Solar Irrigation in India

A Situation Analysis Report

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About SoLAR

Solar Irrigation for Agricultural Resilience (SoLAR) in South Asia aims to sustainably manage the water-energy and climate interlinkages in South Asia through the promotion of solar irrigation pumps (SIPs). The main goal of the project is to contribute to climate-resilient, gender-equitable, and socially inclusive agrarian livelihoods in Bangladesh, India, Nepal and Pakistan by supporting government efforts to promote solar irrigation. This project responds to government commitments to transition to clean energy pathways in agriculture. All countries in this project have NDC commitments to reduce greenhouse gas (GHG) emissions and SIPs can play a significant role in reducing emissions in agriculture.

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Through partnership, IWMI combines research on the sustainable use of water and land resources, knowledge services and products with capacity strengthening, dialogue and policy analysis to support implementation of water management solutions for agriculture, ecosystems, climate change and inclusive economic growth. Headquartered in Colombo, Sri Lanka, IWMI is a CGIAR Research Center.

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All opinions, findings and conclusions expressed in this report are those of the authors and do not necessarily reflect the view of the funding associated or official opinions of CGIAR or Future Earth. IWMI is a member of the CGIAR Consortium and leads WLE program.

Project

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Contents

List of Figures

List of Tables

List of Abbreviations

DISCOMs	Distribution Companies
JNNSM	Jawaharlal Nehru National Solar Mission
NAPCC	National Action Plan on Climate Change
IWMI	International Water Management Institute
SDC	Swiss Agency for Development and Cooperation
SoLAR	Solar Irrigation for Agricultural Resilience
PM-KUSUM	Pradhan Mantri Kisan Urja Suraksha evam Utthaan Mahabhiyan Yojana
MNRE	Ministry of New and Renewable Energy
WEF	Water Energy Food
SKY	Suryashakti Kisan Yojna
GHG	Greenhouse Gas
MT	Million Tonnes
UNFCCC	United Nations Framework Convention on Climate Change
INDC	Intended Nationally Determined Contribution
SPV	Solar Photovoltaic
ST	Solar Thermal
RE	Renewable Energy
PV	Photovoltaic
NABARD	National Bank for Agricultural and Rural Development
BCM	Billion Cubic Meters
NVVN	Vidyut Vyapar Nigam Limited
DSUUSM	Dhundi Saur Urja Utpadak Sahakari Mandali
FiT	Feed-in tariff
EBI	Evaluation Based Incentive
FPO	Farmer Producer Organisations
HP	Horsepower
CUF	Capacity Utilisation Factor
USPC	Universal Solar Pump Controller
CFA	Center Financial Assistance
SERC	State Electricity Regulatory Commissions
SEEMAT	Solar Energy Equipment Manufacturers Association of Telangana
NRDC	Natural Resources Defence Council
SEWA	Self-Employed Women's Association
WUA	Water Users Associations
IE	Impact Evaluation

Executive Summary

This report presents a synthesis of India's solar irrigation policies. It provides a detailed picture of the country's renewable energy transition journey, highlights the current issues faced by the energy and water sector in the context of solar irrigation, and describes how the SDC-SoLAR (Swiss Development Corporation-Solar Irrigation for Agricultural Resilience) project led by the International Water Management Institute (IWMI) aims to navigate these complex issues through its research activities.

India is the world's largest user of groundwater, with an annual draft of 250 km^3. Almost 80% of this is used for irrigation. According to the 5th Minor Irrigation Census conducted in 2013-14, India had 20 million irrigation wells and tubewells, the highest number anywhere in the world. Groundwater- led irrigation was instrumental in the success of the Green Revolution in India. However, an increase in agricultural production came at the cost of groundwater sustainability. Currently, India's water crisis can be primarily traced to growth in groundwater irrigation – a trajectory influenced by India's food and electricity policy since the late 1970s. The 1970s witnessed the abolition of metering, and the introduction of flat electricity tariffs had huge implications on how farmers used groundwater and how electricity utilities managed their agricultural electricity supplies. Later, in the 1990s, some states started providing free electricity to agriculture. While the objective to achieve food self-sufficiency was met by the early 1980s, these policies resulted in unsustainable groundwater use. At the same time, the financial viability of several electricity distribution companies suffered. As the energy source used for lifting groundwater is either diesel or coal-based electricity, by 2014, irrigation accounted for roughly 1/5th of India's agricultural emissions. In brief, India has a water-energy nexus, where India has become food secure, but that food security came at the cost of India's groundwater, electricity and environmental sustainability.

As part of India's efforts to maintain the globally acceptable emission levels, the government of India (GOI) has planned to install 175 gigawatts (GW) of renewable energy capacity by 2022, of which 100 GW will be from solar. Solar energy makes up the lion's share of the country's planned renewable energy mix due to its 750 GW potential and falling prices of solar panels. Solar-powered irrigation is a relatively minor segment of India's renewable sector plans, but we argue that it can play an essential role in India's decentralised clean energy transition story, provided it's backed with appropriate policies and institutions.

The last decade (2010-2019) marked the introduction of a string of reforms to tap into this solar potential in the agricultural sector. Under the National Action Plan on Climate Change (NAPCC), the Jawaharlal Nehru National Solar Mission (JNNSM) was launched in 2010. JNNSM was followed by multiple central and state-level schemes aimed at deploying both off-grid and grid-connected solar irrigation pumps (SIPs) all over India. As of 2019, these schemes have contributed to making India the 5th largest producer of solar energy globally. The Ministry launched the most recent solar irrigation policy, viz., Pradhan Mantri Kisan Urja Suraksha evam Utthaan Mahabhiyan Yojana (PM-KUSUM) in 2019 of the New and Renewable Energy (MNRE) to install 25.75 GW agricultural solar capacity by 2022. The scheme has three components: decentralised ground-mounted grid-connected pumps (Component A), stand-alone off-grid solar pumps (Component B) and grid-connected pumps (Component C).

However, there are several barriers to the implementation and expansion of solar irrigation under the KUSUM scheme. The most important is the financial barrier related to most electricity distribution companies' poor long-term financial health (DISCOMs). This is closely followed by challenges in incentivising farmers to adopt solar irrigation and conserve groundwater by setting appropriate buy-back tariffs. This is particularly challenging against a backdrop of falling solar tariffs and the periodic cancellation of renewable Power Purchase Agreements (PPAs). Finally, on the technical front, implementing components A and C of KUSUM requires feeder segregation, and most states have not segregated their agricultural and non-agricultural consumers into separate feeders.

Furthermore, sustainable groundwater management requires coordination among states' energy and water departments, especially in regions where the groundwater extraction is high, yet such coordination mechanisms are missing. At the same time, the deployment of solar pumps must be inclusive and proportionally target and benefit women, small, large and marginal farmers, which can ultimately be achieved by redefining eligibility criteria for enrolment into solar irrigation schemes. Yet, so far, most of the subsidies have gone to large and politically well-connected farmers.

Before conceptualising the grid-connected solar component by PM-KUSUM, in 2018, Gujarat introduced Suryashakti Kisan Yojana (SKY) - a grid-connected solar irrigation scheme. Given the precarious situation of groundwater levels in much of the state, the scheme has been rolled out to provide uninterrupted daytime electricity to farmers through decentralised grid-connected solar pumps while offering attractive incentives to farmers to reduce pumping. It operates in the buy-back model, allowing farmers to generate solar energy to pump and sell excess power back to the grid to the electricity utilities (DISCOMs). The SoLAR project in India mainly aims to assess this intervention's impact on the energy usage behaviour and subsequent water pumping, farming practice adjustments, and farmers' income.

1. Background

In India, irrigation has contributed immensely towards achieving self-sufficiency in food production. There has been a steady increase in mechanised pumping in the country after the Green Revolution in the 1970s. As surface irrigation was limited, the government at the centre and states have brought in favourable energy policies in the agricultural sector, such as setting up rural electrification corporations to increase energy access. From the late 1970s-1980s onwards, many state governments started to liberalise the energy policies for the agricultural sector to increase food production by subsidising electricity and diesel for agricultural purposes. Unmetered pumping and nominal flat rate or no cost for electric connections brought the marginal cost of pumping groundwater to almost zero. The subsidised energy policy increased farmers' reliance on groundwater for irrigation, which expanded the irrigation area from 29% in 1980 to 48% in 2013 (DES,2017).[1] Currently, of the total irrigated area in the country, 62% is irrigated by massive extraction of groundwater either from deep or shallow tubewells (DES, 2017). Overall, groundwater depletion in India results from its quest for affordable food for its billion-plus population. India's policy thrust for food self-sufficiency has created a nexus leading to unsustainable water and energy use trends and has led to high emissions from irrigation (Mukherji, 2020).

Currently, India is the world's largest user of groundwater, extracting about 250 km^3 per year (a quarter of world groundwater extraction), and about 86% of the total groundwater extraction is used for irrigation (Margat and Van der, 2013). It is estimated that the country has around 20 million tubewells, of which 70% of them are electric-powered, and 30% are powered by diesel (MNRE, 2017). The agricultural sector consumes about 22% per cent of the total electricity and 15% of the total diesel in the country (IEA, 2015). In addition, the primary source (73%) of electricity generation in India remains coal (IEA, 2019). It is estimated that the annual fossil fuel use associated with diesel and electric pumps amounts to more than four billion litres of diesel and 85 million tonnes of coal for electricity generation (KPMG, 2014, CEEW, 2018). In 2014, India's total GHG emission was 3,202 million metric tons of carbon dioxide equivalent (MtCO2e), of which 19% is contributed by the agricultural sector, positioning the agricultural sector as the second-largest contributor to GHG emission in the country (see Figure 1)

[1] % Irrigated area: Net Irrigated area to net sown area.

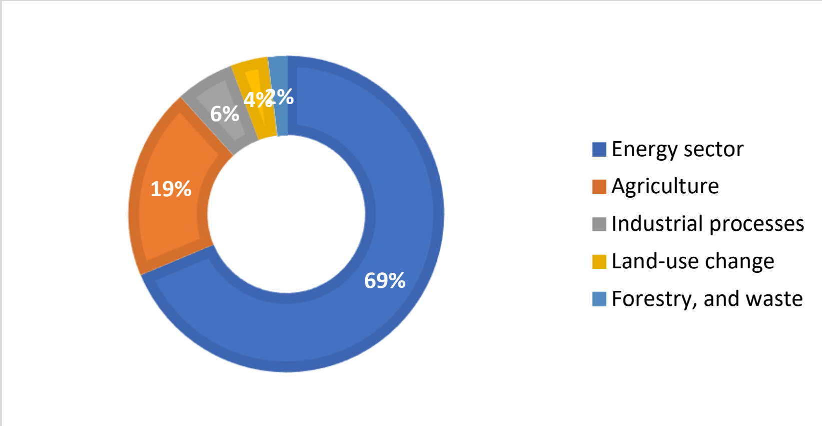

Figure 1: Sectoral contribution to greenhouse gas emission
Source: USAID (2014) [2]

On 1 October 2015, India submitted its Intended Nationally Determined Contribution (INDC) to the United Nations Framework Convention on Climate Change (UNFCCC), outlining its post-2020 climate actions, which once approved by the Indian Parliament, came to be known as Nationally Determined Contribution (NDC). Indian NDC pledges have been classified as sufficient to meet the 2°C climate goal but insufficient to meet the 1.5°C goals[3]. The country has committed to reduce the intensity of GHG emissions per unit GDP by 33% to 35%, below 2005 levels by 2030 and to create an additional carbon sink of 2.5 to 3 billion tonnes of CO_2 through an additional tree cover. To comply with its NDC, India has an ambitious plan to install 175 gigawatts (GW) of renewable energy (RE) capacity by 2022 and 450 GW by 2030. A significant share of planned RE will come from solar energy. This includes solarisation of irrigation, with plans for on-grid and off-grid expansion of solar PV pumps to provide reliable electricity for irrigation and provide additional income generation opportunities for farmers. In the long term, the country has set the target to increase the country's share of renewable energy to 40% to achieve 450 GW by 2030.

Solar irrigation provides the solution to a two-pronged challenge: it enables an uninterrupted supply of clean electricity during the daytime hours and curbs rising electricity demand from the agricultural sector, which can further burden the already financially burdened DISCOMs. Moreover, grid-connected solar can become an additional source of revenue for farmers if farmers get attractive buy-back tariffs. Table 1 shows the potential electricity subsidy that the various states can save should they choose to solarise their irrigation pumps.

[2] https://www.climatelinks.org/sites/default/files/asset/document/India%20GHG%20Emissions%20Factsheet%20FINAL.pdf

[3] https://climateactiontracker.org/countries/india/

State	Annual electricity subsidy on agriculture (in Rs. Crore)	Investment required for installation and solarisation of pumps (in Rs. Crores)	Number of years needed if a yearly subsidy funds the investment
Haryana	7,278.7	24,194.4	3.32
Punjab	7,585.8	29,547.2	3.9
Rajasthan	16,303.1	54,874.8	3.37
Uttar Pradesh	9,492.1	42,639.2	4.49
Gujarat	6,591.2	33,001.2	5.01
Madhya Pradesh	9,753.8	44,396	4.55
Maharashtra	17,729.5	72,835.6	4.11
Andhra Pradesh	7,578.7	30,255.2	3.99
Telangana	12,510.4	48,028.4	3.84
Karnataka	15,263.3	51,375.2	3.37
Tamil Nadu	6,585.6	27,054.8	4.11
Total	116,672.2	458,202	3.93

Table 1:Solarisation of agricultural pumps to reduce electricity subsidies
Source: Ministry of Power and Ministry of New and Renewable Energy

Jawaharlal Nehru National Solar Mission (JNNSM), launched in 2010, was the first mission commissioned under the National Action Plan on Climate Change (NAPCC). The JNNSM adopted a three-phase approach to creating policy conditions for rapid solar technology diffusion across the country.

From 2013-14 to 2019, the renewable power deployment by India has more than doubled, as of 2019, of the total installed power capacity, renewables including hydro (figure 2), contributing about 36% of total power generated in the country (MNRE, 2019). A total of more than 10 million person-days of employment is created in the renewable energy sector annually. In the last five years, solar power capacity increased by more than 14 times, from 2630 MW to 37,505 MW in December 2019. By the end of 2019, the share of solar energy in the total renewable installed power capacity mix was about 9.6%, with a cumulative solar installation of 36.9 GW (MNRE, 2019, Mercom, 2020).[4] Currently, India stands 5th in the global solar power deployment. The initial target of installing 20 GW

[4] Large hydro power constitutes 12.3%, wind power 10.1%, solar power 9.9%, bio-power 2.6%, and small hydro 1.3%.

grid-connected solar power plants by 2022 was enhanced to 100 GW. This target will likely be met as scheduled in 2022, even though the ongoing COVID-19 crisis has slowed down implementation.

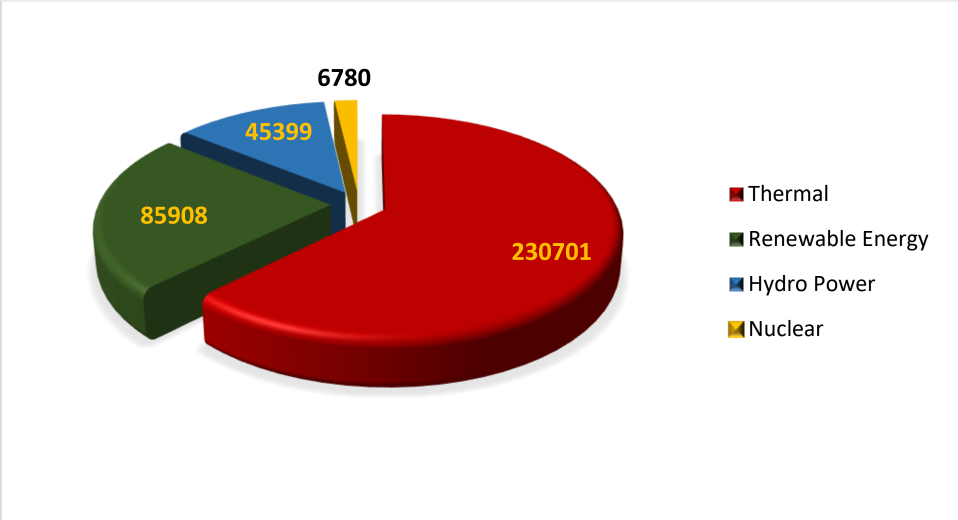

Figure 2:Source wise power installed capacity
Source: MNRE annual report 2019

Section 2 covers the evolution of solar irrigation policies in India, current status, and evidence observed in pilot implementation. Section 3 describes the new solar program in agriculture, and section 4 presents the general concerns about solar pumps and specific challenges regarding solar policies.

2. Evolution of solar irrigation policies in India

Agriculture in India is strongly linked with the power sector as electricity is the main source for lifting the groundwater to produce food grains. The country has dealt with the water-energy-food nexus by mainly relying on demand-side management instruments like rationing electricity, metering of agricultural electricity, setting up institutional permissions for new pumps etc. Different states have implemented various policies for managing groundwater and electricity as water is a state subject and electricity is a concurrent subject. Several studies have looked at the effectiveness of indirect management of groundwater through electricity policies such as feeder segregation and rationing of electricity in Gujarat (Shah et al. 2008), Karnataka and Punjab (Mukherji 2017); metering of electricity in West Bengal (Mukherji et al. 2009; Meenakshi et al. 2012). These studies concluded that political will is the main factor determining the success of these programs (Dubash et al., 2018). More specifically, except in West Bengal (Meenakshi et al. 2012), where there is some evidence that metering of agricultural electricity reduced groundwater pumping, in other states, it is not clear if electricity reforms affected groundwater use (Chindarkar & Grafton,2019). Meanwhile, irrigation continues to consume up to 20-25% of India's total electricity. Therefore, solar energy provides a viable option for India to decarbonise its agricultural sector.

One of India's major advantages today and going forward is its immense renewable energy (RE) potential in agriculture. Tapping into abundant renewable resources could avoid revenue outflows for expensive imported fuels, government subsidies in the power selector and achieve sustainable development (see Table 1). The country has vast scope in the area of solar energy, and the National Institute of Solar Energy (NISE) estimates more than 750 GW solar potential in the country, assuming 3% of the wasteland area to be covered by Solar PV modules (NISE). Accounting for falling solar PV panels price globally, India Energy Security Scenarios show that by 2047, it is possible to install 479 GW of solar PV. Realising this potential, the Ministry of Non-Conventional Energy Sources, now the Ministry of New and Renewable Energy- MNRE, started promoting solar pumps in agriculture. In 1993, the Ministry created a program to install 50,000 solar pump sets for irrigation. Unfortunately, that program failed to achieve the targeted number for several reasons: lack of attractive subsidies and low economic feasibility of solar pumping due to high solar PV cost and upfront costs during that time. However, by 2014 the program installed about 13,964 solar pumps (MNRE, 2014).

2.1 Jawaharlal Nehru National Solar Mission (JNNSM)

On 11 January 2010-11, Jawaharlal Nehru National Solar Mission (JNNSM) was launched by the central government by integrating the solar water pumping program into the off-grid and decentralised component of JNNSM. JNNSM had set a target for developing and deploying 20 GW solar power by the year 2022. However, this target was upgraded to 100 GW in 2015.

JNNSM is a phase-wise program, where the first phase runs from 2010 to 2013, focusing on the off-grid and decentralised solar power generation. Phase II runs from 2014-2017, focusing on large-scale grid-connected solar power generation and solar for lighting, irrigation and drinking water. As the JNNSM has a broad vision for solar energy generation in various sectors, we only discuss the programs related to solar irrigation pumps in this report.

2.1.1 JNNSM PHASE-I (2010- 2013)

Phase I aimed to provide an enabling environment for the penetration of solar technology in the country by replacing kerosene, diesel, electricity, and other fuels wherever possible while providing off-grid and decentralised solar photovoltaic (PV) systems solutions. The program covered large solar power plants based on solar thermal (ST) and solar photovoltaic (SPV) technologies. It targeted to install a 1000 MW grid-connected solar photovoltaic system integrated with 33kV line or above and 100 MW rooftop systems integrated with utility below 33 kV line. The power generated from the commissioned plants is purchased by Vidyut Vyapar Nigam Limited (NVVN), a power trading company and sold to State utilities/ DISCOMs. Phase – I has achieved more than what was targeted by installing 1686 MW of solar PV projects and a 7.01 million square meter area of solar thermal power projects. Phase-I did not have a particular focus on agriculture and had no targets for solar irrigation pumps.

2.1.2 JNNSM PHASE-II (2014-17)

Phase-II of JNNSM gave a special thrust towards solar applications in rural areas, including solar lighting, mini/microgrids, and solar water pumping. Therefore, the focus was more on grid-connected solar plants. It was targeted to achieve significantly higher scales generation up to 100 GW. Among many other programs in the JNNSM Phase-II,[5] the promotion of agriculture-based solar applications like solar pumping is being carried out mainly under two schemes.

A. Solar Pumping Programme for Irrigation and Drinking Water
B. Capital Subsidy Scheme for Solar PV Water Pumping Systems for Irrigation Purpose

A. Solar pumping programme for irrigation and drinking water scheme

The scheme aims to meet irrigation, drinking and other water requirements in rural areas. The programme targets to sanction 100,000 solar pumps for 2014-15 and at least 1 million solar pumps to be deployed by 2020-21 for irrigation and drinking water.

The scheme provides capital subsidy from the central government to up to 30% and an equal share of subsidy from the State Government through various sources. The subsidy was targeted for small and marginal farmers by placing the subsidy cap up to 5 hp and PV array capacity to up to 5000kWp. In addition, the scheme had to achieve the installation of 246,074 solar pumps for irrigation and drinking water as of 2019 (MNRE, 2019). The state-wise details of its achievements are presented in Table 2.

Sl no	State	Solar Home Light (No.)	Solar lamp (No.)	Solar Street Light (No.)	Solar Pump (No.)	Solar Power Plant (kW)
1	Andhra Pradesh	22972	77803	8992	34045	3815.6
2	Arunachal Pradesh	35065	18551	5008	22	963.2
3	Assam	46879	642996	9554	45	1605
4	Bihar	12303	1725478	34468	2813	6770

[5] The phase has around 19 different schemes to promote solar power generation across different sector (refer MNRE 2019 annual report)

5	Chhattisgarh	42232	3311	2042	61970	31249.9
6	Delhi	0	4807	301	90	1269
7	Goa	393	1093	707	15	32.72
8	Gujarat	9253	31603	3267	11522	13576.6
9	Haryana	56727	93853	34625	1293	2321.25
10	Himachal Pradesh	22592	33909	78000	6	1905.5
11	Jammu & Kashmir	144316	51224	14156	39	8129.85
12	Jharkhand	9450	790515	12286	4670	3769.9
13	Karnataka	52638	7781	2694	7420	7754.01
14	Kerala	41912	54367	1735	818	15825.39
15	Madhya Pradesh	7920	529101	11496	17813	3654
16	Maharashtra	3497	239297	10420	9337	3857.7
17	Manipur	24583	9058	11205	40	1580.5
18	Meghalaya	14874	40750	5800	19	2004
19	Mizoram	12060	10512	5325	37	2955.6
20	Nagaland	1045	6766	6235	3	1506
21	Odisha	5274	99843	17111	9551	567.515
22	Punjab	8626	17495	42758	4413	2066
23	Rajasthan	187968	225851	7114	48175	30349
24	Sikkim	15059	23300	504	0	850
25	Tamil Nadu	296505	16818	39419	5459	12752.6
26	Telangana	0	0	1958	424	7450
27	Tripura	32723	64282	1199	151	867
28	Uttar Pradesh	235909	2284425	264179	20546	10638.31
29	Uttarakhand	91595	163386	25168	26	3145.03
30	West Bengal	145332	17662	8726	653	1730

31	Andaman & Nicobar	468	6296	390	5	167
32	Chandigarh	275	1675	898	12	730
33	Lakshadweep	600	5289	2465	0	2190
34	Puducherry	25	1637	417	21	121
35	Others	24047	125797	9150	609	23885
36	NABARD (2015 onwards)	116226	0	0	4012	0
	Total	1721343	7426531	679772	246074	212054.2

Table 2:State-wise Installed Capacity of Off-Grid Solar Pumps under Phase-II
Source: MNRE (2019)

As we can see from Table 2, Chhattisgarh has the highest number of solar pumps installed in the country, followed by Rajasthan and Andhra Pradesh. This is because the state of Chhattisgarh had a political will to provide irrigation access to the tribal regions. In addition, the state-run Saur Sujala Yojana was utilising the JNNSSM fund. On the other hand, Eastern Indian states have a lower number of solar pumps installed. Yet, these are the states which have untapped groundwater resources and moderate solar potential in the country.

B. Capital Subsidy Scheme for Solar PV Water Pumping Systems for Irrigation Purpose

The scheme aims to replace the diesel pump sets with solar PV water pumping systems to meet the irrigation requirements. The program also targets the small and marginal farmers, where beneficiary farmers should contribute a minimum of 20% of the total financial outlay to be eligible for assistance. The repayment period for the loan was set to be ten years to make it attractive for small and medium farmers. The program targeted to support 30,000 solar pumps per year implemented through NABARD. However, the programme has failed to achieve its target, as only 700 farmers received the benefits from the capital subsidy scheme. Moreover, despite high subsidy (~80%) and solar loans, the program faced several challenges, including the high upfront cost for small and marginal farmers, collateral requirements, banks prescinding solar loans and a reluctance among farmers about solar power.

2.1.3 Capacity installed under JNNSM

As of 2019, under JNNSM, the total solar power capacity installed is 33,730 MW (33.73 GW). Tendering and commission are under process for about 51,417 MW, targeted for implementation during 2020 - 2021. The government has finalised tendering trajectory to achieve the mission target of 100 GW by 2022, with a target of 30 GW each in 2019-20 and 2020-21.

Since the inception of JNNSM, there has been an exponential growth in the number of off-grid solar pumps installed in the country. For example, figure 3 shows that at the beginning of Phase-II, the number of solar pumps were 11,626 and currently, it is 246,074 with a cumulative growth of 336%.[6] However, during 2019, solar pump installation slackened due to Covid-19 challenges, and drastic changes occurred in the solar policy for agriculture (see details in the next section).

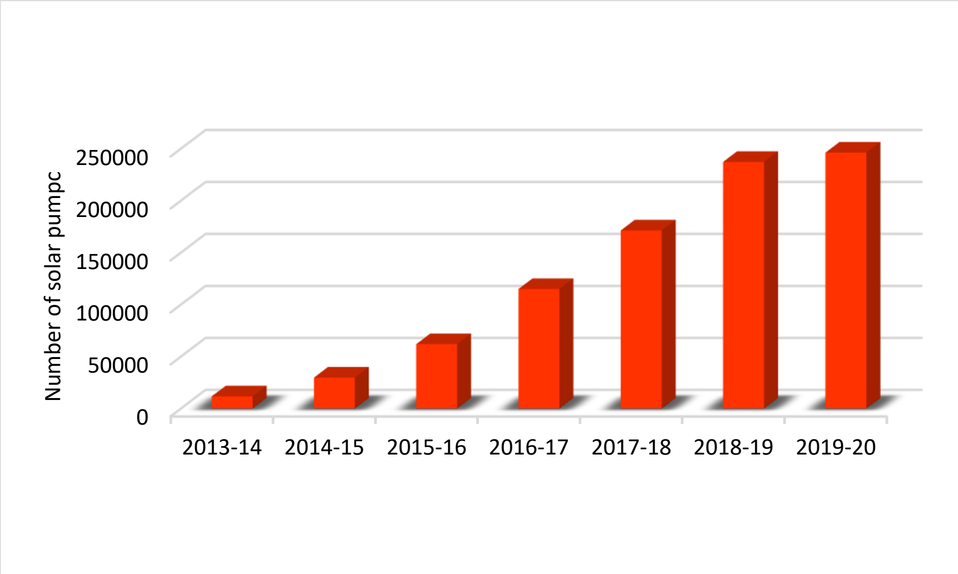

Figure 3:Year-wise deployment of solar pumps in the country
Source: MNRE (2019)

2.2 Grid-interactive solar pumps – State Initiatives

Apart from national-level policies like JNNSM, some states have taken steps to pilot different solar pump installation models (off-grid and on-grid). We discuss these initiatives, their current status and impact on farmers and water resource.

2.2.1 Mukhyamantri Saur Krishi Vahini Yojana, Maharashtra

Realising the lower demand for the off-grid solar pumps by farmers due to high upfront cost, in 2018, the government of Maharashtra planned to solarise the dedicated agricultural feeder by generating solar power through small solar plants. The state aims to get cheap and assured electricity to farmers through a solar feeder scheme in the next three years. The farmers will get electricity at Rs. 1.20 per unit under these feeders. The installed solar plants are small to medium in capacity (0.5 to 5 MW). The state is a pioneer in feeder solarisation, and the speed of deployment was great as there was no upfront payment by either government or farmers. Solar power generation projects have implemented the scheme in Solapur and Latur through a public-private partnership (Shirsath et al., 2020).

[6] Of total off-grid solar pumps installed in the country under, 8954 were installed under PM-KUSUM during 2019-20.

2.2.2 IWMI's Dhundi Pilot, Gujarat

The state of Gujarat and IWMI, in cooperation with CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS), has piloted grid-connected solar pumps in Dhundi village to understand whether the grid connection of solar panels and appropriate power purchase tariff will provide an incentive to farmers to reduce groundwater pumping and increase the farmers' income. In June 2015, six farmer members were formed into a cooperative called Dhundi Saur Urja Utpadak Sahakari Mandali (DSUUSM), and they acquired solar irrigation pumps with a total capacity of 56.4 kWp. The panels installed in the six farmers field were connected to the grid with a single metered point and were offered a contract to purchase solar power at Rs. 7.13/kWh for 25 years.[7] The members of DSUUSM could use the energy generated from the panel for pumping purposes and could evacuate the surplus energy to the grid. The formal evacuation of surplus solar energy under DSUUSM started in May 2016. Early reports from IWMI indicate that DSUUSM members have reduced the solar energy used for irrigation and have increased units evacuated to the grid over time. The number of units used for irrigation was 16,956 before the buy-back tariffs (January-May 2016) were introduced. It was reduced to 15,083 (12%) after introducing the buy-back tariff during Jan-May 2017. Further, the study finds that, after two years of introduction of a buy-back tariff, the energy used for irrigation purposes reduced by 40% compared to the baseline period. From May 2016 to October 2018, DSUUSM members earned ₹9.5 lakhs from the sale of solar energy to the grid. When comparing the last three years of farm income, the study found no significant change. However, the income from solar in 2017-18 resulted in the farmers' income to rise by 60 per cent compared to 2015-16 and 30 per cent compared to 2016-17. In addition to own energy usage and evacuating to the grid, the farmers in the solar cooperatives have served 120 water buyers in the location. The lesson from the Dhundi indicates that grid-connected solar pumps reduce the energy used for irrigation and act as an additional source of income to farmers, which is free of market or climate risks. Therefore, grid-connected solar pumps have the potential to become a remunerative crop for farmers (Shirsath et al., 2020).

2.2.3 Suryashakti Kisan Yojana (SKY), Gujarat

The Dhundi pilot's results have inspired Gujarat's government to launch Suryashakti Kisan Yojana (SKY) program, which targeted setting up grid-connected solar pumps in the state. Under the scheme, the state has targeted to solarise 137 agriculture feeders covering about 12,000 farmers with a total capacity of 175 MW. The program started in 2018, and as of now, 91 feeders are solarised, covering 4171 farmers across DISCOMS in the state (see Annex). The program targets

[7] Madhya Gujarat Vij Company Limited (MGVCL), the local power utility offered Rs. 4.63/kWh, IWMI offered a bonus of Rs. 1.25/kWh as Green Energy Bonus and another ₹1.25/kWh as Water Conservation bonus.

farmers already connected to the grid; however, a farmer gets solarised if only 75% of the farmers in the agricultural feeder agreed to participate. SKY offered a capital subsidy of up to 30% of the total cost, 65% as loan and 5% as down payment by farmers. Design of implementation suggests that the farmers generate energy to feed into the grid, and simultaneously they can draw electricity from the same. Therefore, the net metering was done to calculate the net energy evacuated to the grid after subtracting the energy drawn from the same. After the per-unit net energy is evacuated to the grid, farmers receive Rs. 3.50 per kWh as feed-in tariff (FiT) by utilities and Rs. 3.50 per kWh as an evacuation-based incentive (EBI) by the Government of Gujarat to reduce the farmers' loan burden. The EBI is capped up to 1,000 kWh per hp per year of contract load and is applicable for the first seven years. Other than decarbonising the benefits of solar pumps, it is anticipated that the buy-back tariff incentivises the farmers to reduce the energy consumption for irrigation which eventually is a step for groundwater conservation and reduces government subsidy on electricity. However, the program is yet to be evaluated for its impact on energy usage and groundwater pumping. IWMI's SoLAR project is evaluating the impact of SKY using robust impact evaluation methods.

2.2.4 Surya Raitha Scheme 2019, Karnataka

Based on the state's renewable solar policy in 2014, the Government of Karnataka launched a program to promote grid-connected pumps in the state in 2019 (GOK, 2019)[8]. The program envisages achieving the solar energy targets as well as generating additional income for farmers. The programme targeted farmers who already have a connection (up to 10 HP pumps) to the agricultural feeder. The solar PV capacity installed is 1.5 times more than the energy required for the old pumps. Thus, farmers have an incentive to invest in solar pumps. It is estimated that one-third of the energy generated can be fed to the grid at a buy-back tariff of Rs. 9.56 units if farmers have not taken a loan and Rs 7.2 per unit if farmers have taken a loan. Since the investment is higher, the government provides a 90% subsidy on the capital cost, and only 10% needs to be paid by the farmers. Given that the panels are oversized, it is anticipated that farmers are earning a substantial income from this program. The program has not mentioned any target. However, an anecdotal source noted that around 310 solar pumps were installed under this scheme. However, farmers were hesitant to make a hefty investment, so the implementing agency facilitated a loan and part of the income earned by selling electricity went to a loan account. IWMI, in collaboration with Karnataka Evaluation Authority, have conducted an impact study of the Surya Raitha Scheme (Shirsath et al., 2020).

[8] https://kredlinfo.in/Scrollfiles/Surya%20raitha%20eng.pdf

2.2.5 Grid-connected BLDC Pumps, Andhra Pradesh

Given the agricultural energy subsidy rise, Andhra Pradesh piloted a grid-connected solar pump program in 2018. The program aims to reduce electricity subsidy, provide farmers with quality power supply, additional income, and increase the efficiency of pumps to reduce energy wastage and loss. The scheme offers a 100% grant for installing grid-connected solar pumps, but all the farmers who have a connection to the feeder must agree to get solarised and form a cooperative. The panel capacity installed is slightly higher than the current power rating of the pumps, the excess energy generated is fed to the grid at the rate of Rs. 1.5 per kWh. It is anticipated that the farmers can earn about Rs. 6000 per annum from the excess energy sold to DISCOMS. This scheme was implemented in the Vizianagaram district, and about 250 pump sets were installed, covering about 32 villages (Shirsath et al., 2020).

Table 3 presents all the grid-interacted solar pilots that have been tried out in the country. Overall, each state followed different grid integration designs, tariff and subsidy policies to foster the adoption of SIPs. However, the anecdotal report indicates that none of these models (except the feeder solarisation program by Maharasthra) are promoted for further upscaling by the state due to many reasons, viz., non-availability of funds, increase in transaction cost for the state, a longer time is taken up for farmers participation, and trust issues on the metering and billing. In 2019, a new solar irrigation scheme was launched by the Government of India. This is the KUSUM scheme that we discuss in the next section.

States	Model	Scheme name	Buy-back tariff (Rs. /kWh)	Design	Cooperatives	No. of farmers covered	Subsidy	Estimated income to farmers (Rs. /year)	Billing frequency	Evaluation done
Gujarat	Grid-connected	Dhundi pilot	7.13[#]	Unidirectional metering	Formed	8	~90%	~350000[@]	Bimonthly	YES
Gujarat	Grid-connected	Suryashakti Kisan Yojana (SKY)	3.5+3.5[*]	Bidirectional metering	No compulsion	~5500	30%	-NA-	Annual	NO
Karnataka	Grid-connected	Surya Raita	7.2	Unidirectional metering	Formed	310	90%	50000	Biannual	NO
Andhra Pradesh	Grid-connected	Grid-connected BLDC pumps	1.5	Replacing Solar DC pumps	Formed	250	100%	6000	-	NO

# Contracted from DISCOMC is Rs. 4.63/kWh, and IWMI offered 1.25/kWh * DISCOMS pay Rs.3.5/kWh, and Govt. offers evacuation subsidy of 3.4/kWh. @Actual earnings	

Table 3:Piloted Grid-Connected Solar Scheme in India

3. KUSUM – A new solar policy for agriculture

To mainstream effort towards achieving its NDC in the agricultural sector, MNRE launched the Pradhan Mantri Kisan Urja Suraksha evam Utthaan Mahabhiyaan program (KUSUM) in July 2019. KUSUM aims to add a solar capacity of 25,750 MW (25.75 GW) by 2022 with central government support of ₹344.22 billion (~US $4.99 billion). The program has been divided into three components:

- ***Component A:*** Setting up of 10 GW of decentralised ground-mounted grid-connected solar projects of individual project size of up to 2 MW
- ***Component B:*** Installation of 1.75 million stand-alone solar-powered agriculture pumps of individual capacity up to 7.5 HP
- ***Component C:*** Solarisation of 1 million grid-connected agriculture pumps of individual capacity up to 7.5 HP by 2022.

The program aims to provide clean energy access for irrigation, create an additional income source for farmers who sell electricity back to the grid and reduce costs for farmers relying on diesel pumps. It also aims to reduce the distress of farm communities due to the rationed and irregular power supply. According to the MNRE, components A and C of the program will initially be executed in a pilot mode for 1 GW of solar capacity, and 100,000 grid-connected agricultural pumps will be installed. After successfully implementing the pilot projects for components A and C, the Ministry will scale it up with necessary modifications based on the learnings from the pilot phase.[9] Component B will be implemented fully. The year-wise deployment of each component is presented in table 4. Overall, the central government will provide ₹190.365 billion (~US $2.76 billion) in support.

States	Component-A Capacity (MW)	Component-B (No.)	Component-C (No.)	
2019-20	0	150000	82000	0
2020-21	500	550000	118000	200000

[9] The pilot program will be supported by central government of ₹153.855 billion (~$2.23 billion)

2021-22	4500	600000	200000	250000
2022-23	5000	700000	350000	300000
Total	**10000**	**2000000**	**750000**	**750000**

Table 4:Year-wise targets under KUSUM

Source: MNRE

3.1 Component A

Under the first component, individual farmers, cooperatives, panchayats, farmer producer organisations (FPO) can install renewable power projects of 500 kW to 2 MW on their barren or cultivable lands. The DISCOMs will purchase the power generated from the renewable power projects at a feed-in tariff (FiT) rate determined by their respective state energy regulators.

These projects must be installed within a five-km radius of sub-stations to avoid high transmission costs and reduce transmission losses. DISCOMs will notify sub-station wise surplus capacity, which can then be fed to the grid. DISCOMs will then invite applications from interested beneficiaries for setting up renewable energy projects. In case the aggregate capacity offered by the applicants is more than the notified capacity for a particular sub-station, the DISCOMs will follow a bidding process to select power generators, and in such cases, the pre-fixed levelized tariff will be the ceiling tariff for bidding. If the generator cannot produce the minimum energy corresponding to the capacity utilisation factor (CUF) of 15% or as prescribed by DISCOMs, such a shortfall in the performance will be penalised. However, the penalty will not be levied if the shortfall is due to the non-availability of grid facilities for evacuation. In addition, DISCOMs will be provided performance-based incentives of ₹0.40 (~$0.0056)/kWh for five years by the MNRE.

3.2 Component B

This component focuses on individual farmers. The component supports installing stand-alone solar pumps of capacity up to 7.5 HP (horsepower) in the farmer's field. Solar PV capacity in kW equal to the pump capacity in HP has been allowed under the program. The government will provide central financial assistance (CFA) of 30% of the benchmark cost to help install these pumps. The state government will give financial support to the tune of 30%, and the farmer will provide the remaining 40%. Bank finance will be made available for 30% of the farmer's contribution so that the farmer initially pays only 10% of the cost. In states and union territories like Sikkim, Jammu & Kashmir, Himachal Pradesh, Uttarakhand, Lakshadweep, and Andaman and the Nicobar Islands, a CFA of 50% of the benchmark cost or the tender cost is planned to be provided to promote solar pumps in these regions. The state government will give a subsidy of 30%, and the farmer will provide the remaining 20%. Bank finance will also be made available for the farmer's contribution.

States submit their demand for solar pumps under this component, and the MNRE takes the final call to allocate solar pumps across states within a year after the approval by a screening committee.

The State-wise allocation of capacity under the different components of the KUSUM scheme is presented in Table 5. Maharashtra has been sanctioned the highest number of solar pumps among the states, followed by Madhya Pradesh, Rajasthan, and Chhattisgarh. Among the eastern Indian states, Odisha has taken the lead.

Tendering under this component is centralised through central public service units. The MNRE has specified that three bidders will be selected who match the lowest rates. The quantity awarded will be 50%, 30%, and 20% of the total tender amount allocated to the state in the ascending order of the rates quoted. The installed solar PV capacity can be optimally utilised by using a Universal Solar Pump Controller (USPC). Farmers can use solar PV power for other activities like operating chaff cutter, flour mill, cold storage, drier, battery charges as an additional source of income. An option would be given to the farmers to opt for USPC, which means the entire additional cost of USPC will be borne by the farmer. States can choose to bear this additional cost to facilitate the use of solar energy for other activities and increase farmers' income.

3.3 Component C

Under this component, MNRE plans to install grid-connected solar pumps. Individual farmers will get support to solarise pumps of a capacity of up to 7.5 HP. Solar PV capacity up to two times the pump capacity in kW has been allowed. Farmers can sell the excess available energy to DISCOM. The policy says that priority will be given to small and marginal farmers and farmers who use micro-irrigation for saving water. However, research shows that while micro-irrigation may improve crop per drop (or water productivity), it may not decrease total volumes of water extracted per se, as farmers often bring in new land under irrigation with so-called "saved" water (Van der Kooij et al. 2013). For states, the central government will provide a CFA of 30%. The state government will extend financial support to the tune of 30%, and the farmer will provide the remaining 40%. Bank finance will be made available for 30% of the farmer's contribution so that the farmer initially pays only 10% of the cost. For eastern states and union territories, a CFA of 50% of the benchmark cost or the tender cost, whichever is lower, will be provided.

The solar power fed into the grid and utilised by farmers will be accounted for the fulfilment of solar renewable purchase obligation (RPO) by DISCOM. MNRE has also granted 2% of the eligible CFA to be provided to the implementing agencies as service charges. DISCOMs will purchase excess power from the farmers at the respective State Electricity Regulatory Commissions (SERCs) rate. The feeders under which farmers were solarised must be kept on "ON" mode during sunshine hours so that electricity can be fed into these live feeders. In addition, it is mandatory to install a remote monitoring system to monitor the performance of the system post-installation.

The state of Tamil Nadu has been allocated the highest number of grid-connected solar pumps, followed by Madhya Pradesh, Rajasthan and Maharashtra. But it is not clear how many states have come forward under feeder solarisation and individual pump solarisation under this component C. In general, eastern states have not been allocated any capacity under component C, which might be due to the lack of segregated and dedicated agricultural feeders. A segregated feeder is a requirement for Component C.

Under components B and C of the KUSUM program, the MNRE has specified that successful bidders will provide maintenance services for five years through a formal contract after installing the pumps. The project completion timeline is 15 months from the MNRE approval for the north-eastern states and union territories, while the other states have a shorter time frame of 12 months.

Sl no	States	Component-A Capacity (MW)	Component-B (No.)	Component-C (No.)
1	Chhattisgarh	-	20000	-
2	Delhi	10	-	-
3	Haryana	25	15000	468
4	Himachal Pradesh	-	550	-
5	Jharkhand	10	10000	500
6	Gujarat	40	4000	-
7	Karnataka	50	6000	-
8	Kerala	10	-	5200
9	Madhya Pradesh	100	25000	15000
10	Maharashtra	300	30000	9000
11	Meghalaya	10	1700	60
12	Odisha	-	2500	-
13	Punjab	30	4500	3900
14	Himachal Pradesh	10	-	-
15	Rajasthan	325	25000	12500
16	Tamil Nadu	-	17500	20000
17	Tripura	5	1300	1300
18	Uttar Pradesh	75	8000	1000
	Total	1000	171050	68928

Table 5:State-wise Allocation of Solar Capacity under the KUSUM scheme

Source: MNRE (2019). '-' demand not received

3.4 Challenges in implementation of KUSUM

Many in the renewable political spectrum applauded an ambitious and exclusive initiative for the farm sector, and it gained positive attention across the globe. However, this ambitious target comes with numerous financial, institutional, and technical challenges, given the country's current renewable energy ecosystem. We enumerate some of the challenges below.

3.4.1 Feeder segregation

In 2015, the central government launched the US$ 12 billion Deen Dayal Upadhyaya Gram Jyoti Yojana (DDUGJY) scheme to support the states to separate agricultural feeders from non-agricultural feeders in the rural area.[10] Feeder separation is the state regulatory board's prime consideration for implementing the grid-connected KUSUM schemes in the states (components C and A). However, only nine Indian states have segregated electricity feeders. Out of the nine states with segregated agricultural power feeders, four — Andhra Pradesh, Gujarat, Punjab, and Madhya Pradesh — have achieved or are close to completing a 100 per cent segregation. Others, such as Maharashtra, Chhattisgarh, Karnataka, and Tripura, still have a significant proportion of feeders which are not segregated. Without feeder separation, many states could not place demand for solar pumps under component C and farmers in rural India could not benefit from component A.

3.4.2 Supply constraint of "made in India" solar cells

MNRE has been mandated to use indigenous solar cells and modules to manufacture solar panels in the KUSUM program. This means the vendor must declare the list of imported components used in the system, and this mandate might hinder the implementation of KUSUM in the short run. As per the recent MNRE data (MNRE, 2020), India's solar cell manufacturing capacity is about 3 GW (see table 6). The solar module manufacturing capacity in India is higher than the cell manufacturing capacity. If the usage of indigenous solar cells is made compulsory, the module manufacturers do not have the capacity to source cells of 10 GW target per year. These concerns have been raised by the Solar Energy Equipment Manufacturers Association of Telangana (SEEMAT) to MNRE. In response, MNRE brought a new initiative to subsidise the investment (20-25%) and reimburse the excise duty to set up a solar manufacturing unit. Yet, new production capacity in the domestic market is not developing rapidly as cell manufacturing is highly capital intensive, and most module manufactures are small and medium enterprises. It is recommended that if the government wants to achieve the targeted capacity in the KUSUM scheme, it should allow the import of solar cells until the domestic solar cell production capacity picks up pace.

[10] Feeder segregation allows independent control of power supply to farms and to non-farm users (households, hospitals, etc.). The segregation ensures that non-farm users are not affected by surges in agricultural demand and farmers get a reliable electric supply for specified time which allowing them to irrigate in a targeted area in a effective manner.

Solar PV Cells Capacity	3 GW/year
Solar PV Modules capacity	10 GW/year
Polysilicon/Wafer/Ingots	No manufacturing

Table 6:Present Installed Solar PV Manufacturing Capacities in India
Source: MNRE (2019) [11]

3.4.3 Cancellation and revisiting Power Purchase Agreements (PPAs)

The recent rapid price drop in panels has made solar PV technology more attractive for some DISCOMs. However, as a downside, it has also increased the appetite for states to renegotiate or cancel contracts for projects previously awarded at much higher prices. Although states have followed competitive bidding to hand over the power purchase agreements (PPAs), a few states are cancelling or revisiting their PPAs because of reduced solar panel prices. For example, in July 2019, the government of Andhra Pradesh decided to cancel the PPAs that were in the pipeline unilaterally due to DISCOM's dire financial condition. Finally, the MNRE stated that no contractual agreements could be revisited as this would disturb the national goal of renewables and impede the investors' confidence and trust. As the financial viability of the DISCOMs will be an essential factor in achieving the targeted number, adequate financial support to DISCOMs to meet its solar PPA commitment is crucial.

3.4.4 Appropriate incentives for investors and farmers

The primary reasons behind the low solar tariffs are growing demand, declining module prices, low interest rates, and aggressiveness to capture the market. As a result, India has hit tariffs below Rs 2.50 per kWh (in Gujarat, it reached Rs. 1.9 kWh), which is 20-30% lower than the cost of existing thermal power. In response, investors have reduced their return expectations from 14% to 12%. In addition, the Capacity Utilisation Factor (CUF) rates across different Indian states also have a significant impact on project returns. A declining CUF result in a subsequent fall in equity returns (which, should be noted, is different from project returns) is not economically viable and severely threatens the prevalence and role of solar irrigation systems in the renewable energy transition. It, therefore, becomes imperative for project developers to factor in the risks and accurately estimate the costs of every component.

For farmers to invest in solar pumps, setting an appropriate buy-back tariff is essential. They face an effective trade-off to conserve water by reducing energy use versus using more energy for additional crop production. Currently, KUSUM guidelines do not provide any estimated range for the buy-back tariff and have left it for the open solar market. Setting a correct buy-back tariff will be an issue,

[11] https://mnre.gov.in/solar/manufacturers-and-quality-control

particularly in the individual pump solarisation under component C. If the tariff is set low, farmers are better off pumping more water for self-consumption and selling to other farmers through informal water markets, rather than conserving water and energy to sell back to the grid. Lower tariff levels reduce the economic viability of the farmers' investment; thus, it will decrease the demand from them and the adoption of the solar pump. Anecdotal evidence from the field suggests that the state implementing agencies face difficulties convincing farmers to invest in solar irrigation when the buy-back tariff is low.[12]

3.4.5 Financial viability of DISCOMs

DISCOMs are the key players in India's power sector. Hence, they have an essential role in deploying solar irrigation as conceptualised under the KUSUM scheme. However, experts anticipate that, apart from the pandemic induced challenges, the financial health of the DISCOMS will continue to hinder solar deployment further. At least 40% of the capacity allocated to achieve the NDC targets is assigned to the states with DISCOMS below-average to deficient operational, financial performance (B-C grade) (Figure 4). The financial distress of DISCOMs might have an implication on achieving the targeted numbers, especially in components A and C.

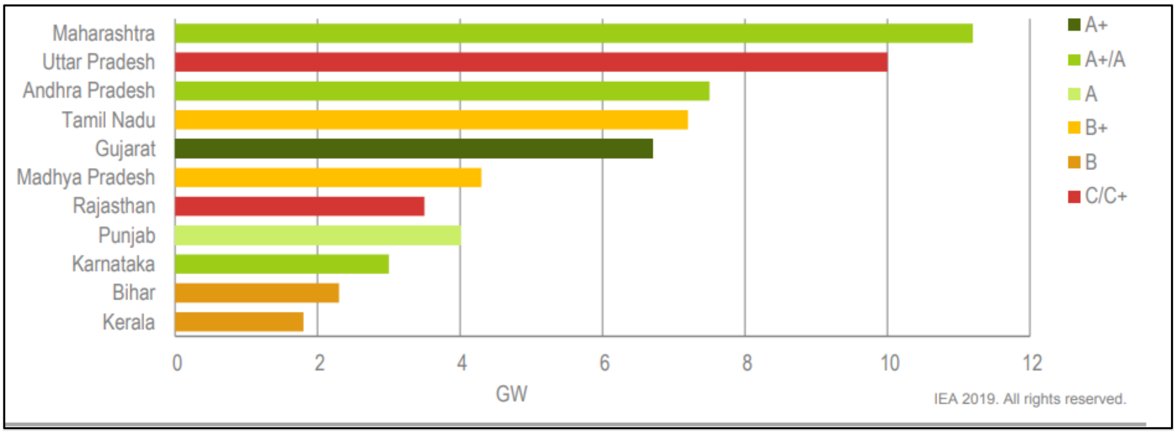

Figure 4: State-wise allocation of solar capacity under 2022 target and financial health of DISCOMS
Source IEA (2018), renewables 2018

Realising this bottleneck, in May 2020, the government announced a ₹900 billion (~US $12.03 billion) one-time stimulus package to be infused to pay the central public sector power generation companies, transmission companies, independent power producers and renewable energy generators. This measure aims to strengthen utilities and equip them with the financial resources to roll out and sustain solar irrigation schemes according to their targeted solar capacity.

[12] https://energy.economictimes.indiatimes.com/news/renewable/indias-current-solar-tariffs-30-per-cent-lower-than-existing-thermal-power-costs-study/75887881

3.4.6 Farmers limited financial capacity

Component A of KUSUM specifies that farmers, cooperatives or FPO's can invest in decentralised mini and micro solar plants and sell back the energy to the local feeders at the specified tariff set by state implementing agencies. The main problem faced by farmers under Component A is that they cannot fulfil the financial requirement to set up decentralised power plants. Banks are hesitant to issue loans by keeping agricultural land as collateral. This might hamper the progress of component A. Only the states of Punjab and Rajasthan have so far requested capacity allocation under this component. In other components, a 40% contribution by the farmer is thought to be too high unless the finances from other programs are converged to reduce upfront equity contribution by farmers. Experts' opinions reveal that solution could lie in collaboration between National Bank for Agricultural and Rural Development (NABARD) and commercial or rural banks. Such a partnership can allow for the creation of specific financial products for this purpose. [13]

3.4.7 Technical challenges

Technical challenges include the adequate in-house technical capacity to design the system and design a real-time remote monitoring system. As the number of feeders and farmers solarised increases, setting up a robust monitoring system will be necessary. Currently, KUSUM has not set up an adequate scope for R&D activities to overcome the challenges faced under the scheme, which need to be addressed.

4. Sustainable deployment of solar technology in agriculture

India's will and commitment to achieve solar energy is commendable. However, the mode in which solar pumps are deployed and planned to be deployed in the country is a cause of concern. We discuss those concerns here and a few possible solutions for the sustainable deployment of solar technology in agriculture.

4.1 Sustainable extraction of groundwater

Indian agriculture is overwhelmingly dependant on groundwater irrigation. However, the zero-marginal cost of pumping and high subsidies to promote solar pumps' adoption may lead to unsustainable groundwater extraction. For example, Gupta (2019) in Rajasthan found that off-grid solar pumps increase groundwater consumption by 16%–39% and cropping intensity by 2-10%. Another downside of deploying off-grid solar pumps is that it rules out indirect co-management of water and energy through electricity tariffs.

[13] https://energy.economictimes.indiatimes.com/news/renewable/budget-could-focus-on-concessional-loans-for-setting-up-power-plants-under-pm-kusum-amit-kumar-pwc-india/80446160

The Central Groundwater Board (CGWB) shows that in 2018, 17% of the assessment units in India were over-exploited (groundwater extraction exceeding the total annual groundwater recharge), and 5% and 14% of the units are critical and semi-critical zone (CGWB, 2018)[14]. A larger part of overexploitation zones belongs to Punjab, Rajasthan, Haryana, Gujarat, Tamil Nadu, Andhra Pradesh and Karnataka, where the farmers have nearly zero marginal cost for pumping groundwater (see figure 5). If we look into the number of solar pumps deployed in the country (Table 2), around 50% of the total deployed pumps are installed in these states, which have already over-exploited its groundwater resources.

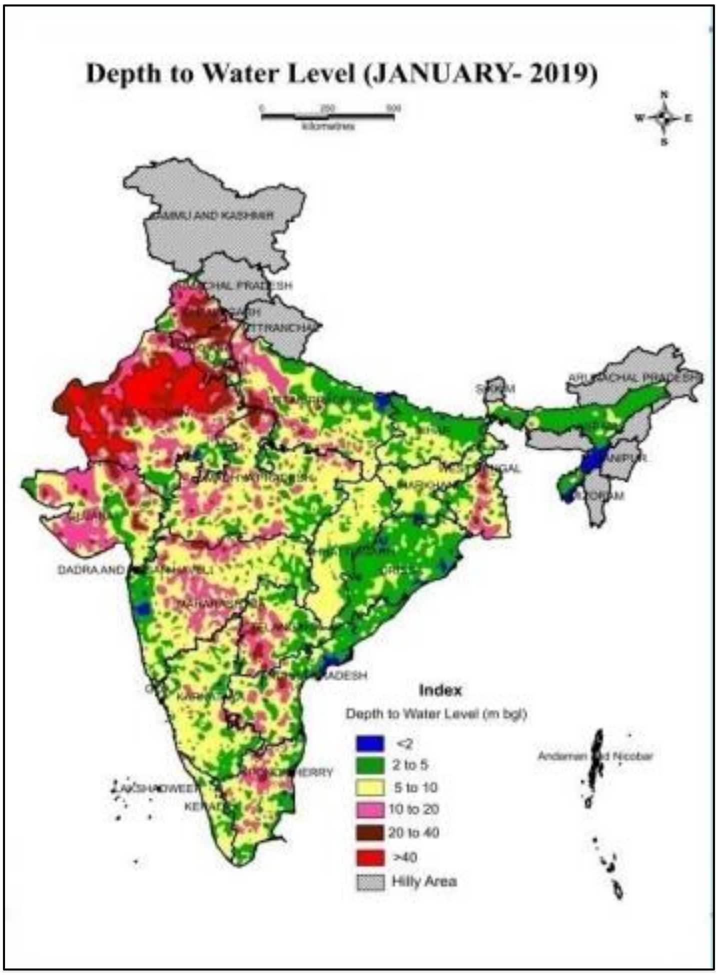

Figure 5:Depth of water level across India
Source: CGWB 2018-19

Currently, the deployment strategy for solar irrigation pumps is mainly designed by the energy department. This is because the main aim of deployment seems to be reducing the yearly electricity subsidy burden. However, since the solar pumps are interlinked with agriculture and groundwater, it is imperative to include the groundwater and agricultural department in planning and deployment

[14] http://cgwb.gov.in/Annual-Reports/ANNUAL%20REPORT%20CGWB%202018-19_final.pdf

strategy to account for food security and groundwater resource dimensions. This will require nexus thinking which is currently lacking.

Promoting grid-connected and buy-back tariffs for solar energy incentivises farmers to reduce the energy used to extract groundwater and sell excess power back to the grid. However, for it to work effectively, the tariff must be set optimally. Farmers must find it lucrative to sell electricity back to the grid compared to growing additional crops. Components A and C in the KUSUM are grid-connected schemes. However, in component A, farmers simply receive solar energy without installing panels on their fields. From the utility point of view, component A has lower transaction costs and feeder level losses than component C. However, component A does not have an inbuilt mechanism for groundwater conservation by farmers. Component C, which connects individual pumps to the grid, allows incentivisation in the form of FiT for changing farmers groundwater pumping behaviour. Component B (stand-alone off-grid pumps) also do not allow for incentivising farmers to reduce groundwater pumping. In the SDC-SoLAR project, we argue that groundwater conservation needs to be a central objective for India's solarisation of agricultural pumps. In that case, schemes that can incentivise farmers to do so (e.g., Component C of KUSUM) should be promoted over schemes that may be easier to execute (e.g., Components A and B of KUSUM).

4.2 Bundling solar pumps with water-saving technology

Deployment of solar pumps is bundled with water-saving technologies like micro-irrigation and intersecting groundwater recharge schemes in some states like Rajasthan. However, it is not clear if such a deployment strategy is effective or not. Further, the deployment design should be tailored to the bio-physical and socio-economic conditions of the location. For example, the guidelines for component B of the KUSUM scheme has mandated the adoption of micro-irrigation technologies in the field, even though micro-irrigation may not be appropriate for all crops and regions.

4.3 Capacity building and maintenance

Creating awareness of the current status of groundwater and imparting the necessary skills to solar irrigation farmers is vital for ensuring its judicious use. Capacity building of farmers in operation and maintenance of solar pumping systems and water management can help create awareness about maximising solar generation and their earnings (e.g., in Component C of KUSUM) and equip them with water conservation techniques. Furthermore, providing farmers with a thorough understanding of the financial design of the programme is essential to increase the level of trust and confidence among farmers. Farmers are generally reluctant to solarise pumps because they fear that metering will eventually lead to the removal of electricity subsidies.

4.4 Inclusive deployment of solar irrigation pumps

Solar pumps have little maintenance and variability cost but have a high upfront cost. The cost of solar pumps is 5-6 times higher than the diesel and electric pumps, which discourages small, marginal and women farmers to adopt solar pumps. Like any other policy, inclusiveness is vital in solar pump deployment as well. Solar irrigation policies need to be sensitive to include women and marginal farmers. A field study by Kishore et al. (2014) in Rajasthan urges that the eligibility criteria for availing of subsidised solar irrigation pumps must be defined to include small and marginal farmers. Given this, in components B and C of KUSUM, 7.5 hp has been kept as a cap to provide the subsidy under the scheme, which is enough to discourage the large farmers from participating. We do not yet have adequate empirical evidence to see who benefitted from these schemes.

Solar irrigation systems have emerged as an opportunity for women to increase their agricultural output collectively, ultimately resulting in their empowerment. Some good examples of the successful implementation of women-centric models have achieved self-sufficiency and strengthened the rural economy. One of these initiatives was introduced in Gujarat, which targeted women salt farmers. The installation of 200 solar-powered pumps replaced diesel pumps allowing for clean energy to be utilised in salt fields. The pilot's success resulted in scaling up and higher uptake to 15000 pumps and has boosted the livelihoods of thousands of households. The Natural Resources Defence Council (NRDC) and Gujarat-based Self-Employed Women's Association (SEWA) responsible for the project's implementation are going one step further to ensure that women actively expand the benefits of solar power beyond agriculture in cooking and lighting, thereby creating a sustainable lifestyle (NRDC,2018; Shirsath et al., 2020). Surprisingly, current guidelines of the KUSUM scheme have not included a gender angle, and this needs to be rectified.

5. Conclusion

Indian agriculture largely depends on diesel and coal-based sources of energy for irrigation. Therefore, food production in India is carbon intensive. Solar irrigation is a potential solution that must be widely explored to decarbonise India's irrigation. Leveraging the falling solar PV panels price, India has set out to invest in 100GW of solar energy by 2022 to achieve its targeted NDC. This yields a golden opportunity to increase investment in creative ways to deploy solar pumps across the country. The main impetus for India's solar policies has been to reduce its agricultural electricity subsidy burden and meet the country's Paris Agreement commitments. However, adequately designed solar irrigation policies can be also a strong incentive for groundwater conservation and achieve co-benefits beyond mitigation. Component C of KUSUM provided that FiT are appropriate, can meet the dual objectives of reducing emissions and creating co-benefits of groundwater conservation. The other two components (A and B) do not have inbuilt mechanisms for groundwater conservation but may still be linked with other appropriate schemes that incentivise farmers to conserve groundwater. In sum, the solar irrigation policies must also focus on co-benefits (including adaptation co-benefits), such as ensuring equitable access and promote sustainable use of groundwater while reducing carbon emissions and improving the financial viability of the DISCOMs. Policy reform needs evidence, and so far, empirical evidence on whether current solar irrigation policies have co-benefits is lacking.

The SoLAR project, led by IWMI and supported by the Swiss Agency for Development and Cooperation (SDC), attempts to fill this evidence gap by generating empirical evidence on the effectiveness of grid connection programs like the SKY scheme in influencing pumping behaviour and groundwater abstraction by farmers. Lessons from this will also be valid for other states as they implement component C of the KUSUM scheme shortly. Further, the SoLAR project also aims to build the capacity of farmers to handle the new technology for irrigation. Finally, the project aims to identify the bottlenecks of the SKY scheme, which hinders its anticipated benefits and provide evidence-based policy recommendations for the sustainable deployment of solar pumps in the country.

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Appendix

Region	DISCOM	Districts	Area Serviced (sq-km)	% of Total Area	SKY Installation Districts	Aquifer Type
Northern	Uttar Gujarat Vij Company Ltd (UGVCL)	Banaskatha, Patan, Mehsana, Sabarkantha, Gandhinagar, Ahemdabad, Aravalli	49,950	24.2%	Banaskatha, Patan, Mehsana, Sabarkantha, Ahemdabad, Aravalli	Alluvial
Central	Madhya Gujarat Vij Company Ltd (MGVCL)	Kheda, Anand, Mahisagar, Panch Mahal, Dahod, Vadodara, Chota Udaipur	23,854	11.5%	Kheda, Anand, Panch Mahal, Dahod, Vadodara	Alluvial
Western	Paschim Gujarat Vij Company Ltd (PGVCL)	Amreli, Bhavnagar, Bhuj, Jamnagar, Junagadh, Porbandar, Rajkot City, Rajkot Rural, Surendranagar, Botad, Morbi, Kutch, Dwarka	1,09,463	52.9 %	Amreli, Rajkot, Surendra nagar, Botad, Kutch, Junagadh, Bhavnagar, Morbi, Porbandar, Dwarka	Hardrock and Coastal
Southern	Gujarat Vij Company Ltd (UGVCL)	Narmada, Tapi, Valsad, Navsari, Bharuch, Dang, Surat	23,307	11.3%	Tapi, Valsad, Navsari, Bharuch, Surat	Hardrock, Coastal and Alluvial

Table 7:DISCOM and District Wise Installation of Grid-Connected Solar Pumps under SKY Scheme