Accelerating Agrivoltaics in Maharashtra

Potential Analysis and Policy Recommendations

Maharashtra State Task Force

India Agrivoltaics Alliance

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Organization
The India Agrivoltaics Alliance is a collaborative platform of 48 organisations anchored at the NSEFI secretariat in New Delhi. The IAA aims to build partnerships and platform voices from the agriculture and solar sectors to address issues at the nexus of food-energy-water, including carbon emissions, rising food insecurity, and a need to enhance agrarian livelihoods and land productivity.

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1. Introduction

1.1 Background

1.1.1 Challenges for the agriculture sector in Maharashtra

Maharashtra is the state with highest GDP in the country and is dominated and fueled by services and industry sectors. The agriculture and allied activities sector plays a pivotal role in the rural economy of the state, livelihoods, and food security, with millions of farmers relying on it as their primary source of income, despite its lower share in overall state GDP. However, the agricultural sector faces multifaceted challenges, including water scarcity, high dependability on rain due to rainfed agriculture, climate change impacts, lower farm power availability and lower income of agricultural households. These challenges are exacerbated by the unreliable electricity supply, hindering agricultural productivity and exacerbating the vulnerability of farmers. The central and state governments have announced their target of doubling farmers' income which could be only achieved by addressing all the above mentioned challenges.

1.1.2 Renewable energy, climate change and ambitious targets

Climate change today poses a significant challenge, driven by the accumulation of greenhouse gas emissions in our atmosphere. While fossil fuels have long been the primary sources of our energy infrastructure, contributing to global warming and its associated impacts. Hence, there is a dire need of the hour to bring a sustainable approach in every sector of human activity. By shifting towards renewable energy resources, we can not only reduce our reliance on fossil fuels but also embrace cleaner, more sustainable energy sources. This transition not only mitigates the impacts of climate change but also paves the way for a brighter, more sustainable future for generations to come.

Understanding the climate change occurring at a stunning pace, a target of 45% reduction in the emission intensity by 2030 was set from 2005 level as per the NDC. This translates to reduction in emission intensity from 0.21 in 2022 to 0.16 in 2028. It requires several measures such as increase in the percentage of energy generated from non-fossil fuel-based sources, increasing penetration of electric vehicles from 2% in 2022 to 30% in 2030 as set by NITI Ayog. This is expected to be achieved through addition of renewable energy capacity in the state. The Maharashtra Economic Advisory Council 2023 chaired by N. Chandrasekaran, submitted their report to the Government of Maharashtra mentioning that the energy demand of the state is projected to rise to 200 TWh by 2028. To achieve the ambitious climate action and renewable energy targets in view of the increasing energy demand, the installed solar energy capacity has to be increased to 16 GW by 2028 from over 5 GW in 2024. This transition is supposed to require 1 lakh acres of land in order to support the renewable energy growth. Considering the consistently falling levelized cost of energy for solar PV (currently ₹2.5-3/kWh), it is feasible for the government to set-up new solar plants for achieving the renewable energy targets. [1]

1.1.3 Integration of renewable energy and agriculture as a solution.

According to a study by NITI Aayog published in 2022, Maharashtra is among the frontrunners in SECI (State Energy and Climate Index) indicating that the state is already paving its way to bringing sustainability in energy sector and mitigating the effects of climate change. However, to address the challenges of climate change even more effectively and unlock the full potential of agriculture in Maharashtra through renewable energy solutions, there is a pressing need to integrate renewable energy solutions, particularly solar power, into the agricultural landscape. By leveraging renewable energy technologies, such as solar photovoltaic systems, Maharashtra can not only achieve its renewable energy and climate change mitigation targets but also revolutionize the agricultural sector. [2]

Integrating renewable energy into agriculture offers a myriad of benefits. Firstly, it provides a reliable and sustainable source of electricity to power irrigation systems, reducing dependency on erratic grid electricity and diesel pumps. This promotes efficient water management, enhances crop productivity, and enables farmers to cultivate their lands throughout the year, regardless of grid outages or fuel shortages. Furthermore, renewable energy facilitates the adoption of mechanized farming techniques, such as drip irrigation and precision agriculture, leading to improved yields, and optimized resource utilization. Overall, by embracing renewable energy in agriculture, Maharashtra can modernize its farming practices, increase agricultural resilience to climate change, and bolster rural livelihoods, improve farmers' income while contributing to the state's energy transition and sustainability goals.

The other additional benefit that comes along the deployment of solar PV is the utilization of generated energy during the daytime. Maharashtra has highest share in the consumption of electricity by agriculture sector. Also, the electricity received by agricultural consumers is unreliable due to being supplied during the daytime on some days and during the night time on the other on a roaster basis. As solar energy has the capability to shift the agricultural load completely to the solar hours, Maharashtra government set the target to solarize 30% of the agricultural feeders of the state by 2025. This will not only decouple the agricultural consumption from the grid supply, but also leave a room for reduction in the cross-subsidy surcharge on industrial consumers. Long high voltage transmission lines will be required to evacuate and transmit the power from large utility grade power plants. Instead distributed solar projects will require only sufficient infrastructure to evacuate power from local project sites to be distributed among nearby consumers through the feeders. This will significantly save a huge amount in the budget, time and efforts. Furthermore, distributed solar also allows reduction in the transmission losses. Hence the solarization of agriculture in the state through distributed solar will play a key role to play in making the targets achievable. [1]

1.2 What is agrivoltaics?

Agrivoltaics is an innovative approach of strategically co-locating the agricultural activities with the generation of electricity from solar energy. Both the solar PV and crops require solar resources for producing their outputs. Agrivoltaics aims to achieve an optimal sharing of the incident solar energy to accrue maximal land utilization. Agrivoltaics can significantly help in addressing the climate change problem without compromising on the crop cultivation, simultaneously powering the energy crisis-ridden agriculture sector and improving the farmers' income. Hence agrivoltaics promises to be an effective solution for addressing the challenges discussed in the previous sections and converting them into opportunities.

The effect of the shade imparted by the solar panels onto the crop yield is different in all crops. Some crops tend to be negatively impacted by the shade while other benefit from them. Leafy vegetables and some of the horticultural crops are known to either be benefited from the shade or unaffected by it. Almost all the cereals such as paddy, wheat, maize, and some of the vegetables and fruits, etc. are usually impacted negatively by the shade for yield. The decrease in the yield, however can be compensated by taking several measures. Agrivoltaics projects across the world and in India have demonstrated several additional benefits apart from improved land utilization. These include a cooler microclimate, protection from scorching sunlight during the brightest hours of summer, reduced evapotranspiration due to the shade imparted by the solar panels allows saving precious water resulting from deduction in irrigation water requirement, improvement in the efficiency of the solar panels, increased bifacial generation of electricity with enhanced albedo, protection of crops from damage due to extreme weather events like squall, hailstorm, heat and cold waves, etc. Hence agrivoltaics encourages climate resilience in agriculture. The energy generated in agrivoltaics farms is cleaner, greener and promotes decarbonization of agriculture sector, thus bringing a sense of sustainability to the agriculture. The electricity generated from agrivoltaics can be utilized not only for fulfilling the energy requirements for agricultural purposes but also for supporting side-businesses and allied activities, protected climate-controlled cultivation, value addition through processing of agricultural produce and buttressing employment opportunities for rural communities through cottage industry.

1.3 Existing agrivoltaics plants in Maharashtra

There are about 23 agrivoltaics projects in India, four of which are located in Maharashtra, higher than any other state in the country. These agrivoltaics projects consist of various structures, designs, configurations and experiment with multiple crops commonly cultivated in the respective region. The agrivoltaics plants have demonstrated improvement in the yield of some of the crops while there was a reduction in the yield of the others. There are also crops yield of which was unaffected due to the shade imparted by the solar panels. The details of four agrivoltaics pilots in the state are as follows:

Table 1: Details of existing agrivoltaics plants in Maharashtra [3]

Sr. No.	Pilot Implementer	Location	Capacity	Crops	Remarks
1.	Jain Irrigation (pilot 1)	Jalgaon	14.4 kWp	Banana, Maize	5 m stilt-mounted, an area of 500 m^2.
	Jain Irrigation (pilot 2)	Jalgaon	9.6 kWp	Paddy	3 m stilt-mounted, an area of 105 m^2.
	Jain Irrigation (pilot 3)	Jalgaon	50.4 kWp	Cotton, Okra	Pole-mounted PV, dual-axis tracking
	Jain Irrigation (pilot 4)	Jalgaon	19.3 kWp	Turmeric. Ginger, Mint	1.7 to 2.5 m stilt-mounted, an area of 400 m^2, semitransparent modules.
	Jain Irrigation (pilot 5)	Jalgaon	200 kWp	Banana, Raising seedlings	Transparent BIPV modules, mounted over a 1,100 m^2 greenhouse, LEDs for crop cultivation.

Sr. No.	Pilot Implementer	Location	Capacity	Crops	Remarks
2.	Sunseed APV, GIZ, Kanoda systems	Manwath, Dist. Parbhani	1.4 MWp	Vegetables, Banana, Floriculture	6000 m^2 elevated (1.25 and 1.75 m) cable-based structure, shade nets, monitoring using sensors.
3.	GroSolar Energy, Panasonic Solar	Sindkheda, Dist. Dhule	10 MWp	Nursery, Karonda, Lime, seed production, Lemongrass, solar grazing.	Stilt-mounted modules with interspace farming. Lower height and higher inter-row separation for interspacing farming costing less for structures.
4.	Sahyadri Farms, Sunseed APV, GIZ, Kanoda	Nashik	500 kWp	Vegetables, Grapes, Oranges, Strawberry	Fully-elevated stilt-mounted PV with single and dual-axis tracking, robotic cleaning.

1.4 Overview of the state

Maharashtra is a state in Western India, third largest in terms of area and second largest in terms of population in the country. The state shares its borders with the states of Gujarat in the North-West, Madhya Pradesh in the North, Chhattisgarh in the East, Telangana and Karnataka in the South, and Goa in the South-West. Maharashtra also shares its border with the Dadra and Nagar Haveli region of the Union Territory of Diu, Daman, Dadra and Nagar Haveli. The western side of the state has a 720 km long coastline with the Arabian Sea, on which Mumbai, the state capital and the centre of economic activities of the country is located. Nagpur is the second (winter) capital of the state located nearly 800 km towards the East in the Vidarbha region.

Maharashtra has 36 districts divided into 6 revenue divisions. These 6 divisions are as follows: Konkan Division (Headquartered in Mumbai), Nashik (North Maharashtra) Division (Headquartered in Nashik), Pune (Western Maharashtra) Division (Headquartered in Pune), Chhatrapati Sambhajinagar (Marathwada) Division (Headquartered in Chhatrapati Sambhajinagar), Amravati (Western Vidarbha) Division (Headquartered in Amravati), Nagpur (Eastern Vidarbha) Division (Headquartered in Nagpur).

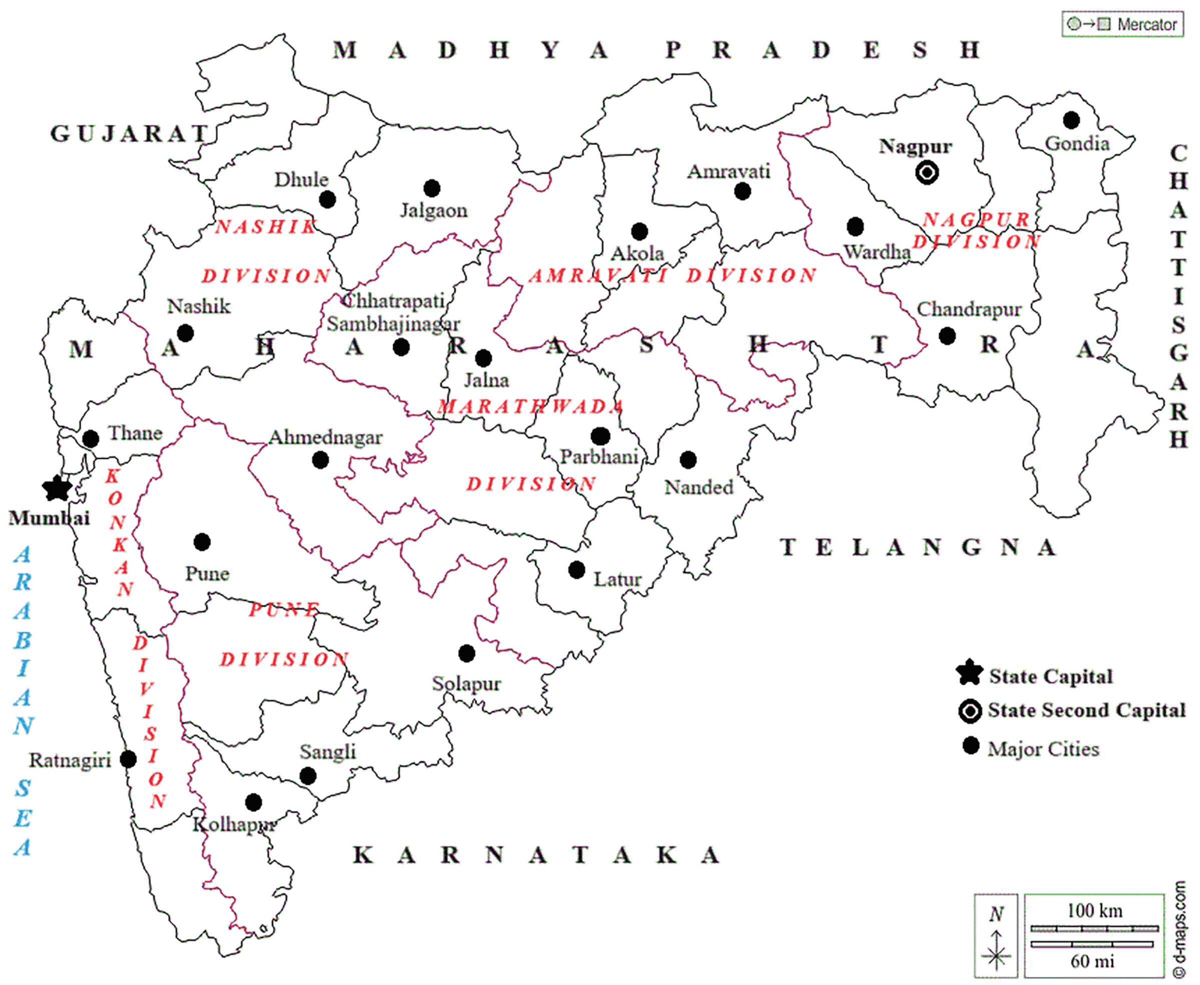

Figure 1: Administrative Map of Maharashtra

1.5 Agroclimatic Zones of the State

The selection of designs, arrangements, structures and configurations of agrivoltaics system is subject to various factors such as available solar insolation, average temperature, rainfall, evapotranspiration, soil, windspeed, humidity, and ultimately targeted crops for cultivation and their cropping patterns. Not all the designs and configurations of agrivoltaics are suitable to all the crops in a geographical area. The generation of electrical energy from solar panels and the yield of crops is greatly governed by all these parameters. It thus becomes very important to understand the agro-climatological characteristics of the geographical area of study.

Maharashtra is a massive state and has huge geographical spread lying between 15^{0} 35' N to 22^{0} 02' N and 72^{0} 36' E and 80^{0} 54' E. There is a great diversity in climatic condition, rainfall, topography, soils, crops and cropping pattern. Based on the topography, hydrology and geology, distribution of soils, and other climatological parameters governing the agriculture such as temperature, amount and pattern of rainfall, the state is divided into 9 different agroclimatic zones. These agroclimatic zones are depicted in the map and listed in the table below.

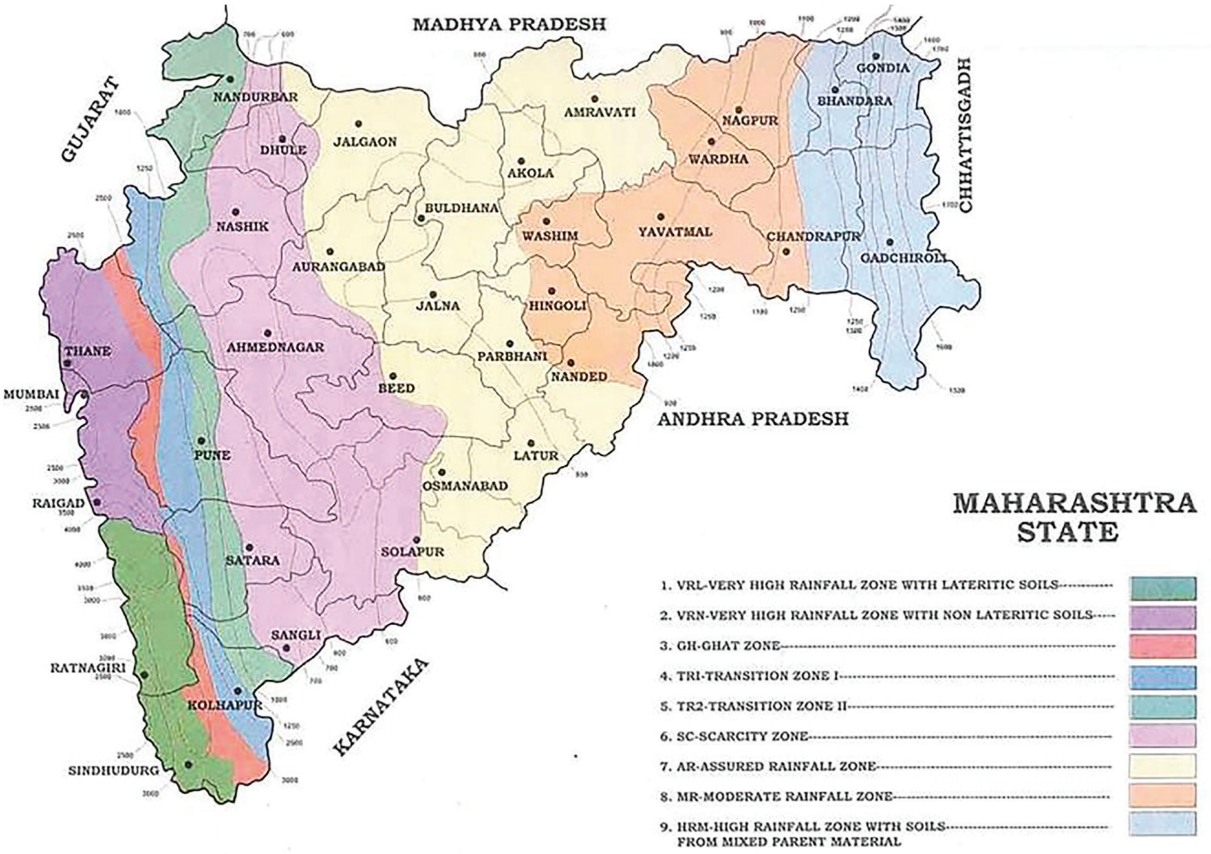

Figure 2: **Agroclimatic zones map of Maharashtra [4]**

The nine agroclimatic zones of Maharashtra show significant diversity in the rainfall, soils and resultantly, crops cultivated. One form of agrivoltaics cannot be applicable for the entire state. The eastern and western parts of the state receive high to very high rainfall and hence are known for cultivation of crops like paddy. The central and western parts of the state receive lower rainfall and thus grow wheat and other cereals like Millets. Areas that are irrigate also cultivate sugarcane which one of the two major cash crops of the state alongside cotton. The east-central parts of the state have black soil and moderate rainfall suitable for cultivation of cotton. Nearly all the districts of Maharashtra cultivate vegetables to some extent, however, western Maharashtra and Parts of Marathwada, Vidarbha and northern Maharashtra have higher productivity of vegetables than the rest of the state. The area, production and productivity of various field crops and horticultural crops in the state is provided in the following sections.

1.6 Research in agriculture and related fields

With a large geographical spread, Maharashtra has several research stations, research centres and laboratories distributed across the state. The nine agroclimatic zones fall under the jurisdiction of four agricultural Universities which are responsible for research in agriculture and related fields. These agricultural universities have adequate laboratory infrastructure and potential to work on research projects related to agrivoltaics. These four universities are listed in a table as follows:

Table 2: List of Agriculture Universities in Maharashtra

Sr. No.	University	Location	Region of Jurisdiction
1	Dr. Babasaheb Sawant Konkan Krishi Vidyapeeth	Dapoli, Dist. Ratnagiri	Seven districts of the Kokan Division
2	Dr. Panjabrao Deshmukh Krishi Vidyapeeth	Akola	Eleven districts of the Vidarbha region
3	Mahatma Phule Krishi Vidyapeeth	Rahuri, Dist. Ahmednagar	Ten districts of the Northern and Western Maharashtra divisions
4	Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani.	Parbhani	Eight districts of the Marathwada division

1.7 Various schemes in solarization of agriculture

Maharashtra is a leader in the electrification and solarization of agriculture sector. With a significant electrification of agriculture already achieved in the state, a total of 45.68 lakh agricultural pumps were electrified in Maharashtra up to March of 2022, whereas 91,914 agricultural pumps were electrified during 2022-23 up to December 2022 as per the Economic Survey of Maharashtra 2022-23. There were over 3.93 lakh diesel pumps in the state as of 2017, significantly lower than most of the large states. The state has well over 16% of the total electric pumps in the country while the number of diesel pumps in the state account for only 3.5% of the total number of diesel pumps in India, indicating the ongoing rapid de-dieselization of the agriculture sector in the state. Following are the schemes implemented by the state and central governments in Maharashtra for solarization of agriculture sector. Other relevant schemes in agriculture sector implemented at both state and central levels are attached in the Annexure. [7]

1. ***Pradhan Mantri Kisan Urja Suraksha evam Utthan Mahabhiyan* (PM KUSUM):** The scheme was launched in 2019 by the Government of India to solarize the agriculture sector. The scheme has three components as follows:

   Component A: Solar power plants of capacity from 500 kW to 2 MW can be setup by individual farmers/group of farmers/cooperatives/panchayats/ Farmer Producer Organisations (FPO)/Water User associations (WUA). However, there is no financial assistance provided by the government in this component. Component A has been seen as potential base for introducing agrivoltaics into the agricultural ecosystem. However, due to lack of finance assistance in component A and high upfront investment costs in agrivoltaics, the implementation of agrivoltaics through component A is apparently far-fetched. According to MNRE, only 2 MW of solar capacity has been installed in Maharashtra as of 31.03.2024.

   Component B: In this component, individual farmers from remote, tribal areas or the areas without grid connectivity can install standalone solar pumps for de-dieselization of the agriculture sector. Two lakh standalone solar pumps have been approved for the state between 2019-20 and 2025-26. Farmers can install standalone solar pumps with a capacity of up to 7.5 HP. A Central Financial Assistance of 30% is provided by the central government, 60% financial assistance is provided by the state while the remaining 10% of the capital cost is to be managed by the general category beneficiary farmer. For a beneficiary farmer from SC/ST categories, the state provides 65% of the capital cost while the farmer has to manage 5% on their own. A total of 84,020 standalone solar pumps have been installed in the state under PM KUSUM as of 31.03.2024.

Component C-I: Individual farmers with existing grid-connected solar pumps are supported for solarizing their electric agricultural pump. A Central Financial Assistance of 30% is provided by the central government, 60% financial assistance is provided by the state while the remaining 10% of the capital cost is to be managed by the general category beneficiary farmer. For a beneficiary farmer from SC/ST categories, the state provides 65% of the capital cost while the farmer has to manage 5% on their own.

Component C-II: The states can solarize agricultural feeders supplying to the pumps instead of solarizing individual pumps. There is also a provision for separation of agricultural feeders if not completed already through various schemes. The project may be implemented in either CAPEX or RESCO models for a period of 25 years. A Central Financial Assistance of 30% on the cost of installation of the solar power plant (up to Rs. 1.05 Cr/MW) will be provided. This financial assistance makes component C-II a better scheme for implementation of agrivoltaics projects currently.

2. ***Mukhyamantri Saur Krushi Vahini Yojana 2.0 (MSKVY):*** The Maharashtra Government launched this scheme in June 2017 to provide electricity to the farmers during daytime through solarization of feeders by installing decentralized solar plants at or nearby distribution substations owned by MSEDCL. The feeder-level solarization for agricultural feeders is being implemented in Maharashtra through MSKVY 2.0 instead of PM-KUSUM component C-II. As per the Economic Survey of Maharashtra 2022-23, a total of 548 MW of capacity has been commissioned up to December 2022-23 while power purchase agreements for 1509 MW were signed. [7]

3. ***Mukhyamantri Saur Krishi Pump Yojana:*** This scheme was launched by the Government of Maharashtra in January 2019. The objective of this scheme is to install 1 lakh off-grid solar pumps, replacing the diesel pumps to decouple the irrigation from the grid reducing the power subsidy burden. The reduction of the power subsidy burden will further allow the minimization of cross-subsidy against commercial and industrial consumers and promote de-dieselization of agriculture providing security of irrigation water and clean energy for the farmers in the remote and tribal areas. The beneficiary farmers with their own land, an assured source of water, and without electric pumps can install the off-grid solar pumps in their farms. It is required to share a 10% contribution for farmers in the general category and a 5% contribution for farmers in the SC/ST categories. As of June 2022, all one lakh off-grid solar pumps were commissioned by the MSEDCL. [14] [7]

2. Evaluation of Agrivoltaics Potential in the State

2.1. Solar Resources of the State

Maharashtra has a solar potential of 64.32 GW and ranks second in the country. According to the Global Solar Atlas data, Maharashtra has an average specific photovoltaic power output of 4.38 kWh/kWp. The abundance of solar resources in this area opens new doors for use of solar PV systems in order to fulfil the electricity demands. Such large-scale solar farms require a huge amount of land. This however challenges the paralleled increasing food demands by the booming population. This conflict between agriculture and solar PV questions the fundamental motivation of sustainability behind the expansion of share of renewable resources. Agrivoltaics can be a very effective step to bring a sense of sustainability to the agricultural sector. Agrivoltaics is now being seen as a promising solution to cater ever-rising demands of both food and energy.

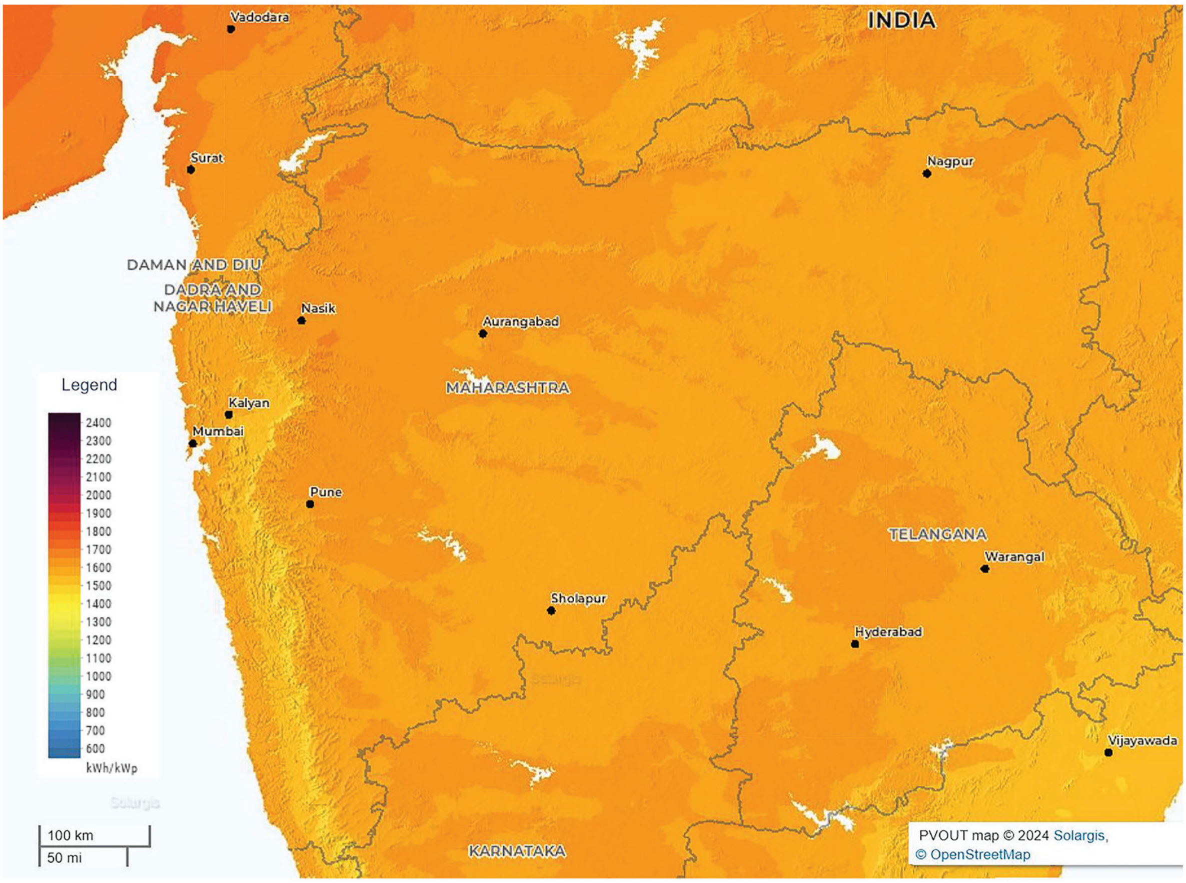

Figure 3: Average specific photovoltaic power output (kWh/kWp) map of Maharashtra. [26]

With a tremendous solar potential, agrivoltaics can promise the generation of solar energy without losing out on agricultural production significantly. The agriculture sector in Maharashtra is the largest consumer of electricity in the country with 36,253.2 GWh of energy sold to agricultural consumers in 2021-22. Considering the 4.38 kWh/kWp as the daily average specific photovoltaic power output and 300 good solar days, Maharashtra would require 27.6 GW of agrivoltaics installations occupying 1,862 hectares of land. Maharashtra has 1.659 crore hectares of net sown area as per the 2021-22 LUS statistics data released by MoAFW, Government of India. Considering just 1% of the total land under cultivation in the state utilized for agrivoltaics projects, assuming six acres of land per MW of capacity will add 27.65 GW of solar PV capacity from agrivoltaics installations. As calculated previously, this is roughly equal to the capacity required for compensating the current agricultural electricity demand of the state. Hence, theoretically just 1% of the total cultivated land of the state will be enough to completely feed the agriculture sector of the state through agrivoltaics without compromising on the cultivation of crops and ensuring daytime reliable supply of clean electricity with minimal distribution losses.

2.2 Wastelands, barren lands and pastures for agrivoltaics

Maharashtra has 9,44,000 hectares of culturable wasteland, 12,03,000 hectares of fallow land (other than current fallow), and 19,75,000 hectares of barren and unculturable land, totaling more than 1.01 crore acres of land that can be utilized for agrivoltaics installation. With the assumptions of setting up agrivoltaics on only 10% of these lands utilizing six acres of land per MW of capacity, this translates to nearly 170 GW of agrivoltaics capacity. With an average daily PV power generation potential of 4.38 kWh/kWp, these installations will be able to produce over 774 GWh of energy every day. With 300 good solar days annually, this translates to 232.2 TWh of electricity produced from solar barren and wasteland agrivoltaics every year. There are agrivoltaics farms in India and abroad that have demonstrated improvement in cultivability in wastelands with cultivation under agrivoltaics. Several methods can also be adopted for improvement in the fertility and quality of soils on such lands for cultivation. Agrivoltaics can be viewed as an effective tool for bringing unutilized lands into cultivation utilizing them for both crop and energy harvesting. [26] [18]

According to the Land Use Statistics 2021-22 released by the Ministry of Agriculture and Farmers Welfare, 1,975 thousand hectares of land were identified as either permanent pastures or other grazing lands. Considering only 10% of this land is utilized for agrivoltaics and cultivation of shade-tolerant fodder crops, 1,97,500 hectares of land will be available for agrivoltaics. This can accommodate nearly 81.34 GW of solar PV installations. Assuming 4.38 as the average PV power generation potential and 300 sunny days a year, these agrivoltaics plants should be able to produce over 356 GWh of energy each day. This is equivalent to the production of more than 106 TWh of energy yearly. The agrivoltaics implemented on pasture and grazing lands judiciously optimized for higher fodder yield can ensure the supply of both fodder in the dry season and daytime electricity supply. The fodder shortage experienced by farmers throughout central, northern, and western parts of Maharashtra can be catered to with a focus centered on fodder cultivation underneath the solar panels. [26] [18]

2.3 Assessment potential based on DISCOM substations

Maharashtra State Electricity Distribution Company has released a list of 2730 substations in the vicinity of which, solar plants can be installed for solarization of substations or agricultural feeders. Assuming that an average of 5 MW of solar PV capacity added through agrivoltaics per substation, a total of 13.65 GW of solar capacity can be added in the state through agrivoltaics powering the agriculture and rural areas. This is remarkable considering the current total solar installed capacity of 5.7 GW (including rooftop, ground-mounted and off-grid solar projects) in the state. With a daily average specific PV power output of 4.38 kWh/kWp, 13.65 GW would produce roughly 5.98 crores kWh of daytime electricity every day. Considering 300 good sunny days in a year, these agrivoltaics installations will be able to produce 17.93 TWh of energy. [26] [18]

2.4 Harvesting precious rainwater with agrivoltaics

Several agrivoltaics projects also demonstrate rainwater harvesting from the modules using gutters or channels that collect the rainwater tripping over the PV module. The collected rainwater can be stored separately for irrigation or cleaning purposes or used to recharge the groundwater level using a percolation pit. The PV panels are also cleaned from time to time to remove the soil and dust layer built-up on the active area. If water is used for cleaning, this water can also be harvested and used for irrigation ensuring minimal wastage. Let us consider a moderate figure of 700 mm for average annual rainfall in a location where the agrivoltaics plant is located. Assuming 330 W panels with the dimensions of 2m x 1m, 3030 panels will be required for 1 MW agrivoltaics plant. The total area of the panels will be 6060 m2. Assuming a 24^{0} average tilt for Maharashtra, the total area of panels projected onto the ground would be 5536 m2. 1 mm of rainfall corresponds to 1 litre of water received on 1 m2 area of ground. Hence 700 mm rainfall incident on 5536 m2. Of area will amount to 38,75,260 litres of rainwater harvested from solar panels which would have flown down the slope over the ground, sweeping away invaluable topsoil.

3. Recommendations to accelerate Agrivoltaics in Maharashtra

Agrivoltaics is a fairly new technology and needs to be explored systematically before finally scaling up to a state-wide implementation. Based on the study of the existing situation of the agriculture and energy sector of the state, and the points that emerged during the discussions of the State Task Force, following recommendations may be considered while formulating the policy around agrivoltaics in the state. The recommendations have been divided into short-term, mid-term and long-term periods for smooth and effective inception of agrivoltaics into the agricultural ecosystem of the state.

3.1 Formal recognition of agrivoltaics

3.1.1 Recognition of agrivoltaics as an innovative farming practice.

As of today, agrivoltaics is not formally recognized by any of the government entities neither at the central level nor at the state level. Agrivoltaics today is mostly implemented under the schemes available for solarization of agriculture either at the central level such as PM KUSUM or at the state level such as MSKVY. There is an absence of a clear requirement on whether or not the agriculture should continue in co-location with the solar PV modules. The fact that these schemes don't stop the farmers from performing agricultural activities underneath or around the panels, has enabled the project developer/owner to implement the solar power plant as an agrivoltaics project. Formal recognition would incentivize farmers and landowners to adopt agrivoltaics by providing them with regulatory clarity and legal protection. This recognition would assure stakeholders that agrivoltaics is a sanctioned land-use practice, reducing uncertainty and risks associated with investment in such projects. This could lead to increased funding and investment in agrivoltaics infrastructure, accelerating its deployment in Maharashtra. Hence agrivoltaics needs to be recognized in the short term to begin with for a smooth induction of agrivoltaics in the agricultural ecosystem of the state.

Without formal recognition, agrivoltaics projects may face regulatory ambiguity, hindering their development and prohibiting potential investors and stakeholders. Lack of clear guidelines and legal status could lead to delays, disputes, and uncertainty surrounding agrivoltaics initiatives. Failure to recognize agrivoltaics as a viable land-use option could result in missed opportunities for sustainable development in Maharashtra. Multiple benefits offered by agrivoltaics may not be fully realized without government support and recognition. In the absence of formal recognition, agrivoltaics projects may be implemented scarcely and inconsistently across Maharashtra. This fragmented approach could lead to suboptimal outcomes, with missed synergies between agriculture and renewable energy sectors, as well as uneven distribution of benefits among different regions and communities.

Taking agrivoltaics further to a wider scale of implementation puts it in the ambit of all the intricacies of the agriculture side and the existing ecosystem for the solarization of agriculture will not be enough. The agriculture is not only limited to growing certain kinds of crops, with fixed cropping patterns and methods. This existent diversity in the agriculture sector may lead to ambiguity when coupled with energy generation on the same piece of land pushing agrivoltaics into a grey area. It is thus of utmost importance that agrivoltaics is recognized by the government properly defining and categorizing it according to combinations of structures, arrangements and other design aspects, crops, farming practices, complementary and allied activities like animal husbandry, sericulture, aquaculture, etc.

3.1.2 Definition of agrivoltaics

As a mid-term task, the definition of agrivoltaics needs to be formulated clearly mentioning what is included in the umbrella of agrivoltaics and what is not. Categorization and definition of agrivoltaics practices would provide stakeholders with a clear understanding of the scope and boundaries of agrivoltaics. Standardized terminology and criteria will ensure consistency in planning, implementation, and evaluation of agrivoltaics projects across different regions and sectors. The disambiguation around agrivoltaics will further ensure effective implementation of the technology optimizing the financial and land resources input into the future projects and schemes. Clear definitions and classifications would facilitate the development of regulations, policies, and standards governing agrivoltaics in the state. Government agencies responsible for agriculture, renewable energy, environment, and land-use planning will use these guidelines to formulate targeted policies that promote sustainable and efficient agrivoltaics practices.

Without clear categorization and a definition, there will be ambiguity and confusion regarding what constitutes agrivoltaics, leading to erroneous interpretations and inconsistent implementations of the concept. Lack of standardized definitions and classifications could result in agrivoltaics projects that are not aligned with the broader objectives of promoting sustainable agriculture integrated with renewable energy, improvement in the income of farmers and rural development.

3.1.3 Technical standards and best practices

There should also be technical standards and best practices for sustainable implementation of the technology and safety of life and equipment. This may be viewed as a long-term activity as it will demand a greater depth of our knowledge as well as a significant database of results and their analyses obtained from the pilots implemented in all the agro-climatic zones of the state. The technical standards would encourage innovation and experimentation in the field. Stakeholders, including farmers, researchers, and technology providers, could explore different approaches and techniques to optimize agrivoltaics systems, leading to the identification of best practices and performance benchmarks. Limits for several factors will be set to eliminate the risks associated with them such as the Ground Coverage Ratio of the panels must be capped to ensure that the crops underneath the PV modules receive an adequate amount of sunlight securing a promising crop yield from the agrivoltaics system. The standards and qualifying requirements will ensure that the primary focus of implementing agrivoltaics is centered on sustaining continued cultivation on the lands utilized for solar energy generation.

It must be ensured that the co-location of agriculture and solar energy generation is not implemented for the sake of robbing the economic benefits sanctioned through the schemes formulated for agrivoltaics, overexploiting the invaluable agricultural lands for solar energy generation. This will safeguard the agricultural productivity and prevent potential losses resulting from inadequate light penetration, shading caused by solar panels or other effects inflicted due to the footprint of the solar subsystem on the crops. Failure to establish limits and caps on key parameters may result in reduced agricultural productivity and compromised crop yields underneath solar panels leading to diminished harvests and stressed food value-chains. This may cause apprehension regarding the technology, prohibiting the policy-makers from prioritizing it over conventional systems. Constantly adhering to the prescribed limits and continuous reporting of the crops in the agrivoltaics farm for vigilance and monitoring would ensure that agrivoltaics projects contribute towards socio-economic development without compromising agricultural productivity. By preventing misuse or overexploitation of agrivoltaics for purely economic benefits, the integrity of agricultural systems can be upheld, promoting equitable distribution of resources and opportunities among stakeholders.

If technical standards and best practices are not made, this could hinder effective planning, policy-making, regulation, and potential investment in agrivoltaics projects, as stakeholders may lack clarity on applicable guidelines and standard practices. In the absence of clear guidance, certain stakeholders may prioritize short-term gains over long-term sustainability, leading to sub-optimal outcomes and missed opportunities from integration of agriculture and energy sectors. Farmers, project developers, investors, policymakers, and researchers will hesitate to participate in agrivoltaics projects if the scope and expectations are not properly defined, leading to limited uptake and slow progress in realizing the potential benefits of agrivoltaics in Maharashtra.

3.2 Incorporating agrivoltaics through schemes

3.2.1 Redirection of power subsidies sustainably

The state government spends a huge budget amounting in thousands of crores every year for subsidy on power supply provided to the agricultural consumers. With an increasing state-wide adoption of irrigation and rising number of connections, this subsidy will grow tremendously every year. Considering the problem of distribution losses in the rural ends of the grid, the cost to the state further intensifies. Furthermore, the scheduling of power and management of load is a challenge for the DISCOMs. As a result, the farmers receive daytime supply of electricity on some days and during the night on other. This not only causes inconvenience but can also be hazardous for the farmer who operates the irrigation pumps during the night. Agricultural consumers benefit from a regular and reliable daytime supply of electricity, which can be provided by agrivoltaics. Redirecting power subsidies towards agrivoltaics projects incentivizes farmers to adopt renewable energy solutions, such as solar-powered irrigation systems integrated with agrivoltaics installations. By providing financial support and higher tariffs for agrivoltaics, the government can accelerate the transition towards sustainable energy practices in agriculture, reducing reliance on conventional power sources and promoting environmental conservation.

Moreover, agrivoltaics is distributed solar PV and the decentralization in the power supply significantly reduces the transmission losses. By generating electricity closer to the point of consumption, agrivoltaics minimize energy losses during transmission, thereby saving revenue for distribution companies and improving overall system efficiency. Agrivoltaics has multiple benefits not just to farmers but to all the stakeholders involved. The state can divert its subsidy on power towards solarization of agriculture and rural areas through agrivoltaics. As the generation of electricity initiates various employment business opportunities in the rural areas, boosting the predominantly agriculture-driven yet, underrepresented work forces of a majority of the districts within the state. DISCOMs which are highly burdened from the sale of electricity at lower tariffs to agricultural consumers, will be relieved along with the fulfilment of their promise of daytime supply of electricity to the farmers. As the farmers receive the electricity from the DISCOMs at a subsidized rate, the cross-subsidy charges are imposed on commercial and industrial consumers. Agrivoltaics can open avenues of reduction of these cross-subsidy charges, reducing the stress on commercial and industrial consumers of electricity.

3.2.2 Amending the existing schemes to accommodate agrivoltaics

Agrivoltaics needs to be proliferated through various central-level and state-level schemes ensuring sustainable uptake of the technology. As our understanding of agrivoltaics, and its impact on the crops, agriculture, and socio-economics of the rural areas is feeble, it is a very difficult task to formulate a scheme exclusively on agrivoltaics in the short term. It is thus convenient to implement agrivoltaics on a pilot scale initially through the various existing schemes. The existing schemes for solarization of agriculture such as PM KUSUM and MSKVY 2.0 can be excellent precursors for agrivoltaics. Currently, as there is no mandate for continuing agricultural cultivation under the panels in either of the schemes, they lack the element of cropping. Existing schemes can be amended to include agrivoltaics proposing the cultivation of crops underneath and in between the solar arrays. As agrivoltaics may need elevated structures which imply higher capital cost and thus must be provided through Viability Gap Funding or any other suitable instruments. Also, priority should be given to bids that propose agrivoltaics plants rather than conventional ones. There can also be tenders floated exclusively for agrivoltaics to ensure its adoption in the agriculture ecosystem.

3.2.3 Introducing new schemes exclusively for agrivoltaics

As a mid-term task, a study may be performed of agrivoltaics project cases implemented through amended versions of the existing schemes will provide great insights into numerous prospects of the technology in the state. The case studies will form a sound base for understanding of potential of agrivoltaics in the context of implementation through government schemes. The results of the study will play a key role in the development of new schemes exclusive for agrivoltaics. The financing structure of these existing schemes may not be suitable for agrivoltaics given the high installation costs. A cost-benefit analysis may be performed to assess the adequate amount of financial assistance and other incentives that may be required for the schemes on agrivoltaics. The schemes must be formulated with the concurrence from all the relevant departments, ministries, universities and experts. This will ensure that the formed schemes are inclusive of all the essential considerations from the agricultural side. In the long-term, the data obtained from the study of the pilots can be utilized for drafting a separate scheme for accelerating the uptake of agrivoltaics in the state.

Various frameworks such as net-metering, group net-metering, virtual net-metering, etc. may be explored for supporting agrivoltaics in the rural areas. Innovative mechanisms such as the peer-to-peer metering, recently drafted by DERC can also be deployed for attracting buyers to procure power from agrivoltaics installations. As per the draft, neither the prosumer nor the consumer engaging in peer-to-peer energy transaction will be required to pay any wheeling charges, cross-subsidy surcharge and additional surcharge. Hence the industrial and commercial consumers within the nearby cities and towns may engage with the agrivoltaics solar power generators for mutual benefits. Mechanisms such as this will contribute to encourage sustainable uptake of agrivoltaics in the rural areas and address the dis-interest shown by stakeholders.

3.2.4 Introducing financial incentives and benefits for implementation of agrivoltaics

Implementation of schemes promoting agrivoltaics would streamline the process for farmers to access financing and loans for setting up agrivoltaics systems. By providing financial incentives, subsidies, and low-interest loans, these schemes can reduce the financial barriers associated with upfront investment costs and enable more farmers to participate in agrivoltaics projects across Maharashtra. Structured schemes offering support and incentives for agrivoltaics would encourage higher adoption rates of agrivoltaics among farmers in the state. By providing technical assistance, capacity building, and knowledge sharing, these schemes can empower farmers to make informed decisions about implementing agrivoltaics systems and capitalize on the benefits of combining agriculture with solar energy generation. One of the examples of financial incentives is the interest subvention provided by Rajasthan government for PM KUSUM component A through *Mukhyamantri Laghu Udyog Protsahan Yojana (MLUPY)*. The financial support from government significantly encourages the uptake of the technology. Rajasthan today is the leader in solar installations under component A with 121 MW of capacity installed alone in the state out of the all-India total of 166 MW.

Without structured schemes to promote agrivoltaics, there may be limited adoption and diffusion of this innovative practice among farmers in Maharashtra. Lack of financial incentives, technical support, and guidance could deter farmers from exploring agrivoltaics opportunities, resulting in slower uptake and implementation rates across the state. Without access to financing, loans, and other resources, farmers may struggle to invest in agrivoltaics projects, limiting their ability to diversify income sources, enhance resilience of agriculture, and improve livelihoods through renewable energy generation.

3.2.5 Periodic Distribution and performance-based award of Benefits for Agrivoltaics Projects

Recognizing the long lifespan of agrivoltaics projects and the importance of ensuring the sustained quality and quantity of agricultural cultivation over their operational period, the state should adopt a policy of periodic distribution of benefits for agrivoltaics projects. Instead of providing upfront benefits to project developers, benefits should be distributed periodically over the project tenure, awarded based on the performance of agrivoltaics systems and the maintenance of agricultural productivity. This approach ensures that the cultivation is not compromised over the lifetime of the project and maintains the competitiveness of agrivoltaics initiatives. Adopting a policy of periodic benefit distribution mitigates risks associated with agrivoltaics projects and enhances their long-term viability reducing the financial burden on public resources and project developers, while incentivizing continuous investment in crop management.

Linking the benefits to key performance indicators such as crop yields, water savings, energy generation, etc. will encourages innovation, efficiency, and sustainable practices in agrivoltaics operations, driving continuous improvement and excellence in project performance. Incentivizing excellence and rewarding high-performing agrivoltaics systems will create a competitive ecosystem that drives innovation, investment, and adoption of best practices, ultimately enhancing the overall quality, reliability, and reputation of agrivoltaics projects across the state. Without periodic distribution of benefits, agrivoltaics projects may face risks to agricultural productivity and long-term sustainability.

3.2.6 Integration of agrivoltaics with the existing schemes on climate resilient and sustainable agriculture

Possibilities of interlinking agrivoltaics schemes with other initiatives may also be explored. Agrivoltaics can be tuned in to align with climate-resilient and sustainable agriculture to reap the most benefits. Various innovative approaches can be adopted in agrivoltaics to accrue benefits against the effects of climate on agriculture. Agrivoltaics promotes resource efficiency by utilizing land, water, and solar resources in a coordinated manner, aligning well with the principles of climate-resilient agriculture, fostering long-term agricultural sustainability. Hence agrivoltaics must be included within the climate-resilient agriculture programmes, both at the central and state levels. A collective scheme on climate resilient agriculture may be formed amalgamating schemes for various individual aspects of the farming systems such as micro-irrigation, protected cultivation, water harvesting and storage, post-harvesting practices, precision agriculture, dryland agriculture, financing for agriculture infrastructure, etc. and other relevant schemes.

The climate-resilient practices under protected cultivation such as solar-powered climate-controlled greenhouses/polyhouses, agrivoltaics shade net houses, and cultivation under anti-hail structures integrated with solar PV, etc. have great potential if included within the umbrella of agrivoltaics. The electricity demanded by these ways of cultivation can be very easily fulfilled through the electrical energy generated within the agrivoltaics farms, reducing the running costs of the system. As the average yield of horticultural crops in protected cultivation is five to seven times higher than in open-field cultivation, security of income through crop yield and secured supply of food in the value chain can be achieved. As agrivoltaics assists in bringing all the essential infrastructure, parallelly solarizing the rural communities, it could also be promoted through various schemes such as the National Horticulture Mission, Horticultural Infrastructure Fund, Agricultural Infrastructure fund, Rural Infrastructure Fund, etc. Neglecting to align agrivoltaics with climate-resilient agriculture programmes will result in missed opportunities for promoting sustainability and resilience for climate change in the agricultural sector of the state. Inadequate integration of renewable energy generation with adaptive agricultural practices could hinder the transition towards more resource-efficient and resilient agricultural systems equipping the farmers with modern and climate-smart farming techniques.

3.2.7 Coupling agrivoltaics with irrigation schemes and water conservation programmes

Recognizing the below-average cultivation area under irrigation in Maharashtra and the importance of promoting sustainable irrigation practices, the state should integrate micro-irrigation and water conservation programmes with agrivoltaics initiatives. By linking these complementary programmes, Maharashtra can leverage synergies, optimize resource utilization, and enhance agricultural productivity while promoting the adoption of sustainable irrigation techniques and renewable energy solutions. Integrating micro-irrigation and water conservation programmes with agrivoltaics addresses the interconnected challenges of water scarcity and energy access in Maharashtra. By deploying solar panels over agricultural land equipped with micro-irrigation systems, farmers can harness solar energy for both electricity generation and efficient water management, optimizing resource use and enhancing agricultural resilience. Incentivizing the use of sustainable irrigation practices such as drip irrigation, sprinkler systems, and other water-efficient technologies in agrivoltaics will encourage efficient water use, minimizes water wastage, and improves crop yields, contributing to agricultural sustainability and water security. Combining solar energy generation with water savings through efficient irrigation, water conservation and reduced evapotranspiration will maximize the co-benefits of agrivoltaics. This will further propel agriculture sector in the state towards achieving dual objectives of renewable energy production and water conservation, particularly in water-stressed regions of central, western and northern parts of the state. The agrivoltaics will not only provide additional income stream through sales of electricity but the water security will also enhance the income from agricultural production by boosting crop productivity and advantage of additional cropping cycle in some regions.

3.2.8 Promoting agrivoltaics through instruments such as RPO and incentivized procurement of power from agrivoltaics projects

Policymakers should consider implementing a Renewable Purchase Obligation (RPO) specifically targeted towards agrivoltaics electricity generation. RPO mandates require electricity distribution companies, consumers, or generators to procure a certain percentage of their electricity from agrivoltaics installations. Implementing RPO for agrivoltaics creates a guaranteed market demand for electricity generated from agrivoltaics installations in Maharashtra. By requiring electricity distribution companies and consumers to procure a portion of their electricity from agrivoltaics, a stimulus can be given for investment in agrivoltaics projects, accelerating market uptake, and encouraging a competitiveness in the market for renewable energy. Absence of a RPO mandates for agrivoltaics may result in limited market demand and investment opportunities for co-location of solar energy generation with agricultural cultivation, as the developers may find it convenient to set up conventional solar plants on agricultural lands instead of agrivoltaics.

To support the widespread adoption of agrivoltaics and promote renewable energy integration, the government may incentivize power procurement from agrivoltaics plants for government and public service consumers, such as government offices, schools, and other public institutions. By leveraging the purchasing power of public entities to support agrivoltaics, the state can create a sustainable market demand for solar-generated electricity, drive investment in agrivoltaics projects, and advance its renewable energy and sustainability objectives. Certain public loads such as schools, colleges and other institutions demand electricity during the daytime which further suits to the energy generation profile of agrivoltaics plants during active solar hours. Encouraging government and public service consumers to procure electricity from agrivoltaics installations will also accentuate the penetration of renewable energy in both rural and urban markets.

3.3 Protection of the farmers' rights

3.3.1 Protecting the land rights

Solar projects including agrivoltaics have a lifetime of at least 25 years and the project owner signs the power purchase agreement for the same period. Farmland is the most important and primary asset for any farmer. Because the farmland is occupied for a significantly long tenure, it is important that the rights of the farmer are preserved. Ensuring that farmers have a voice in project planning, land use negotiations, and revenue-sharing mechanisms, will empower farmers to participate in decision-making processes. This will benefit the farmer from the opportunities presented by agrivoltaics, promoting inclusive and equitable development. It must also be ensured that the farmer remains the sole owner of the land and the project may be owned jointly by the solar developer and the farmers based on share in the investment and the contract. If the farmland is leased by the farmer to the developer, a fair lease rate, incentives, and timely payments of the lease rent must be ensured to the farmer. A portal for attending and tracking farmers' grievances may be developed ensuring their timely resolution. Adequate regulations can safeguard farmland from any potential pressures and land grabs, securing the long-term interests of farmers and rural communities.

3.3.2 Ensuring the rights to uninterrupted cultivation without converting the land from agricultural to non-agricultural category

Agricultural activities are an integral part of an agrivoltaics plant and any solar plant on a farmland cannot be termed as agrivoltaics. Thus, preserving agricultural land for co-existence of solar energy generation with productive farming activities and preventing its unjust conversion for non-agricultural purposes without adequate compensation and consent. It is the responsibility of the project developer to ensure the safe and uninterrupted operation of agricultural activities including deployment of agricultural machineries, cropping practices, post-harvest activities, grazing of animals, and other related practices. Thus, solar project developer must ensure the suitability of the project design for accommodating the cultivation under the modules. The regulations should be set up to ensure the same. As the land is still under cultivation, no change in the land classification must be required and the land should be categorized as agricultural land.

Not prioritizing the protection of farmers' rights may expose farmers' agricultural land to the risk of land grabbing and potential land acquisitions for non-agricultural purposes. This may result in depriving farmers of their livelihoods and undermining food security and rural development objectives of agrivoltaics. Unfair land leasing practices, inadequate compensation, and lack of significant participation in decision-making processes may discourage farmers from engaging in the future agrivoltaics projects. Inadequate protection of farmers' rights may lead to conflict of interest, resistance, and opposition to agrivoltaics projects hindering public trust in renewable energy initiatives.

3.3.3 Devising and implementing innovative farmer-centric business models

There can be numerous possibilities of business frameworks which may be deployed while implementing agrivoltaics. All the various avenues of new and innovative business models must be explored including farmer-owned, FPO-owned, developer-owned, DISCOM-owned, contract-based open access business models, etc. Farmer-centric business models must be developed and piloted securing the benefits to all the stakeholders prioritizing the farmers. It is also important to note that the agrivoltaics require a high upfront investment and hence the investor/project developer are protected against potential threats such as theft, damage inflicted from natural calamities, vandalization, etc. Cooperation from farmers in ensuring the safety and security of agrivoltaics projects helps mitigate physical risks ensuring the safety and security of physical assets of the project. By involving farmers in decision-making processes, risk assessments, and emergency response protocols, agrivoltaics projects can build trust, foster social cohesion, and promote mutual accountability among stakeholders, enhancing project sustainability and acceptance. Lack of trust, communication, and collaboration between project stakeholders could lead to conflicts, disputes, and negative perception of agrivoltaics projects, hindering their social acceptance and integration into rural communities.

3.4 Implementing agrivoltaics pilots

As we look forward to incorporate agrivoltaics into the agricultural ecosystem of Maharashtra, all the intricacies and bottlenecks in various ways and strategies of implementing agrivoltaics must be understood. These include the suitability of different structures and arrangements to all the different crops, agro-climatic zones of the state, different topographies and geographies, compatibility of agrivoltaics with the socio-economic setting of the rural areas, viability and suitability of possible business models and value addition initiatives, etc. This can only be understood by implementing and testing pilots of agrivoltaics in all the agro-climatic regions with all the possible combinations of abovementioned factors. Furthermore, the effect and impact of agrivoltaics on social, economic, ecological ecosystems also needs to be understood.

3.4.1 Cultivation of crops in existing solar PV plants

As short-term phase in implementing agrivoltaics pilots, existing solar plants already set up in the state may be considered for implementing PV-Agro and brought into cultivation. This will ensure that the existing installations are also utilized dually to some extent for cultivation of suitable crops. As these plants would have limited scope for reduction in yield loss, these plants may be exempted from the conditions for yield loss restrictions. When the crops are selected for cultivation based on the existing design and structure of solar plants instead of modifying the design and architecture of the plant in order to properly accommodate agricultural cultivation and other activities beneath and around them, the agri-solar system may be called as ‘PV-Agro’ as distinct from ‘Agrivoltaics’. The existing PV plants with stilt mounted modules may be tested for cultivation of certain crops that tolerate shade to some extent as well as have physical characteristics such that no hinderance is produced to the production of energy. These crops may include green leafy vegetables, root vegetables, climbers, fodder crops, nursery practices such as seedling generation, propagation through cutting and grafting, and other crops with lower growing habits.

3.4.2 Implementation of pilots across the state

In the mid-term, new pilots may be set up from several hundred kW to a few MW scale in various agroclimatic zones of the state to validate the suitability of the technology for the crops cultivated in the respective zones. The pilots will provide actual data of crops and solar generation in real time. This needs to be documented thoroughly documented as reference for the future projects to be initiated in the respective agro-climatic zones. The agro-climatic zone-wise pilots will accommodate the variation in all the essential parameters such as climate and growing seasons, rainfall, soils, crops and cropping patterns, local variations in the agricultural practices, etc. By testing various configurations, structures, and cropping systems, stakeholders can gain a comprehensive understanding of the technical, agricultural, and economic dimensions of agrivoltaics, facilitating informed decision-making and policy formulation. Priority may be given to the barren, uncultivable/ wastelands in degraded areas during the medium-term action, where the micro-climatic conditions may be difficult for cultivation. The barren and uncultivated lands can unfold tremendous potential for agrivoltaics installations as discussed in the previous sections. However, the agrivoltaics implementation must not be limited only to barren or uncultivated lands as in the case of MSKVY 2.0. Considering that agrivoltaics promotes cultivation on the same land, it should be allowed on arable and cultivable lands as well. The lands owned by the Panchayats and other community lands also may be utilized for agrivoltaics pilots.

3.4.3 Research on various aspects agrivoltaics

Agrivoltaics requires a significant level of research both on the technical side and agricultural and ecological sides before it is adopted on a wider scale. The agricultural and technical academic and research universities such as the state agricultural universities and ICAR and CSIR institutes, IITs, NITs and state engineering institutions have great potential to initiate and carry out research on various aspects of agrivoltaics as a part of the long-term vision. There are numerous avenues for research on agrivoltaics such as assessment of suitability of various crops with agrivoltaics, research on the new shade-tolerant varieties of crops, optimization of modules and designs of agrivoltaics systems for maximal sunlight penetration, effect of micro-climate in agrivoltaics installations on the performance of both agricultural and PV subsystems, possible ways of integration of agrivoltaics with the grid, innovative approaches for enhancement of yield in low-light conditions, etc. Various other research aspects of agrivoltaics on the socio-economic or business sides may be addressed through pilots such as the potential impact of agrivoltaics on the rural Agri value chain, potential instruments for making agrivoltaics economically more viable and feasible, various innovative business models and their potential impact on the existing socio-economic landscape of the rural areas, etc. National and international level collaborations may be established among various organizations and institutions for coordinated research on agrivoltaics. Special research programmes such as AICRP may be established for study and research on agrivoltaics.

Without implementing pilot projects and research initiatives for agrivoltaics, Maharashtra may miss opportunities to innovate and optimize the integration of solar energy generation with agriculture. Lack of evidence-based data and research insights could result in sub-optimal implementation of agrivoltaics projects. Inadequate implementation pilot projects and research on agrivoltaics could limit its scalability and replicability, restricting its adoption and proliferation across different regions of the state.

3.5 Benefits through Value-adding infrastructure

It is noteworthy that the average size of land holding in Maharashtra is 1.44 hectares and is as small as 0.75 in some of the districts. Also, an agrivoltaics installation requires huge capital costs (5-5.5 crores per MW). The large capital investment makes the projects prohibitive. This underscores the need of coalescent approach among farmers in implementing agrivoltaics projects. Agrivoltaics ensures the diversification of income streams for farmers and supports the village industries supplying power to the processing and packaging units generating opportunities for employment for the rural youth. Rural women can engage in small-scale industries for value addition enhancing their income through agricultural produce. As Maharashtra has been the leader in forming farmer groups, cooperatives and FPOs, there is an existent ecosystem for adopting agrivoltaics collectively and implementing it with the benefit of economies of scale.

3.5.1 Agrivoltaics for FPOs and farming groups

This pre-existing ecosystem can be leveraged to incorporate the similar approach in bringing agrivoltaics to reality. Various schemes and programmes already exist in the state promoting formation and operation of Farmer Producer Organizations and farming groups. These schemes or programmes can be amended for sharing the expenses incurred by farmer groups for agrivoltaics installations implemented through suitable business models such as net-metering, group net-metering, virtual net-metering, etc. There can be introduced a separate category for agrivoltaics FPOs specializing in the sale of electricity, agricultural produce and processed products. By pooling resources and sharing infrastructure, equipment, and expertise, FPOs can optimize the utilization of agrivoltaics systems, maximizing returns on investment and enhancing the financial viability of projects for smallholder farmers.

3.5.2 Schemes and programmes for supporting FPOs in agrivoltaics

Focusing on the participation of FPOs and farming groups, additional benefits must be ensured such as incentives on or slightly higher tariff for making the agrivoltaics projects more viable. The requirements for applying to avail schemes for agrivoltaics may be diluted to ensure the participation of FPOs and farmer groups through *Gat-sheti* programmes. The other benefits may include waiver of certain charges for commercial and industrial consumers on procurement of power from FPOs and farmer groups, interest subvention and easier availability of loans for FPOs with the government as guarantor, prioritizing women-led groups and FPOs, etc.

3.5.3 Support for value-addition through agrivoltaics

As the production of daytime electricity can power multiple units such as cold storage and other storage facilities, bulk milk chilling and other dairy operations, dryers and other food processing and packaging units, climate-controlled cultivation of special crops such as mushroom, saffron, exotic vegetables, charging stations for electric vehicles, strengthening cottage industry simultaneously empowering rural women through initiatives such as SHGs and *Mahila Bachat Gat*, village/eco-tourism, generation of other forms of clean energy such as energy storage, green hydrogen, biofuels, biogas and bio-fertilizers, biomass energy, waste to energy, etc. The coupling of such units with the agrivoltaics will not only improve the utilization of electricity generated through agrivoltaics but also result in value addition contributing towards self-sufficiency and income diversification of rural communities. Supporting value addition through agrivoltaics has a potential to transform rural areas of the state into centers of economic activity relieving the migration stress on urban areas of the state. By supporting village industries, promoting employment opportunities, and enhancing agricultural productivity and value addition, agrivoltaics projects stimulate economic growth, reduce dependency on agrarian income, and improve livelihoods for rural communities, fostering inclusive and sustainable development across the state.

Without a support for adopting collective approach through FPOs, smallholder farmers in Maharashtra will face significant financial barriers in implementing agrivoltaics projects due to the high capital costs and limited financial resources. Individual adoption of agrivoltaics projects may result in fragmented efforts and limited scalability of the technology due to lower overall economic viability.

3.6 Creation of adequate infrastructure for evacuation

If the lands in the state are to be utilized for implementation of agrivoltaics, it is very important to ensure that adequate substation capacities for effective evacuation of power from the agrivoltaics installations. Adequate substation capacities ensure reliable and efficient evacuation of power from agrivoltaics installations to the grid, minimizing transmission losses and optimizing energy generation. By investing in the expansion and modernization of substation infrastructure, grid stability, resilience, and reliability can be enhanced, facilitating the integration of renewable energy sources. This will further pave the way for proliferating irrigation in the state thereby enhancing the productivity of crops. Better substation capacities will allow the state to enhance the mechanization and technology penetration in its agriculture sector, improving the farm power availability. Availability of sufficient evacuation capacities will streamline the development process for agrivoltaics installations in the state. Developers and investors can have surety knowing that the necessary infrastructure is in place to support power evacuation requirements, reducing project risks, uncertainties, and delays associated with grid connectivity issues.

Inadequate substation capacities for power evacuation may lead to grid congestion, overloads, and voltage fluctuations, compromising the reliability and stability of the electricity supply. Insufficient infrastructure to accommodate the increasing penetration of renewable energy sources could result in curtailment of solar power generation, limiting the economic benefits of agrivoltaics projects. Agrivoltaics project developers will not be able to afford economic losses due to improper evacuation in view of the high investment cost and impact on the economics of the project.

3.7 Sensitization of stakeholders, capacity building and skill development

To accelerate the adoption and uptake of agrivoltaics among farmers and other stakeholders in Maharashtra, the state should prioritize sensitization, capacity building, and skill development initiatives. By raising awareness, providing training, and enhancing technical skills related to agrivoltaics, Maharashtra can empower farmers, communities, and relevant stakeholders to effectively implement, manage, and benefit from agrivoltaics projects, thereby fostering widespread adoption and sustainable integration of solar energy generation with agricultural practices. Sensitization efforts on agrivoltaics increase awareness and understanding among farmers and stakeholders in Maharashtra about the concept, benefits, and potential applications of combining solar energy generation with agricultural activities. By disseminating information through outreach campaigns, workshops, and educational materials, the state cultivates a supportive environment for agrivoltaics uptake and participation.

Capacity building initiatives provide farmers and stakeholders with the necessary skills, knowledge, and technical expertise to plan, implement, and manage agrivoltaics installations effectively. Training and skill development programmes on solar panel installation, crop-solar interactions, irrigation management, and maintenance practices equip participants with the tools and resources needed to optimize agrivoltaics systems and maximize their agricultural and economic potential. By imparting skills in post-harvest handling, packaging, and marketing, Maharashtra empowers farmers to capitalize on the additional income opportunities and market advantages offered by agrivoltaics produce, thus enhancing their overall competitiveness and profitability.

Without sensitization, capacity building, and skill development efforts, agrivoltaics in the state may experience limited awareness and adoption of agrivoltaics among farmers and stakeholders. Without the necessary skills to add value to agrivoltaics produce and access markets, farmers may miss out on income diversification opportunities and fail to realize the full economic potential of agrivoltaics installations, limiting their socio-economic development prospects.

3.8 Selection of crops to be cultivated in agrivoltaics

3.8.1 Background

Maharashtra has the highest GDP in the country and is fueled by services and industry sectors. Agriculture and allied sector, however, is feeble when compared to some of the other states in the country. The overall agricultural output can be improved by securing the availability and reliability of required resources. Maharashtra is a large state and has diverse climatic conditions, soils and thus crops and cropping patterns. This is utmost important to be considered while introducing a new technology. One of the notable observations from the data of agronomic and horticultural crops is that the average productivity of most of the crop in the state is lower than the all-India average. This may be partially due to the fact that the average percentage irrigation coverage of area under most of these crops is significantly lower in the state when compared with the national average. This results in a major share of Maharashtra in the area under cultivation but a disproportionate share in the production. Maharashtra has more minor irrigation schemes than any other state in the country, the highest consumption of electricity in the agriculture and allied sector, profuse electrification of agriculture, yet has a below-average coverage of irrigation in the area under cultivation. The state of groundwater extraction in Maharashtra is significantly stable compared to other states with comparable agricultural output. Hence, the expansion of irrigation has huge potential for improving the production and productivity of most crops. This irrigation would greatly demand clean energy which can be harvested from the solar resources of the state. Hence, agrivoltaics can be a very effective solution for the state of Maharashtra. As per the Horticultural Statistics at a Glance 2022, the state ranks poorly in most of the vegetables and horticulture crops except Onion and a few others, despite its potential. Agrivoltaics provides an opportunity to emphasize horticultural crops enhancing crop diversification in the state.

It is clearly understood that the Net Cropped Area/Net Sown Area in the state has declined to some extent in the past decades losing the lands to urbanization and other developmental projects. Despite this reduction in the Net Sown Area, the production of all the major crops has increased over the same period. This is majorly due to two important factors viz. a significant increase in the Gross Cropped Area and continuous improvement in the average productivity. Both factors are driven largely by the adoption of newer farming practices such as improved varieties, irrigation, etc. by the farmers. Various irrigation projects and individual irrigation systems have created a huge amount of irrigation potential spread over a significant culturable command area. However, a large number of farmers in the state continued rain-fed agriculture relying greatly on the rainfall which has been turning erratic in recent times as an effect of climate change.

With a large number of farmers battling water scarcity induced by prolonged dry periods in several areas of the state, agrivoltaics has the potential to support the crops with lower irrigation minimizing their water requirement. Understanding the fact the agrivoltaics may result in reduction of productivity due to the shade imparted by solar modules on the crops, it may be catered to with a proportional increase with deployment of optimal irrigation and other modern agriculture approaches.

3.8.2 Selection of crops for cultivation in agrivoltaics

There are multiple combinations and possibilities of structures, configurations and designs of agrivoltaics systems with the crops. Selection of crops is a crucial step in cultivation under agrivoltaics installation considering the interactions between the solar PV and cropping subsystems. It has been observed in various pilots across the state, country and the world, that crops such as green leafy vegetables, root crops, tomato, etc. are most suitable for cultivation in an agrivoltaics plant. Various key parameters to be considered for selection of crops include: shade tolerance of the crop, physical dimensions of the shoot of the plant (size of the leaf, height of the stem, spread, etc.), depth of roots, requirement for structural support (e. g. in Tomato, Betel leaves, Pea, Melons, Cucumber, gourds, etc.), part of the plant harvested, water requirements, tolerance against humidity, etc. Most of the crops are suitable for cultivation in the inter-row spacing in an agrivoltaics plant, however, some crops may also be grown directly underneath the solar panels. Following are some of the crops that may be considered in the initial phase of agrivoltaics implementation in the state.

3.8.3 Crops to be considered for cultivation in agrivoltaics systems

Crops such as fenugreek, spinach, Amaranth, *Chiwal, Ghol, Alu* (Taro leaf), Sarson (Mustard), Kardai (Safflower), etc. green leafy vegetables, fruit vegetables such as tomato, brinjal, chilli, Capsicum, Okra, etc. can be grown in agrivoltaics systems with significantly lower ground clearance. Stem vegetables such as cabbage, cauliflower, lettuce, broccoli, asparagus, celery, etc. may be cultivated for lower adverse effects on the crop yield. Root crops in the vegetable and spices category such as ginger, turmeric, potato, yam, arbi, beet, carrot, radish, sweet potato, turnip, onion, garlic, etc. may be selected for cultivation in agrivoltaics systems. Ginger and turmeric are excellent crops Exotic vegetables have recently experienced high demand in the urban markets and can be cultivated in the protective environment of agrivoltaics for higher returns. These exotic vegetables such as lettuce, kale, celery, fennel, broccoli, etc. do not only promote crop diversification, but also provide farmers a direct access to the retail market and open avenues for contract-farming with restaurants chains and other markets. Various fruit crops such as strawberry which benefit from cooler microclimate and fruits with limited shade-tolerance such as Pineapple, Banana, dwarf Papaya, Citrus, Grapes, Apple can also be selected for cultivation in suitable agroclimatic zones. Spices, condiments, plantation crops and medicinal plants such as fennel, cumin, black pepper, cardamom, Coriander, Carom, *Aloe vera*, certain varieties of Coffee, *Ashwagandha*, lemon grass, rosemary, Citronella, etc. may be considered for diversification of crops.

Other crops that are less tolerant to shade such as oilseeds (e. g. Groundnut, Soybean, Niger, Safflower, sesamum, etc.), pulses (e. g. Pigeon-pea, gram, *Mung, Urad, Masur*, etc.), millets (*Jowar, Bajra, Ragi, Vari,* etc.), cotton, jute, etc. may also be cultivated in interspace configuration of agrivoltaics considering higher inter-row separations. Agrivoltaics systems are elevated and stilt mounted, providing a readily available structure for support crops such as tomato, etc. also climbers and creepers. These crops include betel leaves, bottle gourd, cucumber, muskmelon, watermelon, ivy gourd, pointed gourd, pumpkin, sponge gourd, ridge gourd, pea, jasmine, etc. Other non-food crops such as fodder crops, green manure crops and energy crops such as Napiar grass may also be considered for growing underneath the solar modules in agrivoltaics plants. The microclimate and shade in agrivoltaics installations is very suitable for nursery practices such as propagation of plants through cuttings, budding, grafting, seedling nursing, etc. which also promise higher returns. Initially, we may assume that the effect of shade is more or less negative on the crop yield for most of the crops. It is well understood that the availability of irrigation mechanisms provides opportunities for enhancement in the crop yield. In the areas with currently rainfed agriculture, irrigation powered through electricity generated can compensate for the yield loss due to the shade imparted by the solar panels. Furthermore, optimization of density of panels and inter-row separation will minimize the impact on the crop yield.

As per the survey conducted by the government for 'Collection of Farm Activities Data and Other related studies 2018-19', groundnut, horse gram, red chilli, Carom seeds, Garlic, Cucumber, Cauliflower, Onion, Ivy gourd, sweet potato and ridge gourd offer significant returns for smallholder (holding size smaller than 1 Ha) farmers in Maharashtra. For farmers with size of holding between 1 Ha and 2 Ha, Pigeon-pea, Urad, Ginger, Turmeric, Coriander seeds, Muskmelon, Fig, Papaya, Sweet Orange, Capsicum, Radish, Ivy gourd, etc. crops provide sizable returns. For farmers with holdings larger than 2 Ha, Bajra, Gram, Moong, Soybean, Cotton, Watermelon, Banana, Ber, Grapes, Citrus, Strawberry, Beans, Bitter gourd, Brinjal, Beetroot, Carrot, Potato, Sweet Potato, Pumpkin, Tomato, Bottle gourd, pointed gourd, sponge gourd, Peas, green Chillis, Coriander, Fenugreek, Spinach and Cluster beans offer good returns. This data may be considered before selection of crops for cultivation in agrivoltaics plants along considering the size of the holding pertaining to the agrivoltaics project. [27]

3.8.4 Agrivoltaics with protected cultivation

With agrivoltaics integrated protected cultivation of many of the above crops have great potential to offer higher yields and greater reliability. Mushroom farming, Floriculture, aquaculture, animal husbandry and apiculture are other complementary agricultural activities that may be implemented with agrivoltaics for multiplexed benefits. Crops such as sugarcane, Paddy, Wheat, Maize, cotton which need higher amounts of solar intensities should be avoided for a wide-scale implementation of agrivoltaics. Adverse effects on the yields of these crops may result in disruption of value chains of markets of these crops and in turn, income of the farmers. Taller crops that may cast shadow on the solar panels or cause damage to the equipment such as coconut, Arecanut, Mango, Cashewnut, Sapota, other taller crops, etc.

References

[1] "Roadmap to becoming a $1 Trillion economy," Maharashtra Economic Advisory Council 2023, Mumbai, 2023.

[2] S. Pandey, N. K. Vidyarthi, R. Ram and R. Sarwal, "State Energy and Climate Index: Round-I," NITI Aayog, New Delhi, 2022.

[3] S. Pulipaka, M. Peparthy, M. Vorsat and R. Y. V. K, "Agrivoltaics in India, Overview of Projects and Relevant Policies," NSEFI - IGEF SO, New Delhi, 2023.

[4] Z. V. P. ICAR- Agricultural Technology Application Research Institute, Agro Climatic Zones, Pune.

[5] E. I. S. (ENVIS), "Agro Climatic Zones in Maharashtra," Environment Department, Government of Maharashtra, Mumbai.

[6] J. Chintamani, N. Varadaraj, V. Pakhmode, K. Dongre, C. Bhoyar, P. Barahate, D. Tijare, Amarnath and P. Kadam, "Report on the Dynamic Ground Water Resources of Maharashtra 2022," Groundwater Surveys and Development Agency Pune Water Supply and Sanitation Department GoM, Central Ground Water Board Central Region, Nagpur Department of Water Resources, River Development & Ganga Rejuvenation, Ministry of Jal Shakti, GoI, Nagpur, 2023.

[7] Economic Survey of Maharashtra 2022 - 2023, Mumbai: Director of Economics and Statistics, Government of Maharashtra., 2023.

[8] E. a. S. Division and Department of Agriculture and Farmers Welfare, Agricultural Statistics at a Glance 2022, New Delhi: Ministry of Agriculture and Farmers Welfare, Government of India, 2023.

[9] D. o. A. C. &. F. W. Horticulture Statistics Division, Horticultural Statistics at a Glance 2018, New Delhi: Ministry of Agriculture & Farmers' Welfare, Government of India, 2018.

[10] Horticulture Statistics Division, "Horticultural Statistics at a Glance 2022," Department of Agriculture & Farmers Welfare, MoAFW, Government of India, New Delhi, 2023.

[11] Directorate of Economics and Statistics, "District Domestic Product of Maharashtra 2011-12 to 2021-22 (Base Year 2011-12)," Planning Department, Government of Maharashtra, Mumbai, 2023.

[12] "Situation Assessment of Agricultural Households and Land and Livestock Holdings of Households in Rural India, 2019," National Statistics Office, Ministry of Statistics and Programme Implementation, Government of India, New Delhi, 2021.

[13] "Final Report on Monitoring, Concurrent Evaluation and Impact Assessment of Sub-Mission on Agricultural Mechanization," Mechanization and Technology Division, Department of Agriculture, Cooperation & Farmers Welfare, Ministry of Agriculture and Farmers Welfare, New Delhi, 2018.

[14] MSEDCL, "Mukhyamantri Saur Krushi Pump Yojana," MSEDCL, January 2019. [Online]. Available: https://www.mahadiscom.in/solar/index.html. [Accessed March 2024].

[15] M. S. A. M. Board, "Annual Report : Year 2022-2023," Government of Maharashtra, Pune, 2023.

[16] A. C. 2.-1. (Phase-I), All India Report on Number and Area of Operational Holdings, New Delhi: AGRICULTURE CENSUS DIVISION DEPARTMENT OF AGRICULTURE, CO-OPERATION & FARMERS WELFARE, 2019.

[17] D. C. (. Census) and e. al, "Maharashtra State Report on Number and Area of Operational Holdings, Agriculture Census 2010-11 (Phase-I)," Commissionerate of Agriculture, Department of Agriculture, Government of Maharashtra, Pune, 2014.

[18] E. S. a. E. D. M. G. o. India, "Land Use Statistics – At a Glance, latest year data for 2012-13 to 2021-22," 04 December 2023. [Online]. Available: https://desagri.gov.in/document-report-category/land-use-statistics-at-a-glance/. [Accessed 11 March 2024].

[19] C. G. W. Board, "National Compilation on Dynamic Ground Water Resources of India, 2022," Department of Water Resources, River Development and Ganga Rejuvenation, Ministry of Jal Shakti, Government of India, Faridabad, 2022.

[20] P. Bharate, Nelofar, Amarnath, P. Kiran Kumar, D. Verma, R. K. Sharma and S. Bhange, Ground Water Year Book of Maharashtra and Union Territory of Dadra and Nagar Haveli (2021-22), Nagpur, Maharashtra: Dept. of Water Resources, RD and GR, Central Ground Water Board, Central Region, Ministry of Jal Shakti, Government of India, 2022.

[21] Minor Irrigation (Statistics) Wing, 6th Census of Minor Irrigation Schemes Report, vol. 2, Delhi: Ministry of Jal Shakti, Government of India, 2023.

[22] C. E. Authority, "All India Electricity Statistics, General Review 2023," Ministry of Power, Government of India, New Delhi, 2023.

[23] Central Electricity Authority, "All India Installed Capacity (in MW) of Power Stations (As on 29.02.2024)," Ministry of Power, Government of India, New Delhi, 2024.

[24] P&C Division, "State-wise Installed Capacity of Renewable Power Including Off-grid as on 29.02.2024," Ministry of New and Renewable Energy, Government of India, New Delhi, 2024.

[25] "Annual Administrative Report FY 2022-23," Maharashtra State Electricity Distribution Company Limited, Mumbai, 2023.

[26] Global Solar Atlas, "Global Solar Atlas Map," [Online]. Available: https://globalsolaratlas.info/map?c=18.90109,75.635376,7&r=IND:IND.20_1. [Accessed 23 March 2024].

[27] "Final Report On Collection of Farm Activities Data and Other related studies, 2018-19, Vol. I," Directorate of Economics and Statistics, Government of Maharashtra, Mumbai, 2021.

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