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Agrivoltaics in India

January 2024

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AGRIVOLTAICS IN INDIA

January 2024

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This publication has been prepared under the Indo-German Technical Cooperation on Innovative Solar (IN Solar) in India. The project has been initiated under the guidance of the Ministry of New and Renewable Energy, Government of India and is funded by the Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH (GIZ). Ernst and Young LLP (EY LLP) has led this project along with Center for Study of Science, Technology and Policy (CSTEP) and Fraunhofer ISE (Germany) as partners. The project aims to explore potential of the new innovative applications of solar with reduced land utilization having the potential to foster the targeted expansion of solar photovoltaic (PV) applications in India. The NISA areas are agrivoltaics (APV), floating PV (FPV), canal top PV (CTPV), rail/road integrated PV (RIPV) and building integrated PV (BIPV)/ urban PV (UPV).

The project team is grateful for the guidance and support received from the Ministry of New and Renewable Energy (MNRE), especially from Dr Arun K. Tripathi (Scientist G), Dr Anil Kumar (Scientist E), Ms Priya Yadav (Scientist C), Mr Arun Kumar Choudhary (Scientist B). Special thanks to Dr D. K. Singh from the ICAR- Indian Agricultural Research Institute for his guidance through this study.

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Disclaimer

The potential derived for the different integrated PV applications and the methodologies used have been derived with the sole purpose of estimating a national level potential of these technologies for India. It is subject to certain assumptions to extrapolate the potential on a national scale. Statistical potential estimation methodology was utilised wherever there was a lack of precise geographic information system (GIS) data. Realised potential on the ground might differ owing to a more precise system level design at this scale.

FOREWORD

Henrik Personn

Dear Readers,

The G20 declaration under India's presidency this year emphasizes the importance of "accelerating clean, sustainable, just, affordable and inclusive energy transitions," with a strong emphasis on rapidly expanding renewable energy deployment (G20, 2023). Bilateral efforts related to sustainable energy technologies are recognised as crucial in bringing this commitment to fruition.

In this regard, the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH is pleased to present this study on New and Innovative Solar Applications (NISAs). The identified NISAs are Agrivoltaics (AgriPV), Floating Photovoltaics (FPV), Canal Top Photovoltaics (CTPV), Rail/Road Integrated Photovoltaics (RIPV), Building Integrated Photovoltaics (BIPV) and Urban Photovoltaics (UPV). This study is a testament to the Indo-German Technical Cooperation under the Innovative New Solar Areas (IN Solar) project, a bilateral project initiated under the esteemed guidance of the Ministry of New and Renewable Energy (MNRE), Government of India, and funded by the German Federal Ministry for Economic Cooperation and Development (BMZ). The IN Solar project has been at the forefront of exploring NISAs with the potential to revolutionise India's renewable energy landscape.

This report on "Agrivoltaics in India" is the flagship report building upon all previous work on AgriPV that has been conducted by GIZ in India (https://www.agrivoltaics.in/). It provides comprehensive information for the uptake of the sector, analyses potentials, highlights possible business models, elaborates on policy and regulations, and gives an outlook to the skilling requirements. The reader is also encouraged to explore the GIS-based NISA atlas (https://staai.cstep.in) to get a glimpse of potentials as well as information on expected levelized cost of energy (LCOE) for AgriPV applications in every state and district. The analysis of different business models addresses not only power subsidies, losses, and delayed subsidy payments but also the possible higher farmer income due to AgriPV interventions. The recommendations on policy and regulatory frameworks may help to mainstream AgriPV projects and can be further developed, if necessary.

Herewith I express my sincere appreciation to all individuals and organisations who have played a crucial role in the formulation of this report, especially the scientific team led by Ernst & Young (EY) LLP and their distinguished partners, the *Center for Study of Science, Technology and Policy (CSTEP)* (India) and *Fraunhofer ISE* (Germany) but also the project teams, stakeholders, diligent researchers, and of course the invaluable guidance of MNRE.

I hope that this document serves as a valuable resource and inspires continued innovation and collaboration in the realm of renewable energy.

Yours sincerely,

Henrik Persson

Henrik Personn
(Head of Solar Projects in GIZ India)

PREFACE

On behalf of the entire project team, it is with great pleasure that we present this comprehensive report on Agrivoltaics in India, which is a part of a series of six distinct reports showcasing the New and Innovative Solar Applications (NISAs) in India. The reports include:

- Potential Assessment of New and Innovative Solar Applications in India
- Agrivoltaics in India
- Floating PV in India
- Canal Top PV in India
- Building Integrated and Urban PV in India
- Rail and Road Integrated PV in India

The study encompasses potential assessments, various business models, implementation strategies, technical aspects, policy enablers, market dynamics, financial considerations, and the skill sets needed to catalyze the growth NISAs in India.

Another key element of this study includes creation and implementation of an online tool called the Solar Technology and Application Atlas for India (STAAI). This innovative tool is crucial for visualizing and analyzing the solar potential in India, providing stakeholders with a user-friendly experience. The STAAI goes beyond simple potential assessment by including decision tools like the Levelized Cost of Electricity (LCOE) calculator. Additionally, it allows the generation of district-wise or state-wise potential assessment reports for each NISA.

For further details on each of our report and to access the Solar Technology and Application Atlas for India (STAAI), please visit https://staai.cstep.in/

We extend our gratitude to all those who have contributed to the success of this project and express our anticipation for the positive impact that these reports and the STAAI will have on the solar energy landscape in India.

Thanks and Regards

Project Team

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LIST OF ABBREVIATIONS

APV	Agrivoltaics/ Agrophotovoltaics
ARR	Aggregate revenue requirements
AT&C	Aggregate technical and commercial loss
BAU	Business as usual
BIPV	Building integrated photovoltaic
BU	Billion units
CAGR	Compound annual growth rate
CAPEX	Capital expenditure
CAZRI	Central Arid Zone Research Institute
CEA	Central Electricity Authority
CTPV	Canal top photovoltaic
DIN	Deutsches Institut für Normung e.V.
DISCOM	Electricity distribution companies
DSCR	Debt service coverage ratio
EPC	Engineering procurement and construction
ETS	Emissions trading system
FIT	Feed-in tariffs
FPV	Floating photovoltaic
FTE	Full-time equivalent
GBI	Generation-based incentive
GDP	Gross domestic product
GHI	Global horizontal irradiance
GIS	Geographic information systems
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH
GW	Gigawatt

Ha	Hectare
IARI	Indian Agricultural Research Institute
ISRO	Indian Space Research Organization
I-SUN	India - solar usage in new applications
JNNSM	Jawaharlal Nehru National Solar Mission
KUSUM	Kisan Urja Suraksha evam Utthaan Mahabhiyan
kV	Kilovolt
KVK	Krishi Vikas Kendra
kWh	Kilowatt hour
kWp	Kilowatt peak
LCOE	Levelised cost of electricity
MIS	Management information system
MLFBM	Medium-large farmer business model
MNRE	Ministry of New and Renewable Energy
MoAFW	Ministry of Agriculture and Farmers Welfare
MU	Million unit
MW	Megawatt
NISA	New and innovative solar applications
O&M	Operations and maintenance
OPEX	Operating expenditure
PPA	Power purchase agreement
PV	Photovoltaic
QTL	Quintals
RESCO	Renewable energy service company
RIPV	Rail/Road integrated photovoltaic
SFBM	Small farmer business model
SOP	Standard operating procedure
TW	Terrawatt
VGF	Viability gap funding

EXECUTIVE SUMMARY

00

In the quest for sustainable and clean energy solutions, solar power has emerged as a frontrunner in the renewable energy sector. While traditional land-based solar photovoltaic (PV) plants have proven to be effective in generating electricity, there is a growing need to explore new and innovative solar applications (NISA) that offer distinct advantages. In particular, the concept of land-neutral or dual-use applications has gained significant traction. This approach seeks to maximize the utilization of available land by integrating solar installations with existing infrastructure or employing non-traditional spaces. By tapping into these alternative applications, we can overcome the limitation of land availability, remove conflict over land use and enhance overall efficiency and sustainability within the solar energy sector.

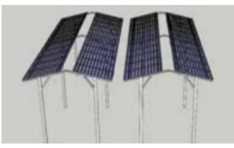
In this context, the Government of Germany and the Government of India signed a new project titled IN-Solar (Innovative-Solar). Under the project, Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH and the Ministry of New and Renewable Energy (MNRE) initiated a program titled India - Solar Usage in New Applications (I-SUN) which aims to explore New and Innovative Solar Applications (NISA) with reduced land utilization having the potential to foster the targeted expansion of solar PV applications in India. The NISA areas are **Agrivoltaics (APV), Floating PV (FPV), Canal Top PV (CTPV), Rail/Road Integrated PV (RIPV) and Building Integrated PV (BIPV)/Urban PV (UPV).**

Agrivoltaics (APV) is also known as Agrophotovoltaics, solar sharing, farming photovoltaics, or solar farming. APV not only reduces land-use impact and potential risks of land conflicts but also bears the potential to deliver improved conditions for crop growth by providing protection against strong solar irradiation and winds, hot temperatures, and improved water availability. Yet, there is no internationally unified definition of agrivoltaics. This report covers APV in detail including the potential assessment, business models, modes of implementation, key technical, policy and market enablers, finance portfolio and skills required to facilitate the acceleration of APV in India.

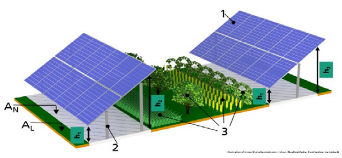
In **Chapter 1**, the concept of agrivoltaics is introduced, which involves the integration of solar photovoltaic panels with agricultural practices to maximize land use efficiency and sustainability. Various configurations are discussed as ways to implement agrivoltaics, including the overhead stilted configurations such as the south configuration and east-west configuration. Additionally, interspace south and interspace vertical configurations are also mentioned as options for combining solar energy generation with agricultural activities.

Overhead South

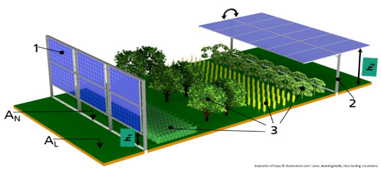
Overhead East-West Configuration



Inter-row South



Interspace Vertical



The overarching potential estimation methodology in **Chapter 2** has been developed for 17 crop which covers 129 million hectares of land area under cultivation till district level was sourced from the Ministry of Agriculture and Farmer Welfare (MoFW). Solar resource availability specific to each district is considered and the overlapped with GIS based technical restriction criteria for identifying the suitability of land parcel, estimating energy generation and financial feasibility. The project team has also developed a solar technology application atlas for India (STAAI), which provides a user-friendly experience of viewing technology potential through its workflow along with providing key insights through decision tools such as levelised cost of energy (LCOE) calculator and state wise potential assessment report. The overall methodology for estimating the potential of APV in India has been illustrated below.

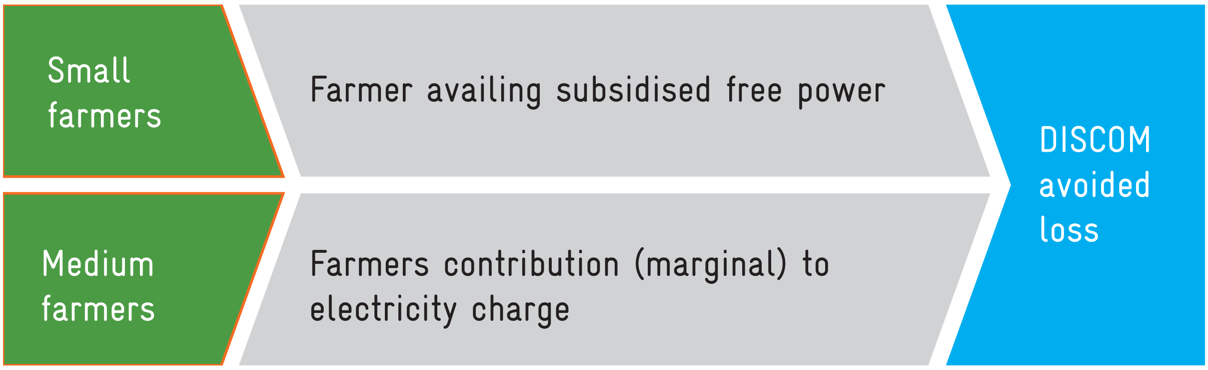
Step 1- Resource Identification	(X) Agricultural area under cultivation in district– MoAFW
Step 2- GIS Restriction Criteria	(Y) Suitable area that fulfils the criteria
Step 3- Overlaying Resource on GIS	R-Value = Y/X
Step 4- Crop specific area cultivation	Area under cultivation of crop(i) considered = C_i
Step 5-Overlaying on crop specific area	Suitable area for AgriPV with crop(i) = R-Value * C_i * Value from crop suitability matrix (Cs)
Step 6- Calculating Power Density	Calculating AgriPV potential with power density

Criteria:
- GHI >4.5 kWh/m2/day
- Distance from Road/Rail < 10 km
- Distance from substation (132kV) < 25 km
- Slope < 8 degrees

Power Density
- Overhead South : 650 kWp/ha
- Overhead EW : 750 kWp/ha
- Inter Space : 400 kWp/ha

Agrivoltaics (APV) potential considers three technology configurations – overhead (south facing and east-west facing), inter-row south and interspace vertical orientation. For each of the 17 selected crops, different suitability for the three technology configurations, which has been considered while calculating overall potential. India's total potential for APV is estimated across minimum and maximum scenarios for respective crops with various APV technologies in each district and it **varies from 3,156 GW to 13,803 GW.**

The business models are discussed in **Chapter 3** of this report, the APV business models have been developed keeping in view of our model objective, fixed boundary conditions and limited stakeholder interactions. The model is created from only energy generation perspective and does not focus on demand side restriction i.e., the technical constraint for offtake of power and who will be the end consumer for the generated power. The business model has been developed for two broad categories of farmer types based on land holding, i.e., medium farmer with more than two hectare land and small farmer with less than 2 hectare. APV technology can provide a huge financial benefit to the electricity distribution companies (DISCOMs) in their supply operations, while simultaneously ensuring continuance of farming activities. The I-SUN program has modelled this scenario for APV and calculated the avoided loss benefit to the DISCOMs with the installation of a 1MW APV project.



In Chapters 4 and 5 of this report, the capacity projection of APV has been done from 2024 to 2040. It is estimated that the cumulative capacity addition of 20 GW and 60 GW of APV under the moderate and optimistic scenario, respectively. The total investment required to realise the 20 GW capacity (moderate case) will be around INR 81,424 crores and INR 2,13,858 crores for 60 GW of APV installation in the country. Based on the national average power procurement price in the day ahead market (DAM) during the 08:00 to 18:00 hours for DISCOMs in India and the LCOE of APV systems, the project team have also highlighted the viability gap funding (VGF) support required to make the business model viable for a 1 MWp APV systems. VGF is only considered in cases where LCOE is greater than the average DAM prices.

In **Chapter 6,** the project team explored and researched the policy and regulatory landscape for APV prevailing in India by referencing published literature, consulting various stakeholders, and understanding the various stages in the lifecycle of the project. This was accompanied by undertaking rigorous engagements with key stakeholders like project developers, regulators, nodal agencies, market developers, etc. along each of the stages.

Barriers and Challenges Identified

Application Stage	Project Approval	Project Execution & Commissioning	Operation & Maintenance
Land usage categorization	Unavailability of standards	Use of ground water for APV	Agricultural yield loss mechanism
APV on barren ands	Grid connection availability	Additional evacuation Infrastructure Cost	Tax on income through electricity generation
	No tariff determination mechanism	Technical standards for connectivity	

Furthermore, based on the above identified barriers and challenges, some key recommendations related to addressing bottlenecks in the effective implementation of APV projects have been made.

Policy	Definition of APV	Definition of APV is required in policies. The percentage of land that can be used for solar and farming, without affecting the crop yield by some percentage, needs to be clearly mentioned.
	Pradhan Mantri FasalBima Yojana	Methodology for calculating anticipated yield loss for APV. It will help in identifying the potential risks and benefits of APV for agricultural productivity and making informed decisions about the adoption of technology.
Regulatory	Model Ground Water Bill 2016	Includes information on compulsory permits and registration of consumers for using ground water. The priority on groundwater may include APV in the model bill.
	Change in Land Act	Classifying APV as an agricultural activity may help address issues related to land conversion and use of groundwater, as it recognises the land is being used for both agricultural and energy production purposes.
	Evacuation	Evacuation infrastructure and network augmentation developed by DISCOMs for APV may be included in the ARR instead of charging the vendor/farmer.
Technical	Technical Standards of Connectivity	DICSOMs to provide evacuation capacity and guidelines for plants below 33/11 kV on the website, giving information to farmers and interested parties.

In the last chapter of this report, the project team has identified several skill gaps where training is necessary to boost the APV sector in India. Creating a skilled workforce is vital for increasing the penetration of APV, and this will ensure better utilization of renewable energy resources with high-quality workmanship on the deployed technologies. Under the moderate case, it is estimated that to meet a demand of 20 GW of APV by 2040, **1.1 lakh full-time equivalent (FTE)** jobs will be required and for the optimistic case, **3.38 lakh FTE** jobs to support distinct roles and responsibilities starting from application, project approval, detailed engineering, project execution-commissioning and operations and maintenance.

INTRODUCTION TO AGRIVOLTAICS TECHNOLOGY

01

There are many definitions of APV technology used throughout the world. The I-SUN program has researched and delved deep into various APV technologies being practised in major countries as part of the literature review for this project. A key finding from the review is that the standardised definition of APV is still divergent across the world. However, the closest and most technically sound definition is proposed by Deutsches Institut für Normung e.V. (DIN), which is being followed in Germany.

DIN Specification (DIN SPEC) portrays a fundamental requirement of APV systems to achieve at least 66% of agricultural reference yield and keep land losses due to mounting structure below 10% for Category I and 15% for Category II (DIN 2021).

In particular, the pre-norm DIN SPEC 91434:2021-05 defines APV as: Agricultural photovoltaics (agrivoltaics) is the combined use of the same area of land for agricultural production as the primary use and for electricity production utilizing a PV system as a secondary use."

AN APV PLANT SUPPORTS FARMERS BY OFFERING THE FOLLOWING BENEFITS:

- Revenue: It creates an additional source of revenue for the farmers by the sale of power.
- Reduced energy costs: A portion of the energy produced by the plant can be used to power pumps, irrigation systems etc., thus reducing the energy cost.
- Reduced water usage: It has been observed that the shading of the panel can reduce water evaporation on the ground.
- Increased land use efficiency: Land may be utilised more efficiently by placing panels above the crops.

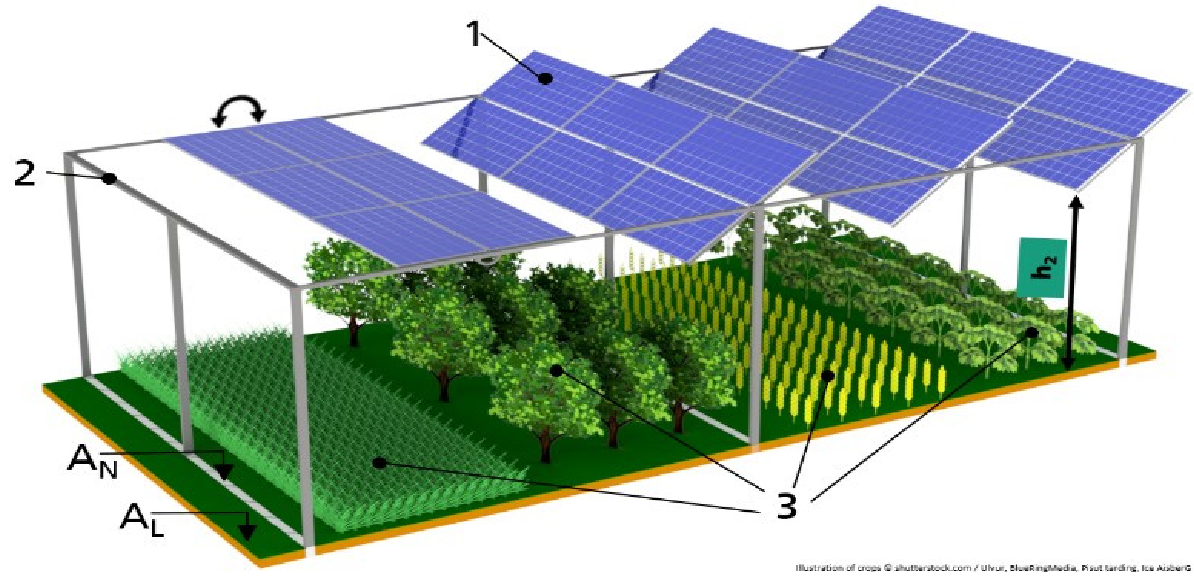


Figure 1: Overhead stilted APV plant configuration

APV CAN BE INSTALLED IN THE FOLLOWING THREE WAYS[1]:

Overhead Stilted: The modules are installed on a raised structure. The land below is used for agricultural activity. The height of solar modules plays an important role in defining the crop that can be grown under it. An optimal elevation mounted at a minimum height of 2.1 m from the ground allows the movement of equipment and promotes more even distribution of sunlight under the solar PV panel.[2]

The following configurations can be used based on the orientation of solar modules for overhead stilted plants:

1 Legend of configurations: AL - Cultivatable agricultural areas; AN - Uncultivatable agricultural area; H1 - Clearance height below 2.10 m; H2 - Clearance height above 2.10 m; 1 - Examples of solar modules; 2 - Mounting structure; 3 - Examples of crops

2 Trommsdorff M.; Gruber S.; Keinath, T et al. Agrivoltaics: Opportunities for Agriculture and the Energy Transition. A Guideline For Germany, 2nd edition; Fraunhofer Institute for Solar Energy Systems ISE: Freiburg, Germany, 2022.

a. **Overhead south configuration (height >2.1m):** Overhead south facing agrivoltaics place the solar panels facing south to maximize the amount of sunlight they receive throughout the day. This orientation allows for greater electricity generation while also minimizing the shading of the crops.

Figure 2: Overhead south APV configuration

b. **Overhead east-west configuration (height >2.1m):** In overhead east-west racking, the solar panels are mounted on structures that run parallel to the ground in an east-west direction. This orientation allows for more solar panels to be installed per unit of land and this particular shape is especially suitable for orchards where the plantations also get protection from the panels providing an alternative to shade nets normally used for this purpose.

Figure 3: Overhead east west APV configuration

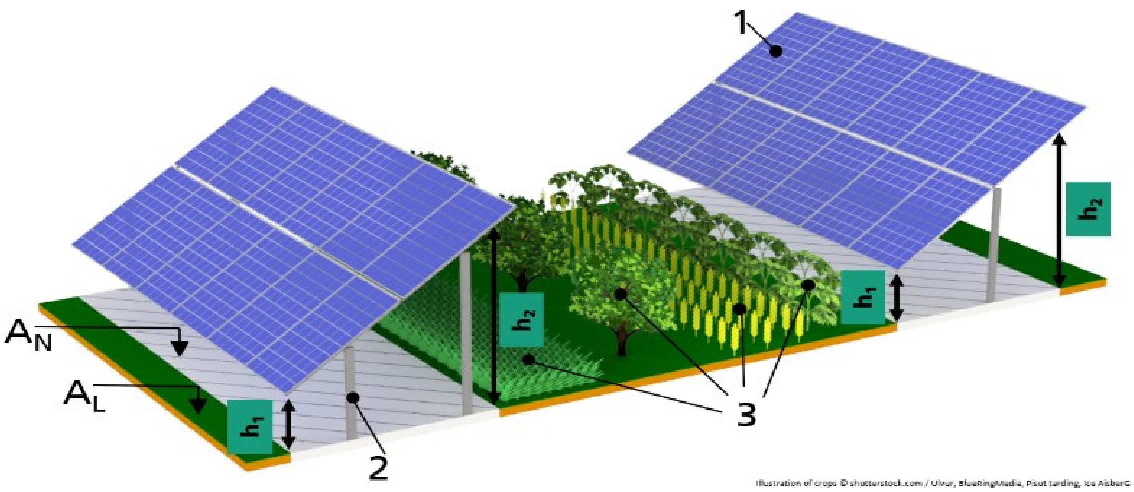


Figure 4: Inter-row spacing APV plant configuration

Interspace: The row spacing between adjacent rows is large enough to accommodate agricultural activities.

- Inter-row south configuration (height < 2.1m): Inter-row PV systems are ones where agricultural output often takes place in the area between the panel rows. In this form of installation, the spacing between two consecutive rows of panels can be quite substantial to allow for the passage of huge agricultural gear.

Interspace vertical configuration: The modules are installed on the periphery of the crops. In this type of installation, the solar panels are mounted vertically on poles acting as a wall in rows with space left between the panels for farming activity.

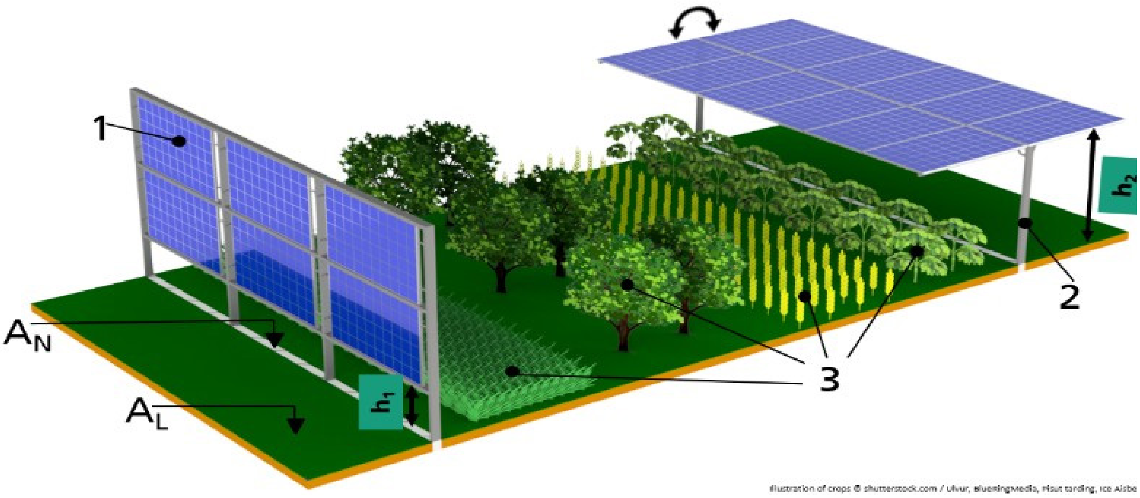


Figure 5: Interspace vertical APV plant configuration

1.1 APV IN INDIAN CONTEXT

India is blessed with more than 300 days of sunshine hours with a solar insolation ranging between 4 to 7 kWh per sq m per day. This makes the use case of exploring all plausible applications of solar PV compelling. Solar energy finds inherent applicability in the agricultural sector, given its high gross domestic product (GDP) contribution from the sector, and large area coverage. However, like any new technology, its applicability in rural India will be governed by regulatory structures and business frameworks suitable for the local communities. Some other factors identified that will most likely govern APV's adoption in India include:

- Policy and regulatory structures
- Change in land use patterns, which are inherently linked with farmer benefits
- Farmers macro-economic consideration
- Socio-cultural frameworks

Consequently, the key enablers for APV technology in India include existing policy schemes such as Kisan Urja Suraksha evam Utthaan Mahabhiyan (KUSUM), which focuses on solar PV systems in agriculture. Solarisation of agriculture feeder program can benefit from APV. Also, being an agrarian economy, dual-use land utilisation with crop production and power generation is highly sought after by farmers and could be a key enabler in adoption of APV systems.

APV TECHNOLOGY SUITABILITY FOR INDIA

Preliminary studies of APV technology in India have shown that there are several pilot APV projects already in operation. A closer look at these projects reveals basic assumptions of technology parameters, equipment, costs, supplier readiness and off-taker buy-in already existing in the market. Given this understanding, and after undertaking several consultations with key program stakeholders, three APV technology types were finalized as the most suitable, keeping the focus on swift technology uptake. These included:

- Overhead E-W facing, >2.1 m height
- Overhead N-S facing, >2.1 m height
- Inter-row spacing, vertical solar.

Agrivoltaics being a new concept in India will require certain support mechanisms that will appeal to and encourage relevant stakeholders to consider and adopt it. This is highly relevant given India's ambitious commitment towards net zero and decarbonization. From a national program perspective, the visualisation of the technical potential of the areas in India being considered for APV will serve to attract attention. To maximize interest from potential stakeholders, information must be usable, adaptable, and presented in a convenient and comprehensive format, for swift onboarding of market participants. Just like an online solar rooftop calculator, technical potential aims to bridge market risks, resolve uncertainties related to technology stereotypes and help quicken the onboarding decision-making process among developers, government, and policy makers to adopt innovative solar applications like APV.

I-SUN program has been instrumental in developing the methodology for potential assessment of APV, basis consultations with Indian Agricultural Research Institute (IARI), Indian Space Research Organisation (ISRO) and Central Arid Zone Research Institute (CAZRI), key stakeholders under the project. The key recommendation proposed by the participating entities was to consider district-level statistical data for cropping/farming in potential estimation exercises as GIS data for agricultural land is unavailable. As a result, the methodology for APV catered to this restriction and devised a scientific approach to calculate the APV potential assessment in India.

POTENTIAL ASSESSMENT OF APV

02

The potential farming area considered for APV is adapted using farming statistical data sourced from the Ministry of Agriculture Farmer and Welfare (MoAFW). The data source encompasses statistical information on crop growing patterns for 17 crops across all districts in the country. The technology restriction criteria have been overlaid on suitable farming areas extracted from the database. An illustration of the approach has been depicted in Figure 6.

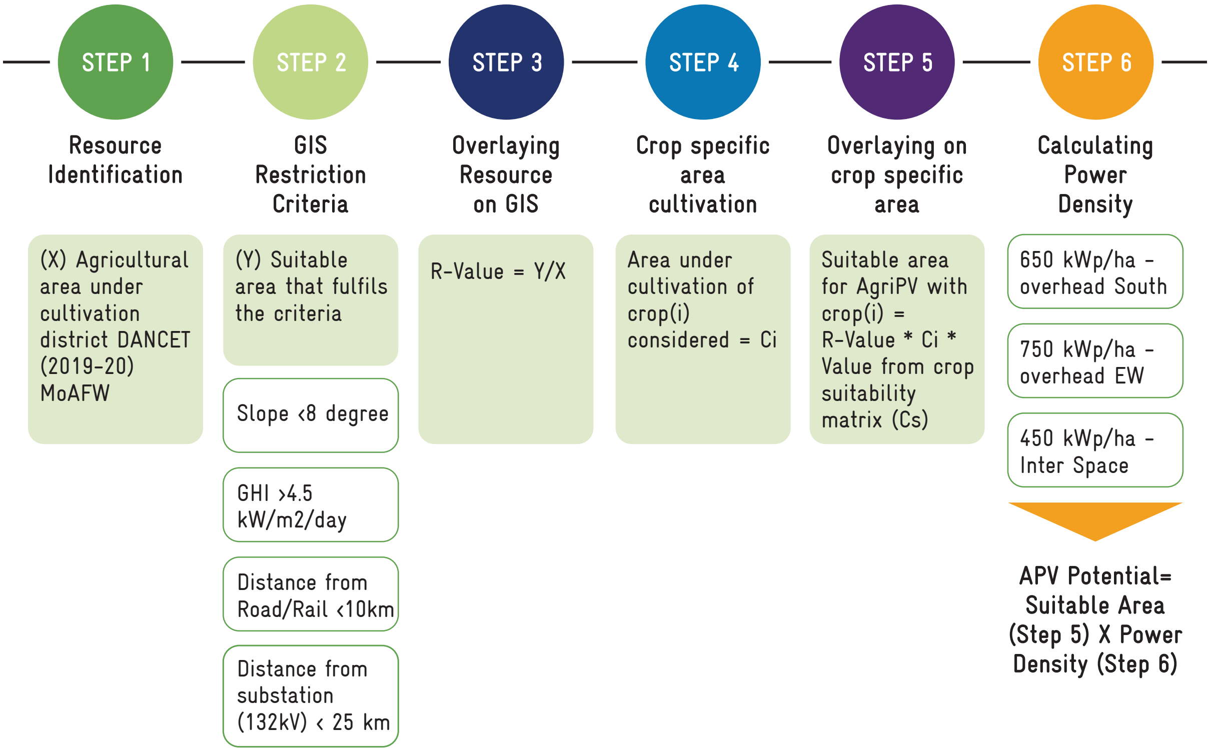


Figure 6: Calculating potential APV area on the basis of restriction criteria

Step 1: The potential assessment begins with referencing the total agricultural area under cultivation in all district for 17 crops (Annexure C). This area represents the total area in hectare (ha) under cultivation in a particular district.

Step 2: We had used LULC data from Sentinel2 with 10-meter resolution to identify the land parcels being cultivated in India. To begin with 129.46 million hectares was considered as the total cultivable land across all districts in India. This area is then exposed to the below mentioned restriction criteria for checking suitability for solar installations

- Global horizontal irradiance (GHI) greater than 4.5 kWh/m2/day, which identifies areas suitable for high solar generation yield. This criterion ensures that the resultant capacity utilization factor (CUF) from overhead south, overhead East-West and interspace APV plants does not drop below 15%, 13% and10% respectively, based on simulations run on Center for Study of Science, Technology and Policy (CSTEP)'s solar techno-economic model (CSTEM) tool.
- Distance from road/rail of less than 10 km (as per the open street maps definition of pakka roads), which ensures access to potential sites with convenient approach and connectivity
- Distance from the substation (132 kV) of less than 25 km, which ensures feasible power off-take to grid. Here, the assumption considers an area under 25 km for a 132 kV substation to have a high likelihood of a low voltage substation (33/66 kV) network within its vicinity. This was considered due to insufficient data availability of comprehensive low voltage distribution network area in the country.
- A slope of less than 8 degrees is considered to ensure maximum power generation from modules, considering minimum shading losses due to topology variations.

The above list of restriction criteria is fundamental to PV project implementation. The criteria related to vicinity from road/rail, evacuation infrastructure and slope have been considered after discussions with various developers of ground-mounted PV plants. Going beyond the threshold values leads to exponential increases in capital costs and renders projects unviable in terms of LCOE and resultant power purchase agreement (PPA) rate requirements. Additional criteria specific to agriculture, e.g. ground water data availability and precipitation pattern, can be integrated into the methodology in the future, on the basis of the availability of relevant datasets.

Step 3: The next step involves calculating the subset of statistical information extracted from the total cropping area (X) in the district (Step 1), and land area calculated after putting the technology restriction criteria (Y) for a district (Step 2). The resulting overlapped ratio (Y/X) of land area identified in Step 2 and Step 1 will provide an R-value for each district.

Step 4: Now with the area available under cultivation of each crop (considering crop(i)) available for every district, we can calculate the suitability of the cropping area (of crop(i)), for installing solar PV project. This is done by multiplying the available crop area (Ci) with the R-value for each district (Step 3).

Step 5: Next, the suitability of the crop is mapped with each APV system configuration, using a crop matrix. The suitability of particular crops is classified based on extensive literature reviews and field experiments conducted around the world in similar climatic zones. These are scientific estimations based on available data and experience. The recommendations of the crop matrix and suitability of crops to a particular system and its shade response can change subject to the availability of more relevant data points in relevant conditions.

The crops are divided according to suitability class (1 to 5) for the overhead south system as an example shown below. Each crop suitability class is assigned to a probability of this crop being cultivated in that specific agrivoltaic system based on its suitability to that system. Suitability of existing crop to agrivoltaics was decided to be an important point of consideration to estimate the existing potential for agrivoltaics in India. There is a lack of spatial data available on the exact crop growing at farm level in every district. Statistical data denotes the overall crops growing in a particular district. Hence such a crop matrix was developed. The unique percentage value then determines the approximate acreage that can be considered for a particular crop in that district to calculate the potential in the next step.

Every crop has a yield response score to shading effect. ***Yield response is the correlation between shading rate and is based on literature review, i.e. the change in yield compared to the reference due to shading.*** These values for all 17 crops in the Indian context have been dealt with in detail by the programme. This yield response score translates to a unique percentage value using the formulas shown in Table 1. The crops will be located in the matrix and mapped for their suitability to agrivoltaics systems.

Table 1: Formula deriving range of crop suitability matrix for overhead south orientation

Suitability Class	Range of APV Yield Score	Range of percentage	Formula, valid in range of percentage
1	1 – 1.49	(0-33%)	= 0.06803 * [APV Yield Score] - 0.6803
2	1.5 – 2.49	(33-42%)	= 0.0404 * [APV Yield Score] + 0.3194
3	2.5 – 3.49	(42-54%)	= 0.0808 * [APV Yield Score] + 0.258
4	3.5 – 4.49	(54-67%)	= 0.0909 * [APV Yield Score] + 0.2618
5	4.5 – 5	(67-100%)	= 0.58 * [APV Yield Score] - 1.9

Example for calculation:

Crop: Tomato, APV-yield score: 3.79 (suitability class 4)

Formula: 0.0909 * (APV yield score = 3.79) + 0.2618 = 60.6%

Result: The probability for implementation of an APV system on a tomato field or its suitability is at 60.6.%

Table 2: Crop suitability matrix for an overhead south system

1 (0-33%)	2 (33-42%)	3 (42-54%)	4 (54-67%)	5 (67-100%)
Eggplants	Chickpeas	Wheat	Lemons and limes	Spinach
Cashew Nuts	Maize	Barley	Oranges	Coriander
Coconuts	Beans, dry	Potatoes	Lettuce and chicory	
Rubber, natural	Rice, paddy	Bananas	Soybeans	
		Rapeseed	Tomatoes	
		Garlic	Spices	
		Apples	Seed cotton	
		Broccoli and cauliflower	Okra	
		Sesame seed	Pumpkins, squash and gourds	
		Cabbages and other brassicas	Chilli	
		Onions, dry	Black pepper	
		Sorghum	Bell peppers	
		Millet	Coffee	

Source: Fraunhofer ISE

With the area for each crop and its suitability for each technology mapped, the potential is calculated directly using power density formulas for each APV technology type.

Step 6: The power density for the three types of APV considered under potential assessment, i.e. Overhead South facing, Overhead East-West facing and Interspaced Vertical, has been referenced from international best practices and on-ground projects. Next2Sun declares that the installed capacity of their APV systems on grasslands is 0.4 MW/ha. Hence, the power density for interspace systems is deemed to be 400 kWp/ha. Based on the measurements from different agrivoltaic systems realised by Fraunhofer ISE and its partners around the world, the range for the power density for overhead systems is between 0.6 and 0.9 MW/ha, depending on the system design. In our calculation, we assume two unique conservative values of 650 kWp/ha and 750 kWp/ha, respectively. The values correspond to the capacity of APV applicable to suitable areas calculated per crop (in Step 4).

Note: The above criteria do not consider crop rotation to be part of the potential assessment methodology. However, the literature review has shown that most of the major crops are either rabi or kharif crops. This means that the other crops are grown in rotation to the main crop in most parts of India. This rotation is either on an annual or biennial basis taking soil fertility conditions into account along with local microclimates. The methodology followed in this project so far has the potential to double/triple count the capacity of APV that can be installed because of crop rotation. To estimate a more realistic number, the research methodology followed in this project divides the crops in each district into either rabi, kharif, winter and summer.

The potential for each crop in a district is calculated for each of the three APV technologies based on the crop suitability matrix. This is done for each cropping season (rabi, kharif, summer and winter) based on the area cultivated for the specific crop in the particular season. The maximum number is taken out of the potential for the three APV technologies as the potential for the crop in each season. Then the maximum and minimum numbers are taken for the four seasons as the range of potential for each crop. The state-wise and country-wise potential numbers are calculated by taking the cumulative numbers of minimum and maximum potential for each crop in each district and then presented as a range. **This approach leads to a revised estimation of a range of ~3.1 – 13.8 TW as the APV potential for India**.

2.1 SAMPLE OF POTENTIAL CALCULATION

To serve as an example, state ABC has been hypothetically chosen as an example. There are two districts. In District 1, there are 2 crops grown in the Rabi season (X_r & Y_r) and 2 crops grown in the Kharif season (A_k & B_k). In District 2, there are 2 crops grown in the Rabi season (U_r & W_r) and 2 crops grown in the Kharif season (H_k & L_k). From the literature survey, it can be deduced that multiple or single PV technologies are applicable for each crop. It is assumed that each crop can be grown along with all 3 APV technologies, viz. overhead south (OHS), overhead east-west (OHEW) and interspace (IS). The potential varies for each of these technologies for each crop. For example, X_r in District 1 has OHS potential of 200 MW, OHEW – 250 MW and IS – 150 MW. The technology with the highest potential is chosen as the suitable technology for the crop in order to maximize utilization. Hence, the potential of X_r is calculated as 250 MW. Similarly, Y_r has a potential of 125 MW. The total potential of Rabi crops in district 1 is the sum of potentials of X_r and Y_r, which is 375 MW. In the case of Kharif crops, A_k & B_k have potentials of 300 MW and 400 MW respectively. The total Kharif potential is estimated to be the sum of these 2 crops – 700 MW. For District 1, the minimum potential is calculated to be the Rabi potential which is the lower of the two seasons assuming that the entire Rabi cropping area overlaps in rotation with the Kharif area. Since PV panels can only be placed at the lower threshold without affecting yield further, the minimum potential is fixed at 375 MW. The maximum potential on the other hand is the Kharif potential of 700 MW and this scenario corresponds to no overlap or rotation between lands with Rabi and Kharif crops.

Table 3: Example of potential calculation for district 1 in state ABC

District 1: Rabi Crops: X_r, Y_r; Kharif Crops: A_k, B_k

RABI	OHS Potential (MW)	OHEW Potential (MW)	IS Potential (MW)	Potential (MW) = MAX (OHS/OHEW/IS)
X_r	200	250	150	250
Y_r	125	100	80	125
$X_r + Y_r$				375
KHARIF	**OHS Potential (MW)**	**OHEW Potential (MW)**	**IS Potential (MW)**	**Potential (MW) = MAX (OHS/OHEW/IS)**
A_k	300	225	20	300
B_k	400	300	200	400
$A_k + B_k$				700

Maximum Potential of District 1 = 700 MW (Kharif number)

Minimum Potential of District 1 = 375 MW (Rabi number)

In District 2, it is the inverse with the maximum potential corresponding to the Rabi potential of 830 MW and minimum potential corresponding to the Kharif potential of 450 MW. The maximum and minimum potentials of the state are calculated by adding the maximum and minimum potentials of the respective districts.

In this case, District 1 Rabi maximum potential + District 2 Kharif maximum potential = 1530 MW; District 1 Kharif minimum potential + District 2 Rabi minimum potential = 825 MW. This is a simplistic method followed to avoid double counting of potential caused due to rotation of crops. More data regarding field level cropping patters in various seasons will help in refining these results for the Indian context at a taluk level.

Table 4: Example of potential calculation for district 2 in state ABC

District 2: Rabi Crops: U_r, W_r; Kharif Crops: H_k, L_k

RABI	OHS Potential (MW)	OHEW Potential (MW)	IS Potential (MW)	Potential (MW) = MAX (OHS/OHEW/IS)
U_r	430	420	200	430
W_r	220	400	80	400
$X_r + Y_r$				830
KHARIF	**OHS Potential (MW)**	**OHEW Potential (MW)**	**IS Potential (MW)**	**Potential (MW) = MAX (OHS/OHEW/IS)**
H_k	255	200	90	255
L_k	40	-	195	195
$H_k + L_k$				450

Maximum Potential of District 2 = 830 MW (Rabi number)

Minimum Potential of District 2 = 450 MW (Kharif number)

Therefore, Potential of State ABC (MAX) = 1530 MW; Potential of State ABC (MIN) = 825 MW

2.2 ENERGY GENERATION ESTIMATION

Energy generation estimations are done using average GHI values considered in districts using Meteosat (European Organisation for the Exploitation of Meteorological Satellites, Darmstadt, Germany) for each district. This GHI data is converted into solar irradiance falling on panels based on APV technology type tilt considered.

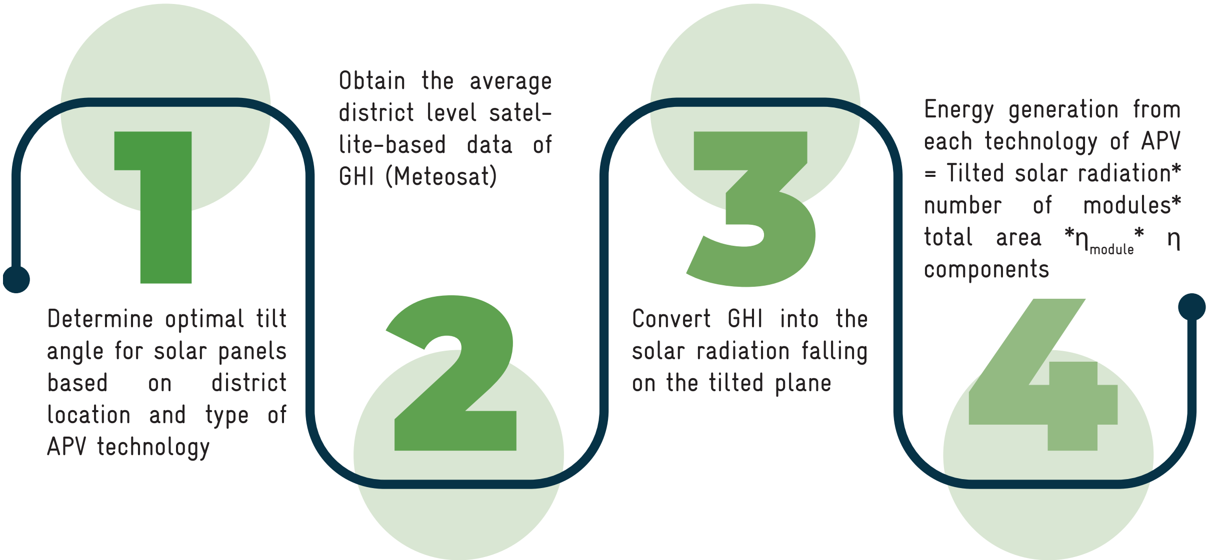


Figure 7: Energy generation estimate

2.3 LCOE CALCULATION

Levelised cost of electricity (LCOE) generation is calculated for different system types using the standard financial parameters like capital expenditure (CAPEX), operational expenditure (OPEX), cost of finance, return on equity, module degradation rate and other.

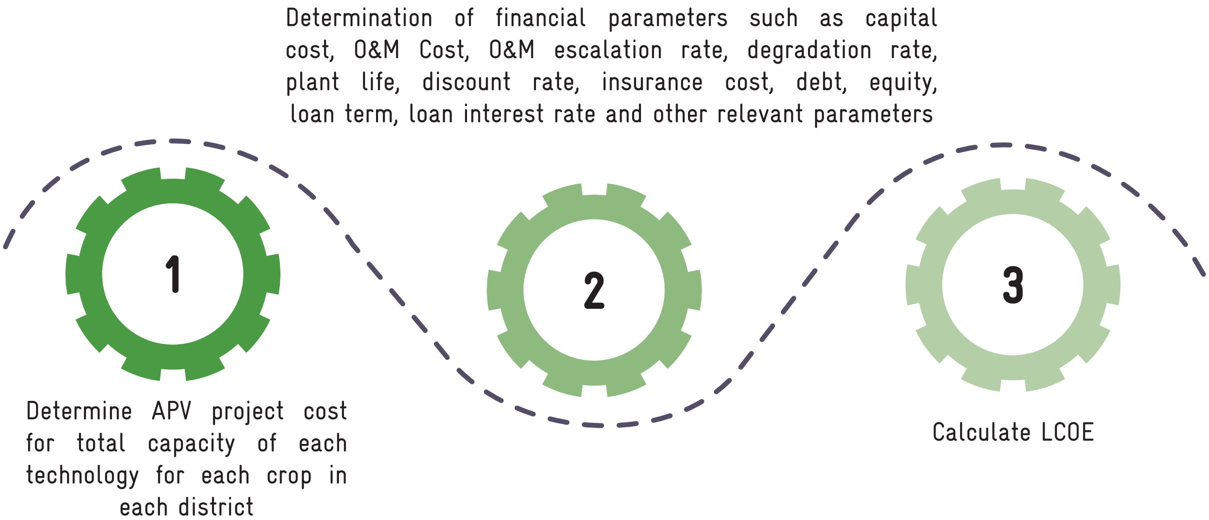


Figure 8: LCOE calculation

2.4 STATE-WISE TECHNICAL POTENTIAL ASSESSMENT

Based on the above methodology for potential assessment of APV in India, the following are the simulation results. Table below highlights state wise minimum and maximum potential of APV.

Table 5: APV India potential assessment results

	APV's technical potential	
State	Minimum (MWp)	Maximum (MWp)
Andaman and Nicobar	-	-
Andhra Pradesh	1,75,169	5,25,375
Arunachal Pradesh	-	-
Assam	51	943
Bihar	4,429	6,72,555
Chandigarh	23	169

	APV's technical potential	
State	Minimum (MWp)	Maximum (MWp)
Chhattisgarh	21,642	4,84,438
Daman and Diu and Dadra and Nagar Haveli	365	365
Delhi	–	–
Goa	2,591	6,179
Gujarat	23,918	10,97,079
Haryana	7,00,221	9,34,128
Himachal Pradesh	47,477	57,766
Jammu and Kashmir	21,479	25,892
Jharkhand	63,933	1,28,454
Karnataka	41,527	7,54,441
Kerala	14,162	14,843
Ladakh	–	–
Lakshadweep	–	–
Madhya Pradesh	2,95,620	17,42,404
Maharashtra	21,095	21,36,513
Manipur	–	–
Meghalaya	–	–
Mizoram	239	3,175
Nagaland	–	–
Odisha	1,641	49,713
Puducherry	66	1,124
Punjab	8,70,799	10,36,001
Rajasthan	5,91,829	13,16,174
Sikkim	–	–
Tamil Nadu	16,031	2,29,203
Telangana	1,08,362	3,55,486
Tripura	2,274	15,172
Uttar Pradesh	26,247	18,91,679
Uttarakhand	10,265	59,491
West Bengal	94,772	2,64,788
Total in MWp	**31,56,227**	**1,38,03,549**
Total in GWp	**3,156**	**13,803**

BUSINESS MODELS FOR APV

03

The APV business models have been developed keeping in view of our model objective, fixed boundary conditions and limited stakeholder interactions. The model limits itself to an energy generation perspective and does not focus on distribution/load side analysis. This is because consumption data for farmer categories vary across the different regions in the country. In addition, cost recovery from each region for energy supplied by the utility varies significantly due to the complex subsidy structure provided by state and central government schemes.

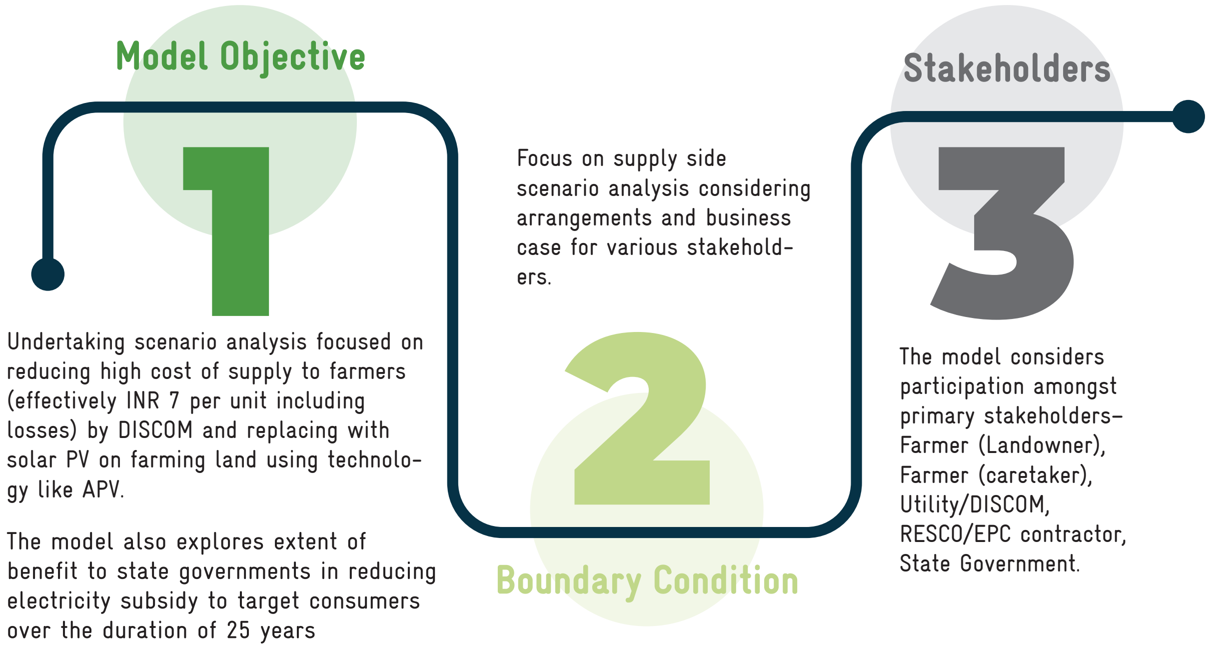


Figure 9: APV business model objective, boundary conditions

As a result, the program defined model objectives, boundary conditions and stakeholders involved before designing the model contours. While considering farmer categories, the program referenced the categorization of farmers defined by Reserve Bank of India (RBI), as depicted in Figure 10.

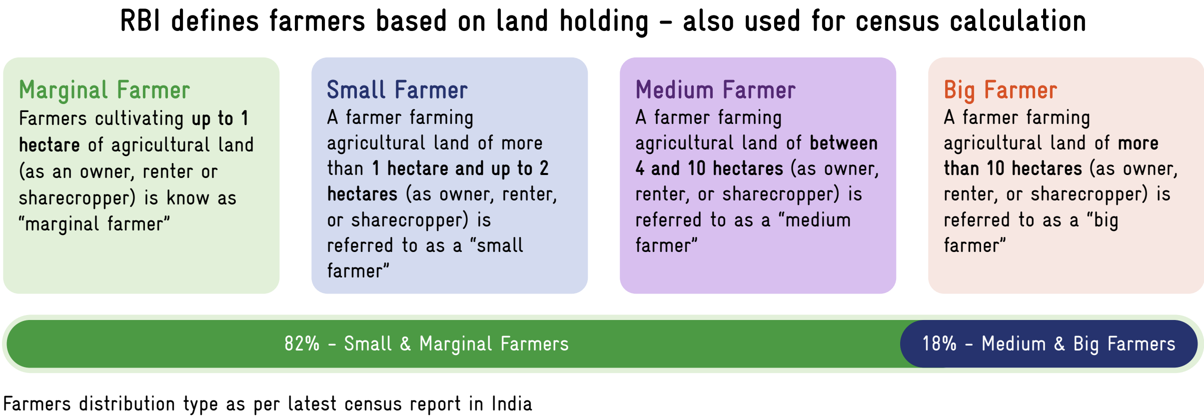


Figure 10: Farmer categorization and distribution

The farmer distribution in Figure 10 indicates that more than three-fourth of the farmers in India belong to the small and marginal category having land holding up to 2 hectares. The remaining quarter consists of medium and big farmers with average holdings greater than 2 hectares. Keeping this finding in perspective, the business model has been developed for two broad categories of farmer types based on land holding anchored around 2 hectares (Figure 11). As a result, the program defines farmers with land holdings lesser than 2 hectares as small farmers and greater than 2 hectares as medium/large farmers.

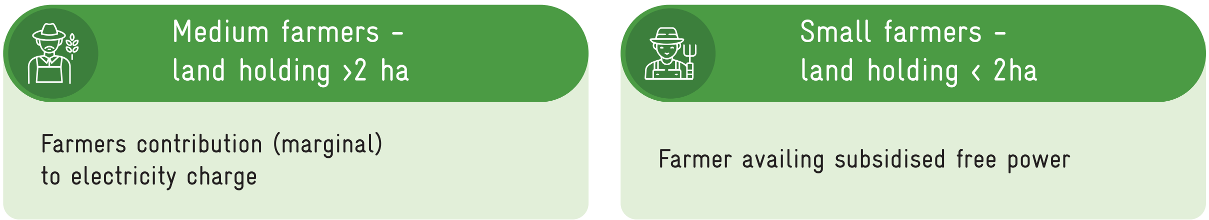


Figure 11: Business model based on farmer categorization

A key insight as part of the farmer categorization, essential for developing a business model, is the cost of electricity being supplied to them by the utility. While the average cost of supply for agricultural consumers in India is INR 7-8 per kWh, the cost retrieved by the DISCOM is marginal and accounted for through cross-subsidizing other high-paying tariff consumers in the states. Some states like Punjab have free electricity for agricultural consumers, making cost recovery extremely challenging.

In line with these findings, the model considers the small farmer category to receive subsidised free power while medium/large farmers contribute marginally to the cost of electricity, which is partially supplemented by state subsidy components.

3.1 DISCOM AVOIDED LOSS

Free or heavily subsidised power supplied to agricultural communities is mostly governed by political narratives in many states. This subsidised power supply is often cross-subsidised by other high-paying tariff consumers such as industrial and commercial sectors. In addition, every state demarcates budgetary provisions in the yearly financial budget towards compensating DISCOM for providing this subsidised power. This implies the average cost of supply calculated by DISCOM to the agricultural consumer is extremely high and is marginally recovered from target segments in the presence of these support mechanisms.

Distributed energy technologies like solar PV, etc. is a boon in this scenario. Not only they shelve off the expensive cost of supply accounted by DISCOMs but also avoid the substantial losses in the distribution network (as high as 25% in states like Bihar[3]) on account of supplying power to peripheral areas (agricultural feeds mostly located in peripheral areas of distribution network). As a result, APV technology can provide a huge financial benefit to the DISCOMs in their supply operations, while simultaneously ensuring continuance of farming activities.

3 *Niti Aayog, India Climate and Energy Dashboard, https://iced.niti.gov.in/energy/electricity/distribution/operational-performance*

The project team has modelled this scenario for APV and calculated the avoided loss benefit to the DISCOM, with the installation of a 1 MW APV project. The avoided loss has been calculated using the formula given in below. Additionally, the state government will also get the advantage of the Goods & Services Tax (GST) benefit on APV equipment to the extent of 5% of the total cost.

$$\left\{ \frac{\text{(APPC of DISCOM or spot market price)}}{\text{(1-AT\&C of agri. consumer)}} - \text{Bill payed by Agri. Consumers} \right\} \text{Units generated by a 1 MW project}$$

3.2 BUSINESS-AS-USUAL SCENARIO FOR FARMER

The business-as-usual scenario for farming consists of two broad approaches (Figure12).

- **Case 1.** Farmer undertakes farming by himself. Here, the original farmer is the only farmer involved in the parcel of land, who undertakes farming by himself and generated revenue from the sale of crop produce to the market.
- **Case 2.** Farmer leasing farming activities to caretaker. Here, the original farmer does not engage directly in farming activities and is limited to receiving rent paid by the caretaker for land use. The caretaker undertakes farming on the leased farmland, by paying monthly rent and gets revenue from the sale of crop produce to the market. Table 6 gives the salient points for each case.

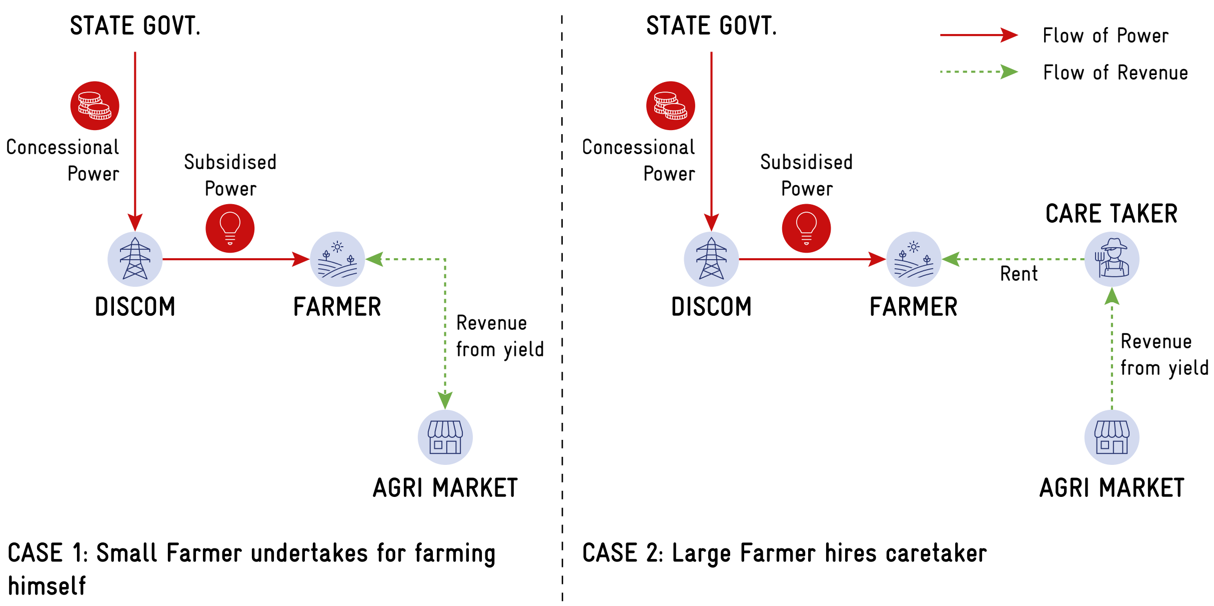


Figure 12: Business-as-usual farming activities

Table 6: Business-as-usual scenario for farming in India

S. No	Case 1	Case 2
1	Farmers are landowners and undertake farming themselves.	Farmers do not undertake farming activities on their own and lease out their farmlands to caretakers for undertaking farming in lieu of rent.
2	This includes small and marginal farmers with a lack of resources to outsource farming and are heavily reliant on farm produce for earnings.	Average rent varies from region to region; however, a good estimate for a farm lease is INR 40,000 per acre per annum.
3	On average, a rice farmer generates a per-acre yield of 30 QTL, with an average market price of INR 2,500 per QTL. For a 7.5-acre land holding, a rice farmer can earn a gross profit of INR 4,22,875 in a season, after accounting for 25% OPEX costs towards crop maintenance.	For a 7.5 acre land holding, with a rent of INR 40,000 per acre per annum, the total revenue from rent will be INR 3,00,000 in a year.

In both cases, the DISCOM procures power from its purchase pool at various rates and supplies to farm feeders that are located at the DISCOM periphery, bearing transmission losses. This inflates the average cost of supply for agricultural consumers to INR 7 per kWh (compared to the national average APPC rate of INR 4.5 per kWh). In addition, this cost is unrecovered from end consumers due to subsidy schemes and political devices and lay a heavy burden on the DISCOMs. Distributed renewable technologies like APV are ideally positioned to tackle this by augmenting local demand.

3.3 FINANCIAL MODEL FOR 1 MW APV SYSTEM

The program devised a financial model for a typical 1 MW APV system consisting of overhead layout configuration. A detailed breakup of the total project cost has been illustrated in Table 7.

Table 7: Cost breakup of a 1 MW APV Plant

EPC Cost for APV	Characteristics	INR Crores/MW	Percentage of Total CAPEX
Solar Panels (1:1.2)	Considering 2,200 modules of 550 Wp with system DC:AC = 1:1.2	3.388	57%
Inverter	Considering string inverters	0.225	4%
Structure (Range)	Overhead structure	1.6 – 2.0	27% - 31%
Site Preparation	Preliminary expenses	0.2	3%
Civil Foundation	Considering hammering techniques	0.055	1%
Fencing	Standard rates	0.08	1%
DC/AC Cables	Standard rates	0.16	3%
Miscellaneous Expenses		0.1	2%
Other Cost		0.15	3%
TOTAL		5.96 – 6.36	

The LCOE was calculated using the financial assumption defined in Annexure A and is INR 5.63-5.99 per unit.

Like any feasible project having predictable returns over time, APV technology despite its nascent stage too needs to adhere to financial metrics. These parameters are mostly from a project financing perspective and focused towards evaluating project finance ability. Some of these evaluation criteria include:

- Risk assessment
- Meeting mini debt service credit ratio (DSCR) of 1.3
- Returns and cash flows

3.3.1 APV BUSINESS MODEL - SMALL FARMER

The first business model caters to small farmers with land holding **lesser than 2 hectares**. Some key assumptions considered in SFBM include:

- Small farmers under SFBM grow only staple crops (as they are risk-averse, and are supported through government Minimum Support Price (MSP) programs)

- The APV project in SFBM are essentially grid-connected projects that do not augment any captive consumption of the farmers connected meters. The energy generated is fed into the grid and sold on a gross basis by the developer. Additionally, the reason for not augmenting the local load is that farm feeders (located at the utility periphery) are generally unreliable with only 4-5 hours of daily power supply. This would not result in any significant benefit for captive consumption for farmers. Correspondingly, the involvement of third-party developers (Renewable Energy Service Company (RESCO)), will ensure generation and business feasibility crucial for project implementation.
- Small farmers in SFBM avail subsidised power and pay marginal electricity charges (almost free) to the utility.
- SFBM scenario analysis (Figure 13) is considered for five states, as part of the scenario analysis, SFBM has been calculated considering the sample state of Punjab, Maharashtra, Madhya Pradesh, Haryana, and Uttar Pradesh to gain insights on project viability.

The overall model schematic for SFBM has been illustrated in Figure 13.

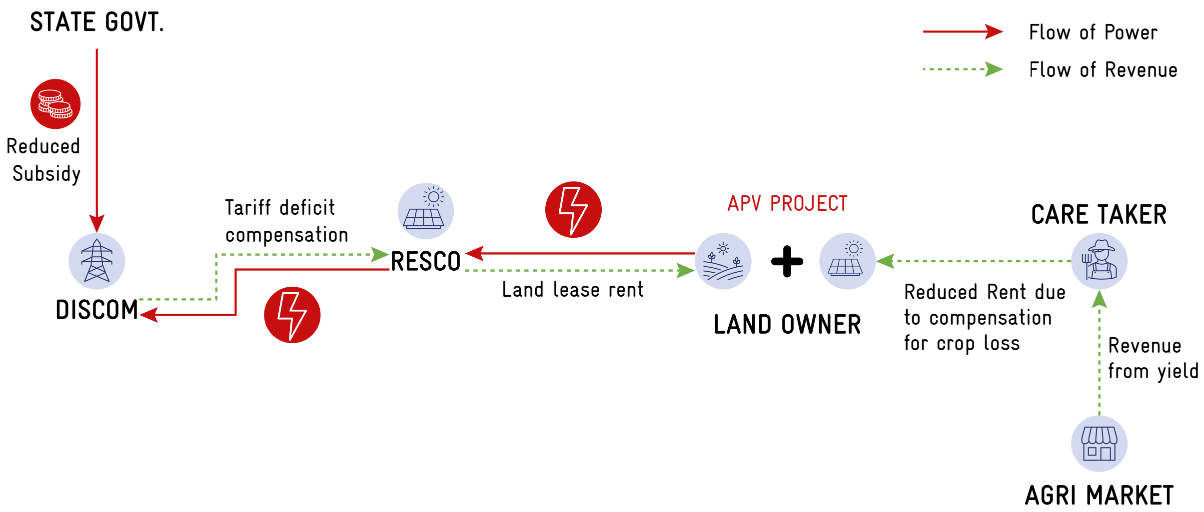


Figure 13: Overall model schematic for small farmers

Table 8: Operational framework for small farmer business model

Operation	State Govt.	DISCOM	RESCO	Landowner	Caretaker
Business as Usual	State Government demarcates electricity subsidy to DISCOM for the augmenting expensive cost of supply (INR 7 per unit) to the agricultural sector	Uses subsidy provided by state govt. to augment ACOS for the agriculture sector Procures expensive electricity from purchase pool and bears transmission losses while supplying to the agriculture sector Under recovery from farmers due to subsidised power and collection efficiency	-	Enjoys free subsidised power Receives rental income from a caretaker, for undertaking farming activities	-
DISCOM avoided loss by business model	Saves on electricity subsidy otherwise demarcated for agricultural consumers provided to DISCOM Channels part of the budgeted subsidy for ensuring viability of APV project	DISCOM procures distributed energy generated from APV through RESCO (@PPA), Shelfs off corresponding units from purchase pool (@ APPC or Spot pricing)	RESCO installs projects under BOOT model for 25 years. Ensures minimum generation and plant upkeep for 25 years	Enjoys free power Engages with RESCO under lease agreement for doubling rental income, and allowing land to be used for setting up APV for 25 years	-

3.3.2 APV BUSINESS MODEL- MEDIUM/LARGE FARMER

Like the SFBM, the second business model caters specifically to medium and large farmers with land holding greater than 2 hectares. Some key assumptions considered include:

- Large farmers have capital available to spend on new crop types (i.e., crop varieties that have not been traditionally grown in a particular region or have recently been developed through breeding or genetic modification) and related farm machinery. This model considers larger farmers growing cash crops, e.g., tomato, spinach.

- The APV project in MLFBM is also grid-connected, which does not augment any captive consumption of the farmers-connected meters. The energy generated is fed into the grid and sold on a gross basis by the developer. Additionally, the reason for not augmenting local load is that farm feeders (located at DISCOM periphery) are generally unreliable with only 4-5 hours of daily power supply. This would not result in any significant benefit for captive consumption for farmers. Correspondingly, the involvement of third-party RESCO players will ensure generation and business feasibility crucial for project implementation.
- Medium to large farmers in MLFBM do not require subsidized power and are more likely to pay electricity charges levied by DISCOM.
- Similar to SFBM, MLFBM too has been assessed for five states.
- Due to large farm holdings, farmers in MLFBM, prefer to engage caretakers to farm on their lands.

The overall model schematic has been illustrated in Figure 14.

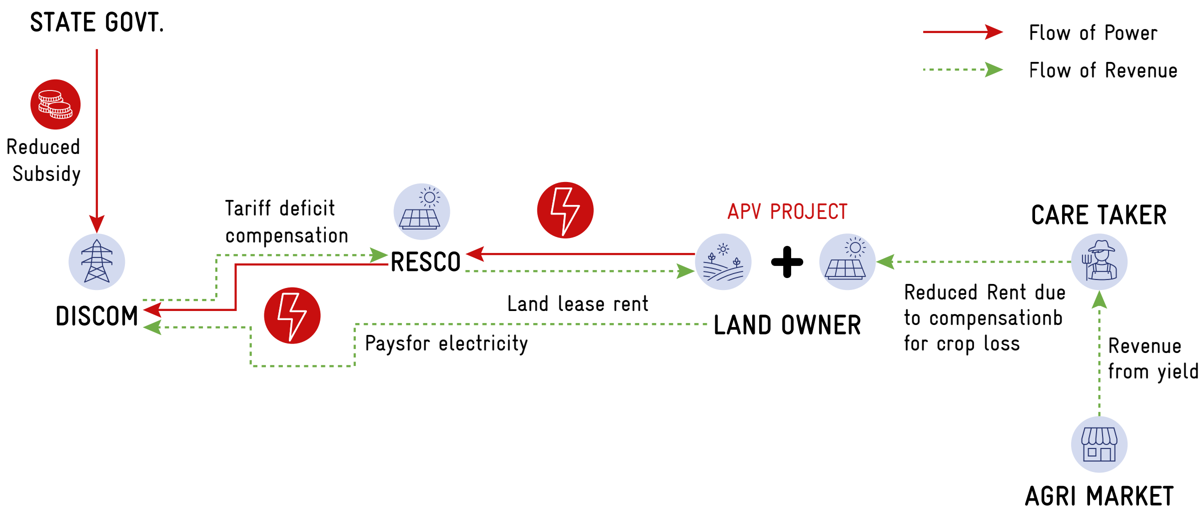


Figure 14: Overall model schematic for medium and large farmers

Table 9: Operational framework for medium and large farmer business model

Operation	State Govt.	DISCOM	RESCO	Landowner	Caretaker
Business as Usual	State Government demarcates electricity subsidy to DISCOM for augmenting expensive cost of supply (INR 7 per unit) to agricultural sector	Uses subsidy provided by state govt. to augment ACOS for agriculture sector Procures expensive electricity from purchase pool and bears transmission losses while supplying to agriculture sector Under recovery from farmers due to subsidised power and collection efficiency Partial cost recovery from farmers	-	Pays marginal energy charges Receives rental income from caretaker, for undertaking farming activities	Provides rent to landowner for undertaking farming on leased land. Earns by selling in market
DISCOM avoided loss by business model	Saves on electricity subsidy otherwise demarcated for agricultural consumers. provided to DISCOM Channels part of the budgeted subsidy for ensuring viability of APV project	DISCOM procures distributed energy generated from APV through RESCO (@ PPA), Shelfs off corresponding units from purchase pool (@ APPC or Spot pricing) Partial cost recovery from farmers	RESCO installs projects under BOOT model for 25 years Ensures minimum generation and plant upkeep for 25 years	Continues to pay energy charges Engages with RESCO under lease agreement for doubling rental income, and allowing land to be used for setting up APV for 25 years	Engages with Landowner to utilise available land parcel for farming and providing land lease. Earnings by selling crop produce in market Caretaker can be engaged by RESCO for undertaking O&M of plant

Scenario 1 – Avoided Loss Surplus – No VGF Required:

Under Scenario 1, we consider the state's average power purchase cost (APPC) range of INR 4.8- 5.5 per unit. For calculating total avoided loss for units replaced as a result of APV generation, amounts to a total savings of INR 890 to 1020 lakh calculated over 25 years. We have considered 25 years as the project life of solar PV modules. The avoided loss is calculated using the following formula:

Avoided Loss p.a for DISCOM with purchase cost between Rs.4.8 to 5.5 per unit

$$= \left\{ \left(\frac{4.8 \text{ to } 5.5}{1-17\%} \right) \right\} *1.5 \text{ MU}$$

This corpus is adjusted against the following costs to ensure business model viability.

- Cost of procuring power from APV, i.e., LCOE calculated by developer, is INR 5.63- 5.99, with a capital expenditure (project cost of INR 596 to 636 lakh).
- Adding GST components to avoid loss corpus. The GST component is calculated at 5% of varying project costs.
- Adding cost recovered from farmers in lieu of energy charges paid to the utility. This has been calculated as INR 0.1- 0.33 after accounting for state subsidies.
- Crop loss due to shading as a result of APV installation has been calculated at shading factor of 20-30%
- Cost to be paid to the farmer as a result of doubling land lease. The total land lease cost has been calculated for leases of INR 40,000-60,000 per acre per annum.

Adjusting all above costs with the total avoided loss corpus calculated for the DISCOM results in a no loss no gain procurement scenario while ensuring benefit to farmers and RESCO developers. For the scenario described above, the cumulative avoided loss for 25 years amounts to a surplus of INR 19 to 134 lakh for the APV Project. This has been depicted in Figure 15.

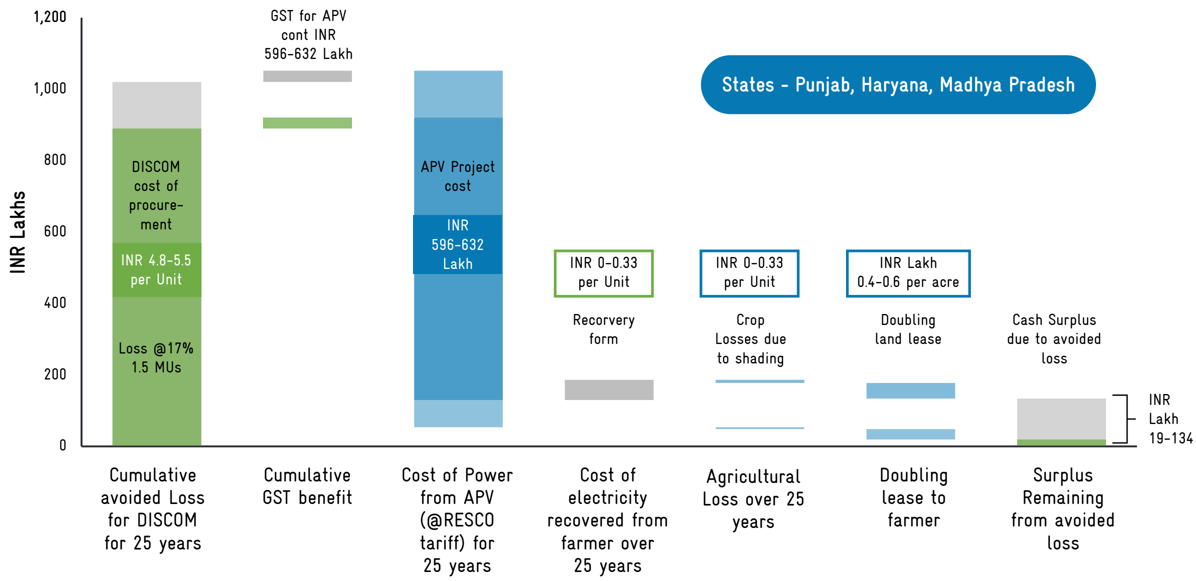


Figure 15: Avoided loss surplus scenario for DISCOMs

Scenario 2 – Avoided Loss Deficit – VGF Required:

Scenario 2 pertains to states with average power purchase costs ranging between INR 3–4 per unit. Calculating total avoided loss for units replaced as a result of APV generation amount to total savings of INR 556 to 742 lakh calculated over 25 years. As mentioned earlier, we have considered 25 years as that is the estimated project life of solar PV modules.

This avoided loss corpus is adjusted against the following costs to ensure business model viability.

- Cost of procuring power from APV, i.e., LCOE cost calculated by the developer, is INR 5.63-5.99, with a capital expenditure (project cost of INR 596 to 636 lakh).

- Adding GST components to avoid loss corpus. The GST component is calculated at 5% of varying project costs.
- Adding cost recovered from medium to large farmers in lieu of energy charges paid to the utility. This has been calculated as INR 0.5-1 per unit after accounting for state subsidies (higher than scenario 1).
- Crop loss due to shading as a result of APV installation has been calculated at a shading factor of 20-30%
- Cost to be paid to the farmer as a result of doubling land lease. The total land lease cost has been calculated for leases of INR 40,000-60,000 per acre per annum.

Adjusting all the above costs with the total avoided loss corpus calculated for the DISCOM results in a net loss for DISCOM under the business model. For the scenario described above, the cumulative loss for 25 years amounts to a surplus of INR 30 to 230 lakh for the APV project. This has been depicted in Figure 16. This loss can be accounted for under VGF for ensuring business viability in the given states, Maharashtra and Madhya Pradesh.

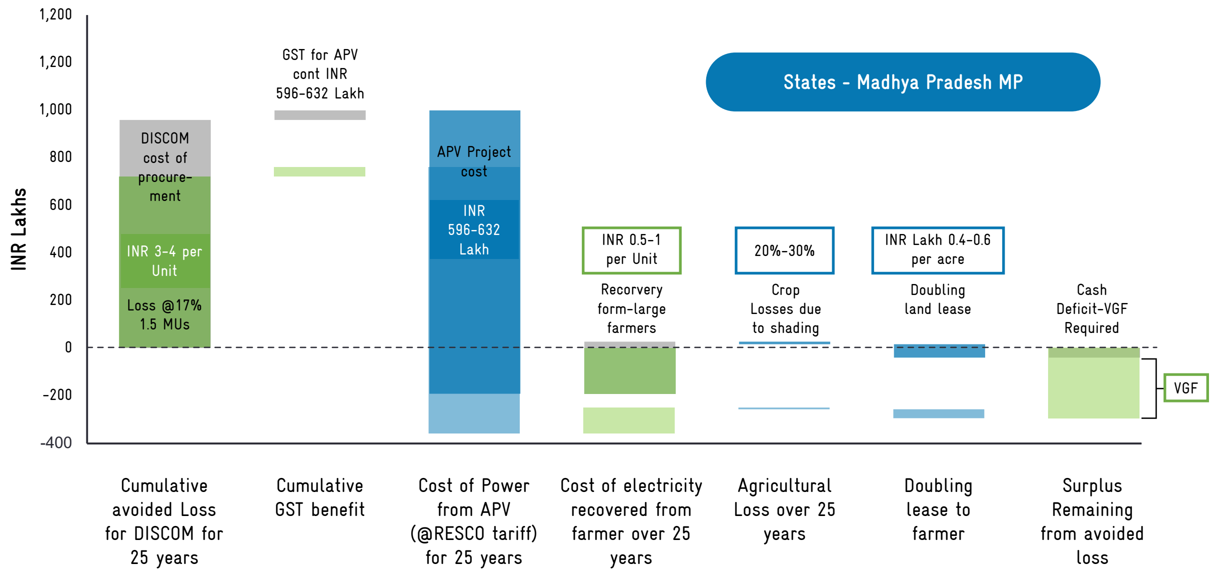


Figure 16: Avoided loss deficit scenario for DISCOMs

3.4 LEARNINGS FROM THE APV BUSINESS MODELS

Some key takeaways for both APV business models are

- Both small farmer business model and medium /large business model covers more than 95% of the farmer categories in India.
- The business model is viable in some states with APPC cost greater than INR 4.5 per unit, with no additional support structure required. Here the avoided loss corpus is adjusted against lease compensation and crop reduction and power purchase from APV without any viability gap funding.
- However, states with an average power purchase cost lesser than INR 4.5 per unit will require VGF in order to make the model viable.
- The LCOE cost of an APV project as part of the financial model has been derived using conservative assumptions. As has been demonstrated with solar PV in the past, the market tends to leverage costs with economies of scale and bring down the tariff to a competent level. This will further improve the viability and use case for APV technology adoptability.
- The business models described above is governed by the underlying theme of DISCOM revenue neutrality while procuring expensive APV power. In addition, another important aspect for DISCOM to consider APV is to reduce the expensive cost of supply to agricultural consumers.
- The DISCOM may choose to provide leeway in procuring marginally expensive power from APV projects (in initial phases), and compensative with growing commercial and industrial consumer costs, in order to lay the foundation for technology uptake. Once the market is matured with technology, DISCOMs can bring the focus towards revenue neutrality.
- Some other benefits of APV technology pertaining to monitory benefits have not been considered. This includes associated opportunities such as a boost in crop production of certain crops due to shading, thereby increasing farmer income. Inclusion of APV under land forestry and renewable energy offsets, which have a significantly higher carbon price ($100 in emissions trading system (ETS)).

CAPACITY PROJECTION OF APV IN INDIA (2024-40)

04

In 2021-22, the power demand of India was 1,374 billion units (BU) and is expected to reach 1,500 BU during 2022-23[4]. As per the Central Electricity Authority (CEA)'s optimal generation capacity mix report for 2029-30, the demand is further expected to reach 2,280 BU by 2030[5]. At present, the renewable installed capacity is around 125.7 GW (excluding large hydro and pumped storage power projects) (as on April 2023), which is 30% of the total installed capacity[6]. It is estimated that the share of renewable energy in installed capacity will increase to 53% by 2030 (excluding large hydro and PSP). The solar PV installed capacity is expected to increase at a compound annual growth rate (CAGR) of 20% from 67 GW in 2023 to 293 GW in 2030 (CEA Optimal energy mix 2029-30). This will be the largest among all other sources of power generation.

The International Energy Agency (IEA) has also done some similar demand projections for electricity in India under the following scenarios:

- **The Stated Policies Scenario (STEPS)** makes the assumption that the current policy settings and objectives are expected to apply to India's energy sector, taking into account a number of practical factors that would prevent their execution.
- **The India Vision Case (IVC)** takes a more optimistic stance on the speed of economic recovery and long-term growth, and on the prospects for a fuller implementation of India's stated energy policy ambitions.
- **The Delayed Recovery Scenario (DRS),** by contrast, examines the implications of a more prolonged pandemic with deeper and longer-lasting impacts on a range of economic, social and energy indicators than is the case in the STEPS.
- **The Sustainable Development Scenario (SDS)** takes a different approach, working backwards from specific international climate, clean air and energy access goals, including the Paris Agreement, and examining what combination of actions would be necessary to achieve them.

4 *Outlook India, Power Consumption Grows 9.5% To 1,503 Billion Units In 2022-23: Govt Data, Aug 2023*
5 *CEA, Report on Optimal Generation Mix 2030- version 2.0, Apr 2023*
6 *MNRE and CEA installed Capacity Reports*

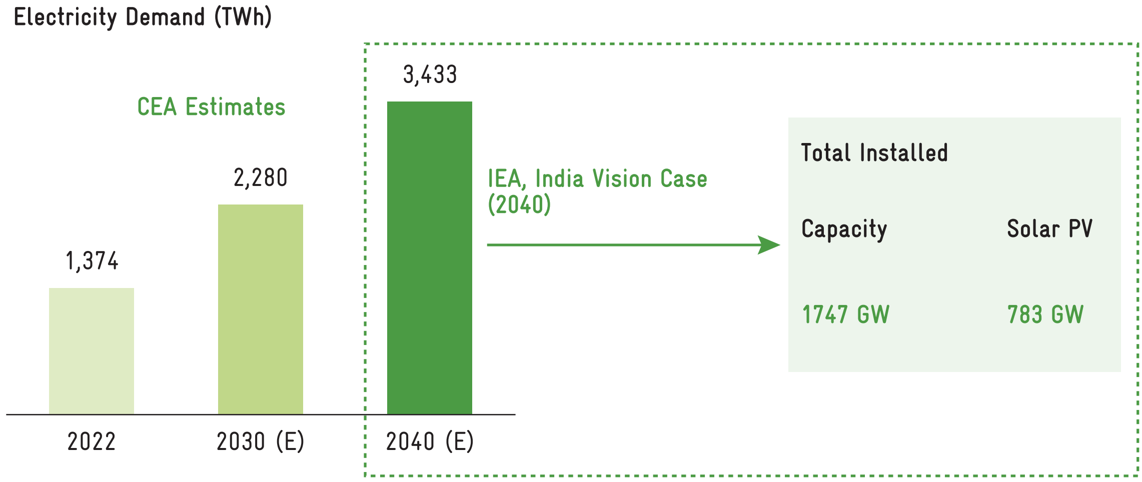


Figure 17: Electricity demand of India in 2030 and 2040

The IVC scenario, considers the achievement of 450 GW of non-hydro renewable energy capacity by 2030, with a higher level of financial de-risking supported by an enabling regulatory environment. Further, it encompasses higher penetration of natural gas for power generation and batteries for widespread uptake of electric vehicles in the transport sector along with bioethanol/biodiesel as a fuel. It has a longer-term focus on the industrial sector's deep decarbonization, which entails a boost in carbon capture and storage technology, along with early efforts to investigate hydrogen production pathways that result in some initial output from low-carbon sources. The estimated installed capacity for 2030 and 2040 is illustrated in Figure 17.

4.1 CAPACITY PROJECTION OF NISAs

For calculating the capacity for NISAs based on the IVC scenario, three different cases were considered.

- **Business as usual (BAU):** The total solar PV installed capacity remains the same as stated under IEA's IVC scenario, i.e. 783 GW by 2040, with no additional NISA getting installed by 2040. The solar PV mentioned here only covers ground mount and rooftop solar.

- **Moderate:** The total solar PV installed capacity remains the same as stated under IEA's IVC scenario, i.e. 783 GW by 2040. It is assumed that under this scenario, the percentage share of NISA grows to 10%, which will be 78 GW and the rest is ground mount and rooftop solar PV.
- **Optimistic:** the total solar PV installed capacity remains the same as stated under IEA's IVC scenario, i.e., 783 GW by 2040. It is assumed that under this scenario, the percentage share of NISA will be 30%, which will be 235 GW, followed by ground mount solar at 50% and rooftop at 20%.

Table 10: Capacity projection scenarios of NISAs

	BAU		Moderate		Optimistic	
	% Share	Cumulative capacity (GW)	% Share	Cumulative capacity (GW)	% Share	Cumulative capacity (GW)
Total Solar PV Installed Capacity (2040)		783		783		783
Ground Mount	90%	705	60%	470	50%	392
Rooftop solar PV	10%	78	30%	235	20%	157
NISA	**0%**	**-**	**10%**	**78**	**30%**	**235**

Based on the above scenarios, the annual demand of NISAs for both moderate and optimistic scenarios is illustrated in Figure 18. The capacity projections for each NISAs are done using the optimistic scenario trajectory.

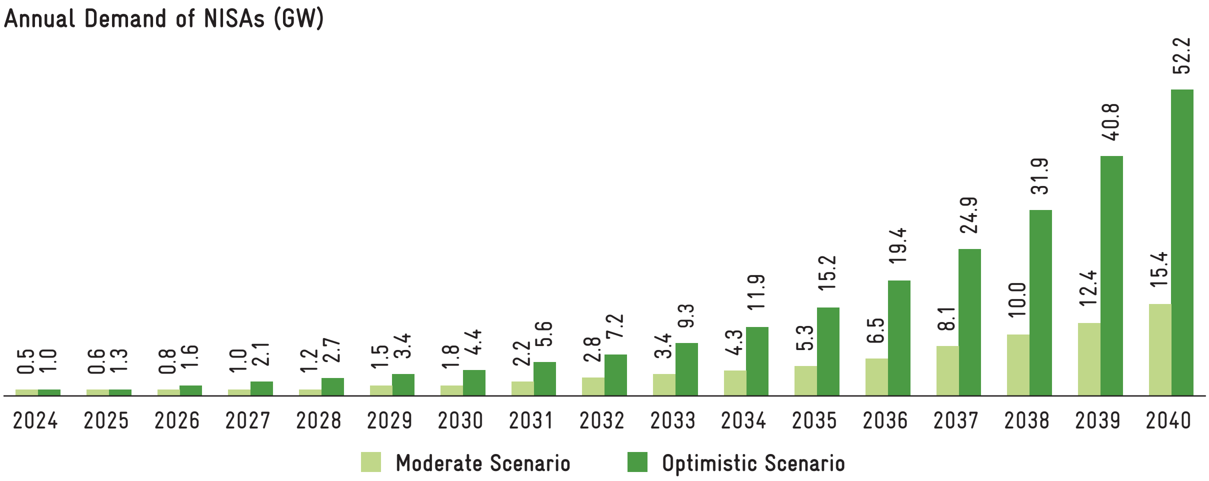


Figure 18: Annual demand of NISAs (moderate and optimistic case)

4.2 PENETRATION OF APV AMONGST OTHER NISA (2024-40)

Amongst all NISAs, it is challenging to predict with certainty which specific solar integration technology will penetrate more in India by 2040. However, based on current trends, considerations, stakeholder inputs and future demand, some key observations are highlighted below.

Table 11: Penetration matrix of NISAs

	2024			2030			2040		
Annual penetration matrix of NISAs	% Share	Annual Demand (Moderate) MWp	Annual Demand (Optimistic) MWp	% Share	Annual Demand (Moderate) MWp	Annual Demand (Optimistic) MWp	% Share	Annual Demand (Moderate) MWp	Annual Demand (Optimistic) MWp
APV	20.0%	100	200	22.5%	407	992	27.5%	4,241	14,368
Other (FPV, CTPV, BIPV, RIPV)	80.0%	400	800	77.5%	1,402	3,416	72.5%	11,180	37,880

- FPV: Due to their potential for using water bodies like reservoirs, lakes and ponds, floating solar power projects have gained popularity both internationally and in India. The use of floating solar projects is projected to rise in the upcoming years due to India's abundant water bodies. The capacities that are being installed in India are usually in Megawatts, with LCOE of INR 3-4 per unit, therefore making it one of the most feasible technologies amongst all NISA in the initial years. The current penetration level is considered to be 50% in the initial years and reducing to 35% by 2040.
- APV: Land utilisation plays a significant role in the implementation of APV in India, which allows dual use of land where power generation as well as an agricultural activity can simultaneously take place on a single piece of land. Given the enormous potential of APV found under this project, it is expected to penetrate from 18% in 2024 to 27.5% by 2040.
- CTPV: India has already witnessed the implementation of canal top solar projects in certain regions under the MNRE's pilot scheme for CTPV and canal bank solar PV projects. Presently, the penetration of canal top projects is assumed at 15% and is expected to decrease to 10% by 2040 as other NISAs also grow.

- RIPV: The Indian Railways has invited bids for 3 GW solar projects on vacant land parcels and land parcels along the railway track through Railway Energy Management Company Ltd. (REMCL). Given this ongoing procurement, the current penetration level is 10% amongst all NISAs and will be 12.5% by 2040. For roadways, there has been no target or long-term vision, hence for estimating capacity for RIPV, it is assumed that new projects might take off a bit late (after 2028) as compared to other NISAs.

Based on the above trends and assumptions, the annual capacity projection for APV is illustrated in Figure 19 for both moderate and optimistic cases.

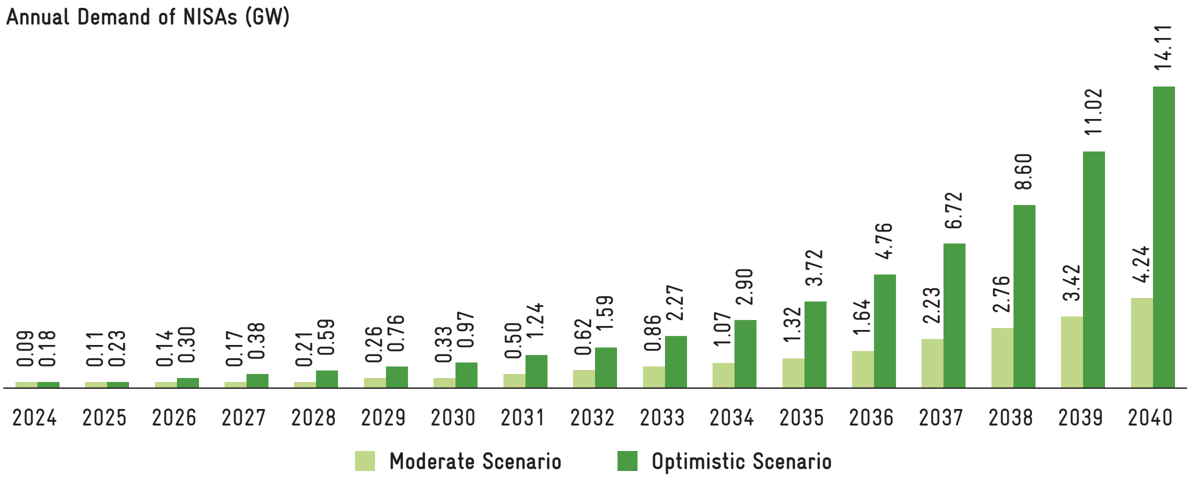


Figure 19: Capacity projections of APV from 2024-40

FINANCING APV PROJECTS IN INDIA

05

5.1 INTERVENTIONS TO SUPPORT FINANCING OF APV

Governments, financial institutions and development organizations throughout the world are supporting clean energy projects through various means such as budgetary support, easy finance and running various programs for building the right ecosystem, respectively. These are primarily done to

- overcome barriers to developing renewable energy and
- promote the adoption and growth of renewable energy

The section will primarily cover government interventions. These interventions can be classified into two types:

- Capital support
- Revenue support

Capital support reduces the capital required for the project and therefore reduces the requirement of debt to be raised and equity infusion. Cashflow support comes every year once the project gets commissioned and, therefore, it does not reduce the capital requirement.

Below are some of the interventions classified under both heads:

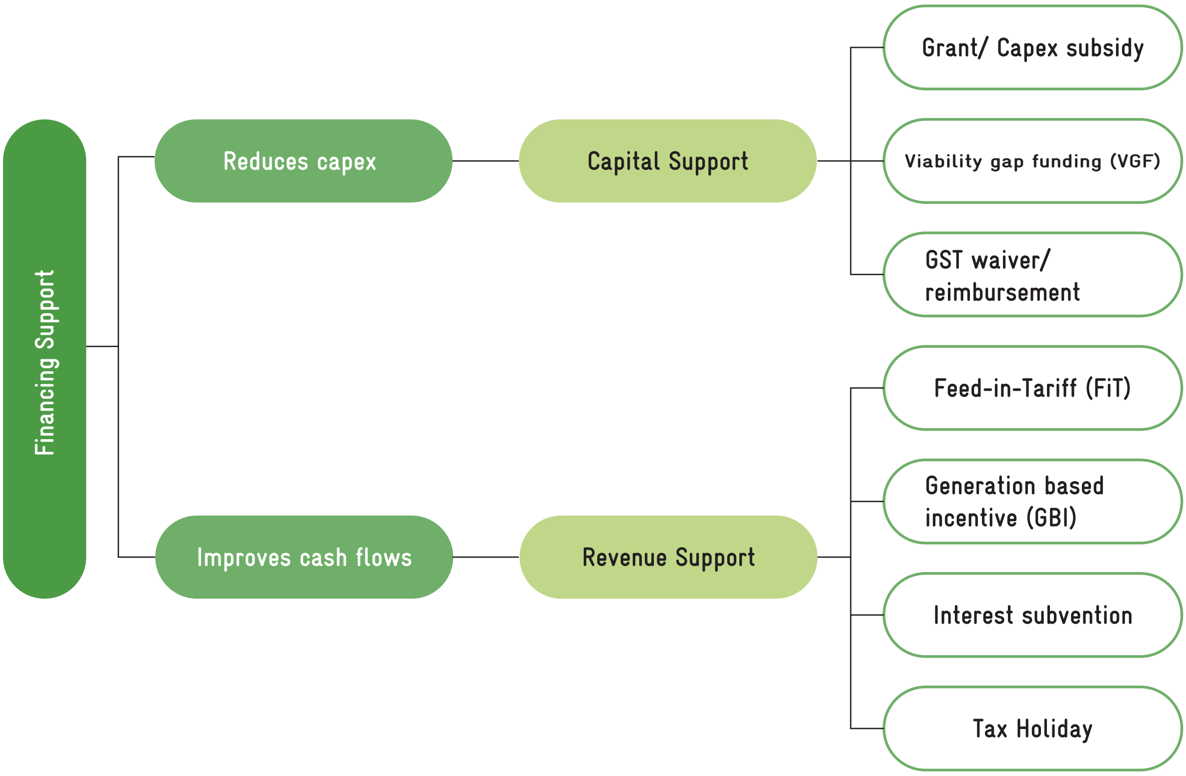


Figure 20: Financing interventions

A comparative analysis of the above interventions is shown in the table below:

Table 12: Comparative analysis of financing interventions

Support mechanism	Type	Impact on developer	Impact on Exchequer/ Authority
Grant	Capital Support	Grants reduce the funding obligation upfront.	Upfront burden on budgetary support
VGF	Capital Support	For VGF the funding may be done on milestone achievement (such as linked to commissioning milestones). While this also reduces the funding requirement, usually the VGF realised goes towards retirement of debt.	
GST reimbursement	Capital Support	It does not reduce funding obligations upfront but boosts cash inflow once reimbursement is met.	
FIT	Cashflow Support	Improves the cash flows	Benefits need to pass over a period based on an indicator. Budgetary support spread over a longer period. Improves ability to finance more capacity.
GBI	Cashflow Support		
Interest subvention	Cashflow Support	Reduces the financing cost	Benefits need to pass over a period. Monitoring and verification to be done through the existing tax compliances network. No separate monitoring mechanism needed.
Tax holiday	Cashflow Support	Reduces tax burden but developers generally use financing instruments such as quasi-equity instruments to reduce the tax burden	

GRANTS:

Grants in the renewable sectors refer to financial assistance provided by governments, multilateral financing institutions, philanthropic, non-profit organizations and other entities to support the development, installation or research of new technologies. The funds can be used to offset the upfront expenses and make solar installations more affordable for individuals, businesses or communities. The implementation of pilot demonstration projects may be supported through grants. These initiatives demonstrate the viability and advantages of any project in practical contexts like residential communities, business structures or public infrastructure. Equipment, installation and monitoring costs might all be partially covered by the financing.

VIABILITY GAP FUNDING (VGF):

VGF is a financial assistance to close the financial gap between project costs and expected developer revenues. It tries to make projects profitable and appealing to private investors. The VGF mechanism was established by the Indian government under the Jawaharlal Nehru National Solar Mission (JNNSM) in 2013 to support grid-connected solar power plants. Through a process of open competition, the government supplies VGF. For instance, solar projects were chosen through a reverse auction procedure in Phase-II Batch-I of JNNSM where developers stated their tariffs. The government awarded the projects with the lowest tariffs, and VGF was granted to close the viability gap and support the projects' financial sustainability. This is shown in Figure 21.

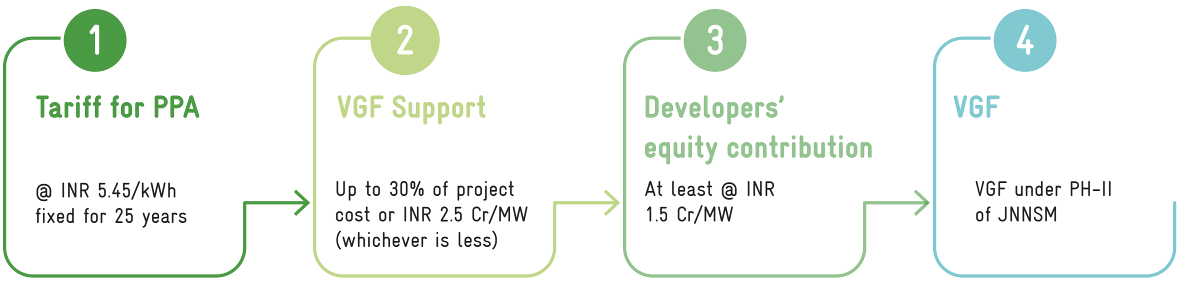


Figure 21: Viability gap funding under Ph-II of JNNSM

FEED-IN TARIFFS (FiT):

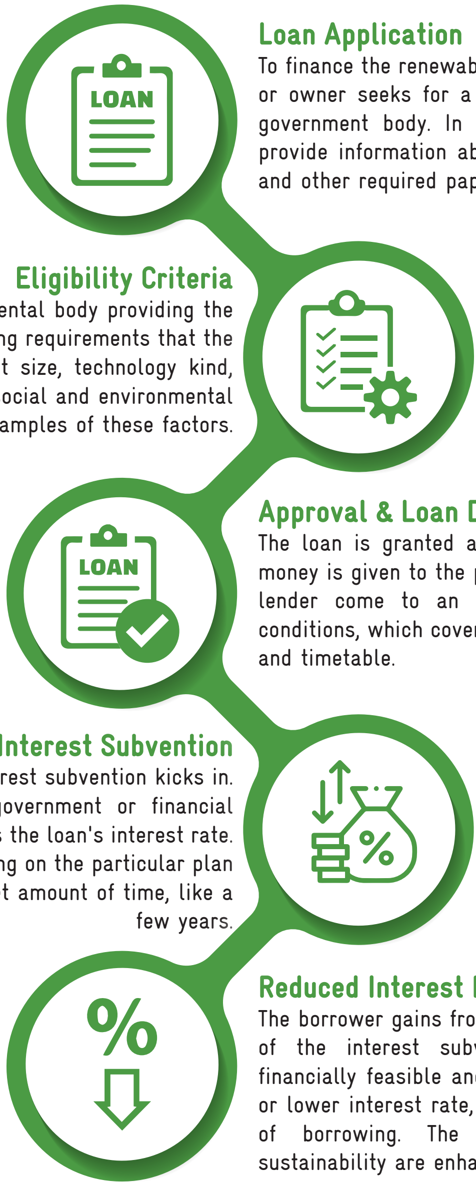
FiTs is a policy tool to promote the use of renewable energy technology, particularly in the production of electricity. It is a type of monetary reward given to producers of renewable energy, who are often individuals or companies, for the electricity they produce and feed into the grid. The government or regulatory authority establishes a predetermined payment rate per kWh of electricity produced by renewable energy sources under a FiT programme. This rate is often guaranteed for a specific period, frequently between 10 and 20 years. A reasonable return on investment for the renewable energy project is ensured by the payment rate level.

To give producers of renewable energy a financial incentive, FiTs are often higher than the going rates for power on the market. This helps to make renewable energy technologies more economically viable and appealing to investors by offsetting their greater upfront costs.

FiT's primary goals are to encourage the growth of renewable energy projects, raise their proportion in the total energy mix, and lower greenhouse gas emissions. They minimise the financial risks involved with such investments by ensuring a fixed payment rate and offering renewable energy providers a steady and predictable revenue stream. Many nations around the world, including Germany, Spain and numerous other European countries, have effectively implemented FiTs. India too, had witnessed FiT support by many states for the wind energy sector – later moving to the auction model. To assist the development of renewable energy, several nations have switched to alternate mechanisms such as auctions or quota systems. It is important to note that the acceptance and efficacy of feed-in tariff schemes have fluctuated over time.

INTEREST SUBVENTION:

Interest subvention in solar projects refers to a financial support mechanism where the government or another entity provides a subsidy or reduces the interest rate on loans taken for financing solar energy projects. It aims to make the cost of borrowing for solar projects more affordable, thereby incentivizing investment in the sector. In certain situations, the government might offer a subsidy or reimburse a portion of the interest paid by the borrower rather than lowering the interest rate directly. Direct payments or interest amounts offset against taxes or other debts may be used to accomplish this. The process of how interest subvention typically works for a renewable energy plant is shown in Figure 22.



Loan Application

To finance the renewable energy project, the project developer or owner seeks for a loan from a financial institution or a government body. In order to apply for a loan, you must provide information about your project, financial projections, and other required paperwork.

Eligibility Criteria

The financial institution or governmental body providing the interest subsidy has certain qualifying requirements that the loan applicant must satisfy. Project size, technology kind, project location, and adherence to social and environmental standards are a few examples of these factors.

Approval & Loan Disbursement

The loan is granted after completing the requirements, and money is given to the project developer. The borrower and the lender come to an agreement on the loan's terms and conditions, which covers the interest rate, repayment duration, and timetable.

Interest Subvention

When the loan is disbursed, the interest subvention kicks in. For a set amount of time, the government or financial institution offers a subsidy or lowers the loan's interest rate. This time frame can change depending on the particular plan or policy, but it is normally for a set amount of time, like a few years.

Reduced Interest Payment

The borrower gains from a lower interest payment as a result of the interest subvention. The project becomes more financially feasible and appealing as a result of the subsidy or lower interest rate, which also decreases the overall cost of borrowing. The project's feasibility and financial sustainability are enhanced as a result.

Figure 22: Steps of interest subvention

GENERATION-BASED INCENTIVE (GBI):

The governments are often concerned about providing tax incentives for setup of renewable capacity. This may often lead to excess capacity being setup without the actual energy yield. GBI is a policy tool that converts the capacity incentives into energy yield and is disbursed to renewable developers based on output from the renewable capacity setup. It is thus a financial incentive offered by the government to encourage the production of energy from solar power facilities. The GBI scheme provides solar power developers with a subsidy based on the actual electricity generated to encourage them to produce clean and renewable energy.

Developers of solar power gain an extra incentive under the GBI programme for each unit of electricity their solar power plants generate. Usually, this incentive is given in addition to the money made by selling electricity to the grid. The GBI aids in closing the cost gap between the production of conventional power and the production of solar power, increasing the viability of solar projects.

- In 2008, India implemented the first GBI for renewable energy, including solar capacity.
- The GBI policy was initially developed for four RE technologies including Solar PV power projects to encourage the construction of grid-connected solar power plants. In addition to the applicable FiT or PPA prices, the GBI was offered to the power producers.
- The GBI programme was created to last from 2010 to 2020, a period of 10 years. However, because each state in India had the freedom to choose whether to adopt the GBI plan and set its unique terms and conditions, the GBI's implementation and depth varied from states and regions.
- Presently, new mechanisms like competitive bidding, tariff-based auctions, and subsidies under various state and central government schemes are being adopted to support renewable energy development in India. However, GBI provided a much-needed IPP ecosystem for renewable energy in early 2010s focusing on production linked incentives and a push to achieve a larger participation and portfolio development in the initial years.

TAX HOLIDAY:

A tax holiday is a governmental incentive that temporarily reduces or eliminates taxes for businesses. By providing a tax holiday for a specified number of years, the effective tax rate in those years shall be zero. The business losses and/or unabsorbed depreciation guidelines may remain as such. Such a scheme reduces the tax outgo and hence boosts the cash flows and returns. This will enable developers in lowering the LCOE. This is however focused on encouraging investments from large developers/ corporations with large balance sheets and reserves. The government realising this has now provided tax incentives / holidays for new organisations. Section 115BAB provides a concessional tax rate of 15 percent for new manufacturing/ power generating companies. To avail this benefit, the company should be set up after 1 October 2019 and power generation should commence on or before 31 March 2024.

5.2 LENDER'S PERSPECTIVE ON APV

Lenders evaluate borrowers from a financial and risk perspective to determine whether they are creditworthy and whether it is prudent to lend money to them. Lenders will decide the SOP basis on the borrower, whether it is an individual or a company. The perspective on borrowers is typically decided by considering various factors as highlighted in the table 13.

Table 13: Information required by lenders from borrowers

Category	Individual (Farmer)	Company (RESCO)

Information required by lender from borrower	Annual income
	Credit Information Bureau (India) Limited (CIBIL) score
	Collateral which will be offered – agricultural land is generally not preferred
	The end use of the funds – for the project
	• Details of CAPEX and technology
	• Vendors from whom procurement will be done
	• Queries may be asked about the protection of PV systems against theft, vandalism and natural disaster, maintenance mechanism etc.
	• For the said purpose, hypothecation/ mortgage/assignment of pertinent movable and immovable assets may be opted in addition to collateral
		• About promoters
		  • Experience of promoters
		  • History of default of promoters or any of the affiliates of promoters
		  • Director's profile
		  • Reputation
		  • Financial health – the ability to bring corresponding equity, group leverage
		  • Nature of promoter contribution instruments
		  • Corporate governance
		  • Credit rating
		• About project company
		  • Experience with the project company
		  • Details of concession/contract
		  • Details of technology and suppliers
		  • Management profile
		  • Credit rating
		  • Leverage – debt to equity, debt to earnings before interest, taxes, depreciation, and amortisation (EBITDA)
		  • Projected finances around the following profile
		    – Debt service coverage ratio (average and minimum)
		    – Debt to EBITDA
		    – Project internal rate of return (IRR)
		    – Loan life coverage ratio

Security required	Primary security • By Mortgage of borrower's all immovable assets, present and future including the project land • By Hypothecation of all the borrower's movable properties, including plant and machinery, machinery spares, equipment, tools and accessories, furniture, fixtures, vehicles, stocks and all other movable assets, present and future, and of all Borrower's present and future book debts, bills, receivables, monies including bank accounts, claims of all kinds and stocks including consumables and other general stores. • By Assignment. A first charge by way of assignment or creation of security interest including all rights, title, interest, benefits, claims and demands whatsoever of the borrower. • By Pledge of shares Secondary security • Corporate guarantee • Personal guarantee	Primary security • By Mortgage of borrower's all immovable assets, present and future including the project land • By Hypothecation of all the borrower's movable properties, including plant and machinery, machinery spares, equipment, tools and accessories, furniture, fixtures, vehicles, stocks and all other movable assets, present and future, and of all Borrower's present and future book debts, bills, receivables, monies including bank accounts, claims of all kinds and stocks including consumables and other general stores. • By Assignment. A first charge by way of assignment or creation of security interest including all rights, title, interest, benefits, claims and demands whatsoever of the borrower. • By Pledge of shares Secondary security • Corporate guarantee • Personal guarantee

5.3 INVESTMENT AND VGF REQUIRED FOR APV

5.3.1 MODERATE SCENARIO (20 GW BY 2040)

Under the moderate scenario, the cumulative demand for agrivoltaics in India is projected to be 20 GW from 2024 to 2040 (as discussed in Chapter 4). We have assumed 1 MW of APV plant having CAPEX of INR 5.96 crore, which is equivalent to an LCOE of INR 5.63/kWh.

Over the past four years, the costs associated with traditional solar power plants have exhibited a fluctuation ranging from INR 3.4 to 4.8 Crore per MW[7]. In contrast, when considering APV plants, a greater portion of capital expenditure is incurred towards elevated structural expenses. However, it is important to note that as demand grows and a more predictable project pipeline emerges, economies of scale may kick-in. This, in turn, is expected to drive down both the costs of the supporting structures and the solar PV modules. Consequently, we have assumed an annual reduction of 3% in the capital expenditures (CAPEX), resulting in a gradual decline of the LCOE from APV plants, starting from 2024 and extending through 2040. The CAPEX and LCOE for each year are illustrated in table 14 below.

VGF support for APV:

It is likely that the electricity generated from APV systems are fed to the electricity distribution grid and this generation is likely to replace the marginal energy procurement by DISCOMs. There are two approaches to assess the potential savings for DISCOMs.

- **Approach 1: In general, it is expected that this will replace the energy supplied from the coal-fired capacity tied up by DISCOMs.**

The national average variable cost of coal-fired power capacity is INR 2.71/kWh for FY 2022-23. This energy is provided from the long-term/medium-term capacities tied up by the DISCOMs under a power purchase agreement. The energy is scheduled and dispatched on day-ahead basis based on the merit order of stations (from cheapest to highest variable cost).

It is anticipated that generation from these APV sources may help DISCOMs avoid this marginal cost of procurement. Assuming the above as marginal costs for DISCOMs, there is a potential saving of INR 2.71/kWh for DISCOMs in the form of avoided energy procurement.

- **Approach 2: Another approach to assessing the potential savings of DISCOMs is to consider the energy procurement from spot markets for solar hours (i.e., 08:00 – 18:00 hrs). It is observed that the national average power procurement price in the DAM (0800 hrs - 1800 hrs) for FY 2022-23 was INR 5.12/kWh .**

It is anticipated that generation from these APV sources may help DISCOMs avoid this marginal cost of procurement from the spot market during solar hours. Assuming the above as marginal costs for DISCOMs for solar hours, there is a potential saving of INR 5.12/kWh for DISCOMs in the form of avoided energy procurement.

7 Based on the cost analysis of utility scale solar PV projects conducted by the ISUN team from 2017 to 2023

It is apparent from the above two approaches that the DISCOMs can avoid purchasing power from both the sources at INR 2.71/kWh and INR 5.12/kWh (from Approach 1 and 2 above). When compared with the expected APV system energy cost of INR 5.63/kWh (at CAPEX of INR 5.9 Crore per MW), it is observed that there is a realization gap of INR 0.51 to 2.92/kWh for the developer who will invest and set up the Agri PV system. This is equivalent to INR 0.54 to 3.09 Cr/MW of capital support on Agri PV system cost.

For purpose of our analysis we have used marginal cost of procurement under Approach 2 (i.e. **INR 5.12 per kWh) as tariff threshold for viability gap eligibility**. This means that a tariff rate of INR 5.12/kWh is kept as the benchmark or threshold to determine whether an APV project is financially viable or not for the DISCOMs. When the LCOE of APV plant is higher than INR 5.12 per kWh, the difference between the LCOE and the INR 5.12/kWh tariff rate is used as Viability Gap Funding (VGF). It is to be noted that VGF will only be required for initial years, when LCOE is greater than tariff viability benchmark.

In our model, the LCOE of APV plant and CAPEX is expected to decline in coming years due to capex decline, therefore the VGF amount per MW will vary for each year. It is calculated by using the following formula:

- Per MW VGF required in 20XX year = (LCOE in 20XX – Tariff threshold) X (Cost per MW (CAPEX)/LCOE in 20XX)

Further, the per MW VGF required amount is multiplied with the associated annual capacity to get the Annual VGF required (INR Crore). Note that for purpose of VGF, escalation / decline in marginal cost of procurement under approach 2 is not considered. However, this threshold tariff can be computed periodically based on historic data (say a quarter) and be VGF may be updated on a periodic basis.

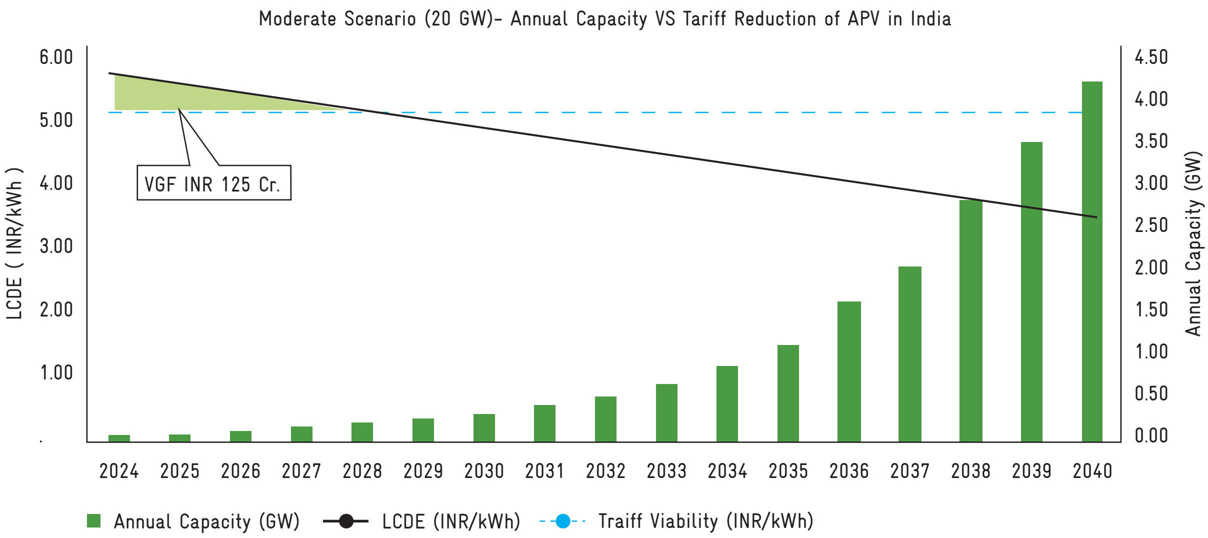


Figure 23: Annual capacity vs tariff reduction of APV (moderate scenario)

The total VGF required will be around INR 125 Cr for a total capacity of 510 MW till 2027-28 (Figure 23). Year wise VGF amount for the associated annual capacity is mentioned in the VGF calculations column of Table 14.

The total investment that will be required to realise the above-mentioned capacity (i.e., 20 GW) is INR 81,424 crores. Table 14 highlights the year-on-year capacity and investment potential.

Table 14: Investment and capacity projection for APV (moderate scenario)

Year	Investment and Capacity Projection for APV (Moderate Scenario)				VGF Calculations	
	Annual capacity (GW)	Cost per MW (INR Crore)	LCOE (INR/ kWh)	Investment required (INR Crore)	Per MW VGF required for project viability (INR Crore)	Annual VGF required (INR Crore)
2024	0.09	5.96	5.63	536	0.54	48.59
2025	0.11	5.78	5.47	645	0.37	41.32
2026	0.14	5.61	5.31	775	0.20	27.79
2027	0.17	5.44	5.16	931	0.04	7.25
2028	0.21	5.28	5.01	1,119	-	-
2029	0.26	5.12	4.87	1,345	-	-
2030	0.33	4.96	4.73	1,616	-	-
2031	0.50	4.82	4.59	2,428	-	-
2032	0.62	4.67	4.46	2,918	-	-
2033	0.86	4.53	4.34	3,897	-	-
2034	1.07	4.40	4.21	4,684	-	-
2035	1.32	4.26	4.09	5,629	-	-
2036	1.64	4.14	3.98	6,765	-	-
2037	2.23	4.01	3.87	8,944	-	-
2038	2.76	3.89	3.76	10,749	-	-
2039	3.42	3.77	3.65	12,918	-	-
2040	4.24	3.66	3.55	15,525	-	-
Total	**19.98**			**81,424**		**125**

Note: *The VGF calculations that we have explained above have been derived at CAPEX of INR 5.96 Cr/MW with LCOE of INR 5.63/kWh. However, this is an indicative number based on our discussion and consultations with developers and concerned stakeholder. The per MW cost APV system may vary from INR 5.9 to 6.4 Cr, with LCOE ranging from 5.63 to 6/kWh. The cumulative VGF upto year 2027 may vary from INR 125 to 363 Crores.*

5.3.2 OPTIMISTIC SCENARIO (60 GW BY 2040)

Under the optimistic scenario, the cumulative demand for agrivoltaics in India is projected to be 60 GW from 2024 to 2040. Similar to the moderate scenario, we have assumed an annual reduction of 4% instead 3 % in the capital expenditures (CAPEX), resulting in a gradual decline in the LCOE from APV plants, starting from 2024 and extending through 2040. The CAPEX and LCOE for each year is illustrated in table 15 below.

Similar to the moderate scenario, we have used marginal cost of procurement under Approach 2 (i.e. **INR 5.12 per kWh) as tariff threshold for viability gap eligibility.** This means that a tariff rate of INR 5.12/kWh is kept as the benchmark or threshold to determine whether an APV project is financially viable or not for the DISCOMs. When the LCOE of APV plant is higher than INR 5.12 per kWh, the difference between the LCOE and the INR 5.12/kWh tariff rate is used as Viability Gap Funding (VGF). It is to be noted that VGF will only be required for initial years, when LCOE is greater than tariff viability benchmark.

In our model, the LCOE of APV plant and CAPEX is expected to decline in coming years due to capex decline, therefore the VGF amount per MW will vary for each year. It is calculated by using the following formula:

- Per MW VGF required in 20XX year = (LCOE in 20XX – Tariff threshold) X (Cost per MW (CAPEX)/LCOE in 20XX)

Further, the per MW VGF required amount is multiplied with the associated annual capacity to get the Annual VGF required (INR Crore). Note that for purpose of VGF, escalation / decline in marginal cost of procurement under approach 2 is not considered. However, this threshold tariff can be computed periodically based on historic data (say a quarter) and be VGF may be updated on a periodic basis.

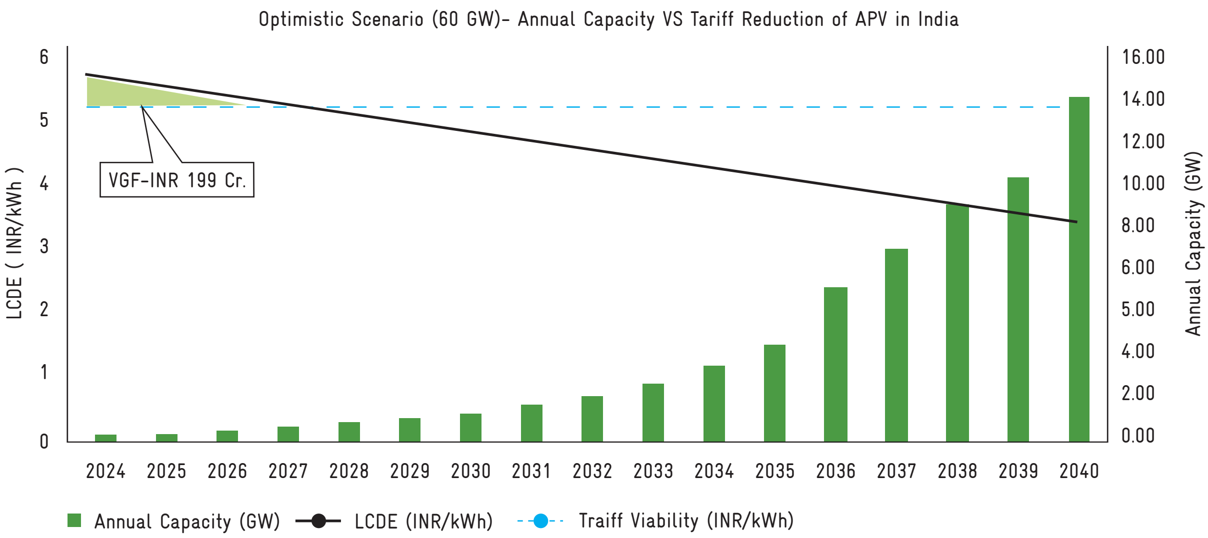


Figure 24: Annual capacity vs tariff reduction of APV (optimistic scenario)

The total VGF required will be around INR 199 Cr for a total capacity of 710 MW till 2026-27 (Figure 24). Year wise VGF amount for the associated annual capacity is mentioned in the VGF calculations column of table 15.

The total investment that will be required to realise the above-mentioned capacity (i.e., 60 GW) is INR 2,13,858 crores. Table 15 highlights the year-on-year capacity and investment potential.

Table 15: Investment and capacity projection for APV (optimistic scenario)

Year	Investment and Capacity Projection for APV (Optimistic Scenario)				VGF Calculations	
	Annual Capacity (GW)	Cost per MW (INR Crore)	LCOE (INR/kWh)	Investment required (INR Crore)	Per MW VGF required for project viability (INR Crore)	Annual VGF required (INR Crore)
2024	0.18	5.96	5.63	1,073	0.54	97.18
2025	0.23	5.72	5.42	1,319	0.32	73.20
2026	0.30	5.49	5.21	1,621	0.10	28.12
2027	0.38	5.27	5.01	1,993	-	-
2028	0.59	5.06	4.82	2,994	-	-
2029	0.76	4.86	4.63	3,681	-	-
2030	0.97	4.67	4.46	4,525	-	-
2031	1.24	4.48	4.29	5,562	-	-
2032	1.59	4.30	4.13	6,837	-	-
2033	2.27	4.13	3.97	9,360	-	-
2034	2.90	3.96	3.82	11,506	-	-
2035	3.72	3.80	3.68	14,144	-	-
2036	4.76	3.65	3.54	17,387	-	-
2037	6.72	3.51	3.41	23,554	-	-
2038	8.60	3.37	3.28	28,955	-	-
2039	11.02	3.23	3.16	35,594	-	-
2040	14.11	3.10	3.04	43,755	-	-
Total	**60.33**			**2,13,858**		**199**

Note: *The VGF calculations that we have explained above have been derived at CAPEX of INR 5.96 Cr/MW with LCOE of INR 5.63/kWh. However, this is an indicative number based on our discussion and consultations with developers and concerned stakeholder. The per MW cost APV system may vary from INR 5.9 to 6.4 Cr, with LCOE ranging from 5.63 to 6/kWh. The cumulative VGF upto year 2026 may vary from INR 199 to 561 Crores.*

5.4 FINANCING INTERVENTIONS REQUIRED FOR APV

The MNRE has been administrating the Pradhan Mantri Kisan Urja Suraksha evam Utthan Mahabhiyaan (PM-KUSUM) scheme. The scheme aims add solar capacity of 30,800 MW by 2022 with total central financial support of INR 34,422 Crore.

The Scheme consists of three components:

- Component A: 10,000 MW of solar capacity through installation of small Solar Power Plants of individual plants of capacity upto 2 MW.
- Component B: Installation of 20 lakh standalone Solar Powered Agriculture Pumps.
- Component C: Solarisation of 15 Lakh Grid-connected Agriculture Pumps.

A detailed review of the scheme reveals multiple categories of support embedded in the scheme.

Under Component A there is a mix of FiT and generation-based incentive policy at play. Details include:

- The solar power generated will be purchased by DISCOMs at a feed-in-tariff (FiT) determined by respective State Electricity Regulatory Commission (SERC).
- DISCOM would be eligible to get PBI @ INR 0.40 per unit purchased or INR 6.6 lakh per MW of capacity installed, whichever is less, for a period of five years from the Commercial Operation Date (COD).

For component B, we see an upfront capital support in the form of grant. Concessional finance is not mentioned explicitly, however, it is more than likely that the agencies involved in providing the loan component for such schemes may be providing interest subvention under different government schemes:

- CFA of 30% of the benchmark cost or the tender cost, whichever is lower, of the stand-alone solar Agriculture pump will be provided. The State Government will give at-least a subsidy of 30%; and the remaining at-most 40% will be provided by the farmer.
- Bank finance can be availed by farmer, so that farmer must initially pay only 10% of the cost and remaining up to 30% of the cost as loan.

For component C, there are two categories viz., Individual pump solarisation (IPS) and Feeder level solarisation (FLS). However, both are supported by upfront capital support from central and state government.

Specifically, for IPS:

- CFA of 30% of the benchmark cost or the tender cost, whichever is lower, of the solar PV component will be provided. The State Government will give at-least subsidy of 30%; and the remaining at-most 40% will be provided by the farmer.
- Bank finance can be availed by farmer, so that farmer must initially pay only 10% of the cost and remaining up to 30% of the cost as loan

While for FLS, CFA of 30% on the cost of installation of solar power plant (up to INR 1.05 Cr/MW) will be provided.

As evident, the existing policy support to PV systems for agriculture have a blended approach to proliferate sustainable energy use in agriculture.

APV naturally fits into the existing PM KUSUM scheme. Under component A, the APV systems of capacity 500 KW to 2 MW can be setup by individual farmers/ group of farmers/ cooperatives/ panchayats/ Farmer Producer Organisations (FPO)/Water User associations (WUA). In case the above entities are not able to arrange the equity required for setting up the APV system, they can opt for third party developers or even the local discom which can be considered as the Solar Power Generator (SPG). APV systems.

APV systems also fit into the component B, where individual farmers install standalone solar agriculture pumps of capacity upto 7.5 hp in off-grid areas. The business case for farmers deploying standalone solar agriculture pumps is improved if they consider APV systems. With APV system they can continue to produce the crop alongwith the energy generation which was otherwise a trade-off at first place. APV systems will also help marginal farmers with lower farming acreage improve the chances of deployment of agriculture pump sets under component B which was otherwise constrained due to small area available for farming. Needless to mention, the crop suitability must be evaluated by farmers before considering APV systems in either case.

For component C, APV systems also seem to complement IPS and FLS. IPS just like standalone systems under component B, improve the business case for farmers who intend to benefit from net metering and farming. However, for FLS system the APV system deployment depends on whether the land being used for FLS is an agriculture land or not. In case the agriculture land is being used by Discoms/ Developers to setup such systems from existing farmers/ landowners, then APV is a natural fit as it will help reduce the concerns of ''land loss". It is likely that Discoms/ Developers will have to aggregate land for deployment of FLS under Component C. This aggregation task will be far easier if APV systems are used.

In summary, we propose the following interventions to promote APV systems that may be considered by MNRE under the ambit of PM KUSUM:

- APV systems are likely to accelerate the deployment of solar PV systems in the country. While the PM KUSUM scheme is sufficiently covering for the incentives, we propose, that a clarification/ notification by MNRE to include APV system in the definition of solar PV systems for all components will bring more clarity to investors/ financing institutions and discoms.
- Further, a differential incentive for APV systems (in the form of CFA over and above existing 30% for Component B and C and additional PBI over and above existing INR 0.40 /kWh for discoms) will develop interest from stakeholders to evaluate APV systems. This additional incentive should be sufficient to compensate for increased LCOE (INR 5.63/kWh – as explained in 5.3.1 above) due to higher capital costs when compared with conventional solar systems envisaged in the PM KUSUM scheme. The proposed additional incentive will thus be:
    a. For CFA: the difference of APV system cost of INR 5.96 Crore and the system cost assumed for computed the CFA of 30% under the PM KUSUM scheme for Component B and C.
    b. For PBI: the difference of APV LCOE of INR 5.63 INR/kWh and the LCOE/tariff assumed for computing the PBI of INR 0.40/kWh.
- R&D budget may be provided to SNAs or designated agencies for setting up more APV pilots to study the crop impact and identify suitable crops in the local climate. The grant support for pilots may be to cover up the additional capex required by APV systems over and above conventional solar PV systems under PM KUSUM.

POLICY AND REGULATORY ANALYSIS OF APV

06

6.1 INTERNATIONAL POLICY AND REGULATIONS FOR APV

Agrivoltaics, at the intersection of agriculture and renewable energy, represents a promising approach to address both global food security and sustainable energy production. As the world grapples with the urgent need to combat climate change and its associated challenges, international policies and regulations have begun to play a pivotal role in shaping the development and deployment of agrivoltaic systems. These policies aim to strike a delicate balance between promoting renewable energy generation and ensuring food production remains resilient and abundant. The concept of agrivoltaics is rapidly evolving, with several countries like Germany, France, Japan and Italy leading research and development on agrivoltaics having successfully implemented pilot projects in their region.

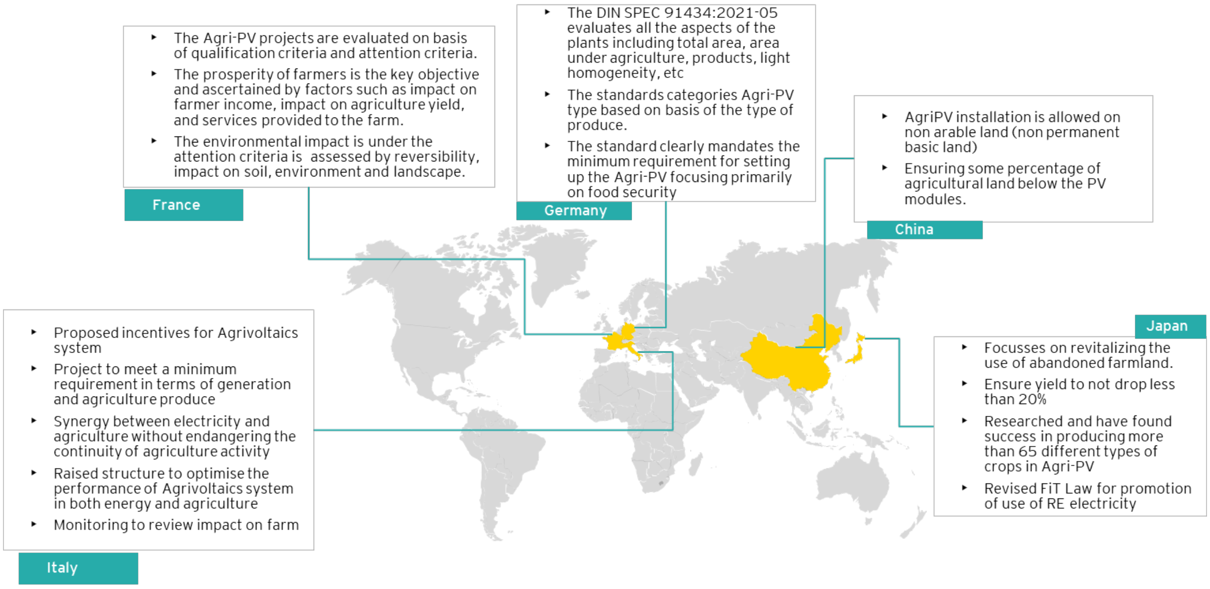


Figure 25: International policies on APV

Germany's DIN SPEC, provides a comprehensive framework for the integration of agrivoltaics, emphasizing the importance of maintaining agricultural productivity as the primary objective. According to these standards, agricultural land is primarily dedicated to farming activities, with electricity production through photovoltaic (PV) systems considered a secondary use. To strike a balance between these dual purposes, the DIN SPEC allows for a maximum allowable reduction in agricultural yield of up to 34%. Furthermore, the DIN SPEC establishes specific land loss thresholds for different types of APV systems. For overhead stilt-mounted APV plants with a width of less than 10 meters and a height exceeding 2 meters, the permitted land loss is set at less than 10%. Similarly, for inter-row APV systems, where solar panels are integrated between crop rows, the allowable land loss is even lower, capped at less than 15%. These guidelines not only ensure that agricultural production remains a priority but also encourage efficient land use and minimal interference with traditional farming practices, thus contributing to sustainable energy generation and food production in Germany[8].

8 *German DIN SPEC 91434:2021, Agri-Photovoltaic Systems - Requirements For Primary Agricultural Use, 2021*

In 2021, **Japan's** New Energy and Industrial Development Organization (NEDO) and the Ministry of Economy, Trade and Industry (METI) took significant steps to promote the adoption of agrivoltaic systems by releasing updated guidelines for agrivoltaic Photovoltaic (APV) installations. These guidelines mark a pivotal shift in Japan's approach to solar PV installations, as they now allow for solar panels to be installed not only on degraded farmland but also on class 1, 2, and 3 agricultural land. This expansion of permissible land types underscores Japan's commitment to harnessing renewable energy while minimizing the impact on its agricultural sector[9]. Under these new guidelines, the maximum acceptable reduction in agricultural yield due to APV installations is set at less than 20%. This limit demonstrates Japan's dedication to preserving the productivity of its agricultural land, even as it integrates renewable energy infrastructure. Additionally, the guidelines emphasize the importance of maintaining a flexible and non-intrusive approach to APV installation. Foundation support columns are required to have a simple structure and be easily removable, further ensuring that the land can be returned to its original agricultural use if necessary.

In **Italy**, regulations governing the implementation of solar photovoltaic (PV) systems on overhead stilts, commonly referred to as agrivoltaics, are tailored to accommodate various agricultural activities while preserving land productivity. Depending on the nature of the agricultural use, specific minimum height requirements for the solar panels are enforced. In cases involving livestock activities, such as grazing or animal husbandry, a minimum approved height of 3 meters is mandated. This elevated height allows ample space for unhindered livestock movement beneath the solar panels. Conversely, when the land serves primarily for cultivation purposes, such as crop farming, the minimum height is reduced to 1 meter. This lower height ensures that the solar panels cast minimal shadows, enabling crops to receive sufficient sunlight for photosynthesis and growth. Furthermore, Italy upholds a crucial maximum permitted land loss of 30% to safeguard agricultural productivity. This means that the installation of agrivoltaic systems should not result in an agricultural yield reduction exceeding 30%, thereby upholding the coexistence of renewable energy generation and agriculture while prioritizing the integrity of the land's primary function[10].

China has implemented a forward-thinking approach to agrivoltaics, permitting the installation of APV systems on general agricultural land, which excludes highly productive and arable land categories. In line with this policy, PV companies seeking authorization to establish APV plants must adhere to specific conditions. First and foremost, they are required to engage in crop cultivation beneath the PV panels. This requirement is essential to ensure that the shade cast by the solar panels does not significantly impede crop growth, thereby maintaining the land's agricultural productivity. Additionally, to obtain permission for APV plant construction, PV companies are obligated to guarantee a minimum level of agricultural output.

6.2 INDIA'S POLICY FRAMEWORK ON PM-KUSUM

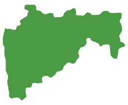
in 2019 , the Government of India launched the KUSUM scheme where component A of the scheme encourages farmers to install solar PV on their land for the sale of power to DISCOMs as a pre-determined tariff. The scheme also provides for feeder-level solarisation under component C, which involves the installation of solar power plants on agricultural feeders.

9 PV Magazine, Japan releases new guidelines for agrivoltaics as installations hit 200 MW, Dec 2021, Link https://www.pv-magazine.com/2021/12/13/japan-releases-new-guidelines-for-agrivoltaics-as-installations-hit-200-mw/

10 PV Magazine, Italy publishes new national guidelines for agrovoltaic plants, Jul 2022, Link https://www.pv-magazine.com/2022/07/05/italy-publishes-new-national-guidelines-for-agrovoltaic-plants/

Most states in India have formulated their programs under the Pradhan Mantri (PM)-KUSUM scheme to ensure effective implementation of the scheme. The state-level programs vary in terms of the specific incentives and benefits offered to farmers, the process for availing of the scheme, and the extent of support provided by the state government in terms of installation, operation, and maintenance of the solar power plants.

Table 16: Key states and their programs

Sate/UT	Policy/Scheme	Key Points
Delhi 	Delhi Solar Policy, 2022 (Draft)	The policy encourages deployment of solar on agricultural land via different models including, but not limited to, group net metering and community solar.
Uttar Pradesh 	Draft Uttar Pradesh Solar Energy Policy, 2022	Land Bank not suitable for agriculture and wastelands will be created by UPNEDA across the State and specifically in the Bundelkhand region. The State shall provide a facility of deemed land conversion from agriculture uses to non-agriculture use on approval by the State Nodal Agency.
Maharashtra 	Mukhyamantri Saur Krushi Vahini Yojana and PM KUSUM	Tariff ceiling has been approved for INR 3.05/unit to supply electricity to the farmers during the daytime by installing ground mounted decentralized solar power projects. (Previously it was 3.11/unit as signed by Maharashtra State Electricity Distribution Co. Ltd and Energy Efficiency Services Limited.)
Odisha 	PM KUSUM	Odisha State Electricity Regulatory Commission has determined the tariff of INR 3.08/- per unit of electricity generated through decentralized solar PV plants under KUSUM Scheme
Haryana 	PM KUSUM	Haryana Electricity Regulatory Commission has approved a tariff of INR 3.11/unit for plants under KUSUM (A)
Punjab 	PM KUSUM	Punjab State Electricity Regulatory Commission has approved a tariff of INR 2.7/unit for SPV plants under KUSUM component A for 217 MW capacity
Rajasthan 	PM KUSUM	Saur Krishi Ajivika Yojna was launched under PM KUSUM component C for feeder level solarization. In 2020, Rajasthan Electricity Regulatory Commission also determined a tariff of INR 3.14/unit under Component-A, without central financial assistance (CFA).

The PM-KUSUM scheme is primarily focused on promoting decentralized solar power generation by providing financial incentives to farmers for the installation of solar power plants on their land. On the other hand, agrivoltaics is the practice of integrating solar panels into agricultural land, allowing crops to be grown in the same space where solar panels are installed.

- One issue that arises is that the PM-KUSUM scheme incentivises the installation of solar power plants on uncultivable lands, such as barren or fallow land, while agrivoltaics requires cultivable land to be used. This could lead to a conflict between the two approaches as farmers may have to choose between using their land for crop cultivation or for installing solar power plants.

- Another issue is that agrivoltaics require careful planning and design to ensure that the crops and solar panels do not interfere with each other's growth and productivity. This requires specialised expertise and could add to the overall cost of the installation.

Despite these issues, there is also potential for synergy between the PM-KUSUM scheme and agrivoltaics. By combining the two approaches, farmers can generate both electricity and crops from the same piece of land, leading to increased productivity and income. This would require careful planning and design to ensure that the two approaches are compatible and complementary.

The following section tries to unearth the barriers and challenges in the adoption of agrivoltaics in India.

6.3 METHODOLOGY FOR UNDERSTANDING BARRIERS AND CHALLENGES

The I-SUN program has explored and researched the policy and regulatory landscape for APV, prevailing in India, referencing published literature, consulting various stakeholders, and understanding the various stages in the life cycle of the project. This was accompanied by undertaking rigorous engagements with key stakeholders like project developers, regulators, nodal agencies, market developers etc. along each of the stages. In addition, a questionnaire was prepared and floated to large audiences to understand the policy and regulatory barriers to large-scale adoption of APV in India. The framework included the steps shown in Figure 26.

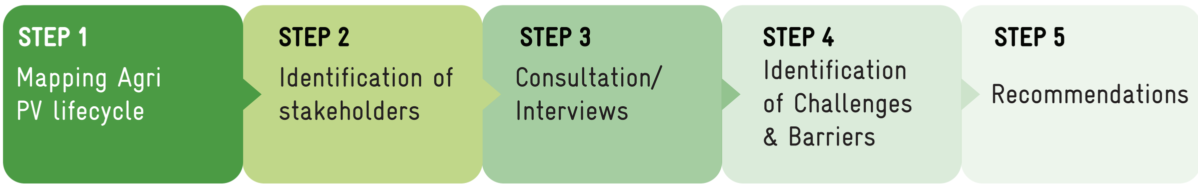


Figure 26: Methodology for understanding barriers and challenges

In **step 1**, the project team has analysed and mapped out the various stages involved in building an agrivoltaics plant. Analysing the full lifecycle allows stakeholders to make informed decisions and establish strategies for successful implementation by identifying the barriers and challenges connected with each step of the lifecycle.

The lifecycle of APV has the following phases (Figure 27):

- **Application Stage:** The first stage is the application stage where the consumer applies to set up the solar plant. The stage is important for understanding the prerequisites of setting up the APV plant.
- **Project Approval:** The next stage in setting up an APV plant is getting project approval from concerned government departments. At this stage, the concerned DISCOM will do a feasibility study. The plants are evacuated at 11 kV/ 33kV.
- **Detailed Engineering:** Once the feasibility is approved, the EPC does a detailed engineering of the plant. This includes designing the plant, evacuation infrastructure etc.

- **Project Execution:** The EPC installs the plant on agricultural land.
- **Commissioning:** EPC obtains all the necessary approvals for the project from the concerned stakeholder.
- **Maintenance:** The EPC provides maintenance for the agreed period as per the contract. The owner can then decide to take the O&M services of the same EPC or find another company.

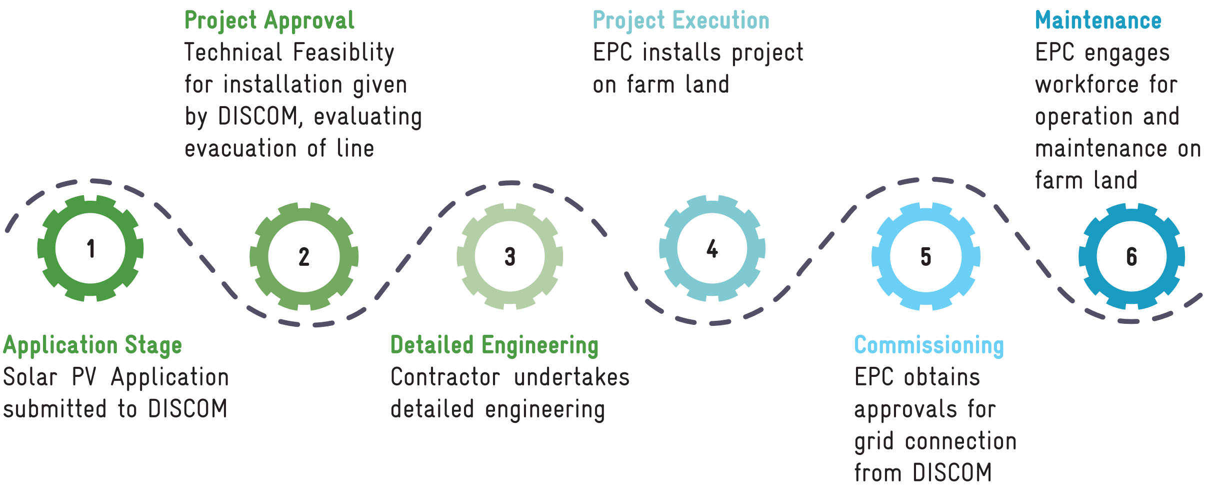


Figure 27: Lifecycle of an APV plant

During **step 2**, the project team engaged in extensive conversations with key stakeholders in the agrivoltaic domain, ranging from those responsible for project implementation to the authority's overseeing regulations, agencies coordinating efforts, and individuals shaping the market.

Simultaneously, a structured questionnaire was created in **step 3** and shared widely among a diverse set of respondents. The primary goal was to gather comprehensive information about the hindrances caused at each stage of project lifecycle. The questionnaire allowed for a more inclusive and holistic understanding of the challenges in this domain by collecting insights from a broad cross-section of stakeholders, ultimately aiding in the formulation of strategies and policies for overcoming these impediments. In order to understand the barriers and challenges in implementing APV in India, the project team consulted a variety of different stakeholders (Figure 28). Detailed list can be referred from Annexure B.

Figure 28: Stakeholder consulted

6.4 IDENTIFICATION OF BARRIERS AND CHALLENGES IN APV

Based on the in-depth literature review and stakeholder consultations, the project team was able to identify the following barriers and challenges in different stages of the plant life cycle. This is a part of step 4 of the methodology as discussed in the section above (figure 26). A summary of barriers and challenges is illustrated in Table 17.

Table 17: Summary of barriers and challenges

Barriers and Challenge	Category	Criticality Factor	
Land Usage Categorization	Regulatory	High	★★★
Unavailability of Standards	Technical	High	★★★
Grid Connection Availability for APV	Technical	Low	★☆☆
Tariff Determination for APV	Regulatory	Low	★☆☆
Ground Water Bill	Regulatory	Medium	★★☆
Technical Standards for Connectivity	Technical	Medium	★★☆
Agricultural Yield Loss Mechanism	Regulatory	Low	★☆☆
Tax on Income Through Electricity Generation	Economical	Low	★☆☆

APPLICATION STAGE

Regulatory

- **Land Usage:** Land is largely classified as agricultural, residential or commercial based on the type of usage. The land can only be used for the purpose it is registered. Therefore, many state policies state/union territories where agricultural land can not be used for any other purpose.

  Since APV allows the farmers to sell the power to DISCOMs, the overall transaction may be categorised as a commercial activity. States like Rajasthan (Rajasthan Land Revenue Act 1956) and Uttar Pradesh (Uttar Pradesh Revenue Code) require additional approval from authorities for the use of land for purposes other than agriculture.

Regulatory

- **Barren Lands:** While the state of Rajasthan is implementing KUSUM component A, it has its state policy which promotes APV on the barren lands only (Rajasthan Solar Policy 2019), which means that farmers in the state cannot install solar panels on recently cultivated land or the land that is unused.

Land usage laws limit the use of agricultural land for non-agricultural purposes like installing solar PV systems. This makes it more difficult for farmers or landowners to install solar panels on their land.

PROJECT APPROVAL STAGE

Unavailability of standards and evacuation capacity of sub station in rural areas posesses a challenge for APV users

Technical
- **Standardisation:** Although the MNRE KUSUM scheme states that "DISCOMs shall assess and notify renewable energy generation capacity that can be injected into all the 33/11 kV or 66/11 kV or 110/11 kV sub-station of rural areas and place such information on its website for information of all stakeholders"11, the information related to the capacity is either not readily provided by the state DISCOM on its website or is obsolete.

Technical
- **MIS:** There is no existing practice in DISCOMs to provide a database (which may be periodically updated) or MIS on spare capacity availability at each 33/11 kV station for APV.

Technical
- **Methodology:** The methodology for estimating the evacuation capacity is not developed/standardised in many states. There is limited focus by DISCOMs on providing guidelines for the procedure for applying for APV.

Regulatory
- **Tariff determination for APV:** Presently there is no mechanism to determine tariffs for APV plants; however, several state regulatory commissions have derived tariffs based on the petitions filed by their respective DISCOMs under KUSUM scheme component A (decentralized solar power plant) and component C (feeder level solarization).
  - The state regulatory commissions derive tariffs based on the financial modelling of PV plants under certain assumptions, which are further shared with DISCOMs and stakeholders for comments. The DISCOMs in return can file petitions to update the assumptions used to derive tariffs.

PROJECT EXECUTION

The Model groundwater bill does not support use of ground water for Agri-PV, and consumers have to bear the cost of evacuation infrastructure. Right of way is an issue for distribution lines.

Operational
- **Water Usage:** The construction of APV requires the use of water for civil structures. Further water is also used during the operation of the power plant to clean the modules. The national green tribunal has laid down stringent use for ground water usage that includes approval from concerned officials.

Regulatory
- **The Model Groundwater Bill:** The bill prioritises the right of water for life, followed by allocation for achieving food security, supporting sustenance agriculture, sustainable livelihoods and eco-system needs. The bill for the Conservation, protection, regulation and Management of Ground Water, 2016, does not support the use of groundwater for normal solar PV projects along with APV and additional permits and clearances are required.

Regulatory
- **Evacuation Infrastructure:** In some states (eg, Rajasthan), the consumers have to bear the cost of the evacuation infrastructure (Rajasthan Solar Policy, 2019). The additional cost of infrastructure is large for a small farmer. Right of way for building evacuation infrastructure is an issue for distribution lines.

11 *KUSUM guidelines – Clause 3 (Implementation mechanism), sub clause A (Selection and implementation of decentralised renewable energy power plants)*

COMMISSIONING

Technical

- Technical standards: The CEA's Technical Standards for Connectivity of the Distributed Generation Resources, 2013 (amended 2019) clearly define regulations related to the interconnection of renewable energy plants below and above the 33kV level.
  - However, for plants below 33kV, the enforcement is not carried out as per the stated regulations. The states and DISCOMs are more inclined towards larger projects.

MAINTENANCE

Technical

- **Agriculture Insurance:** The farmers have the option to avail of insurance coverage and financial support in case of failure of the crop as a result of natural calamities, pests and diseases under the Pradhan Mantri FasalBina Yojana (PMFBY). The yield loss is estimated after crop-cutting experiments conducted by the government and the actual yield of the land. This methodology will not be able to estimate the real yield loss to an APV plant. Hence, it needs to be modified appropriately.

There is no mechanism for Agri-PV plants to accurately estimate crop yield loss.

Economic

- **Taxation:** Agriculture income is free from taxation under Section 10 (1) of the Income Tax Act of 1961. Thus, a farmer's income from farming pursuits, such as cultivating land or selling agricultural products, is not subject to taxation.
  - However, the income is not tax-free, and if the farmer makes money by selling the electricity an APV system produces, electricity sales revenue would be regarded as business income and subject to income taxation under the Income Tax Act.

6.5 KEY RECOMMENDATIONS BASED ON THE BARRIERS IDENTIFIED

In this section, the project team have formulated recommendations based on the insights and findings gathered during the previous steps. This constitutes the step 5 of the methodology as illustrated in Figure 26 above. These recommendations are essential for guiding the project's direction, addressing identified challenges, and optimizing its overall success. I-SUN Program proposes the following recommendations.

- **Change in Land Act:** Most states prohibit commercial activity other than farming on farmland unless it is reclassified as commercial land. A key obstacle to the development of agrivoltaics is this division between agriculture and other uses.
  a. By classifying APV as an agricultural activity, it may help address some of the issues related to land conversion and use of groundwater, as it recognises the land as being used for both agricultural and energy production purposes. However, there should be some criteria defined for usage of agricultural land along with power generation and it should not hamper the ongoing crop yield.

b. This would allow farm communities to build revenue-generating APV projects while maintaining land ownership by establishing a unique category of APV land. The agricultural activity along with electricity generation through APV should happen in silos, without discontinuing farming.

- **Definition of APV is required for India:** Percentage of the land that shall be available after installation of solar for farming needs to be defined as well as the percentage of crop yield that shall be there after the installation of the solar system in comparison to the original field.

  a. An example of this could be derived from Japan's APV policy, which states that the agricultural yield loss should be less than 20%. Similarly, countries like Italy have included a restriction on the maximum permitted land that can be used for solar PV power generation.

- **State Solar Policy:** The state policy of Rajasthan supports the development of APV on uncultivable lands. The Rajasthan Solar Policy clause 8.2.1 that states, "Farmers on their own or through a developer, can set up decentralised power project on their un-cultivable agriculture land" may be changed to "Farmers on their own or through a developer can set up decentralised power projects on their agriculture land". However, farming and power production should happen simultaneously, on the same piece of land without affecting any one of them.

- **Model Bill for the Conservation, Protection, Regulation, and Management of Groundwater, 2016:** Obtaining permits is compulsory and users are required to be registered for using groundwater. The priority on groundwater may include APV in the model bill. This may also help incentivize the adoption of water-efficient technologies and practices that minimise water uses and improve water productivity. For instance, APV systems that use drip irrigation, rainwater harvesting or other water-saving techniques may be prioritized over those that rely solely on groundwater extraction. Further, the water used for cleaning the solar modules can be reused for agricultural activity. However, this would restrict the use of chemical agents for cleaning the modules.

- **PM FBY:** To propose methodology for calculating unprecedented yield loss against anticipated loss for APV. It will help in identifying the potential risks and benefits of APV for agricultural productivity and make informed decisions about the adoption of this technology.

- **State Solar Policy/Electricity Tariff Guidelines and Regulations:** The development of evacuation infrastructure and network augmentation for APV evacuation is a critical component for ensuring the effective integration of solar power into the grid. However, the costs associated with these activities can be significant and may deter farmers or vendors from investing in APV systems. Evacuation infrastructure and network augmentation developed by DISCOMs for APV evacuation may be passed in the ARR instead of charging the vendor or the farmer.

- **Technical Standards for Connectivity of Distributed Generation Resources,** 2013 (amended 2019): It already provides comprehensive guidelines for interconnection of renewable energy plants below 33kV. However, most of the states are more inclined towards renewable energy projects above 33kV -Inter State Transmission System (ISTS). It is required that the DISCOMs should also prioritise the smaller APV projects. DISCOMs should also consider including the voltage and frequency ride-through requirement in addition to existing CEA requirements. As the number of small projects becomes large, their disconnection from the grid due to voltage and frequency events could cause significant problems.

SKILL GAP ASSESSMENT AND JOBS REQUIRED IN APV SECTOR

07

Skilling is vital for increasing the penetration of NISA. By creating a skilled workforce, we can ensure better utilization of renewable energy resources with high-quality workmanship on the deployed technologies. The skilling interventions must ensure better sustainability of the technology, quality of the deployment and increased rate of deployment, which will create new jobs and livelihood opportunities for many. Skill development initiatives will be majorly required in project engineering, project execution, project commissioning, operation and maintenance and creating awareness, and the four given in Figure 29 are crucial for increasing adaptation of NISA:

Technical Expertise
As solar technology advances, there is a growing need for skilled workers who can design, install, operate and maintain these systems. Skilled workers are required to ensure that the solar systems are installed and maintained correctly, which in turn ensures maximum energy output and efficiency.

Quality Assurance
Solar energy systems must meet strict quality standards to ensure their safety, reliability, and performance. Skilled workers are essential to ensure that these standards are met, which is especially important for ensuring the safety of people and the environment.

Innovation and Research
Skilled workers are required to innovate and research new solar solutions, which are vital for the industry's growth. With skilled workers, there is a greater chance of identifying and developing new solar technologies, which can help in improving the efficiency and reducing the cost of solar systems.

Education and Awareness
Skilling can help to educate and raise awareness about the benefits of solar energy, which can lead to increased demand and adoption of solar solutions. By creating a skilled workforce, people will be better informed about solar technology and its benefits.

Figure 29: Crucial requirements for skilling

Number of Jobs

- Sector Experts, Policy/Regulator/ Financial/ Designers
- Project Managers / Site Managers/ Supervisors
- Installation / operation and Maintenance Technician and their assistants/ Helpers

Figure 30: Number of jobs as per skills and designations

The targeted skilling measures not only increases the penetration of new innovative solar application but also creates numerous direct and indirect jobs across the sector, most jobs will be at the operational level of manufacturing, installation and maintenance.

The majority of the jobs will be created at the technician level or below, whereas the high-paid jobs with value addition in the sector will be comparatively less.

Though all the skilling initiatives will not result in new job creation, they may provide better/alternate livelihood opportunities for existing manpower migrating from other sectors to these new sectors.

7.1 SKILLING REQUIRED IN APV

The project team has identified several gaps where skilling becomes necessary to boost the APV sector in India.

Table 18: Skill gap assessment and interventions

Stakeholder	Gaps	Skilling Required	Skilling Intervention
DISCOM Officials	Grid connectivity of the APV poses an implementation challenge (less than 33 kV)	Capacity development of the DISCOM engineers to perform the grid interconnection may be carried out for APV plants.	A handbook for DISCOM officials needs to be developed and circulated on NISAs
Krishi Vikas Kendra (KVK) officers	KVK officials are not aware of APV technology, and not able to provide consultation about APV compatible fertilizers, insecticides and pesticides	Capacity development of the KVK officials needs to be done to provide technical guidance to the farmers	Interactive content should be developed for KVK officials. Short-term capacity building programs need to be crried out for KVK officials
Technicians	Non-availability of trained/skilled manpower in rural areas to operate and maintain agricultural equipment as well as APV systems	Skilling programs are needed for technicians on the operation and maintenance of APV systems in rural areas to provide technical knowledge of solar PV to existing electronics/pumps repair and maintenance workforce	A short-term course needs to be developed. This course may be carried out in industrial training institutes, engineering colleges, agricultural institutes, and skill development institutes.
Farmers	Farmers lack awareness of APV systems	Capacity building of farmers/ farmer associations/FPOs needs to be carried out at block/ panchayat level	A capacity-building program can be integrated within existing schemes like PM KUSUM, highlighting the benefits of APV to farmers.

CAPACITY BUILDING FOR DISCOM OFFICIALS

The objective of the skilling interventions is to upgrade the knowledge and skills of the DISCOM engineers. This will ensure the grids are safer for the operators as well as users. Also, the reliability of the grids will increase. Following are the three major benefits of the capacity building of the DISCOM officials:

Upgrading Knowledge

The energy sector is constantly evolving, with modern technologies and methods emerging all the time. Grid connection engineers need to be trained in these modern technologies and methods to ensure that they can design, build and maintain grids that are safe, reliable and efficient.

Ensuring Safety

The grid connection infrastructure can be dangerous if not designed and built correctly. Capacity building of grid connection engineers can help ensure that safety measures are implemented and followed, reducing the risk of accidents or other incidents.

Improving Reliability

The reliability of the grid connection infrastructure is critical for the functioning of modern society. Capacity building of grid connection engineers can help improve the reliability of the grid, reducing the risk of power outages and other disruptions

CAPACITY BUILDING FOR TECHNICIANS

The capacity building of technicians needs to integrate into the existing skilling programs in India. This skilling program will ensure that the technicians are equipped with the right technical and regulatory knowledge and have the skills to implement the projects. APV solar is different from ground mount. APV project designs are dependent upon the crops and the customer's PV requirement. A technician must take care of all the agricultural related factors while implementing the project.

Capacity building of technicians will ensure the following:

- Identify and use the tools and tackles used for solar PV system installation
- Install the civil/mechanical and electrical components of a solar PV system
- Test and commission solar PV system
- Maintain solar PV system
- Maintain personal health and safety at the project site

CAPACITY BUILDING FOR FARMERS

Capacity building of farmers on agrivoltaics can be done through various approaches and initiatives.

Awareness Programmes: Arrange seminars and training sessions aimed at educating farmers about agrivoltaics. These programmes can cover subjects including the advantages of combining agricultural and solar energy, how to install and maintain solar panels, how to choose and manage crops in shady areas, and system integration in general.

Training Programmes: Visit demonstration farms where farmers can see effective agrivoltaic systems in action and learn more about them. These farms can work as learning centres and offer possibilities for practical training, enabling farmers to comprehend the practical aspects of fusing agriculture with solar energy.

7.2 WORKFORCE REQUIRED FOR APV

To analyse the number of jobs created and workforce required in the APV sector based on the potential derived under this assignment, the project team referred to previously developed reports on skilling and workforce by Council on Energy Environment and Water, Natural Resources Defence Council and Skill Council of Green Jobs, along with stakeholder consultations.

The analysis was done under different job roles during the application stage, project approval, detailed engineering, project execution and commissioning, and maintenance, i.e. the workforce required to perform these job roles per MW of installation. The full-time equivalent is simply a ratio of the time spent by an employee on a particular task/project each year to the standard total working hours in that particular year.

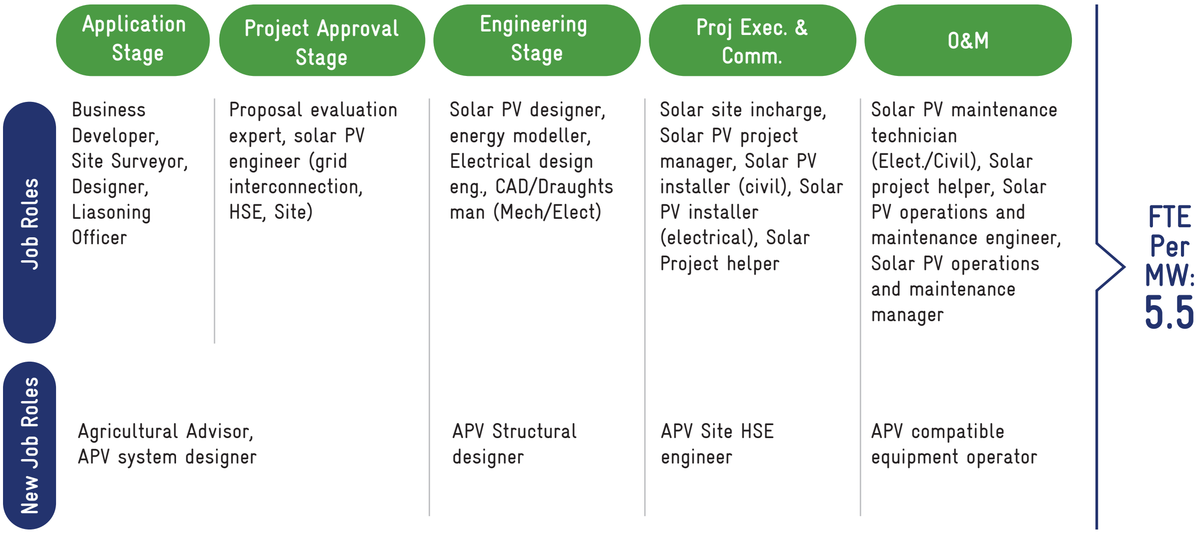


Figure 31: FTEs required in the APV sector

Source: Author's analysis, stakeholder discussions and literature review[12]

12 *India's expanding clean energy workforce- opportunities in solar and wind energy sector (2022), CEEW, NRDC, SCGJ; Greening India's workforce- gearing up for expansion of solar and wind power in India (2017), CEEW, NRDC; Skill gap report for solar, wind and small hydro sector (2016), SCGJ*

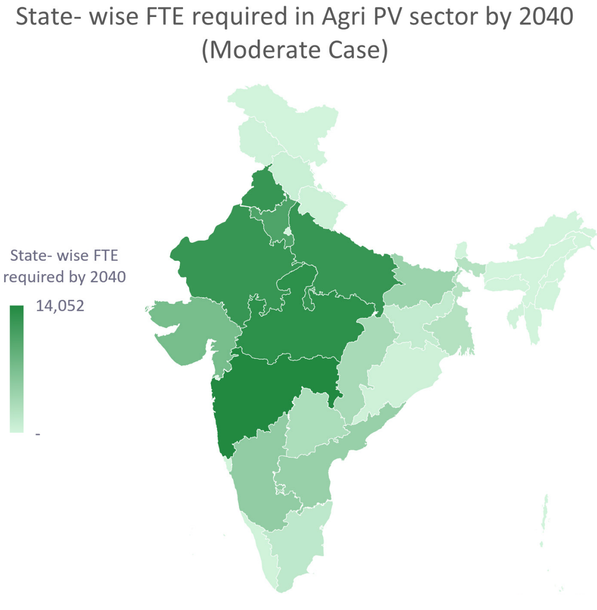
7.3 STATE-WISE DEPLOYMENT OF APV BY 2040

Based on the annual demand trajectory of agrivoltaics in India, and the potential derived under this project, the state-wise annual demand was mapped. This was further used to find the full-time equivalent jobs that would be required in each of the states.

Under the moderate case, it is estimated that to meet a demand of 20 GW of APV by 2040, **1,09,879 FTE** jobs will be required and for optimistic case, **3,31,825 FTE** jobs to support distinct roles and responsibilities starting from application, project approval, detailed engineering, project execution-commissioning and operations and maintenance.

Table 19: FTE required under moderate and optimistic case

Moderate Case	Optimistic Case
It is estimated that the total capacity that may be installed during 2024-40 in India will be **20 GW**	It is estimated that the total capacity that may be installed during 2024-40 in India will be **60 GW**
To realise 20 GW of capacity, a total of **1,09,879 FTE manpower** will be required in 2024-40	To realise 60 GW of capacity, a total of **3,31,825 FTE manpower** will be required in 2024-40



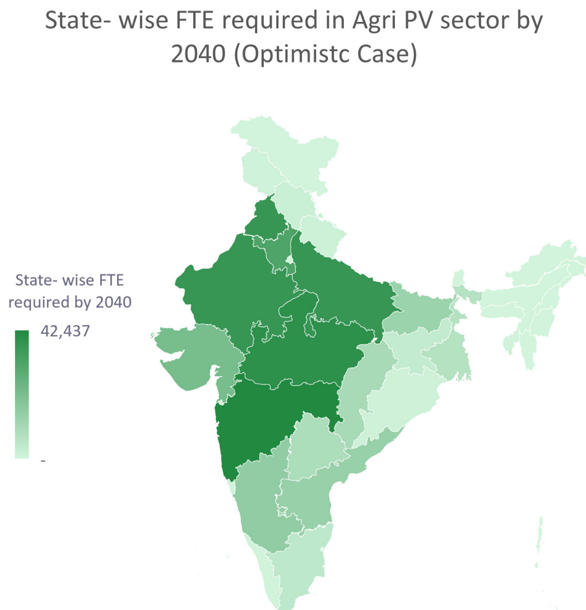


Figure 32: State wise FTEs required in the APV sector by 2040

CONCLUSION AND WAY FORWARD

08

In this report, we have undertaken an exhaustive examination of agrivoltaics (APV) in the context of India. The purpose of the report is to map the potential and assess gaps in achieving the potential for APV systems. While this report doesn't substitute the need for detailed feasibility and crop suitability, our study encompassed potential assessments, various business models, implementation strategies, technical aspects, policy enablers, market dynamics, financial considerations, and the skill sets needed to catalyze the growth of APV technology within India.

This report on APV in India will benefit various stakeholders. Government agencies and policymakers can utilize the insights to shape renewable energy and agricultural policies, including defining APV, specifying land usage, and creating incentives for APV adoption. Farmers and the agriculture industry can explore APV as a supplementary income source while safeguarding crops and conserving water. The solar energy sector can identify new market opportunities and business models through APV, focusing on scalability and cost-efficiency. Investors and financial institutions can assess the financial viability of APV projects, exploring funding options and monitoring market dynamics. Energy regulators and distribution companies (DISCOMs) can consider APV to reduce the cost of supplying power to agricultural consumers and improve energy distribution. Lastly, environmental and agricultural researchers can use the report's findings to advance knowledge about APV's impact on crop yields and environmental sustainability, conducting local and regional studies.

Our research involved an intricate potential assessment, incorporating district-level statistical data sourced from the Ministry of Agriculture Farmer and Welfare (MoAFW). Given the unavailability of GIS data for agricultural land, we devised a scientific approach that leveraged statistical information on crop cultivation patterns for 17 crops across all districts in the country. This innovative methodology provided a range for APV potential in India, estimated to be approximately 3.1 – 13.8 TW. Further data refinement at the field level for different seasons could enhance the accuracy of these estimates at a taluk level.

In addition to this, our report has provided crucial insights into business models and the Levelized Cost of Energy (LCOE). We've identified two primary APV business models, catering to both small-scale and medium/large-scale farmers, encompassing over 95% of farmer categories in India, thus fostering inclusive growth opportunities.

- Our analysis revealed that in states with an Average Power Purchase Cost (APPC) exceeding INR 4.5 per unit, the APV business model can operate without additional support structures. Here, the avoided loss corpus offsets lease compensation and crop reduction, ensuring the financial viability of power purchase from APV.
- However, states with an APPC cost lower than INR 4.5 per unit may require Viability Gap Funding (VGF) to make the model economically feasible, thus requiring a strategic approach to deployment.
- The LCOE for APV projects, based on conservative assumptions, offers significant room for cost reduction through economies of scale. As demonstrated in the solar PV industry, scalability can lead to more competitive tariffs, rendering APV technology more financially attractive.

This report has illuminated the critical aspects of skills required and the potential for new job creation within the agrivoltaics (APV) sector, in line with the data shared earlier. As APV gains momentum in India, a skilled workforce becomes paramount for successful implementation. To meet the demand associated with a 20 GW capacity addition by 2040, as estimated in the moderate scenario, approximately 1.1 lakh full-time equivalent (FTE) jobs will be required. In the optimistic scenario projecting 62 GW by 2040, this escalates to around 3.38 lakh FTE jobs, encompassing distinct roles and responsibilities spanning from application and project approval to detailed engineering, project execution-commissioning, and operations and maintenance.

These new employment opportunities present a significant avenue for job creation and economic development. Skilled workers will be essential to ensure the effective deployment, maintenance, and optimization of APV systems, thereby enhancing the country's renewable energy capabilities while concurrently generating employment across various skill levels. This emphasis on job creation underscores the multifaceted advantages of APV, extending beyond its direct impacts on energy and agriculture to contribute to India's socioeconomic growth and sustainability goals.

As next steps, collaboration is key as stakeholders from diverse sectors must work together to facilitate APV adoption. Continued research and development efforts are essential to refine APV methodologies and understand its long-term impacts. The policy recommendations emerging from this report emphasize the importance of clarity in defining agrivoltaics (APV) and specifying the allowable land usage for both solar and farming activities to ensure minimal impact on crop yields. Additionally, there is a call for the development of a methodology to assess yield loss in APV systems, facilitating informed decisions about technology adoption. Policies should also consider mandatory permits and registration for groundwater usage, with a specific focus on integrating APV into bills addressing groundwater priority. Furthermore, classifying APV as an agricultural activity can help navigate issues related to land conversion and groundwater usage. Capacity building is also crucial, ensuring a skilled workforce is available for APV projects. Monitoring and evaluation of APV project performance are necessary for ongoing improvements. Lastly, market development efforts, including awareness campaigns, can promote APV as a viable and sustainable solution. By addressing these next steps, stakeholders can collectively unlock the potential of agrivoltaics in India, leading to sustainable energy generation, enhanced agricultural practices, and economic benefits for all involved parties.

In conclusion, to promote the adoption of Agri-Photovoltaic (APV) systems within the framework of the PM KUSUM initiative, several key recommendations are proposed. Firstly, it is advised that the Ministry of New and Renewable Energy (MNRE) issue a notification that explicitly includes APV systems within the definition of solar PV systems for all components, thus providing clarity to investors, financing institutions, and DISCOMs. Secondly, to generate interest in APV systems, it is suggested to offer additional incentives, such as a differential capital subsidy (CFA) and a supplementary performance-based incentive (PBI) to compensate for the higher Levelized Cost of Electricity (LCOE) of APV systems compared to traditional solar systems. These incentives would be based on the disparities in costs and LCOE between APV and conventional solar systems. Additionally, allocating research and development funding to State Nodal Agencies (SNAs) or designated bodies would enable the establishment of more APV pilot projects to evaluate the impact of APV systems on crops and determine the most suitable crops based on local climate conditions. Grants for these pilot projects should cover the extra capital expenditure needed for APV systems, surpassing that of traditional solar PV systems under the PM KUSUM scheme.

ANNEXURE A: PROJECT AND FINANCIAL ASSUMPTION

Sl. No.	Assumption Head	Sub-Head 1	Sub-Head 2	Unit	Value
1	Power Generation	Capacity	Installed Power Generation Capacity	MW	1.0
			Capacity Utilization Factor (CUF)	%	15.00%
			Useful Life	Years	25.00
2	Project Cost	Capital Cost/MW	Power Plant Cost	INR Lakh	596.00
			Land Required	acres/MW	7.50
			Land Lease to Farmer	INR Lakh/acres	0.40
			Land lease escalation	%	2%
			Capital Subsidy allowed	%	0.00%
			Power Plant Cost post Subsidy	INR Lakh/MW	596.00
3	Financial Assumptions		Tariff Period	Years	25.00
		Debt Equity	Debt	%	70.00%
			Equity	%	30.00%
			Total Debt Amount	INR Lakh	417.20
			Total Equity Amount	INR Lakh	178.80
		Debt Component	Loan Amount	INR Lakh	417.20
			Moratorium Period	Years	-
			Repayment Period(Including Moratorium)	Years	12.00
			Interest Rate	%	9.00%
		Equity Component	Equity Amount	INR Lakh	178.80
			Nominal ROE	%	14%
			Return on Equity for First 20 Years	% p.a	16.96%
			Return on Equity remaining years	% p.a	21.52%
			Weighted Average of ROE	% p.a	20.55%
			Discount Rate (Post Tax WACC)	%	9.19%
4	Financial Assumptions	Fiscal Assumptions	Income Tax	%	34.94%
			MAT Rate	%	17.47%
		Depreciation	Book Depreciation Rate for First 12 Years	%	4.67%
			Book Depreciation Rate 13th Year Onwards	%	2.00%
			Depreciation tax purpose SLM	%	5.28%
			Depreciation tax purpose AD	%	40.00%
5	Working Capital	For Fixed Charges	O&M Charges	Months	1.00
			Mantainance Spare(% age of O&M Expenses)	%	15.00%
			Receivables from Debtors	Months	2.00
		For Variable Charges	Interest on Working Capital	%	10.00%
6	Operation & Maintenance	Power Plant	O&M Charges	INR Lakh	8.94
		O&M Expense Escalation		%	3.71%

LEVELIZED COST OF GENERATION

	Unit	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
O&M Expenses	INR Lakh		8.94	9.27	9.62	9.97	10.34	10.73	11.12	11.54	11.96	12.41	12.87	13.35	13.84	14.36	14.89	15.44	16.01	16.61	17.22	17.86	18.52	19.21	19.92	20.66	21.43
Depreciation	INR Lakh		27.83	27.83	27.83	27.83	27.83	27.83	27.83	27.83	27.83	27.83	27.83	27.83	27.83	27.83	27.83	11.92	11.92	11.92	11.92	11.92	11.92	11.92	11.92	11.92	11.92
Interest on Term Loan	INR Lakh		35.98	32.85	29.73	26.60	23.47	20.34	17.21	14.08	10.95	7.82	4.69	1.56	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Interest on WC	INR Lakh		1.70	1.71	1.72	1.73	1.73	1.74	1.75	1.76	1.77	1.78	1.79	1.80	1.82	1.83	1.84	1.85	1.87	1.88	1.89	1.91	1.92	1.94	1.96	1.97	1.99
Return on Equity	INR Lakh		30.33	30.33	30.33	30.33	30.33	30.33	30.33	30.33	30.33	30.33	30.33	30.33	30.33	30.33	30.33	30.33	30.33	30.33	30.33	30.33	38.48	38.48	38.48	38.48	38.48
Land Lease Requirement	INR Lakh		3.00	3.06	3.12	3.18	3.25	3.31	3.38	3.45	3.51	3.59	3.66	3.73	3.80	3.88	3.96	4.04	4.12	4.20	4.28	4.37	4.46	4.55	4.64	4.73	4.83
Total COG	INR Lakh		107.79	105.06	102.34	99.64	96.96	94.28	91.63	88.99	86.37	83.76	81.18	78.61	77.63	78.23	78.85	63.58	64.25	64.94	65.65	66.39	75.30	76.10	76.92	77.76	78.64
Discount Rate	%	9.19%																									
Discount Factor			1.00	0.92	0.84	0.77	0.70	0.64	0.59	0.54	0.50	0.45	0.42	0.38	0.35	0.32	0.29	0.27	0.25	0.22	0.21	0.19	0.17	0.16	0.14	0.13	0.12
Present Value of COG	INR Lakh		107.79	96.22	85.84	76.55	68.21	60.75	54.07	48.10	42.75	37.97	33.70	29.89	27.03	24.95	23.03	17.01	15.74	14.57	13.49	12.50	12.98	12.01	11.12	10.30	9.54
Per Unit COG	Levellized																										
Per Unit of O&M	INR/kWh		0.56	0.53	0.51	0.48	0.46	0.43	0.41	0.39	0.37	0.35	0.34	0.32	0.30	0.29	0.27	0.26	0.25	0.23	0.22	0.21	0.20	0.19	0.18	0.17	0.16
Per Unit value of Depreciated Amount	INR/kWh		1.75	1.60	1.47	1.34	1.23	1.13	1.03	0.95	0.87	0.79	0.73	0.67	0.61	0.56	0.51	0.20	0.18	0.17	0.15	0.14	0.13	0.12	0.11	0.10	0.09
Per Unit Interest of Term Loan Interest	INR/kWh		2.26	1.89	1.57	1.29	1.04	0.82	0.64	0.48	0.34	0.22	0.12	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Per Unit value of WC Interest	INR/kWh		0.11	0.10	0.09	0.08	0.08	0.07	0.07	0.06	0.06	0.05	0.05	0.04	0.04	0.04	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Per Unit Value of ROE	INR/kWh		1.91	1.75	1.60	1.47	1.34	1.23	1.13	1.03	0.94	0.86	0.79	0.73	0.66	0.61	0.56	0.51	0.47	0.43	0.39	0.36	0.42	0.38	0.35	0.32	0.29
Per Unit Land Lease Requirement	INR/kWh		0.19	0.18	0.16	0.15	0.14	0.13	0.13	0.12	0.11	0.10	0.10	0.09	0.08	0.08	0.07	0.07	0.06	0.06	0.06	0.05	0.05	0.05	0.04	0.04	0.04
Per Unit Value of Cost of Generation	INR/kWh		6.78	6.05	5.40	4.81	4.29	3.82	3.40	3.03	2.69	2.39	2.12	1.88	1.70	1.57	1.45	1.07	0.99	0.92	0.85	0.79	0.82	0.76	0.70	0.65	0.60
Levellised Tariff	INR/kWh	5.63																									

ANNEXURE B: LIST OF STAKEHOLDERS CONSULTED

Organisation	Name of Person
Dayalbagh Educational Institute, Agra	Prof. Ajay Sharma and Prof G.S. Sailesh Babu
Centre for Science and Environment	Mr Binit Das
Amity University	Dr Abhishek Verma
Amity University	Dr V.K. Jain
Central Ground Water Committee	Dr Ranjan Rai
APV Farmer	Mr R K Nagar
Developer	Mr Kunal Shah
Rajasthan Renewable Energy Corporation Limited (RRECL)	Mr Rajiv
Jaipur Vidyut Vitran Nigam Limited (JVVNL)	Ms Deepti Mathur
BSES Rajdhani Power Limited (BRPL)	Mr Pankaj Khargeti
A leading Renewable Design and Development Company	Kept Anonymous as per request
Agency for New and Renewable Energy Research and Technology (ANERT)	Mr Narendra Nath Veluri

ANNEXURE C: LIST OF CROPS REFERENCED FROM MOAFW

List of Crops Considered for Potential Assessment

Wheat, Rice, Cotton, Soyabean, Rapeseed and Mustard, Maize, Jowar, Potato, Sesame, Coriander, Onion, Barley, Garlic, Small Millets, Peas and beans, Banana, Dry chillies

Crop	Area Considered for Selected Crop (Hectare)				Total Area (Hectare)
	Kharif	Rabi	Summer	Winter	
Banana	5,679	-	72,213	-	77,892
Barley	827	5,59,520	-	-	5,60,347
Coriander	33	27,852	-	-	27,885
Cotton	1,21,31,695	90,684	-	-	1,22,22,379
Dry Chiilies	2,74,099	68,640	-	-	3,42,739
Garlic	52,010	-	-	-	52,010
Jowar	18,73,917	30,16,759	5,069	-	48,95,745
Maize	69,38,942	15,63,158	4,56,193	78	89,58,371
Rapeseed and Mustards	346	61,27,277	-	6,755	61,34,378
Onion	1,90,774	1,73,727	33,037	-	3,97,538
Peas and Beans	16,379	6,07,363	-	-	6,23,742
Potato	35,174	10,15,503	10,337	80,170	11,41,184
Rice	2,58,88,906	14,23,223	26,52,269	-	2,99,64,398
Sesame	12,25,067	83,663	2,98,221	9,973	16,16,924
Small Millets	3,78,843	21,628	47	-	4,00,518
Soya	1,20,13,356	203	-	-	1,20,13,559
Wheat	-	3,46,46,709	118	-	3,46,46,827
Total Area					**11,40,76,436**

ANNEXURE D: DISCOMS OVERVIEW OF POWER IN INDIA (2022-23)

Source: NITI Aayog, India Climate and Energy Dashboard

State	DISCOM	AT&C Losses (%)	Average power purchase cost (Rs./kWh)	Average Cost of Supply (Rs./ kWh)	Average Billing Rate (Rs./ kWh)
Andhra Pradesh	Andhra Pradesh Eastern Power Distribution Company Limited	10.92	4.24	6.72	5.71
Andhra Pradesh	Andhra Pradesh Southern Power Distribution Company Limited	12.84	4.40	7.18	5.07
Andhra Pradesh	Andhra Pradesh Central Power Distribution Company Limited	12.38	4.24	7.09	5.63
Arunachal Pradesh	Department of Power Arunachal Pradesh	37.31	3.08	12.11	3.70
Assam	Assam Power Distribution Company Limited	N.A.	4.14	8.14	7.68
Bihar	North Bihar Power Distribution Company Limited	15.00	4.29	7.69	7.19
Bihar	South Bihar Power Distribution Company Limited	15.00	4.33	6.96	7.36
Chandigarh	Chandigarh Electricity Department	N.A.	3.75	5.71	5.13
Chhattisgarh	Chhattisgarh State Power Distribution Company Limited	N.A.	3.35	5.56	6.08
Delhi	New Delhi Municipal Council	8.96	5.22	10.18	9.41
Delhi	BSES Rajdhani Power Limited	8.36	4.09	8.99	6.70
Delhi	BSES Yamuna Power Limited	8.98	3.99	9.04	6.56
Delhi	Tata Power Delhi Distribution Limited	8.16	4.71	9.26	7.03
Goa	Electricity Department, Government of Goa	N.A.	3.96	5.68	4.70
Gujarat	Uttar Gujarat Vij Company Limited	N.A.	3.45	5.54	3.47
Gujarat	Madhya Gujarat Vij Company Limited	N.A.	3.45	6.47	4.52
Gujarat	Paschim Gujarat Vij Company Limited	N.A.	3.45	6.01	4.03
Gujarat	Dakshin Gujarat Vij Company Limited	N.A.	3.45	6.96	5.01
Haryana	Uttar Haryana Bijli Vitran Nigam	14.43	4.43	7.53	5.10
Haryana	Dakshin Haryana Bijli Vitran Nigam	14.43	4.43	7.35	5.69
Himachal Pradesh	Himachal Pradesh State Electricity Board Limited	N.A.	2.76	5.99	6.90
Jharkhand	Jharkhand Bijli Vitran Nigam Limited	N.A.	3.89	N.A.	N.A.
Jharkhand	Damodar Valley Corporation, Jharkhand	N.A.	6.35	N.A.	N.A.

Karnataka	Hubli Electricity Supply Company Limited	N.A.	3.85	8.31	8.31
Karnataka	Mangalore Electricity Supply Company Limited	N.A.	3.28	8.13	8.13
Karnataka	Bangalore Electricity Supply Company Limited	N.A.	4.56	8.70	8.70
Karnataka	Chamundeshwari Electricity Supply Corporation Limited	N.A.	3.68	8.11	8.11
Karnataka	Gulbarga Electricity Supply Company Limited	N.A.	4.09	8.11	8.11
Kerala	Kerala State Electricity Board	12.11	3.91	7.22	6.17
Madhya Pradesh	Madhya Pradesh Madhya Kshetra Vidyut Vitaran Company Ltd	N.A.	3.16	6.89	6.78
Madhya Pradesh	Madhya Pradesh Pashchim Kshetra Vidyut Vitaran Company Ltd	N.A.	3.15	6.67	6.61
Madhya Pradesh	Madhya Pradesh Poorv Kshetra Vidyut Vitaran Company Ltd	N.A.	3.16	6.77	6.66
Maharashtra	Maharashtra State Electricity Distribution Company Limited	N.A.	4.73	7.41	7.96
Manipur	Manipur State Power Distribution Company Limited	N.A.	4.33	11.33	7.26
Meghalaya	Meghalaya Energy Corporation Limited	14.64	3.45	5.80	6.33
Mizoram	Power & Electricity Department, Mizoram	N.A.	5.02	9.46	6.99
Nagaland	Department of Power Nagaland	N.A.	4.72	8.85	5.88
Odisha	Tata Power Northern Odisha Distribution Limited (erstwhile NESCO)	19.17	2.54	5.49	5.50
Odisha	Tata Power Southern Odisha Distribution Limited (erstwhile SouthCO)	25.75	2.54	5.13	5.14
Odisha	Tata Power Central Odisha Distribution Limited (erstwhile CESCO)	23.70	2.54	5.49	5.87
Odisha	Tata Power Western Odisha Distribution Limited (erstwhile WESCO)	24.16	2.54	5.46	5.51
Punjab	Punjab State Power Corporation Limited	N.A.	4.50	6.76	6.47
Rajasthan	Jaipur Vidyut Vitran Nigam Limited	16.81	4.00	8.61	8.00
Rajasthan	Jodhpur Vidyut Vitran Nigam Limited	18.20	4.00	8.77	7.32
Rajasthan	Ajmer Vidyut Vitran Nigam Limited	12.73	3.99	7.82	7.88
Telangana	Telangana State Northern Power Distribution Company Limited	N.A.	4.69	7.57	3.95
Telangana	Telangana State Southern Power Distribution Company Limited	N.A.	4.71	6.80	4.58
West Bengal	Damodar Valley Corporation, West Bengal	N.A.	6.35	N.A.	N.A.
Average			3.98		

ANNEXURE E: STATE WISE CAPACITY PROJECTION AND FTES (OPTIMISTIC CASE)

Year-wise demand (MW)	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	Total Demand (MW)	State- wise FTE required from 2024-40
Andaman and Nicobar Islands	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-
Andhra Pradesh	8	10	13	16	25	32	41	53	68	96	123	158	202	285	365	468	599	2,562	14,093
Arunachal Pradesh	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-
Assam	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	4	19
Bihar	7	9	12	15	23	30	39	49	63	90	115	148	189	267	342	438	560	2,396	13,179
Chandigarh	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	4
Chhattisgarh	6	7	9	12	18	23	30	38	49	70	90	115	147	207	265	340	435	1,861	10,238
Daman and Diu	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3	14
Delhi	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-
Goa	0	0	0	0	0	0	0	1	1	1	1	2	2	3	4	6	7	31	171
Gujarat	12	15	19	25	39	50	64	82	105	149	191	245	313	442	566	725	928	3,968	21,822
Haryana	17	22	28	36	57	73	93	119	152	217	278	357	457	644	825	1056	1353	5,785	31,816
Himachal Pradesh	1	1	2	2	4	5	6	8	10	14	18	23	29	42	53	68	87	373	2,051
Jammu and Kashmir	1	1	1	1	2	2	3	3	4	6	8	10	13	19	24	31	39	168	923
Jharkhand	2	3	3	4	7	9	11	14	18	26	33	42	54	76	97	124	159	681	3,745
Karnataka	9	11	14	18	28	36	46	59	75	107	138	176	225	318	407	522	668	2,857	15,713
Kerala	0	0	1	1	1	1	2	2	3	4	5	6	8	11	15	19	24	103	565

Year-wise demand (MW)	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	Total Demand (MW)	State- wise FTE required from 2024-40
Ladakh	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-
Lakshadweep	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-
Madhya Pradesh	22	28	35	45	71	91	116	148	190	271	347	445	569	803	1029	1317	1687	7,213	39,674
Maharashtra	23	29	38	48	76	97	124	159	203	290	371	476	609	859	1100	1409	1804	7,716	42,437
Manipur	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-
Meghalaya	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-
Mizoram	0	0	0	0	0	0	0	0	0	0	1	1	1	1	2	2	3	12	66
Nagaland	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-
Odisha	1	1	1	1	2	2	3	4	5	7	9	12	16	22	28	36	46	197	1,081
Puducherry	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	4	23
Punjab	20	26	33	42	66	85	108	139	178	254	325	416	533	752	962	1232	1578	6,749	37,120
Rajasthan	20	26	33	42	66	85	109	139	178	254	325	416	533	752	963	1233	1579	6,753	37,143
Sikkim	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-
Tamil Nadu	3	3	4	5	9	11	14	18	23	33	42	53	69	97	124	158	203	868	4,774
Telangana	5	6	8	10	16	21	27	34	44	62	80	102	131	185	236	303	388	1,658	9,121
Tripura	0	0	0	0	1	1	1	1	2	2	3	4	5	7	9	11	14	62	340
Uttar Pradesh	20	26	33	43	67	85	109	140	179	255	327	418	536	756	968	1240	1587	6,788	37,336
Uttarakhand	1	1	1	2	2	3	4	5	7	9	12	15	19	27	35	45	58	247	1,358
West Bengal	4	5	6	8	12	16	20	26	34	48	61	78	100	142	181	232	298	1,273	7,000
Installation Per year (MW)	180	230	295	378	591	757	970	1242	1590	2268	2904	3718	4761	6719	8604	11017	14107	60,332	3,31,825

ANNEXURE F: STATE WISE CAPACITY PROJECTION AND FTES (MODERATE CASE)

Year wise demand (MW)	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	Total Demand (MW)	State- wise FTE required from 2024-40
Andaman and Nicobar Islands	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-
Andhra Pradesh	4	5	6	7	9	11	14	21	27	37	45	56	69	95	117	145	180	848	4,667
Arunachal Pradesh	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-
Assam	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	6
Bihar	4	4	5	7	8	10	13	20	25	34	42	52	65	89	110	136	168	793	4,364
Chandigarh	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Chhattisgarh	3	3	4	5	7	8	10	16	19	27	33	41	50	69	85	106	131	616	3,390
Daman and Diu	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	5
Delhi	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-
Goa	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	2	2	10	57
Gujarat	6	7	9	11	14	17	21	33	41	57	70	87	108	147	182	225	279	1,314	7,226
Haryana	9	11	13	16	20	25	31	48	60	82	102	127	157	214	265	328	407	1,916	10,535
Himachal Pradesh	1	1	1	1	1	2	2	3	4	5	7	8	10	14	17	21	26	123	679
Jammu and Kashmir	0	0	0	0	1	1	1	1	2	2	3	4	5	6	8	10	12	56	306
Jharkhand	1	1	2	2	2	3	4	6	7	10	12	15	18	25	31	39	48	225	1,240
Karnataka	4	5	7	8	10	12	15	24	30	41	50	63	77	106	131	162	201	946	5,203
Kerala	0	0	0	0	0	0	1	1	1	1	2	2	3	4	5	6	7	34	187
Ladakh	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-

Year wise demand (MW)	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	Total Demand (MW)	State- wise FTE required from 2024-40
Lakshadweep	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-
Madhya Pradesh	11	13	17	20	25	31	39	60	75	103	127	158	196	267	330	409	507	2,389	13,138
Maharashtra	12	14	18	22	27	34	42	64	80	110	136	169	209	285	353	438	542	2,555	14,052
Manipur	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-
Meghalaya	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-
Mizoram	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	4	22
Nagaland	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-
Odisha	0	0	0	1	1	1	1	2	2	3	3	4	5	7	9	11	14	65	358
Puducherry	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	8
Punjab	10	12	15	19	24	29	36	56	70	96	119	148	183	249	309	383	474	2,235	12,292
Rajasthan	10	12	15	19	24	29	36	56	70	96	119	148	183	250	309	383	475	2,236	12,299
Sikkim	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-
Tamil Nadu	1	2	2	2	3	4	5	7	9	12	15	19	24	32	40	49	61	287	1,581
Telangana	2	3	4	5	6	7	9	14	17	24	29	36	45	61	76	94	117	549	3,020
Tripura	0	0	0	0	0	0	0	1	1	1	1	1	2	2	3	4	4	20	112
Uttar Pradesh	10	13	16	19	24	30	37	57	70	97	120	149	184	251	311	385	477	2,248	12,363
Uttarakhand	0	0	1	1	1	1	1	2	3	4	4	5	7	9	11	14	17	82	450
West Bengal	2	2	3	4	4	6	7	11	13	18	22	28	35	47	58	72	89	421	2,318
Installation Per year (MW)	90	112	138	171	212	263	326	504	625	860	1066	1320	1636	2230	2762	3423	4241	19,978	1,09,879

NOTES

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Implemented by

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