the project will achieve a two-star rating. Finally, an ideal project that fulfils additional best-in-class criteria (best practice criteria), which maximise agro-energetic synergies or provide significant ecosystem services, will be awarded a full three-star rating. Notably, while fulfilling the minimum acceptable criteria is a basic requirement to be considered Agrisolar, fulfilling recommended and best practice criteria should remain optional. Not fulfilling one or more of these optional criteria would not preclude any system from achieving a higher quality rating. Importantly, the criteria identified in these guidelines are non-exhaustive and are meant only indicatively.

40 Ministry of Skill Development & Entrepreneurship (2019).

TABLE 3 AGRISOLAR CRITERIA

	MUST CRITERIA ★☆☆	SHOULD CRITERIA ★★☆	COULD CRITERIA ★★★
DIMENSION 1: Agriculture	• SAC which includes general information on the agricultural activity and PV system, assessment of needs of agricultural stakeholder, information on project land, technical plan of Agrisolar system, assessment of the use of equipment/machinery. • Fulfils the needs of agricultural activity and generates green electricity. • Selection of suitable crops: adaptation of crops that tolerate the partial shading caused by the solar panels to maximise agricultural productivity while allowing solar energy production. • Multi-layer farming and crop combination matrix for various geographical conditions (i.e. soya + pigeon pea, turmeric + leafy vegetables, etc.).	• Demonstrate synergies between PV and agriculture. • Evaluation of light distribution and micro-climatic conditions. • Water management performed. • Demonstrate transition towards sustainable practices like reintroduction of trees and animals on the site, introducing regenerative agriculture (applicable guidelines such as FAO guidelines on regenerative agriculture practices). • Use of softwares or approaches for design, light simulations (i.e. PVSyst, HOMER, Helios, Helioscope, • Use of software such as STICS and DSSAT for crop modelling and yield predictions).	• Maximise synergies between PV and agriculture. • Demonstrate improvements in the resilience of agricultural activity. • Demonstrate a net saving of water consumption on the farm. • Change the agricultural model to a polyculture model (transition away from monoculture practices). • Favour agroecological practices (avoid chemicals, pesticide use, etc.), to enrich soil and restore biodiversity. • Implement efficient irrigation: install water-saving irrigation systems for agricultural crops to minimise water losses and optimise the use of water resources.

TABLE 3 AGRISOLAR CRITERIA - *continued*

	MUST CRITERIA ★☆☆	SHOULD CRITERIA ★★☆	COULD CRITERIA ★★★
DIMENSION 2: Environment	• Effective assessment of environmental impact of the project (standard Environmental Impact Assessment). • Assessment of impacts on soil erosion, soil silting, assessment of water availability.	• Set min. standards for soil preservation during construction and dismantling. • Efficient tech, degradability of structures. • Apply a lifecycle approach. • Transition towards sustainable agricultural practices by enhancing local flora and fauna. • Introduce net water savings in water consumption. • Reduce land disturbances. • Reduce soil pollution. • Create ecological corridors: provide habitats for native flora and fauna, e.g. incorporate areas of native vegetation, provide habitats for insect pollinators, birds and other species beneficial to the agricultural ecosystem.	• Provision of ecosystem services. • Apply environmental guidelines such as National Biodiversity Action Plan • Provide soil regeneration and carbon capture services; provide monitoring of the data. • Change microclimate conditions to adapt to climate change: as part of a biodiversity enhancement, use assisted migration methods to accelerate species migration processes. • Carry out afforestation or reforestation measures, particularly within or between land parcels to support biodiversity quality. • Increase tree cover on the site. • Increase land productivity. • Accommodate projects that can contribute to climate change adaptation.
DIMENSION 3: Socioeconomics	• Assessment of farm working conditions, including safety considerations.	• Analysis of lifetime financial savings from replacement of short-lived materials. • Impacts on the local supply chain are considered.	• Local action plan that integrates local communities and their views. • Establishment of/integration within the local agriculture and renewable energy community. • Accommodate local and energy-efficient distribution channels.
DIMENSION 4: LCA	• Performance monitoring of the system.	• Data collection on performance (Agricultural, Environmental, Energy, Socioeconomics).	• Provide detailed evaluation of the performance of ecosystem and socioeconomic services. • Apply a definition of a set of indicators, methodology, and reporting of KPIs to the project.

3 Best existing business cases

The sustainable agriculture concept provides a wide range of benefits not only to the environment, but also to the social and economic segment. Building on the existing knowledge, this chapter will showcase existing Agri-PV projects across India. It will outline existing, operating Agrisolar PV projects, and include information on the design and concept of PV application, as well as providing insights into the development and implementation process. In addition, the chapter will build upon existing Agri-PV case examples that have monitored data on sustainability features. This section delves into these criteria to present a systematic analysis of the Indian Agrivoltaics sector.

CASE STUDY 1 SUNMASTER AGRIVOLTAICS PLANT, NAJAFGARH, DELHI

The SunMaster Agri-PV plant in Delhi, commissioned in 2021, has a capacity of 2 MW and integrates solar energy generation with agricultural cultivation. The plant adopts an overhead configuration with a 4.3m elevation, using a Hot Dip Galvanised mounting structure. The solar panels employ a fixed tilt tracking system, optimising energy capture, while cleaning and water management are facilitated through a telescopic water brush and manual dry-cleaning processes. SunMaster is responsible for the plant's operation and maintenance.

SunMaster Agrivoltaics plant, Najafgarh, Delhi. © SunMaster.

The Agri-PV plant serves as a research field, fostering the cultivation of a diverse range of crops, including brinjals, lettuce, spinach, lady finger, potatoes, tomatoes, bottle guard, fenugreek, coriander, and cucumber. Additionally, the plant supports the cultivation of fruit crops such as mango, turmeric, and pomegranate, showcasing its versatility in accommodating different agricultural needs.

The economic benefits of Agri-PV are strikingly evident in this case. Before its implementation, the income per acre stood at 30,000 INR. However, with the integration of solar panels, the income surged to 1.2 lakhs INR (120,000 INR) per acre, reflecting a substantial fourfold increase. This economic transformation underscores the potential for Agri-PV to enhance the financial viability of agricultural land.

The temperature difference between the Agri-PV test field and an adjacent open field is approximately 10°C on hot summer days. This significant temperature differential is indicative of the cooling effect underneath the solar panels, contributing to improved crop conditions and potentially extending growing seasons.

Agri-PV has successfully reduced water evaporation by 50% compared to an open field, showcasing the water-saving potential of these systems. This reduction in evaporation not only conserves water resources but also contributes to the enhanced performance of solar panels. The Agri-PV setup demonstrated a 12% increase in production compared to industrial installations, emphasising the symbiotic relationship between energy generation and agriculture.

Furthermore, soil health has improved by an impressive 30%. This improvement underscores the potential of Agri-PV not only as an energy-efficient solution but also as a sustainable agricultural practice.

SunMaster Agrivoltaics plant, Najafgarh, Delhi. © SunMaster.

CASE STUDY 2 SUNSEED APV AGRIVOLTAICS PLANT, PARBHANI, MAHARASHTRA

Situated in the Marathwada region of Maharashtra, Western India, the Agri-PV farm has an installed capacity of 1.4 MW and spans 5 acres as part of a larger 50 MW solar project. The facility is the result of a partnership between SunSeed APV, Kanoda Energy, and GIZ German Development Cooperation.

The project's scope includes four distinct Agri-PV configurations and an open farming area designated for research purposes. The system has an elevation of 3.75m and contains an integrated with a shade net house, fostering the growth of trellising vegetables. The incorporation of highly reflective shade nets not only enhances PV generation efficiency but also induces the albedo effect, contributing to increased overall energy yields. Additionally, three Agri-PV installations, positioned at lower elevations (1.25m and 1.75m), demonstrate cost-effectiveness with only marginally higher capital costs compared to conventional solar projects. The mounting structures are made using 'Light weight cable technology' which reduces the weight of steel immensely.

Water optimisation is a key focus, facilitated by an advanced water management system. This includes a drip irrigation network and soil moisture sensors in each crop section, ensuring precise and efficient water usage. The shading effect of the PV panels, coupled with the application of mulch, contributes to reduced evapotranspiration, further enhancing water conservation practices.

Instrumentation plays a crucial role in the project, serving as a comprehensive platform for research and development in both crop cultivation and solar energy generation. This extensive research initiative aims to unlock scientific insights into the design and adaptation of Agri-PV projects. Additionally, it fosters the development of cultivation strategies specifically tailored to the unique conditions presented by Agri-PV systems.

SunSeed APV Agrivoltaics plant, Parbhani, Maharashtra. © SunSeed APV.

TABLE 4 CONFIGURATION OF SUNSEED APV SECTIONS I-IV, PARBHANI

SunSeed APV Parbhani Section I	
Type of Agri-PV plant	Elevated structure with shade house
Area	1.6 acres
Module technology	Polycrystalline
Mounting structure	• Overhead: 3.75 m • Fixed tilt: 11° • Pitch distance: 5.64 m
Cleaning & water management	• Robotic dry cleaning • Fogger system and drip irrigation system
Crops	Cherry tomato, capsicum, cucumber, betel leaves, turmeric, ginger, basil, spinach, methi, coriander, mint, rose, chrysanthemum, tuberose, hibiscus, marigold, watermelon, muskmelon

SunSeed APV Parbhani Section II & III	
Type of Agri-PV plant	Below and interspace
Area	0.8 acres (each section)
Module technology	Mono PERC
Mounting structure	• Height: 1.75m • Fixed tilt: 11° • Test field with two pitch distances: 10m (II) and 7.5m (III)
Cleaning & water management	• Occasional wet cleaning • Drip irrigation system
Crops	Section II: Muskmelon, coriander, spinach, fenugreek Section III: Marigold, basil

SunSeed APV Parbhani Section IV	
Type of Agri-PV plant	Interspace
Area	0.8 acres
Module technology	• Bifacial PERC
Mounting structure	• Height: 1.25m • Fixed tilt: 11° • Pitch distance: 10m
Cleaning & water management	• Occasional wet cleaning • Drip irrigation system
Crops	Watermelon

CASE STUDY 3 INDRA SOLAR FARM, AGRIVOLTAICS PLANT, TIKAMGARH, MADHYA PRADESH

The Indra Solar Farm is being developed in three distinct phases. Phase 1 was successfully commissioned in December 2022, and it comprises two distinct plants, each with its own unique characteristics.

Plant – A

Plant A represents a conventional solar PV plant with an installed capacity of 500 kWp. The technology employed in this phase utilises Gautam Solar polycrystalline Si 335 Wp modules. These panels are mounted on two-metre-high HD GI single column ground mounted structures, which are fixed at a tilt angle of 24°. The inter-row spacing measures seven metres, with three metres between columns. This innovative approach categorises it as a 'solar grazing' plant, where goats graze beneath and around the solar panels. Regular cleaning and maintenance of panels is carried out manually with pipes and wipers. It accommodates about 70 goats for grazing purposes.

Plant A, Indra Solar Farm, Agrivoltaics plant, Tikamgarh, Madhya Pradesh. © Khare Energy Private

Plant – B

Plant B, also under phase 1, boasts an installed 500 kWp capacity across 1.5 acres of land. Here, solar panels have been retrofitted onto a polyhouse Agri-PV structure. The technology employed mirrors Plant A with Gautam Solar's polycrystalline Si 335 Wp modules. However, the panels are raised on five-metre-high GI polyhouse structures, allowing easy movement of tractors and farming equipment. These panels are fixed at a tilt angle of 26° with inter-row and inter-column spacing set at five metres. The panels are arranged in a zigzag pattern, ensuring sunlight penetration to every part of the land beneath. Crop rotation throughout the year is carried out with crops such as wheat during Rabi season (April-June), green gram during Zaid season (March-July), and maize & turmeric during Kharif season (September-October) thrive under these panels.

Notably, there has been no crop yield loss in Plant B despite crops being grown under the Agri-PV system. Furthermore, water consumption for crop cultivation has been reduced by approximately 50% due to the shade provided by the solar panels.

Plant B, Indra Solar Farm, Agrivoltaics plant, Tikamgarh, Madhya Pradesh. © Khare Energy Private Ltd..

CASE STUDY 3 INDRA SOLAR FARM, AGRIVOLTAICS PLANT, TIKAMGARH, MADHYA PRADESH, *CONTINUED*

Project Phase – 2

Phase 2, currently under implementation, features an elevated Agri-PV plant with an installed capacity of 1 MW. This phase introduces Goldie Solar's PERC mono-crystalline Si bifacial 540 Wp modules, mounted on Reinforced Concrete Columns (RCC) and the lightweight Galvalume (coating consisting of zinc, aluminium and silicon that is used to protect steel from oxidation) structures at a height of four metres. The panels are fixed at a tilt angle of 10°, with inter-row spacing of seven metres and inter-column spacing of five metres, facilitating the movement of tractors and farming equipment. The crop cultivation methods and the crops to be grown will be the same as seen in phase 1.

Phase 2, Indra Solar Farm, Agrivoltaics plant, Tikamgarh, Madhya Pradesh. © Khare Energy Private

Project Phase – 3

Phase 3 is a vertical bifacial Agri-PV plant with an installed capacity of 250 kWp. Panels in this phase will be installed with a fixed tilt with an East-West orientation. Khare Energy Pvt Ltd. has signed a Memorandum of Understanding (MoU) with the specialised German firm Next2Sun to serve as the scientific partner for this project. The tentative commissioning date for phase 3 is set for the end of December 2023.

The CAZRI Agri-PV plant, commissioned in 2017, is situated in the arid climate of Jodhpur, where the average irradiance on a horizontal surface is 6.11 kWh/m2/day and cloud-free skies prevail for approximately 300 days annually. This project exemplifies the potential for sustainable practices in challenging environments.

Managed by CAZRI, this research-focused project boasts an installed capacity of 105 kWp, utilising monofacial PV modules with a capacity of 260Wp each. The unique layout features three distinct arrays with interspaces of 3m, 6m, and 9m, allowing for efficient land use and facilitating the use of heavy machinery for ploughing.

The mounting structure of the PV arrays has a tilt angle of 26°. The height variations across arrays—1.22m, 1.94m, and 2.66m—accommodate interspace configurations that enable ploughing, with manual intervention required in specific cases.

The project has a projected net income of 80,000 INR/ha/yr. from crops and a Feed-in Tariff (FiT) of 4 INR/kWh. The overall economic structure encompasses a capital expenditure (CAPEX) of 2.25 Cr. INR (22.5 million INR), translating to 50,000 INR/kWp. The total system cost amounts to 57,142 INR/kWp for the installed capacity of 105 kW.

The Agri-PV plant incorporates a rainwater harvesting system, collecting approximately 1.5 lakh litres (150,000 litres) of rainwater annually from the surface of PV modules. This harvested water serves a dual purpose: cleaning the module surfaces and acting as a valuable resource for irrigation. The efficiency of the rainwater harvesting system ranges from 70% to 80%, contributing to sustainable water management.

Agriculturally, the sandy and loamy soil of the region supports a diverse range of crops, including mungbean, mothbean, clusterbean, isabgol, cumin, chickpea, aloe vera, sonamukhi, sankhpuspi, chili, cabbage, onion, and garlic. With 49% of the land area used for agriculture, the Land Equivalent Ratio (LER) stands at an impressive 1.41, emphasising the efficiency and synergy achieved in the dual use of land.

Central Arid-Zone Research Institute (CAZRI) Agrivoltaics plant, Jodhpur, Rajasthan. © CAZRI.

CASE STUDY 4 CENTRAL ARID-ZONE RESEARCH INSTITUTE (CAZRI) AGRIVOLTAICS PLANT, JODHPUR, RAJASTHAN

CONTINUED

TABLE 5 EFFECTS ON YIELD OF DIFFERENT CROPS AS EXAMINED IN INTERSPACING AREA AT CAZRI JODHPUR PLANTS

Crop category	Interspacing (crops)	Yield affection by
Kharif	Mungbean (*Vigna Radiata*) Mothbean (*Vigna Aconitifolia*) Clusterbean (*Cyamopsis Tetragonoloba*)	Growth and yield of mungbeans (Vigma Radiata) was not affected by the shade of PV module, whereas rest two are affected.
Rabi	Isabgol (*Plantago Ovata*) Cumin (*Cuminum Cyminum*) Chickpea (*Cicer Arietinum*)	Growth and yield of isabgol (*Plantago Ovata*) and cumin (*Cuminum Cyminum*) are signficantly affected by shade of PV module.
Medicinal slants	Alovera (*Aloe Vera*) Sonamukhi (*Cassia Angustifolia*) Sankhpuspi (*Convolvulus Pluricaulis*)	Performance of medicinal crops were superior in the interspace area than over control.
Vegetables	Chilli (*Capasicum Annum*) Cabbage (*Brassica Oleracea var. Capitat*) Onion (*Allium Cepa*) Garlic (*Allium Sativum*)	Growth and yield of *Solanum Melongena* was significantly affected by shade of PV module.

Central Arid-Zone Research Institute (CAZRI) Agrivoltaics plant, Jodhpur, Rajasthan. © CAZRI.

Renkube Private Ltd, a solar startup, based in Bangalore, installed a 10kW Agri-PV system at the Professor Jayashankar Telangana State Agriculture University (PJTSAU) Seed Research Technology Centre (SRTC). This pilot project, launched in 2022, focuses on testing the efficiency of panels designed with motion free optical technology (MFOT). The technology consists of light redirectors in the solar glass that gather more sunlight and redirect it to the solar cells. The company applied machine learning algorithms to design a glass that can capture more sunlight purely by the nature of its geometric design without any chemical coating or electro-mechanical components. The pilot also studied changes in the micro-climate under the installation during crop growth, evaluating the effect it has on the yield of different crops and water use efficiency, to discern the economics of Agri-PV systems using MFOT. During the summer of 2023, Amaranthus, palak, green gram, and black gram crops were fed by a drip irrigation system and administered needs-based plant protection measures. The results indicated that from the beginning of April 2023 to the end of June 2023 the total electricity generated was 3982.52 kWh of which 3017.20 kWh was generated from Renkube panels and 965.32 kWh was from traditional panels. The average electricity production was 43.76 kWh per day. The microclimate and photosynthetic performance of the crops under the Agri-PV system was similar to that of crops under open field conditions. This implies that Agri-PV installations do not harm the development of the related crops, and therefore the productivity of agricultural land is maintained. Moreover, total incoming radiation and light intensity were lower in the Agri-PV plant. With Renkube panels effectively blocking more sunlight from reaching the plants beneath the installation, water evaporation was reduced, and shade-tolerant plants flourished. Compared to regular PV panels, the Renkube ones allow to increase the energy yield of the solar panel by 20%. The electricity generated monthly is presented in Table 6 below.

TABLE 6 DETAILS OF ELECTRICITY (KWH) GENERATED BY THE RENKUBE AGRI-PV SYSTEM DURING SUMMER 2023. (SOURCE: PROFESSOR JAYASHANKAR TELANGANA STATE AGRICULTURAL UNIVERSITY.)

Month	Days	Renkube panel (kWh)	Traditional panel (kWh)	Total electricity	Renkube /day	Traditional /day	Avg./ day	RP/ kWh	TP/ kWh
April 2023	30	1,035.20	283.28	1,318.48	34.51	9.44	43.95	4.42	3.15
May 2023	31	1,041.60	359.75	1,401.35	33.60	11.60	45.20	4..31	3.87
June 2023	30	940.40	322.29	1,262.69	31.35	10.74	42.09	4.02	3.58
Total Summer 2023	91	3,017.20	965.32	3,982.52	33.16	10.61	43.76	4.25	3.54
Total Nov 2022 - June 2023	232	7,048.70	2,351.45	9,400.15	30.38	10.14	40.52	3.90	3.38

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The installation of Agri-PV systems requires unique EPC and O&M considerations, with implications on the design, installation, and operation of both the solar system, and the agricultural processes.

Depending on the type of farming and the agricultural operation of each Agri-PV site, Agri-PV systems need to be designed, installed, and operated in a way which allows the free and safe movement of farm machinery, farm workers, and livestock, while ensuring sufficient transmission of light and rainwater.

Traditionally, the design, construction, and installation of PV systems aims to maximise energy production. However, in Agri-PV systems the main target is the optimisation of the relationship between energy generation and agricultural production. To achieve this, the following parameters described in this chapter are particularly important.

4.1. EPC of Agri-PV systems

4.1.1. Structure height

The size and the height of Agri-PV systems should be adapted to the agricultural activity that will be carried out on the plot of land. Requirements related to Agri-PV structure height can be found in a few Agri-PV Technical Guidelines, where the definition of height, as well as the requirement for minimum height of different Agri-PV systems are included. There are different existing guidelines that establish certain criteria for Agri-PV structure height. These include:

1. In 2022 France's environmental agency Ademe released a set of new guidelines that clearly define "Agrivoltaics".
2. The German 'DIN-SPEC 91434',68 which set out criteria for Agri-PV installations and their height parameters.
3. The Italian 'Agri-PV Technical Guidelines' document, which sets out a minimum criterion for the height of Agri-PV structures.
4. Japanese guidelines for Agri-PV installations.

Installing Agri-PV systems with the appropriate structure height is crucial for allowing agricultural activity. However, the system height could also have an impact on energy production, when bifacial PV panels are installed, as well as on the economic feasibility of projects. The albedo and returning light to the rear side of the panel could be affected by the ground type, coverage, and panel height.

When designing elevated Agri-PV plants, the clearance profile must comply with occupational health and safety legislation. Critically, attention must be paid to ensure the PV system does not endanger workers or machinery.

4.1.2. Panel Tilt

The importance of tilt and azimuth in Agri-PV installations is emphasised by a recent systematic review of Agri-PV research, which analyses Agri-PV studies. The authors conclude: "On one hand, the

BOX 1: USE CASE FOR SINGLE- AND DUAL-AXIS TRACKING IN AGRI-PV

PV Single-Axis Tracking in Agri-PV

- Use Case: Crop-Integrated Solar Farms
- In Agrivoltaics, where solar panels are combined with agricultural activities, single-axis tracking can be employed in large-scale solar farms integrated with crop fields. The solar panels are mounted on trackers aligned in the east-west direction. As the sun moves across the sky, the trackers adjust the tilt of the panels, ensuring they capture maximum sunlight. This configuration allows sunlight to penetrate between rows of crops, promoting better growth conditions by optimising light exposure. It strikes a balance between energy production and agricultural productivity.

PV Dual-Axis Tracking in Agri-PV

- Use Case: High-Density Crop Integration
- In scenarios where a higher level of precision is needed for light optimisation in Agrivoltaics, dual-axis tracking is beneficial. Solar panels with dual-axis trackers can dynamically adjust both their tilt and orientation to track the sun's position more accurately. This level of control is particularly useful in areas where sunlight conditions vary significantly throughout the day or in regions with complex topography. Integrating dual-axis tracking with Agrivoltaics ensures that both energy production and crop growth are optimised, offering a more sophisticated solution for high-density crop integration.

orientation and position of the PV array affect the extent of electricity generation; on the other, they influence plant growth rates through their control of the amount of crop-available irradiation. Therefore, in setting the tilt and azimuth angle in Agri-PV installations, crop-available irradiation should be carefully considered".

The ideal panel tilt will depend on the agricultural activity, the module size, the typical weather conditions, and the windward side profiles of the project site. Dynamic systems which allow changing the panel tilt will add extra flexibility and bring benefits for both agricultural and electricity generation activities.

In terms of agricultural activity, special attention should also be paid to the growth direction of crops.

Developers should ensure sufficient plant protection from weather events and ensure that Agri-PV systems provide a homogeneous distribution of precipitated water to the crops under the modules. In this regard, draining water from the modules must be appropriately managed.

In Agrivoltaics, both single-axis and dual-axis tracking systems can contribute to sustainable and efficient practices by harmonising solar energy generation with agricultural activities. The choice between them depends on the specific requirements of the crop, local climate conditions, and the desired balance between electricity generation and agricultural yield.

4.1.3. Row Distance

Row distance plays an important role in the shading and light transmission in Agri-PV systems, as well as the energy production and agricultural operations. As such, the inter-row distance should be adapted to the agricultural activity and should be assessed on a case-by-case basis. Some national technical guidelines often prescribe an allowed ground coverage ratio, which can impact the row distance decision-making. In all cases, the rows should also provide sufficient space for workers and agricultural machinery to safely carry out their duties.

For Agri-PV systems combined with light-sensitive crops, alignment and spacing between the module rows must be designed to optimise light availability and homogeneity, to avoid negatively affecting plant growth. Ideally, the distance between rows should maximise the synergies between the PV system and the crop, created through shading and light homogenisation.

Achieving a balanced row distance enhances the Land Equivalent Ratio (LER), a widely used indicator of the yield advantage of multi-crop farms over sole-crop farms, and usually measured using crop biomass yield per unit area. An adequate row distance allows for sustainable and integrated land use where solar energy production and agriculture complement each other effectively.

4.1.4. Water

Water is essential for practically any type of agricultural activity; therefore, it is critical that Agri-PV installations do not interfere with the water needs of agricultural operations. Generally, project developers should ensure an even distribution of precipitated water to the Agri-PV crop. This can either be provided naturally, in which case an assessment of the crop water requirements, and the typical climate conditions of the site should be carried out. In cases where local climate conditions do not meet the crop's water requirements, an irrigation system should be deployed. Irrigation methods, such as drip irrigation and micro irrigation, which improve water-use efficiency must be inculcated in Agri-PV plants in India.

The positive impacts of Agri-PV systems on crops grown beneath solar panels may also have an impact on the design and installation of an Agri-PV site. As such, when installing Agri-PV on shade-tolerant crops in dry-hot areas, higher ground coverage ratio can be deployed.

4.1.5. Soil

Draining water from the modules can lead to a drip edge, and associated dispersing of the soil. For all Agri-PV systems, crop-adapted rainwater collection systems, rainwater distributors, or similar devices can be used. Appropriate measures should be taken to restore the original soil structure during construction, and/or during the dismantling of the plant. The foundation of the Agri-PV system must minimise impacts on soil quality. Both when installing and dismantling the systems, there should be no negative consequencse to the soil through compaction and land movement. In this regard, deploying the system when the ground is dry, using special tires and machinery, and/or moveable tracks is recommended. Agri-PV systems combined with crops should be deployed outside the growing season.

4.1.6. `Foundations and Mounting Structures

Local construction standards must be respected, particularly with regards to the impacts of harsh weather conditions. To preserve agricultural land, the foundations of the Agri-PV system must be designed to ensure the system is fully removable.

Construction methods which provide secure foundations via removable fixtures in soil or soft ground should be used. In this regard, using a piling method, and avoiding the use of concrete or cementing whenever possible is recommended. Certain regions or soils require the use of solid and specific foundations. For more information on installing mounting structures, please see the *EPC Best Practice Guidelines: India edition*.[41]

Using trellises made of wood to plant vegetables and fruits can double or triple the yield per acre as well as reduce diseases/pests, ease harvesting and make cleaner produce. Cultivars such as cucumbers, grapes, kiwi, melons, peas, passion fruit, pole beans, pumpkins, strawberries, squash, and tomatoes are all grown with trellises. Many of these cultivars showed increased yield with partial shading with semi-transparent solar PV systems.[42]

4.2 Light Distribution, PV Modules, and Installation Type

There are various techniques to achieve optimal crop growth and animal welfare, while maximising energy production in Agri-PV sites.

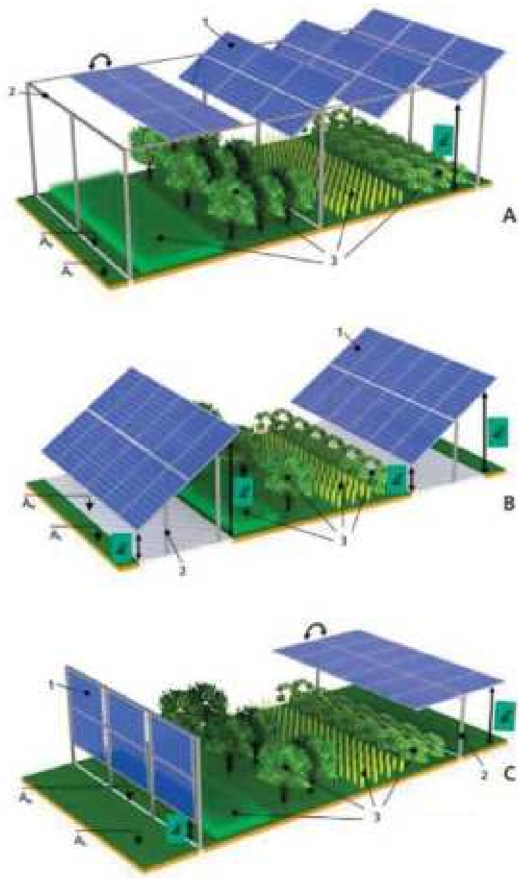
4.2.1. Installation Techniques

Different types of installation techniques are used, the most common (elevated, vertical PV, and between rows) are described in Figure 4 on the following page.

Choosing the appropriate installation technique should be based on the type of agricultural operation, geographic location, and technical guidelines (where they exist).

41 NSEFI and SolarPower Europe (2022).
42 Jamil et al. (2023).

FIGURE 4 DIFFERENT TYPES OF AGRI-PV INSTALLATIONS



A ILLUSTRATION OF A CATEGORY I SETUP.

B ILLUSTRATION OF A CATEGORY II SETUP, VARIANT 1.

C ILLUSTRATION OF A CATEGORY II SETUP, VARIANT 1 AND 2.

Legend

A_L	Cultivatable agricultural areas
A_N	Uncultivatable agricultural areas
h_1	Clearance height below 2.1 m
h_2	Clearance height above 2.1 m
1	Examples of PV modules
2	Mounting structure
3	Examples of crops

SOURCE: Fraunhofer ISE.

4.2.2. PV Module Technology

Different PV module technologies can be used to optimise light transmission in Agri-PV sites. Some innovative technologies have been used for Agri-PV research, such as Concentrator Photovoltaic (CPV) modules, which use direct and diffuse solar rays. Direct irradiance is used for electricity production, while diffuse irradiance is used for photosynthesis of the crops. This technology is yet to be mass produced; therefore, costs are still high. Some suitable qualification tests are defined in the standard IEC 61215-2, which is the basis for type approval and design qualification of PV modules. The sampling method is typically Special Inspection Level S1 to S3 according to ISO 2859-1 with consideration of all bills of materials and potentially different production lines to be represented.

4.3. O&M of Agri-PV Systems

Overall, existing electrotechnical and static regulations, as well as corresponding test requirements in the field of PV systems, should be respected in all Agri-PV projects.

Considerations related to O&M of Agri-PV sites involve additional elements and challenges, resulting from the elevation of PV panels, limited access for O&M workers to farms, and the requirement to consider the impact which any O&M related activity may have on food production.

4.3.1. General Maintenance of Agri-PV sites

Overall, the necessary maintenance work must be recorded by the installer of the plant in the operating manual and observed by the operator.

The verified parameters of recorded data should be kept in a plant-specific operating protocol.

On the agriculture side, objects, crops, and pasture should be carefully maintained to avoid fire hazards. During extreme weather events, like torrential rain and hailstorms, as well as extreme wind loads, for safety reasons, work should not be carried out on the plant. Sensible preparation, like rainwater distribution systems, can prevent the formation of icicles.

4.3.2. Fault Detection and Problem Fixing

In cases of reduction in energy production or problems in the PV systems, O&M workers may need to visit the Agri-PV site, enter the farm, and potentially interact with the farming operations. Therefore, clear coordination among farmers and O&M workers needs to be facilitated. Detecting and fixing faults in the Agri-PV sites (elevated or between rows of crops) may require additional measures such as climbing to reach the panels or working in close physical proximity to valuable crops. A PV monitoring system could be used for detecting faults or module mismatches in the PV system, therefore reducing interference with farming operations and preventing unnecessary entrance to a farm by O&M workers. For more information on monitoring for PV power plants, please see the *O&M Best practice Guidelines: India edition.*[43]

4.3.3. Health and Safety of Agri-PV Sites

Special care is required when maintaining Agri-PV systems, as people work on the site and as intensive agricultural use can take place, increasing the risk of damage and contamination. Farmers and workers should be well informed and, where possible, properly trained about any specific maintenance needs or risks associated with the PV systems. For more information about on-site health and safety, please see the *O&M Best Practice Guidelines: India edition.*[44]

4.3.4. Cleaning of Modules

Soiling and dust on the surface of PV modules can cause a significant decrease in PV power output. In Agri-PV sites, where PV panels are located above or adjacent to agricultural land, farming activity, such as the use of machinery, can generate large amounts of dust, leading to losses in energy yields.76 The first research to analyse the impact of dust and soiling in Agri-PV plants, found an average daily soiling losses of 0.35% per day, and performance ratio decrease to values as low as 40% in summer months without precipitation or cleaning.

As such, Agri-PV systems should be cleaned periodically. Agricultural soil cultivation and the application of plant protection products can cause contamination. Therefore, a plant-specific, regular cleanliness check is recommended.

Furthermore, to minimise yield loss, the Agri-PV system and modules should be cleaned in case of heavy contamination. If a detergent is used then food, feed, and pharmaceutical legislation must be complied with. In general, cleaning procedures should only be initiated whenever strictly necessary, to avoid unnecessary loads or accidental damage to the PV system.

Cleaning may be more challenging in Agri-PV sites, due to the elevated panels. The use of a hydrophilic coating on the PV panel surface could be helpful to maintain an optimal electrical output.

Similarly, certain agricultural activities and treatments can lead to chemical alteration of materials. Chemically, the most effective detergent will depend on the type of soil, and therefore on the crops and products applied to them.

Farming practices can generate occasional soiling, requiring rapid clean-up. It is sometimes impossible to clean up without damaging farming activity. As farming activity is highly dependent on the weather, synchronisation with conventional preventive maintenance and cleaning schedules is unlikely. These operations must be carried out in "fire department" mode, such as curative maintenance, and are therefore less economical. Alternatively, the farmer will have to be a co-actor in the maintenance: for example, by rinsing the panels after certain operations.

43 NSEFI, SolarPower Europe (2020).
44 See 43.

4.4. Electric safety

Safety must be considered very carefully when planning and designing any PV installation, and in particular Agri-PV. PV plants, like every electric installation, hold a certain risk potential such as the occurrence of fire and personal danger from electric shock. Safety of Agri-PV plants is in the core interest of the farmer, the developer, the installer, and maintenance teams, as well as insurance companies, policymakers, and regulatory bodies. Moreover, incidents of fire and electric shocks could be detrimental to the growth and public acceptance of Agri-PV, especially in the early stages of the market, when dedicated binding standards and regulations are yet to be published or enforced. Therefore, the safety of Agri-PV plants needs to be investigated in detail.

Existing research shows that safety in Agri-PV installations is very important for policymakers, farmers, and solar industry professionals. As an example, in a research study, risk, safety, and liability were mentioned as the main barriers for the development of Agri-PV in the US. In the German DIN-SPEC 91434, it is mentioned that, "special care shall be taken when maintaining Agri-PV systems, as people work on the area and (intensive) agricultural use may take place, which increases the risk of damage and soiling ." Safety considerations should be taken into account during the design, construction and operation of Agri-PV sites. The two main safety considerations in solar sites are electric shock and arcs. In Agri-PV sites there are several unique features which increase risks of electric shocks and electric arcs.

4.4.1. Key Safety considerations in Solar Systems

a. Electric Shock

Electric voltage is produced by solar panels from the moment they are exposed to sunlight. Since each panel produces around 40 volts (on average), a string of connected panels produces a high voltage of about 400 volts to 1500 volts (depending on the type of solar inverter, and the lengths of the strings). This voltage is created by the mere exposure of the solar panels to the sun radiation. Turning off the solar inverter, or disconnecting the device from the grid, does turn off the current passing through the system circuit. However, it does not lower the voltage produced by the exposure of panels to the sun, called direct current (DC) voltage. High voltage may pose a safety risk to the installer of the system, and people working in adjacent areas. To lower the DC voltage, a function that reduces the voltage on a panel level is needed.

Agri-PV installation. © SunSeed APV.

b. Electric arcs (Fires)

An electric arc is created as a result of discontinuation of a conductor or connector. In a solar system consisting of many connection points and cables, an electric arc can be created if the cable is not connected as required or is damaged. Electric arcs have two prominent features: strong light and very high heat. As such electric arcs are a common cause of ignition and fire in any electrical equipment, especially a solar installation.

Electric arcs can also 'electrify' the system including the construction and endanger anyone who encounters it. The older the system, the greater the risk of arcing as a result of ageing wiring, and loosening connections.

Unique characteristics of Agri-PV sites which may increase risk of arcs and electric shocks:

- Agri-PV sites without fencing: While solar sites are generally fenced to prevent unauthorised entrance and ensure that only trained solar professionals will enter the site, in Agri-PV sites this is not always the case; fencing may interfere with farming operations. In the few countries where there general fencing requirement for solar sites exists, such as Israel and Japan, this requirement is specifically removed for Agri-PV installations.
- Farmworkers, farm machinery, and livestock in physical proximity to the solar system: By definition, the dual use of land for solar energy and food production entails that the land will be used by both solar professionals and farmers. Farmers and farm workers may be less aware of the risks of solar systems. Further, there is a higher risk of damaged wiring and equipment than in normal PV systems. The presence of livestock also increases the risk of damage, which then becomes a risk for farm operations, machinery, and workers.

4.4.2. Best practices & solutions to address Safety challenges in Agri-PV

Existing Agri-PV guidelines and best practice documents from various Agri-PV markets mainly focus on awareness, electrical safety, and cabling, to address and tackle safety challenges in Agri-PV:

a. Awareness

As a first step, all relevant stakeholders involved in the installation and operation of Agri-PV plants must be aware of the relevant risks and safety considerations. Awareness can be found in several best practices and technical guidelines documents. Best practices include:

- Ensure that all personnel are trained and educated and know how to work and operate an electrical facility. This will eliminate work accident risks, including farmers.
- Implement signs that signal the power generation facility, and prevent any accidents caused by a third party:
    - Add safety signs such as electric shock warnings to electrical equipment such as power conditioners and connection boxes.
    - Add a safety sign that indicates buried cables.
- Create awareness among farmers of the potential risks.
- Ensure that EPC business operators are responsible for risk communication with farmers..

b. Module Level Power Electronics (MLPE) – Reducing System DC Voltage and mitigating arc risks

As previously stated, to be able to reduce the solar system voltage generated by the panels' exposure to sunlight, there is a need to reduce the voltage generated on the panel level (the DC voltage). This can be done by Module Level Power Electronics technology. MLPE devices are attached to one or more PV modules in a PV String. MLPE devices may include capabilities such as Connector Fault Sensing, and the ability to lower output voltage to a very low (and safe) voltage level.

Since DC voltage is generated whenever the panel/panel array is exposed to the sun, MLPE solution tackles the risks of arcs and electric shock by actively reducing the voltage generated by the panels and collectively reducing the voltage on the array to a safe level when needed or triggered. In addition, some advanced MLPE solutions can detect the potential for arcs in advance and mitigate the risk with pre-emptive action. MLPE should be applied in Agri-PV systems to reduce the risk of electric shocks and fires.

c. Protecting Cables from Damage and Exposure

Cables need to be protected, and not exposed to damage by livestock, farm workers, or farm machinery. This should be done by either burying the cables or installing them at an appropriate height. Below are a few examples of cabling related requirements, and guidelines found in Agri-PV guidelines:

Good practice includes:

- Cables and cable tranches should be installed at a safe depth, to avoid any damage caused by ploughs and other agricultural machinery.
- Minimising the number of cables in the ground by directing them under module roofs, alongside the mounting structure. This approach also protects the cabling from direct rain or sun exposure and increases the lifespan of the system.
- Additional elements include the installation of ram protections to cover cable trenches around the system structure posts.
- If animal husbandry is being considered, the height of cables and connectors should be properly defined to avoid animals damaging the systems and hurting themselves, either by touching or biting. For the same reason shelters are advised to use electric components such as string inverters or junction boxes.[45]
- Many sites bury cabling, but on sites with above ground cabling, sufficient marking and safety measures must be implemented to ensure animal and human safety. The depth of buried cabling should be enough to not disrupt agricultural activities, such as tilling. Various standards refer to proper cabling and connection practices, such as IEC 62930:2017 resp. EN 50618 (Electric cables for PV systems), IEC 62790 (junction boxes for PV modules), IEC 62852 for DC connectors and IEC 62738 (Design guidelines).
- Arc Fault Detectors reduce the risks of arcs and resulting fire risks and their use in Agri-PV installations is recommended.

45 SolarPower Europe (2021).

© Aga Khan foundation/Flickr

As Agri-PV is at the crossroads of solar PV and agriculture, several challenges need to be addressed to ensure and accelerate its adoption and development. To address those challenges, science, research, and innovation are, and will remain, strong contributors to the Agri-PV sector for years to come. Researchers and innovators are key to improving the understanding of interactions between energy and agriculture systems, documenting and quantifying impacts and benefits to build more accurate business models, improving and scaling technology (hardware or software) and, developing test sites to show the realities of Agri-PV, and de-risk its adoption.

This chapter will reflect on ongoing research and innovation trends that promote Agri-PV in India. It will also highlight case studies that entail various innovative aspects such as technology installations, new agricultural applications, and other elements. It will be divided into sub-chapters and will include the following elements:

- Vertical Bifacial PV Technology
- PV on Greenhouse/Polyhouse
- Semi-Transparent PV panels Technology
- PV-Agro

5.1. Vertical Bifacial PV Technology

In the realm of Agri-PV, a prominent trend and technological innovation that holds immense promise is the integration of vertical bifacial PV modules. This cutting-edge approach is well-suited to Agri-PV in the Indian context. Vertical bifacial PV modules deviate from conventional solar panel configurations by adopting a unique vertical orientation, facilitating optimal capture of sunlight from both the front and rear sides. This design is especially conducive to the Agri-PV landscape, where conventional horizontally mounted panels may pose challenges due to shading effects and limited sunlight penetration.

One of the primary technical advantages of vertical bifacial PV modules lies in their enhanced light-capturing capabilities. The bifacial nature of the panels ensures that incident light on the front side, as well as reflected light from the ground, contributes to the overall energy yield. Moreover, the adaptability of vertical bifacial PV modules to varying sun angles throughout the day is a critical factor in optimising energy generation. This is particularly pertinent in Agri-PV settings where the height and structure of crops can vary significantly. By capturing sunlight at different angles, these modules ensure that even lower layers of vegetation receive adequate solar insolation, minimising shading effects on the crops.

In the context of land-use efficiency, vertical bifacial PV modules offer a promising solution. Their vertical orientation enables the dual use of land for both solar energy generation and agricultural cultivation. This aligns with the imperative in India, where arable land is a precious resource, to achieve a harmonious coexistence of renewable energy infrastructure and farming activities. From a technical standpoint, the reduced shading effects of vertically oriented panels enhance the agronomic viability of crops beneath. Traditional inclined solar panels can cast shadows on

5 kWp pilot site with vertical bifacial modules. © National Institute for Solar Energy (NISE).

the ground, potentially affecting crop growth. The vertical bifacial configuration mitigates this issue, providing a more uniform distribution of sunlight across the crops.

In conclusion, the integration of vertical bifacial PV modules in Agri-PV in India represents a pioneering technological trend. Its technical advantages, including enhanced light-capturing capabilities, adaptability to varying sun angles, and dual land use efficiency, position vertical bifacial PV modules as a frontrunner in the evolution of sustainable Agri-PV systems in the Indian landscape.

5.2. PV on Greenhouses/Polyhouses

Exploring the technical intricacies of integrating PV modules on greenhouses/polyhouses within the context of Agri-PV unveils a compelling trend and innovation that holds significant promise for sustainable energy production and agricultural enhancement in India. The deployment of PV modules on greenhouses, often referred to as Agrivoltaics greenhouses or solar greenhouses, represents a sophisticated and synergetic approach to harnessing solar energy while concurrently supporting agricultural activities.

From a technical perspective, the integration of PV modules onto greenhouse structures involves the strategic incorporation of solar panels onto the roof or walls of the structure. The design of the mounting system plays crucial roles in optimising energy capture and ensuring compatibility with greenhouse functionalities. The PV panels retrofitted onto a polyhouse, as shown in figure 18 installed at Indra Solar farm by Khare Energy and Building Integrated PV (BIPV) panels integrated onto the roof of a greenhouse by Jain Irrigation as shown in the images on the following page, are some examples of meticulous structural design of PV panels on greenhouses. One of the primary technical advantages of this integration lies in the efficient use of space. The roof and walls of greenhouses, areas that would otherwise remain unused, become active surfaces for solar energy harvesting. This dual-purpose use minimises the land footprint and enhances the overall energy density of the Agri-PV system.

Furthermore, the orientation of the PV modules on greenhouses is strategically aligned to capture sunlight throughout the day. This adaptability ensures that the solar panels track the sun's trajectory, optimising energy yield and synchronising with the varying light requirements of crops within the greenhouse. This dynamic energy capture mechanism is particularly beneficial in maintaining optimal conditions for crop growth and improving overall energy efficiency. In the context of greenhouse agriculture, where precise control of environmental parameters is critical, the integration of PV modules introduces an additional layer of innovation. The overhead shading provided by the solar panels can mitigate excessive sunlight and

PV panels retrofitted onto a polyhouse. © Khare Energy Private Ltd.

temperature variations, creating a microclimate conducive to the specific needs of crops. This shading effect, when properly managed, contributes to enhanced crop yield and quality.

Technical considerations extend to the electrical integration of the PV system with the greenhouse infrastructure. Inverter technologies, monitoring systems, and grid connectivity are key components that ensure seamless energy flow and enable real-time performance monitoring. Smart control systems may be implemented to manage the energy distribution between the greenhouse, on-site storage, and the grid. In conclusion, the technical integration of PV modules on greenhouses/polyhouses in Agri-PV represents a cutting-edge innovation. This approach optimises land use, enhances energy efficiency, and introduces a dual-purpose functionality that aligns with the sustainable development goals of India.

Greenhouse PV using Building Integrated Photovoltaic (BIPV) modules. © Jain Irrigation.

5.3. Semi-Transparent PV Technology

Renkube has pioneered the development of a semi-transparent PV panel tailored for Agri-PV. This technological innovation ensures that 100% of the land can be used for both purposes concurrently.

Traditional solar panels often impede agricultural activities due to the shadow created by the opaque backside, hindering sunlight penetration and rendering the shaded area unsuitable for crop cultivation. Semi-transparent panels overcome this limitation by allowing more sunlight to permeate the ground beneath, thereby fostering an environment conducive to the growth of a diverse range of crops.

The efficacy of Agri-PV systems, featuring semi-transparent panels, has been rigorously evaluated at the Seed Research and Technology Centre (SRTC), PJTSAU, Rajendranagar, Hyderabad. A comparative study was conducted involving a 10 KW capacity Agri-PV system alongside a traditional panel setup. Over three seasons spanning from November 2022 to November 2023, the Agri-PV system demonstrated exceptional results, with a 95% crop yield for Rabi crops such as carrot, cabbage, broccoli, groundnut, and a near 100% crop yield for summer crops like palak and other green leaves.

Semi-transparent PV panels mean farmers can seamlessly integrate regular agricultural activities beneath the solar panels, simultaneously harnessing solar energy and cultivating crops. The dual usage model provides farmers with a reliable income stream of 30,000 INR/acre/annum, acting as a financial buffer against the uncertainties of monsoons and climate change.

This innovative approach also extends benefits to solar developers, who gain access to agricultural land without compromising its primary function. This not only alleviates the pressure on developers to acquire dry and arid sites but also fosters a sustainable model where solar energy generation coexists harmoniously with traditional farming practices. The potential application of this concept to industrial districts opens avenues for micro-, small-, and medium-sized enterprises (MSMEs) to invest in adjacent farmland for solar power generation, contributing to the decarbonisation of industry while supporting local farmers.

Semi-transparent PV panels installed at Seed Research and Technology Centre (SRTC), PJTSAU, Rajendranagar, Hyderabad. © Renkube.

5.4. PV-Agro

In the evolving landscape of Agri-PV, a novel concept known as PV-Agro (coined by NSEFI) is emerging as a pioneering trend that delineates a distinctive approach to land use within solar parks. In contrast to traditional Agri-PV, where agriculture takes precedence, PV-Agro places agricultural activities as a secondary priority, emphasising the primary function of solar energy generation where agriculture is a complementary activity in an existing solar plant. This concept introduces a nuanced paradigm shift, presenting a technical synergy between existing solar parks and agricultural adaptability.

Technically, PV-Agro involves the coexistence of solar panels and agriculture within the same spatial domain, capitalising on the inherent advantages of solar parks. The key distinction lies in the hierarchy of priorities, with solar energy generation taking precedence over agriculture.

From a technical standpoint, the design and layout of PV-Agro systems are optimised to ensure minimal interference with solar panel efficiency. In the context of PV-Agro, the emphasis on solar energy generation is paramount. The technical configuration of the solar panels, their tilt angles, and spacing are meticulously calculated to optimise the overall energy output of the system. This necessitates considerations such as shading patterns, solar panel orientation, and the interplay between energy production and crop growth.

The technical nuances of PV-Agro extend to the selection of appropriate crops that can thrive in the partial shade created by the solar panels. This requires a meticulous understanding of crop physiology, light requirements, and the microclimatic conditions created by the solar park. Crop selection, therefore, becomes a critical factor in achieving a harmonious balance between solar energy generation and agricultural productivity. PV-Agro, with its unique technical focus on solar energy generation and supplementary agricultural adaptability, presents a versatile approach to land use within solar parks. This concept aligns with the evolving needs of the energy and agriculture sectors, fostering a synergistic relationship that maximises the utility of available land while ensuring efficient and sustainable resource utilisation. As a trend and innovation in Agri-PV, PV-Agro contributes to the ongoing dialogue on optimising land use and integrating renewable energy with conventional agricultural practices.

Mahindra Susten plant at Tandur with lemon grass. © Mahindra Susten.

5.5. Aquavoltaics

Aquavoltaics, a pioneering dual-use approach, combines PV technology with aquaculture to co-produce aquatic animals and solar electricity. This innovative integration capitalises on synergies, leveraging module shading effects to benefit aquatic farming during high-temperature conditions. Simultaneously, the efficiency of PV modules is enhanced due to their proximity to cool water environments.

Aquaculture systems are known for their high energy input, primarily driven by the necessity for artificial oxygen supply. This poses a significant challenge to the sustainability of these systems. The introduction of Aquavoltaics addresses this concern by providing a renewable energy source, potentially substituting fossil-based energy, without requiring additional land occupation.

Aquavoltaic systems can be implemented through various configurations, including floating and elevated structures. The choice of design depends on the specific requirements of the aquaculture site. The integration forms play a crucial role in determining the overall efficiency of the system and its impact on aquatic life. Floating platforms, for instance, may offer flexibility but require careful consideration to ensure stability and functionality.

To achieve maximum productivity, thoughtful consideration must be given to the coverage of PV modules and the overall system design. Balancing shading effects for aquaculture benefits with efficient light exposure for PV modules is critical. Additionally, strategic placement of modules should account for factors such as water depth, sunlight availability, and potential impacts on aquatic life.

One key advantage of Aquavoltaics is the temperature regulation it offers to aquatic farming. The shading effects of PV modules provide a cooling effect, which is particularly beneficial during periods of elevated temperatures. Simultaneously, the cool water environments surrounding the modules contribute to enhancing the efficiency of PV technology, resulting in improved electricity generation.

Aquavoltaics thus stands out as an eco-friendly solution, mitigating the need for additional land occupation. By utilising water surfaces for both aquaculture and solar electricity generation, this approach minimises environmental impact. The careful planning of module coverage and system mounting is essential to optimise productivity while maintaining ecological balance.[46]

Aquavoltaics site in Bhaloj, Rajasthan.

46 Hermann et al. (2022).

References

Bioremediation and Bioeconomy (2016), *Rainfed Agriculture*, web: https://www.sciencedirect.com/topics/earth-and-planetary-sciences/rainfed-agriculture

Bramka Arga Jafino, Brian Walsh, Julie Rozenberg, and Stephane Hallegatte (2020), Revised Estimates of the Impact of Climate Change on Extreme Poverty by 2030, *Poverty and Shared Prosperity 2020*, World Bank Group, web: https://documents1.worldbank.org/curated/en/706751601388457990/pdf/Revised-Estimates-of-the-Impact-of-Climate-Change-on-Extreme-Poverty-by-2030.pdf

Chhabilendra Roul, Prem Chand and Suresh Pal (2020), Developing Agricultural Sustainability Index for the Indo-Gangetic Plains of India, ICAR – National Institute of Agricultural Economics and Policy Research, web: https://niap.icar.gov.in/pdf/pb46.pdf

Council of Agricultural Research (ICAR), National Bureau of Soil Survey and Land Use Planning (NBSS&LUP), web: https://nbsslup.icar.gov.in/

CSTEP (2023), Exploring Business Models for Agrivoltaics in India, (CSTEP-PB-2023-01), web: https://cstep.in/drupal/sites/default/files/2023-03/policybrief_agrivoltaics_final.pdf

Dinesh, Harshavardhan & Pearce, Joshua. (2016), The Potential of Agrivoltaic Systems. Renewable and Sustainable Energy Reviews, web : https://www.researchgate.net/publication/284130981_The_Potential_of_Agrivoltaic_Systems

Dr. Priyom Bose (2022), Importance of Healthy Ecosystems for Global Health, *AZO Life Sciences*, web: https://www.azolifesciences.com/article/Importance-of-Healthy-Ecosystems-for-Global-Health.aspx

FAO (2024), World Food Situation, web: https://www.fao.org/worldfoodsituation/foodpricesindex/en/

Food and Agriculture Organization of the United Nations, the World Bank Group and the World Trade Organization (2023), Rising Global Food Insecurity: Assessing Policy Responses. A report prepared at the request of the Group of 20 (G20), web: https://www.fao.org/3/cc5392en/cc5392en.pdf

Hassanpour Adeh E, Selker JS, Higgins CW (2018) Remarkable agrivoltaic influence on soil moisture, micrometeorology and water-use efficiency. PLoS ONE 13(11): e0203256, web: https://doi.org/10.1371/journal.pone.0203256

Hermann et al. (2022), Chapter 6 - Aquavoltaics: dual use of natural and artificial water bodies for aquaculture and solar power generation, *Solar Energy Advancements in Agriculture and Food Production Systems*, ISBN 9780323898669, https://doi.org/10.1016/B978-0-323-89866-9.00009-2

India Meteorological Department (2023), Statement on Climate of India during 2022, Ministry of Earth Sciences (MoES), Government of India, web: https://mausam.imd.gov.in/Forecast/marquee_data/Statement_climate_of_india_2022_final.pdf

IPBES (2019), Media Release: Nature's Dangerous Decline 'Unprecedented'; Species Extinction Rates 'Accelerating', web: https://www.ipbes.net/news/Media-Release-Global-Assessment

IRENA and FAO (2021), Renewable energy for agri-food systems – Towards the Sustainable Development Goals and the Paris agreement, Abu Dhabi and Rome, web: https://doi.org/10.4060/cb7433en

Jamil et al. (2023), Solar photovoltaic wood racking mechanical design for trellis-based agrivoltaics. PLoS ONE 18(12): e0294682. https://doi.org/10.1371/journal.pone.0294682

References

Koll, Roxy & Ghosh, Subimal & Pathak, Amey & Radhakrishnan, Athulya & Mujumdar, Milind & Murtugudde, Raghu & Terray, Pascal & Rajeevan, M. (2017), A threefold rise in widespread extreme rain events over central India. Nature Communications, web: 10.1038/s41467-017-00744-9

Ministry of Agriculture and Farmers Welfare (2023), Land Use Statistics, Government of India, web: https://desagri.gov.in/document-report-category/land-use-statistics-at-a-glance/

Ministry of Environment, Forest and Climate Change (2019), Implementations of India's National Biodiversity Action Plan - An Overview, Government of India, web: http://nbaindia.org/uploaded/pdf/IndiaNationalBiodiversityActionPlan2019.pdf

Ministry of New and Renewable Energy (2023), Physical achievements, Government of India, web: https://mnre.gov.in/physical-progress/

Ministry of Power, 500 GW Nonfossil Fuel Target, Government of India, web: https://powermin.gov.in/en/content/500gw-nonfossil-fuel-target

NSEFI and SolarPower Europe (2022), Engineering, Procurement and Construction (EPC) Best Practice Guidelines India edition, web: https://www.solarpowereurope.org/insights/thematic-reports/epc-best-practice-guidelines-india-edition

NSEFI, SolarPower Europe (2020), Operations & Maintenance Best Practice Guidelines India edition, web: https://www.solarpowereurope.org/insights/thematic-reports/operations-and-maintenance-o-and-m-best-practice-guidelines-india

PIB Delhi (2023), Impact of Climate Change on Agriculture, Ministry of Agriculture & Farmers Welfare, web: https://pib.gov.in/PressReleaseIframePage.aspx?PRID=1909206#:~:text=In%20absence%20of%20adoption%20of,and%205%25%20in%202080%20scenarios

PM KUSUM Scheme, Ministry of New and Renewable Energy, web: https://pmkusum.mnre.gov.in/landing.html

Sarr, Aminata, Y. M. Soro, Alain K. Tossa, and Lamine Diop (2023), "Agrivoltaic, a Synergistic Co-Location of Agricultural and Energy Production in Perpetual Mutation: A Comprehensive Review" *Processes 11*, no. 3: 948, web: https://www.mdpi.com/2227-9717/11/3/948

Saurav Anand (2023), India sets sight on 40 GW renewable energy capacity by 2024, *ET Energy World*, web: https://energy.economictimes.indiatimes.com/news/renewable/india-eyes-hydrogen-and-bio-fuels-for-25-of-global-incremental-energy-demand-hardeep-singh-puri/103934309

SolarPower Europe (2021), Agrisolar Best Practices Guidelines Version 1.0, web: https://www.solarpowereurope.org/insights/thematic-reports/agrisolar-best-practice-guidelines

Sophie Boehm and Clea Schumer (2023), 10 Big Findings from the 2023 IPCC Report on Climate Change, World Resources Institute, web: https://www.wri.org/insights/2023-ipcc-ar6-synthesis-report-climate-change-findings

Tariq Khokhar (2017), Globally, 70% of Freshwater is Used for Agriculture, *World Bank Blogs*, web: https://blogs.worldbank.org/opendata/chart-globally-70-freshwater-used-agriculture#:~:text=In%20most%20regions%20of%20the,percent%20increase%20in%20water%20withdrawals

References

Umesh Sah, Use of Digitization in Rural, web: https://www.riverpublishers.com/pdf/ebook/chapter/RP_9788770222174C20.pdf

Wagner, M.; Lask, J.; Kiesel, A.; Lewandowski, I.; Weselek, A.; Högy, P.; Trommsdorff, M.; Schnaiker, M.-A.; Bauerle, A. (2023), Agrivoltaics: The Environmental Impacts of Combining Food Crop Cultivation and Solar Energy Generation. Agronomy 2023, 13, 299, web: https://www.mdpi.com/2073-4395/13/2/299

Wester, Philippus & Mishra, Arabinda & Mukherji, Aditi & Shrestha, Arun (2019), The Hindu Kush Himalaya Assessment: Mountains, Climate Change, Sustainability and People, web: 10.1007/978-3-319-92288-1

World Food Programme (2023), Global Food Crisis, web: https://www.wfp.org/emergencies/global-food-crisis

Water Technology Centre (2023), PJTSAU, Progress Report on Agri Photo Voltaic System

Y. Elamri, B. Cheviron, J.-M. Lopez, C. Dejean, G. Belaud (2018), Water budget and crop modelling for agrivoltaic systems: Application to irrigated lettuces, Agricultural Water Management, Volume 208, Pages 440-453, ISSN 0378-3774, web: https://doi.org/10.1016/j.agwat.2018.07.001

Yue, Shengjuan & Guo, Mengjing & Zou, Penghui & Wu, Wei & Zhou, Xiaode (2021), Effects of photovoltaic panels on soil temperature and moisture in desert areas. *Environmental Science and Pollution Research*. 28, web: https://www.researchgate.net/publication/348237738_Effects_of_photovoltaic_panels_on_soil_temperature_and_moisture_in_desert_areas

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