



Mapping Policy for Solar Irrigation Across the Water– Energy–Food (WEF) Nexus in India

REPORT



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Table of Contents

1.0 Introduction	1
2.0 Scope and Approach	2
3.0 Key WEF Interlinkages for Off-Grid Solar Pumps	4
3.1 Global and Indian Context	4
3.1.1 Irrigation from Groundwater in India.....	5
3.2 WEF Interlinkages for Off-Grid Solar Pumps in India: Drivers and impacts.....	6
3.2.1 Drivers	7
3.2.2 Impacts.....	8
3.3 Visualizing WEF Interlinkages and Feedback Loops.....	11
4.0 Mapping Relevant Policies for Off-Grid Solar Pumps Across the WEF Nexus	14
4.1 Structure of Mapping.....	14
4.2 Results of Mapping.....	15
4.2.1 Solar Support Policies.....	16
4.2.2 Efficiency Policies.....	19
4.2.3 Water Resource Management	20
4.2.4 Production-Based Interventions to Increase Farmer Incomes	23
4.2.5 Price Interventions, Instruments in Food Markets and Others	26
4.3 Key Findings	28
5.0 Recommendations	30
References	32



Acronyms and Abbreviations

AgDSM	Agriculture Demand Side Management
BEE	Bureau of Energy Efficiency
CEA	Central Electricity Authority
DISCOM	distribution company
DoACFW	Department of Agriculture, Cooperation & Farmers' Welfare
eNAM	National Agriculture Market
FAO	Food and Agricultural Organization of the United Nations
FRP	Fair and Remunerative Price
FY	fiscal year
IRENA	International Renewable Energy Agency
JNNSM	Jawaharlal Nehru National Solar Mission
KUSUM	Kisan Urja Suraksha evam Utthaan Mahaabhiyan
MGNREGA	Mahatma Gandhi National Rural Employment Guarantee Act
MIF	Micro Irrigation Fund
MNRE	Ministry of New and Renewable Energy
MSP	minimum support price
PDS	Public Distribution System
PIB	Press Information Bureau
PMKSY	Pradhan Mantri Krishi Sinchayee Yojana
PV	photovoltaic
RKVY-RAFTAAR	Rashtriya Krishi Vikas Yojana—Remunerative Approaches for Agriculture and Allied Sector Rejuvenation
SASM	Scheme for Assistance to Sugar Mills
SDG	Sustainable Development Goal
UNICEF	United Nations Children's Fund
WEF	water–energy–food
WHO	World Health Organization



1.0 Introduction

This paper seeks to assist policy-makers and researchers in India who are working to promote the uptake of off-grid, solar-powered pumps for groundwater irrigation (“off-grid solar pumps”).

Implementing such policies can be challenging because of the complicated interconnections between water, energy and food—often referred to as the “water–energy–food nexus” or WEF nexus. This briefing sets out key WEF linkages of importance for off-grid solar pumps. It then establishes an approach for identifying policies across the WEF nexus that are key for off-grid solar pumps and maps these policies at the Central Government level and in two states: Bihar and Rajasthan. Based on these findings, the paper concludes with recommendations for policy-makers.



2.0 Scope and Approach

There are many ways that solar energy can power irrigation. According to the most recently published planning documents,¹ the Government of India’s upcoming Kisan Urja Suraksha evam Utthaan Mahaabhiyan (KUSUM) scheme will support the installation of: (i) stand-alone off-grid solar pumps to replace existing diesel pumps; (ii) decentralized ground or stilt-mounted, grid-connected solar power plants (~0.5–2.0 MW) by individual or group farmers, cooperatives or *panchayats* based on expressions of interest issued by distribution companies (DISCOMs) and available sub-station surplus capacity; and (iii) “solarizing” existing grid-connected pumps by outfitting them with solar panels, and allowing owners to sell excess electricity back to DISCOMs (Ministry of New and Renewable Energy [MNRE], n.d.). Pumps can also draw from different water sources: surface water or groundwater.

This brief is focused exclusively on off-grid solar pumps that draw from groundwater—for ease of expression, this is referred to throughout this paper as “off-grid solar pumps.” This is not intended to imply that off-grid solar pumps are the only approach to increasing access to affordable irrigation services. Rather, it is a scoping decision that was taken to limit the complexity of an initial foray in this issue area. The paper is not intended to quantify the costs and benefits of different forms of irrigation or to provide detailed guidance on the circumstances in which different forms of irrigation are best and worst suited.

The term “WEF nexus” is defined as the principle that “these sectors [are]... inextricably linked so that actions in one area commonly have impacts on others, as well as on ecosystems” (United Nations Economic Commission for Europe, n.d.). As an “approach,” it means holistically considering all three areas, regardless of an intervention’s original entry point. “Food” is used as a proxy term that encompasses all issues linked to agriculture, including both food-producing and non-food-producing activities. While all three sectors are interlinked, they are not considered to have equal weight: a person can survive a lifetime without energy, days to weeks with no food but only a few days without water. This should be taken into account when prioritizing between different WEF challenges and impacts. A WEF approach can help address policy incoherence, gaps in knowledge, technology lock-ins, equity and access to resources for vulnerable populations (de Amorim et al., 2018; International Centre for Integrated Mountain Development, 2012; Organisation for Economic Co-operation and Development, 2014; Reinhard, Verhagen, Walters, & Ruben, 2017; World Economic Forum, 2011; World Energy Council, 2016).

In the context of off-grid solar pumps, this paper distinguishes between two contexts where policy-makers and researchers may be concerned about interconnections:

- **Drivers:** People seeking to promote the deployment of solar pumps may be interested in existing water, energy and food policies that affect technology adoption, such as energy subsidies or income transfers for farmers.
- **Impacts:** People monitoring the effects of large-scale deployment of off-grid solar pumps may be tracking the positive and negative impacts of increased deployment, particularly on groundwater resources.

In practice, many impacts of off-grid solar pumps may also be “drivers” that influence deployment: for example, water scarcity may increase demand for irrigation services, but unsustainable irrigation practices may have

¹ As of the time of writing, the exact status of the government’s KUSUM scheme is not fully clear. Launch of the scheme was approved by Cabinet before the 2019 election, at which time a budget allocation of INR 34,422 crore over three years was announced (Press Information Bureau [PIB], 2019a). There is no explicit line allocation for KUSUM in the expenditure report for the budget for FY 2019/20, but press reports in late 2018 suggested that it might be funded through borrowing by the Indian Renewable Energy Development Agency (IREDA), following challenges with securing funding (Ministry of Finance, 2019c; Mishra, 2018). It is not clear when the program will formally launch, and it remains feasible that there could be delays or changes in its design.



impacts on scarcity. While acknowledging this tension, the paper maintains these categories to reflect the different entry points that policy-makers and researchers may have with this issue area.

The paper begins with a targeted review of literature to identify the key WEF interconnections of importance for off-grid solar pumps. This is then used to develop a causal loop diagram—a visual illustration of causes and effects across all three sectors. Subsequently, the causal loop diagram is used to develop a simple analytical framework that can be used to identify and map the most important policies for practitioners who are working on drivers and impacts. This mapping focuses on policies of the Central Government and two states, Bihar and Rajasthan, to illustrate how different issue areas are addressed at different levels of government. These states were chosen based on an assessment of multiple criteria, including the need to include one water-abundant and one water-scarce state, as well as net sown area, net area under irrigation from tube wells, food and power subsidy expenditure, and the number of diesel and electric pumps deployed. The results of the policy mapping are summarized in this paper and can be found in full detail online at the following link:

<https://www.iisd.org/sites/default/files/uploads/india-wef-mapping-2019.xlsx>



3.0 Key WEF Interlinkages for Off-Grid Solar Pumps

3.1 Global and Indian Context

Globally, many people do not have adequate access to water, energy and food: 2.1 billion people lack access to safely managed drinking water (World Health Organization & United Nations Children’s Fund [UNICEF], 2017); almost 1 billion lack access to electricity and 2.7 billion lack access to clean cooking (International Energy Agency, 2017); and 821 million face chronic food deprivation (Food and Agricultural Organization of the United Nations [FAO] et al., 2018). Yet water, energy and food systems are all under increasing pressure from rapid growth in economies, consumption patterns and population. By 2050, it is estimated that the demand for energy will nearly double globally, with water and food demand estimated to increase by over 50 per cent (FAO, 2011a; International Renewable Energy Agency [IRENA], 2015). Growing scarcity can worsen access to basic needs and the integrity of ecosystems, as well as fuel conflicts (FAO, 2014).

The Sustainable Development Goals (SDGs) recognize the need to deliver access sustainably through dedicated goals on each theme: SDG 2 (zero hunger), SDG 6 (clean water and sanitation) and SDG 7 (affordable and clean energy) (United Nations Development Programme, 2015). As targets, the SDGs cannot themselves recognize or address linkages, but if all three targets are to be met by 2030, then it is important to weigh up potential trade-offs when implementing policies in one area that have impacts on another (Fade, Cranmer, Lawford, & Engel-Cox, 2018; Pahl-Wostl, 2019). The interconnections between water, energy and food are striking: agriculture accounts for around 70 per cent of fresh water withdrawn globally (AQUASTAT, 2016; FAO, 2011b). The energy sector (primary energy production and electricity generation) accounts for 10 per cent of water withdrawals and 3 per cent of total global water consumption (International Energy Agency, 2016). Food production and supply is estimated to contribute to 30 per cent of the world’s energy consumption (FAO, 2011a).

In India, pressure on water, energy and food systems is anticipated to be more intense than the global average, despite great improvements in the last decade. It is estimated that 600 million people in India face high to extreme water stress and 7 per cent of India’s population did not have access to at least basic drinking water services in 2017 (NITI Aayog, 2018; UNICEF & World Health Organization [WHO], 2019). While India has achieved almost universal connections to electricity, there are still challenges with service reliability, and many households continue to rely on biomass for cooking (Jain et al., 2018). Adequate access to food remains a challenge, with 14.8 per cent of the population estimated to be undernourished and stunting estimated to be prevalent among 38.4 per cent of children under five years of age in the period 2015–17 (FAO et al., 2018). Agriculture is a key sector, having contributed 14.9 per cent of India’s gross value added in fiscal year (FY) 2017/18, and crops alone contributing 8.7 per cent of gross value added in the same year (Ministry of Finance, 2019a). It is estimated that jobs in the sector made up 43 per cent of total employment in 2018 (World Bank, n.d.a).

As an emerging economy with a rising population, India’s high growth in incomes and consumption will also create added pressure on water, energy and food systems. The latest economic survey estimates that India’s per capita energy consumption needs to increase by 250 per cent to reach a middle-income level and 400 per cent to reach very high human development level (Ministry of Finance, 2019a). By 2050, it is estimated that water requirements may be as high as 1,180 billion m³ in comparison to present-day availability of 695 billion m³ and a total availability of 1,137 billion m³ (NITI Aayog, 2018). The importance of agriculture to meeting basic needs and the economy also makes India particularly vulnerable to rising average temperatures and changing rainfall patterns (Rathore, Das, & Chauhan, 2018).



3.1.1 Irrigation from Groundwater in India

The FY 2018/19 economic survey reports that almost 89 per cent of the groundwater extracted in India is for irrigation (Ministry of Finance, 2019a). The *Statistical Year Book India 2018* provides a breakdown of irrigation by state and by type of irrigation (Ministry of Statistics and Programme Implementation, 2018). In FY 2014/15, out of a total net area sown of 140 million hectares, around 49 per cent was irrigated in some way. Of this, approximately 46 per cent was drawn from groundwater by tube wells and a further 17 per cent by other types of wells.

It is hard to identify good data on the number of pumps powered by different energy sources. Data on agricultural pumps have not yet been made available from the latest agricultural census (2015/16). According to the previous census in 2010/11, there were around 14.3 million pumps powered by grid electricity and 6.3 million powered by diesel (Ministry of Agriculture and Farmers' Welfare, 2015). According to the *Fifth Census of Minor Irrigation Schemes Report* (Government of India, 2017), which covers irrigation schemes with a culturable command area up to 2,000 hectares, there were 21.7 million irrigation schemes in 2014/15, of which the large majority (94.5 per cent) drew on groundwater. Of the 20.2 million schemes with a water lifting device, around 72 per cent were fully or partially powered by grid electricity and 23.7 per cent were fully or partially powered by diesel. The census identified only 2,874 pumps (0.01 per cent) fully powered by solar energy. A further 10,112 (0.05 per cent) were powered by a mix of solar and grid electricity and 2,270 (0.01 per cent) by a mix of solar and diesel. It is likely that deployment of solar pumps has increased considerably in recent years, driven by government programs, high diesel prices and declining groundwater. According to the Ministry for New and Renewable Energy, close to 150,000 solar pumps had been installed as of end-December 2017 and 196,000 by end-October 2018 (MNRE, 2018; PIB, 2018a).

Energy consumption linked to conventional irrigation pumps is significant. The Central Electricity Authority (CEA, 2018a) reports that agriculture accounted for 18.1 per cent of total electricity consumption in India in FY 2017/18. According to the last review of national petroleum product demand in 2013, agricultural pumpsets accounted for 3.3 per cent of all end-use diesel consumption, with the highest usage in north and east India (Nielsen, 2013). This does not include the large volume of subsidized kerosene that is diverted for use in diesel pumps. The potential for off-grid solar pumps depends on many factors, but if the technology continues to improve in its cost-effectiveness then it is feasible to assume it could be as large as the existing stock of grid-connected electric and diesel pumps. When its launch was approved by Cabinet, it was announced that the KUSUM scheme would aim to deploy 1.75 million solar pumps by 2022. The Institute for Energy Economics and Financial Analysis estimated that replacing 21 million on-grid electric pumps and 8.8 million diesel pumps with solar alternatives would alone achieve 38 per cent of India's target for renewable energy capacity (Garg, 2019).

Much irrigation today is highly inefficient. Among minor irrigation schemes surveyed in FY 2014/15, the majority (63 per cent) used open water channels that are subject to evaporation and more likely to have issues with leakage (Government of India, 2017). Surface pipes and underground pipes were used by 25.8 per cent and 15 per cent of schemes, respectively, while only 3.3 per cent used sprinkler systems and 1.9 per cent drip irrigation (Government of India, 2017). Cropping patterns have also created more reliance on irrigation: water-intensive crops are grown in water-scarce areas, and large-scale hybrid crops, introduced as part of the green revolution, are more water intensive than indigenous species (Flachs, 2016).

India has seen a steady decline in renewable internal freshwater resources per capita over the last decades, from 3,082 m³ in 1962 to 1,444 m³ in 1997 and 1,155 m³ in 2014 (World Bank, n.d.b). As of the last groundwater assessment in 2013, India's total groundwater availability was 411 billion m³ and the annual withdrawal rate was 253 billion m³ (Central Ground Water Board, 2017). An assessment of 1,034 sites found that around 10 per cent were in a semi-critical state (consumption above 70 per cent of availability), 4 per cent in a critical state

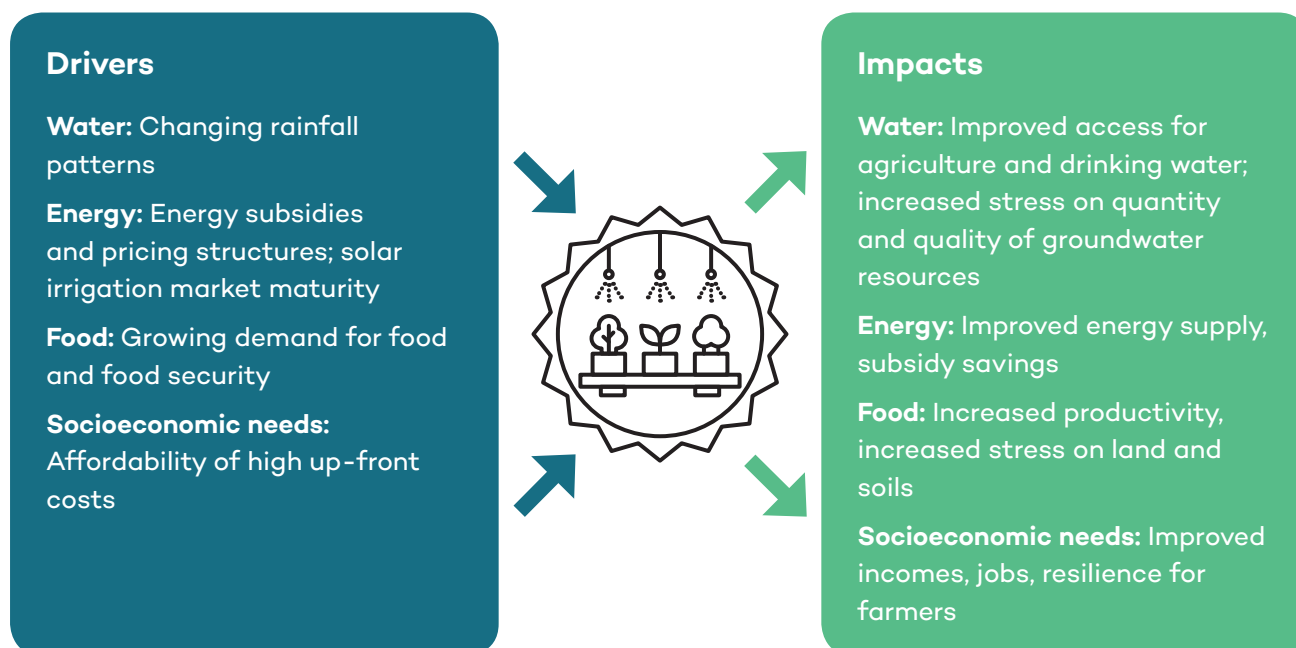


(consumption above 90 per cent of availability) and 15 per cent were overexploited (consumption above 100 per cent of availability) (Central Ground Water Board, 2017). Overexploitation was clustered in the northwest, including Punjab, Haryana, Delhi and Western Uttar Pradesh; in the west, particularly parts of Rajasthan and Gujarat; and in the south, including parts of Karnataka, Andhra Pradesh, Telangana and Tamil Nadu (Central Ground Water Board, 2017). Analysis of more recent Central Ground Water Board data on well depth by the Vasudha Foundation shows that, in the pre-monsoon period, groundwater levels are close to drought-like conditions in many regions and that most regions are likely to be included in the “water-stressed” category by 2040 (Krishnaswamy & Singh, 2018).

3.2 WEF Interlinkages for Off-Grid Solar Pumps in India: Drivers and impacts

Some policy-makers and researchers in India are principally concerned with driving the deployment of solar pumps, while others are focused more on the potential impacts of increased deployment. In both areas, there are key WEF interlinkages that influence outcomes. Figure 1 summarizes this at a high level.

Figure 1. Summary of main drivers and impacts





3.2.1 Drivers

Key drivers that help or hinder efforts to increase deployment of off-grid solar pumps are summarized below, with illustrative arguments and estimates from a range of literature.

1. Affordability of high up-front costs

The high up-front cost of off-grid solar pumps is a primary barrier to technology deployment: the average up-front cost of solar pumps is estimated at 5–15 times their diesel equivalents (Lazard, 2014, in Closas & Rap, 2017; Pullenkav, 2017; Shah, 2018). Over the long term, solar pumps are cheaper than diesel pumps because they do not have any significant recurring costs. Pullenkav (2017) estimates that over 10 years, the net cost of a solar photovoltaic (PV) pump is 64.2 per cent the net cost of a diesel pump. Agrawal and Jain (2016) estimate that solar pumps remain more costly than grid-connected electric pumps but note that they may still be preferred due to ongoing challenges with the unreliability of electricity supply in some parts of the country.

Many policy interventions are focused on this driver, with the earlier National Solar Mission and now the KUSUM scheme offering capital subsidies to farmers for solar pumps (MNRE, n.d.; Pullenkav, 2017; Shah, 2018). In the past, MNRE has also provided soft loans and accelerated depreciation to support solar PV pump investments (Pullenkav, 2017). In some cases, such subsidies can also create barriers or distributional inefficiencies if policies fail to operate as intended (Closas & Rap, 2017; Pullenkav, 2017). As subsidy transfers are reliant on policy consistency, they may also constitute an unreliable revenue stream, such as in Morocco where targeted subsidies for solar pumps were put on hold over concerns about the depletion of groundwater (Closas & Rap, 2017).

The relative affordability of high up-front costs is also indirectly affected by average farmer incomes. This may be affected by numerous initiatives, such as allowing farmers to sell excess electricity back to the grid or more general agricultural sector policies such as price floors for certain crops or fertilizer subsidies. The impacts of such policies also have complex WEF interlinkages.

2. Energy subsidies for conventional pumps

Subsidies for conventional energy lower the prices paid by farmers for grid-based and diesel pumping, decreasing running costs and making it harder for solar pumps to compete. Most states in India provide some degree of electricity subsidy for agricultural consumers, and in many cases they are substantial. Blanket Central Government subsidies for diesel were removed in 2014, but some state governments, challenged by drought, have continued to provide diesel subsidies to farmers (Jayan & Mishra, 2019). Electricity subsidies for farmers are estimated to be around INR 300 billion (USD 6.9 billion) per year (Garg, 2019). Reforming subsidies is complex: in Punjab, for example, research has shown that popular pressure and lobbies have ensured free or highly subsidized power to farmers (Prajapati, 2018).

Pricing structures also affect usage. In some states, such as Gujarat, electricity tariffs are flat, thus making the marginal cost of electricity for tube well owners zero. Subsidies also mask the true cost of irrigation, reducing incentives for efficient water use and contributing to the overdrawing of groundwater and depletion of aquifers.



3. Solar irrigation market maturity

The state of markets for solar irrigation (supply, sales expertise, service delivery, maintenance and repairs) has had a significant impact on the viability of solar irrigation (Closas & Rap, 2017). The sustainability of the market can be supported or undermined depending on the effectiveness of the policy tools and frameworks used to promote a new technology. India's experiences with solar PV for lighting would also suggest that an insufficiently mature market can also create problems post-deployment, particularly when after-sales services such as maintenance and repair have not been accounted for in costs and are in low supply (Gill, Shardul, Sharma, & Bridle, 2018). IRENA (2016) argues that four “building blocks” are required to support solar irrigation: distribution channels; delivery model and access to financing; awareness raising and capacity building; and policy and regulatory environments.

4. Changing rainfall patterns and water availability

Irrigation can play a critical role to help farmers adapt to changing rainfall patterns and water availability driven by climate change (Pullenkav, 2017; Shah, 2009). Shah (2009) highlights some of the potential impacts of climate change on surface and groundwater in India. While the change in overall water availability is unknown, the increase in variability is certain, promising more intense and larger rainfall events followed by longer dry spells. In turn, this means heightened risks of floods and droughts for kharif crops and more evapotranspiration for rabi crops, leading to more water storage and irrigation needs across the year. Groundwater sources—if they are used sustainably—provide a more resilient, long-term water supply, as they respond more slowly to drought and evapotranspiration.

5. Demand for food and food security

India's growing population and incomes will drive significant growth in food consumption in the coming decades. Increasing demand can be anticipated to drive higher food prices, which in turn ought to influence the profitability of investments in the most cost-effective means of irrigation. While food prices are fixed for a large share of the population through Public Distribution System (PDS) prices, it is assumed that this dampening of price signals will not fully counteract this feedback mechanism.

3.2.2 Impacts

Key “impacts” that might derive from increased deployment of off-grid solar pumps are summarized below. Many of these are positive: solar irrigation is being promoted in India because of its potential to address challenges in a range of areas, including agricultural productivity, greenhouse gas emissions, energy system demand and drinking water supplies. In other areas, particularly water, solar irrigation could add new pressures on the WEF system, depending on how and where it is implemented.



1. Agricultural productivity, farmer incomes and employment

For farmers who do not already use some form of irrigation, the deployment of solar pumps will improve agricultural productivity and thereby incomes. This can be done by improving yields on existing cropped lands, allowing for the expansion of the total cropped area, allowing the growth of more diverse higher-value crops and, in some cases, increasing the possibility of growing two or three crops in a year (multiple cropping). In Bihar, for example, irrigation allows for a third crop—consisting of paddy, maize or vegetables—that can be grown in the summer season (Pullenkav, 2017). A World Bank (2018) project in West Bengal estimates that micro-irrigation projects have been able to more than double farmers' income.

For farmers who already use some form of conventional pump, there will still be an effective increase in income because of the extremely low recurring costs of solar pumps. For the same reason, they may be able to run pumps for longer than before, with benefits for productivity and incomes. In Rajasthan, for example, Gupta (2019) found that solar pumps resulted in higher profits from increased gross cropped area and the cultivation of fruit and vegetables, as well as lower electricity consumption by those farmers who are using electric or diesel pumps in addition to solar pumps. Kishore, Shah and Tewari (2014) also found that there were time savings from labour associated with the operation of diesel pumps. These benefits for farmers also create indirect benefits for the local rural community (IRENA, 2015).

Solar pumps can also generate income if policy frameworks allow farmers to sell excess electricity back to the grid (Closas & Rap, 2017). Electricity sell-back schemes could be particularly well-suited for water-stressed areas, because they create a financial value for excess energy and therefore reduce incentives for overexploitation of water resources (Shah & Kishore, 2012). The distributional impacts of these policies will depend on whether policy benefits are provided to all farmers or targeted specifically at small landholders. In a survey of three districts in Rajasthan, the majority of beneficiaries of a 2011 solar pumps scheme had larger-than-average landholdings and none was a small-scale or marginal farmer (Kishore et al., 2014).

2. Financial savings and carbon savings associated with conventional energy

To the extent that solar pumps can replace existing conventional pumps, they can reduce the need for government subsidy expenditure on electricity and diesel. Electricity subsidies for farmers are estimated at over INR 500 billion (USD 7.3 billion) per year, including state transfers and cross-subsidies (Garg, 2019). Solar pumps can also reduce the significant import bill associated with these fuels, improving the current account deficit (Shim, 2017). The replacement of conventional pumps will similarly reduce greenhouse gas emissions associated with grid- and diesel-based pumpsets. Shah (2009) estimates that conventional groundwater pumping was responsible for 16 million–25 million tonnes of carbon emissions, equal to around 4–6 per cent of India's total carbon emissions. Agrawal and Jain (2016) estimate that replacing 10 million diesel pumps could reduce emissions by 26 million tonnes annually, equal to 1.2 per cent of total carbon dioxide emissions in 2010.



3. Impacts on energy and drinking water services

By replacing existing grid-connected pumps with solar pumps, demand on electricity DISCOMs will fall, reducing grid failures and voltage fluctuations. In some cases, farmers have even used capacitors to convert two-phase power to three-phase power, in turn affecting household supply (Reinhard et al., 2017).

Where it is possible for farmers to sell excess electricity back to the grid or water to local markets, this service also has a value beyond its immediate impact on farmer incomes. The sale of electricity back to the grid can further relieve pressure on DISCOMs, also contributing to improved power supply. Improved availability of fresh water for drinking can help rural households meet their basic needs, which in some cases is currently dependent on unreliable grid electricity (Chandel, Naik, & Chandel, 2015). Both the National Solar Mission and KUSUM schemes recognize the contribution that solar energy can make to pumps for drinking water.

4. Increased stress on water resources due to low-cost energy and higher productivity

The extremely low recurring costs of solar pumps mean that there is no economic incentive to use groundwater conservatively because there is no financial cost associated with either energy or water when irrigating. If this allows farmers to grow more crops per season or in an additional season, it will increase their total water withdrawals. This can aggravate the stress on existing water resources.

A review of international experience found that this risk is generally inadequately evaluated by feasibility studies (Closas & Rap, 2017). In practice, the extent to which solar pumps increase water stress is dependent on many factors. In India, risk varies significantly between regions that are relatively groundwater-abundant, such as northern and eastern India, and regions where groundwater stress is already severe, such as western and southern India (Pullenkav, 2017; Shah & Kishore, 2012). It will also vary by the way that states' cropping patterns create different demand for water at different times of year: for example, in Bihar, Uttar Pradesh and Madhya Pradesh, wheat irrigation in the winter season (rabi); in West Bengal, summer paddy irrigation (zaid); and in Punjab and Haryana, during monsoon season (kharif) (Shah & Kishore, 2012). In the medium term, it is anticipated that solar pumps could drive an emphasis on crops during the winter and summer seasons, including pre-summer boro rice (Shah & Kishore, 2012). Water stress can also vary significantly within a state. Another factor is time: data on present-day water stress may fail to account for anticipated future trends. Projections have estimated that most regions in India are likely to be in the “water-stressed” category by 2040 (Krishnaswamy & Singh, 2018).

Policy frameworks can potentially also influence the likelihood of water stress. As noted above, allowing farmers to sell back excess solar energy to the grid helps to create financial value for energy that incentivizes farmers to minimize unnecessary pumping (Shah & Kishore, 2012). Similarly, eligibility restrictions on assistance schemes can be used to help promote more efficient irrigation practices. In Rajasthan, the Solar PV Pumping Programme of 2011 required farmers to have a drip irrigation system (Kishore et al., 2014). Agarwal and Jain (2018) note the relationship between the capacity of promoted pumps and their ability to draw water. Other policies that generally promote efficient water usage in agriculture could



also help complement impacts of lower recurrent irrigation costs, such as the use of water meters and monitoring (Closas & Rap, 2017, citing IRENA, 2016). Policies can also inhibit economic feedback mechanisms that would naturally influence farmer cropping choices. For example, minimum support prices for agricultural producers will prevent price signals from affecting an oversupply of goods.

Increased stress on groundwater has significant negative feedback loops with many of the desired impacts from solar irrigation: reducing yields, incomes, jobs, resilience and stocks of fresh water for drinking and energy production. Shim (2017) argues that many such impacts have already taken place in some parts of India following the provision of subsidies for grid-based and diesel irrigation pumpsets.

5. Declining water quality from groundwater overuse

Groundwater overuse can result in a decline in water quality (Greene et al., 2016; Krishnan, Patel, Raychoudhury, & Purohit, 2009; Shankar et al., 2011). Greene et al. (2016) highlight irrigation-associated salinity as salinity caused by the accumulation of salts in the root zone of aquifers due to over-extraction and inadequate drainage. A study involving 593 districts in India found that 203 districts have high fluoride content, 206 have high iron content, 137 have high salinity, 109 have high nitrate content and 35 have high arsenic content (Department of Drinking Water Supply, 2006). To the extent that increased cropping is associated with higher rates of fertilizer use, this may also have impacts on water quality. According to a review of the impacts of nitrogen-rich fertilizer in India, a number of states, including Haryana, Punjab and Western Uttar Pradesh, have nitrate limits that exceed the levels set by the WHO. A review for the Lok Sabha noted that this risk is highest in areas with light textured soils and can be mitigated by restricting fertilizer use and promoting more sustainable cropping patterns (Standing Committee on Agriculture, 2016). Policy frameworks can influence the extent to which farmers use fertilizer. The Central Government's Aadhaar-enabled Fertilizer Distribution System (AeFDS) provides substantial subsidies for fertilizer use but also aims to limit the quantity of subsidized fertilizer according to the size of a farmer's land holding (Babu, 2016).

3.3 Visualizing WEF Interlinkages and Feedback Loops

One of the main challenges for policy-making on off-grid solar pumps is that water–energy–food drivers and impacts are all interlinked. For example, lowering the up-front capital cost of agricultural pumps may increase productivity and farmer incomes, but if they contribute to high levels of groundwater stress, then over the medium term they may end up reducing productivity and incomes. This, in turn, may affect the affordability of irrigation.

Figure 2 summarizes the various drivers and impacts identified in the literature review by visualizing an interconnected system of feedback loops. Parts of the system that share direct relationships with one another are connected by arrows, and the nature of the relationship is indicated by a plus (+) or a minus (-) sign. With a positive relationship, an increase in the first variable will result in an increase in the second variable. With a negative relationship, the second variable will decrease. Symbols also identify some of the major “reinforcing loops” (where changes drive one another to larger and larger impacts) and “balancing loops” (where system



constraints naturally check reinforcing loops). The main loops are food prices—where higher supply can reduce prices and stimulate further demand for more supply—and water stress—where the finite availability of water acts as a balancing force on food demand. The places that are significantly influenced by government policy are highlighted in green.

The causal loop diagram attempts to present the complexity of WEF interrelationships without becoming overly detailed in complex subsystems. There are necessary limits to its complexity: for example, it does not attempt to illustrate non-linear relationships, and it does not attempt to estimate the relative magnitude of positive and negative relationships.

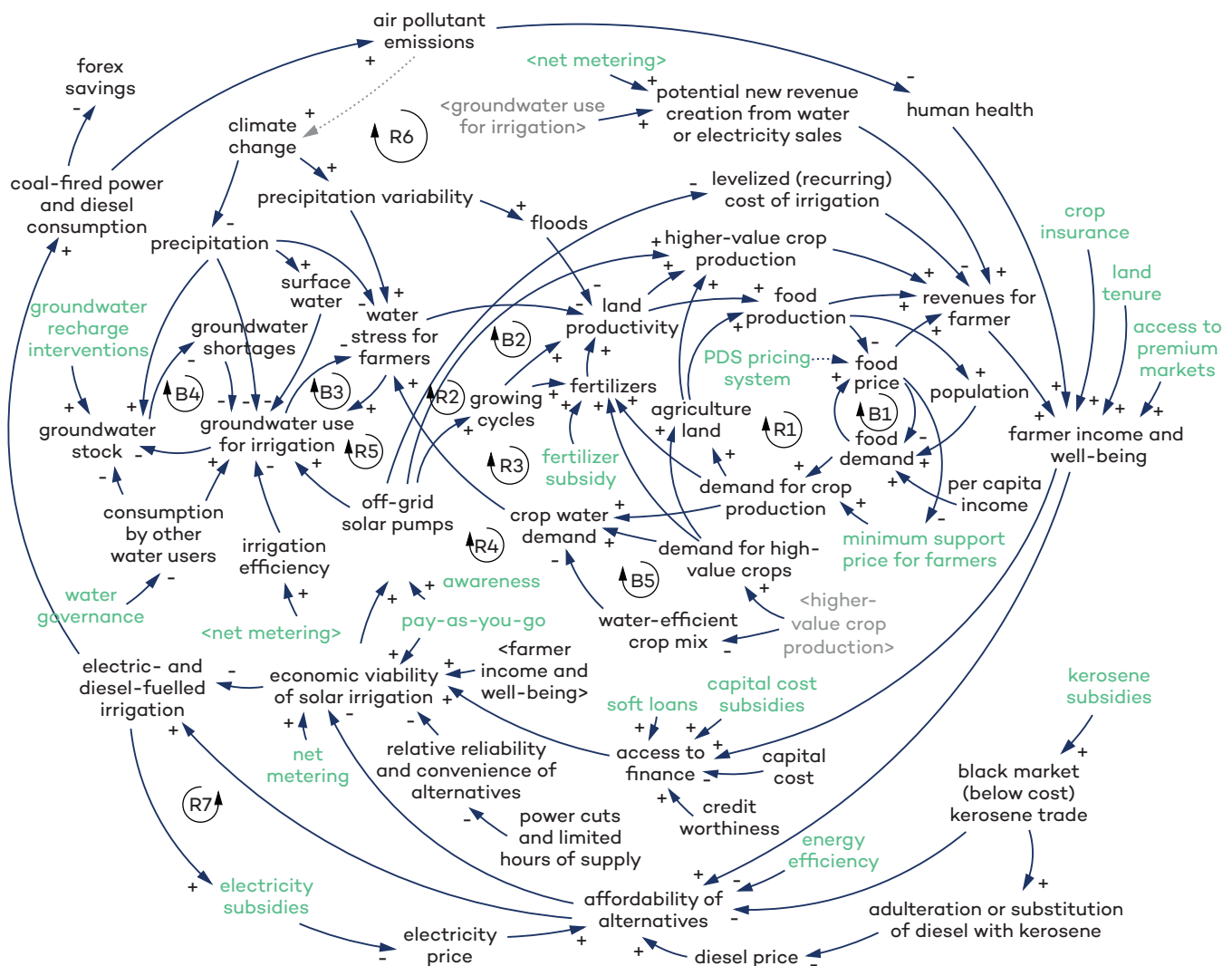


Figure 2. WEF interlinkages of off-grid solar pumps: Drivers and impacts

Notes: Green text denotes key areas where policy interacts with the other variables. “R” denotes a reinforcing loop. “B” denotes a balancing loop.

In the agricultural subsection of the figure, the main reinforcing loop (R1) is the link between food demand and food production: higher demand stimulates higher production and higher food availability enables ongoing population growth, which in turn stimulates food demand. The main balancing loop (B1) in this cycle is the link between food prices and food demand. Higher food demand will typically drive higher food prices, which will in turn reduce demand. The key policy levers interacting with this system are within food markets, where the PDS reduces the consumer price for critical products for consumers and the minimum support price scheme guarantees farmers can sell strategically relevant crops at a minimum price.



The main linkage with water systems is food production: everything else being equal, higher food production is associated with higher water demand and relatively higher water stress for farmers. This forms a second main balancing loop (B2), where water stress can have a negative impact on food production, as long as no new water resources are exploited. This water stress is in turn alleviated through another balancing loop (B3), where farmers increase their use of groundwater for irrigation purposes. Surface water and groundwater are finite resources, so if water extraction for irrigation and non-agricultural uses increases beyond the recharge rate of rivers and groundwater reservoirs, depletion takes place, and a final balancing loop is triggered (B4) when a groundwater shortage takes place. This final balancing loop is a key part of the system dynamic: as groundwater stock depletes, there is no immediate feedback mechanism encouraging users to reduce their withdrawals. It is only at the point that a shortage occurs that a balancing factor kicks in, with knock-on effects across the rest of the system.

When off-grid solar pumps are introduced, this increases farmers' access to water for irrigation, leading to higher land productivity and food production, but also reducing groundwater stock and hence increasing the risk of over-extraction. The increase in water availability is linked to possible behavioural changes that stimulate food production such as: using more water to increase yields on existing crops and using more water to expand the size of cultivated areas (R5); shifting to use new higher-value crops that have higher water demand (R2); or growing crops in an additional season per year (R3). Finally, the positive impact that these changes have on farmer incomes triggers beneficial reinforcing loops (R4, R6), where higher revenue from agricultural goods, revenue from electricity and water sales, and improved health all contribute to improving farmer incomes and well-being. This, in turn, makes off-grid solar pumps a more viable investment decision. This system is influenced by numerous policy efforts that target improved farmer incomes in other areas.

As before, higher productivity from higher groundwater use is expected to increase crop water demand and ultimately increase water stress for farmers, resulting in a balancing effect that reduces food production (B2, B5) and that may be offset by a further balancing loop (B3) that increases access to and dependence on groundwater until stocks are depleted to the point of a groundwater shortage (B4). The result is the emergence of desirable social and economic outcomes in the short term, possibly followed by undesirable ones in the medium and long terms. For this reason, policies that govern water usage by different users intervene to influence water recharge rates and promote irrigation efficiency. These policies are key tools that can determine outcomes.

The key factor affecting the uptake of off-grid solar pumps is their economic viability, which is in turn influenced by a range of factors, including access to finance, up-front capital costs of the technology, the relative cost of alternatives (on-grid or diesel pumps), and the relative reliability and convenience of alternatives. There are many policies that can influence these variables, including soft loans or capital cost subsidies for off-grid solar pumps; provisions to enable net metering (e.g., the sale of solar-generated electricity back to the grid); and existing subsidies for electricity, diesel and kerosene. There is a reinforcing loop that connects lower reliance on on-grid and diesel pumps with lower subsidies for electricity, diesel and kerosene (R7).

On the one hand, the introduction of solar water pumps can create opportunities for social empowerment and economic development. On the other hand, it is crucial that investments are planned that take into account the carrying capacity of surface water and groundwater resources, especially in light of climate change. While many constraints to growth are removed with the use of solar water pumps, the balancing factor represented by water availability can be weakened only by using water more efficiently and avoiding excessive water stress.

Aside from the way in which it helps highlight these interrelationships, the main purpose of this diagram is to help identify the key policy levers that matter for off-grid solar pumps, given complex WEF interrelationships. These variables, highlighted in green in the causal loop diagram, are subsequently used to help define a much simpler framework for mapping key policies at the level of the Central Government and the governments of Bihar and Rajasthan.



4.0 Mapping Relevant Policies for Off-Grid Solar Pumps Across the WEF Nexus

4.1 Structure of Mapping

At both the central and state levels, policies across water, energy and food themes are typically designed by different ministries and departments that have a mandate to address one sector, rather than the nexus in its entirety. The extent of interlinkage calls for a comprehensive review of these policies, such that activity in one sector does not build problems in another. Mapping central- and state-level policies can help policy-makers and researchers understand and engage with the network of policies that influence the drivers and impacts of solar irrigation.

In order to structure this mapping, the visualization of key water–energy–food interrelationships was distilled into a highly simplified framework drawing on the causal loop diagram (Figure 2) and focusing on a limited number of clustered areas of policy-making:

- Solar support policies, both at a framework level and specifically for off-grid solar pumps
- Efficiency policies, both for energy and irrigation
- Water resource management policies, both at a framework level and specifically with respect to irrigation
- Production-based interventions to increase farmer incomes, such as cash transfers or subsidies to improve affordability of farm inputs
- Policies that directly influence the price and demand for farmers' crops.

The term “policy” was defined very broadly, including framework laws setting out principles and objectives for governing sectors, sector-wide policies and plans, as well as issue-specific schemes, guidelines and campaigns. Policies were only chosen if they were considered highly relevant to off-grid solar pumps, and subjective judgement was used to determine when to include and exclude items on this basis. The review did not include pilot projects or any scheme not operating at scale. The exercise searched for a range of information fields per policy. This included each policy's major WEF linkages and whether the linkages are recognized in formal policy documentation; the budget or expenditure associated with the policy; and any major findings on the policy's performance. On budget or expenditure, it should be noted that this mapping was not a formal attempt to quantify expenditure on different schemes. As such, the best available data was taken from the information sources that were reviewed while attempting to ensure consistency between policies. Care should be taken in comparing values that may not be in common terms (e.g., proposed, budgeted or allocated values) or may apply to different years and time scales.

In addition to Central Government policies, two states were chosen for this mapping: Bihar and Rajasthan. As explained in the scoping chapter of this paper, they were chosen based on an assessment of multiple criteria, including the need to consider one water-abundant (Bihar) and one water-scarce state (Rajasthan), as well as net sown area, net area under irrigation from tube wells, food and power subsidy expenditure, and the number of diesel and electric pumps deployed.



4.2 Results of Mapping

The results of the central-level policy mapping are summarized in Figures 3 and 4, followed by a summary table and analysis of key central and state findings for each policy area. In the figures, policies are grouped by colour according to their principal policy area. The summaries provide a high-level description of what was identified and some narrative on the most important policies. In every case, more detailed information on each policy can be found in an Excel data resource that accompanies this briefing, available online: <https://www.iisd.org/sites/default/files/uploads/india-wef-mapping-2019.xlsx>



Figure 3. Central government WEF policies of key importance for solar irrigation pumps

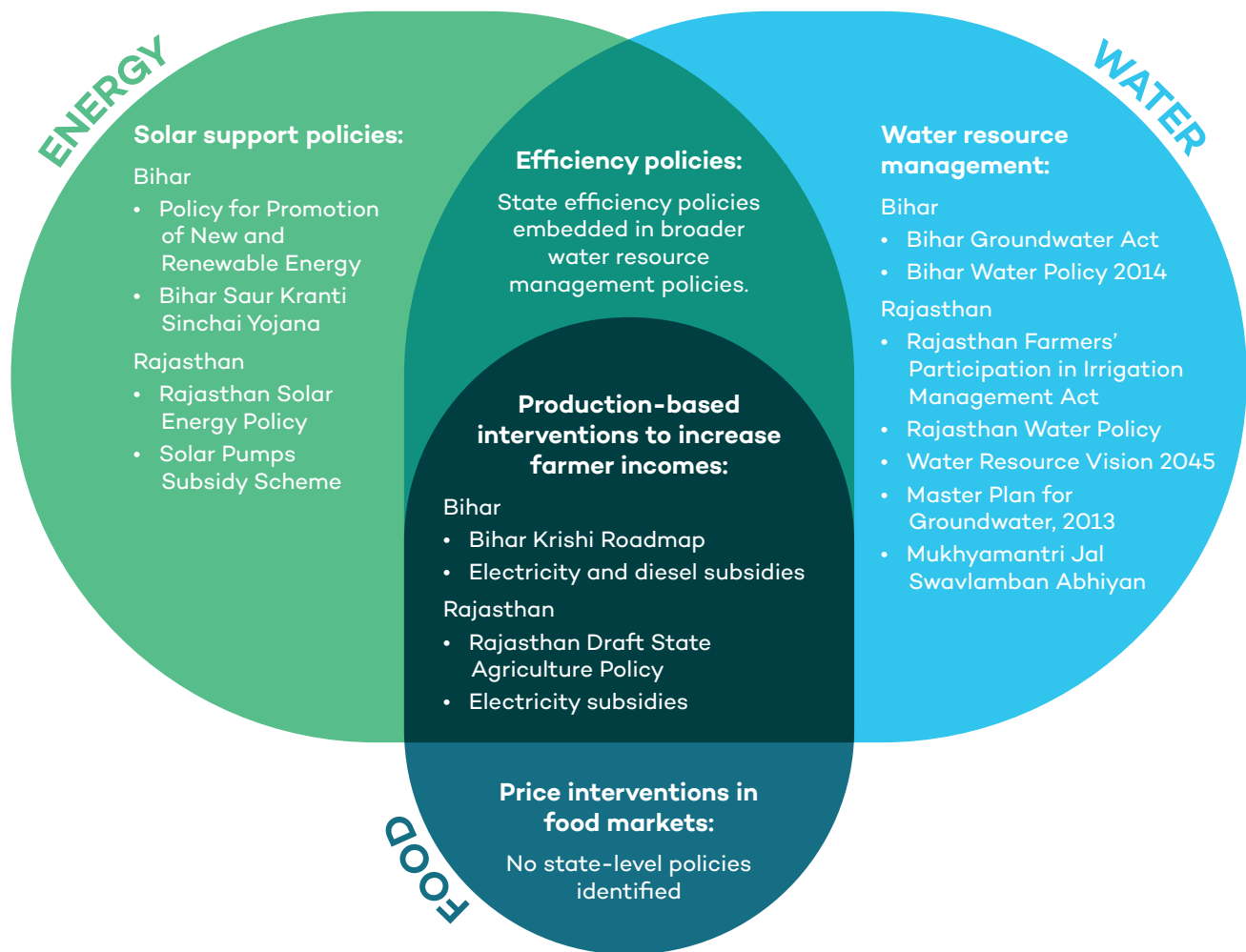


Figure 4. Bihar and Rajasthan WEF Policies of key importance for off-grid solar pumps by state

4.2.1 Solar Support Policies

The Central Government’s strong focus on renewable energy, especially solar energy, is a driving framework behind the support for off-grid solar pumps, particularly as costs for solar modules have been declining. In 2014, the Jawaharlal Nehru National Solar Mission (JNNSM) set a solar energy target of 100 GW by 2022, and a number of state-level schemes were established to achieve this ambition. According to the National Electricity Plan (CEA, 2018b), a further 50 GW of solar energy capacity will be added from 2022 to 2027. In coming years, targets to deploy solar power capacity may increase yet further. The Central Electricity Authority (2019) estimates that an optimum power mix would see solar power contribute 300 GW of an estimated total 831 MW capacity in FY 2029/30. Key information policies that were identified promoting solar power and off-grid solar pumps specifically are summarized in Table 1.

**Table 1. Key solar support policies: Central Government, Bihar and Rajasthan**

Policy	Objectives	Dates	Institution	Budget allocated
Central Government				
Kisan Urja Suraksha evam Utthaan Mahabhiyan (KUSUM) (approved but not launched)	Install solar power plants, incentivize farmers to use off-grid solar pumps and “solarize” grid-connected pumps	2019–2022	MNRE	INR 34,422 crore (total central contribution, proposed)
Jawaharlal Nehru National Solar Mission (JNNSM), and sub-component: Solar Pumping Programme	Establish India as a global leader in solar energy; install 10 lakh solar pumps	2010–2022	MNRE	INR 400 crore (FY 2014/15)
Bihar				
Policy for Promotion of New and Renewable Energy	Promote deployment of renewable energy, including 10,000 off-grid pumps by end of FY 2021/22	2017–2022	ED-B	—
Bihar Saur Kranti Sinchai Yojana	Subsidize 2 kWp solar pumps (90% capital subsidy)	2012–ongoing	ED-B	n.d.
Rajasthan				
Rajasthan Solar Energy Policy	Promote deployment of solar energy, including for off-grid pumps	2014	DoE-R	—
Solar Pumps Subsidy Scheme	Subsidize off-grid solar pumps (35% for 3 HP and 40% for 5 HP in FY 2018/19)	FY 2011/12 to ongoing	DoA, DoF, DoE; MoA, MNRE	n.d.

Notes: For further details about each policy or scheme and sources for the data in this table, see the [data file](#) that accompanies this paper. HP = Horsepower; MNRE = Ministry of New and Renewable Energy; ED-B = Energy Department, Government of Bihar; DoE-R = Department of Energy, Government of Rajasthan; n.d. = no data on budget was identified.

The main Central Government scheme today to promote the uptake of off-grid solar pumps and other forms of solar irrigation is the recently approved—but not yet introduced—KUSUM scheme. Approved by the Cabinet Committee of Economic Affairs in February 2019, the draft description of the scheme encompasses three key components: i) installation of 10,000 MW of solar power capacity on barren land with capacity up to 2 MW; ii) installation of 1.75 million stand-alone off-grid solar pumps; and iii) “solarization” of 1 million existing grid-connected irrigation pumps. KUSUM has a proposed Central Government contribution of close to INR 35,000 crore (USD 5.1 billion) over its three-year lifespan (PIB, 2019a). The scheme is expected to increase the availability of irrigated land to farmers at a lower cost than diesel pumps and to ease the financial burden of agricultural electricity subsidies for DISCOMs. Under its third component, the scheme also plans to enable the sale of excess electricity supply to the grid. This is intended to help farmers earn additional income, contribute toward their renewable purchase obligation targets and incentivize efficient water use, though this sub-component will only be in a piloting stage for the first 1,000 MW of capacity (PIB, 2019a). Before the announcement of KUSUM, the main Central Government policy promoting off-grid solar pumps was a sub-component of the JNNSM. Under Phase 2 of the scheme, the government had set a target of deploying 25,000 solar pumps by the end of FY 2016/17 and 100,000 pumps by the end of FY 2021/22 (MNRE, 2012).



At the state level, in Bihar, the Saur Kranti Sinchai Yojana (2012) was launched as a solution to the lack of adequate electricity for irrigation. It is aimed at increasing irrigated area by providing highly subsidized (90 per cent capital subsidy) small solar pumps (2 kWp) to farmers having one to five acres of land, a functional borewell and a willingness to contribute 10 per cent of the capital cost: INR 28,000 (USD 407) for alternating current (AC) pumps and INR 29,700 (USD 431) for direct current (DC) pumps. While the scheme has aided in vegetable cultivation and benefited farmers who were experiencing drought conditions, it has also experienced significant challenges. Another important initiative from Bihar is the policy for Promotion of New and Renewable Energy, 2017. It targets installed capacity of 2,969 MW solar to meet growing demand for power, including decentralized renewable energy for agriculture through deployment of 10,000 solar pumps by 2022. The Bihar Renewable Energy Development Agency has already taken steps to set up implementation guidelines for all technologies covered by the policy. It is expected to open up a significant number of new jobs, particularly in supply chain and operation and maintenance.

In Rajasthan, in order to realize the potential of solar radiation intensity, the government launched the Solar Energy Policy 2014 to deploy 25,000 MW in solar capacity. The policy aims to contribute to the state's long-term energy security and clearly recognizes and promotes off-grid solar pumps. There is no clear roadmap, however, to how off-grid solar pumps must be promoted in close coordination with agriculture and water departments. Another important initiative in Rajasthan is the Solar Pumps Subsidy Scheme (2011/12), which introduced 3 horsepower DC submersible pumps to farmers to narrow the gap between grid-powered demand and supply, with support from the JNNISM (Energy Department, Government of Rajasthan, n.d.). The scheme requires beneficiary farmers to have some form of water storage and to use drip irrigation (Gupta, 2017). Subsidies available under various programs were merged, including the JNNISM solar pumping program, resulting in a subsidy equal to 86 per cent of the capital cost (Gupta, 2017).

In terms of total deployment, policies to promote solar pumps have been successful, with the MNRE reporting a total of 196,000 installed off-grid solar pumps as of October 2018 (PIB, 2018a). This is much higher than the target of JNNISM's solar pumping program, presumably reflecting the concerted efforts of this central policy and numerous state-level policies. This total is, however, still fairly small as a share (0.9 per cent) of the 21.7 million irrigation schemes identified by the most recent Census of Minor Irrigation Schemes in FY 2014/15 (Government of India, 2017). At a state level, evaluations also suggest that policies have encountered a number of challenges. In Bihar, under the Saur Kranti Sinchai Yojana, Durga et al. (2016) found that solar pumps were not powerful enough (2 kWp) to irrigate all the lands of farmers operating with non-contiguous landholdings. They also found that there was not enough water in the shallow aquifer for the pumps to be operable throughout the winter and summer seasons, which limited the total number of pumps deployed—with the majority found to be distributed to influential village elites. Since the subsidy largely benefited medium- and large-scale farmers who already had access to irrigation in the form of diesel and electric pumps, the pumps tended to act as “back up” and were routinely under-used (Durga, et al., 2016).² This suggests that it may be important to monitor the beneficiaries under KUSUM to assess the extent to which benefits are clustered on farmers most in need of assistance.

In terms of WEF interrelationships, the review found that only KUSUM and Rajasthan's Solar Pumps Subsidy Scheme seemed to reflect possible impacts on groundwater scarcity in their design. In KUSUM, however, the facility to sell excess electricity back to the grid is still being developed, and it does not address possible groundwater over-extraction by off-grid users, who would be a major beneficiary of the scheme, assuming it is introduced as described in draft descriptions of the policy. No formal description of a monitoring and evaluation system for sustainability impacts was identified as part of the program. In Rajasthan, the solar pumps subsidy scheme recognized the need for efficient irrigation methods, and it required farmers to be using a drip

² As per answers provided by the Ministry of Agriculture and Farmers' Welfare in Rajya Sabha (2016), medium- and large-scale farmers are defined as farmers who have operational land holdings above 4 hectares and 10 hectares, respectively.



irrigation method in order to be eligible. This was an effective way to ensure off-grid solar pumps were aligned with efficient irrigation, but in a large-scale scheme it might also pose an additional up-front cost barrier for low-income farmers. Rajasthan’s scheme also stood out as a policy that had formally established relationships between different sectoral stakeholders, although water remained conspicuously absent from the team of institutions working in tandem on policy implementation: the state departments of agriculture, finance and energy and the Central Government’s Ministry of Agriculture and the MNRE.

4.2.2 Efficiency Policies

Key information about the main policies that were identified promoting energy and water efficiency with respect to off-grid solar pumps are summarized in Table 2.

Table 2. Key energy and water-efficiency policies: Central Government, Bihar and Rajasthan

Policy	Objectives	Dates	Institution	Budget allocated
Central Government				
National Energy Efficient Agriculture Pumps Programme/AgDSM	Replace farmers’ inefficient pumps with Bureau of Energy Efficiency (BEE) star-rated pumps	2016, ongoing	MoP	INR 400 crore (FY 2018/19)
Pradhan Mantri Krishi Sinchayee Yojana (PMKSY)	Ensure access to irrigation for all agricultural farms, bringing together many ongoing related schemes	2015, ongoing	MoAFW, JS (previously MoWR), MoRD	INR 50,000 crore (over 5 years)
Per Drop More Crops under PMKSY	Subsidies for micro-irrigation, covering 55% of costs for small and marginal farmers, 45% for other farmers	FY 2015/16, ongoing	MoAFW	INR 1,751 crore (realized, FY 2018/19)
Micro Irrigation Fund (MIF) under PMKSY	Additional resources for states for innovative, integrated micro-irrigation projects	FY 2018/19, ongoing	Advisory Committee, chaired by DoA	INR 2,000 crore (FY 2018/19) and INR 3,000 crore (FY 2019/20)
Bihar				
No dedicated energy or water-efficiency policies identified. See Section 4.2.3 Water Resource Management for policies that integrate efficiency into broader water management structures.				
Rajasthan				
No dedicated energy or water-efficiency policies identified. See Section 4.2.3 Water Resource Management for policies that integrate efficiency into broader water management structures.				

Notes: For further details about each policy or scheme and sources for the data in this table, see the [data file](#) that accompanies this paper. MoP = Ministry of Power; MoAFW = Ministry of Agriculture & Farmers Welfare; JS (previously MoWR) = Jal Shakti, previously the Ministry of Water Resources, River Development & Ganja Rejuvenation; DoA = Department of Agriculture.

At a central level, the only major energy-efficiency policy that was identified with a focus on off-grid solar pumps was the 2016 scheme to replace 200,000 energy-inefficient pumps with BEE star-rated agricultural pump-sets at no cost to farmers. The scheme was intended to create energy savings of 30 per cent by 2019 and annual savings of approximately INR 20,000 crore on agricultural energy subsidies (PIB, 2016). According to Patankar et al. (2018), the scheme was reduced in scope because the pace of scale-up was not adequate to meet the government’s efficiency targets. It appears to have picked up pace again in 2018, although under the name



AgDSM (Revathy, 2018). It should also be noted that the aforementioned newly approved KUSUM scheme is also expected to have an energy- and water-efficiency incentive embedded in its third component, though this is still at a piloting stage for the first 1,000 MW (PIB, 2019a).

Two central policies to promote water-use efficiency in irrigation were also identified: the Per Drop More Crops (Minor Irrigation) and Micro Irrigation Fund (MIF) both under the Pradhan Mantri Krishi Sinchayee Yojana (PMKSY), which brings together many related schemes that were previously located under the Ministry of Water Resources, River Development and Ganga Rejuvenation, the Department of Land Resources and the Department of Agriculture and Cooperation. While the PMKSY’s primary goal is to ensure access to irrigation for all agricultural farms in the country, its Per Drop More Crops (Minor Irrigation) scheme is a large sub-component and is focused specifically on helping states subsidize “micro-irrigation”—such as drip or sprinkler irrigation—which is much more water-efficient than traditional methods. The MIF was established to support innovative, “integrated” micro-irrigation projects. PMKSY also includes an Accelerated Irrigation Benefit Project for medium-sized and multipurpose irrigation projects (National Water Development Agency, n.d.).

At the state level, a number of policies were identified that addressed water efficiency, but as part of larger legal and institutional mechanisms for managing water resources. As the scope of these policies is larger than only efficiency, they are described alongside water resource management policies (Section 4.2.3). The Per Drop More Crops scheme has supported minor irrigation projects in both Bihar and Rajasthan, with FY 2016/17 state-wise allocations of INR 36 crore and INR 215 crore, respectively (PMKSY, n.d.b).

A main objective of the effort on energy efficiency at a central level seems to be that energy savings will create significant fiscal savings by reducing the amount of energy that is sold to farmers at subsidized prices. A recent BEE (2019) review, however, found that interventions to improve irrigation’s water-use efficiency can deliver energy savings close to pump replacement while also addressing groundwater stress, suggesting that water-efficiency policies may be the best balance between cost savings and sustainability. While the Central Government’s water-efficiency programs are well aligned with the need to promote efficient irrigation at the same time as agricultural pumps, there may be a need to increase efforts in this area. According to a NITI Aayog review, state performance on micro-irrigation is poor: the median share of irrigated area over which micro-irrigation had been installed was only 2 per cent in FY 2016/17 (NITI Aayog, 2018). An independent review by the *Hindustan Times* in 2018 found that five states accounted for 78 per cent of progress in micro-irrigation (Haq, 2018). There may be better scope to link off-grid solar pump schemes explicitly with improved irrigation, as no formal recognition of these potential synergies was found in scheme guidelines. “Solar-linked systems” are mentioned as one of the types of innovative projects that may receive extra support under the MIF, but among numerous other brief examples (Department of Agriculture, Cooperation and Farmers’ Welfare [DoACFW], 2018). The MIF is notable, however, for its multistakeholder Advisory Committee management structure, which includes representatives from the Ministry of Agriculture and Farmers’ Welfare, the Ministry of Water Resources, River Development and Ganga Rejuvenation, the MNRE and the Ministry of Rural Development (DoACFW, 2018).

4.2.3 Water Resource Management

Water resource management is a growing priority for the Central Government, with the recently announced formation of a Jal Shakti Ministry, which merges the previous Ministry of Water Resources, River Development and Ganga Rejuvenation with the Ministry of Drinking Water and Sanitation. This is intended to ensure a more integrated approach to water issues nationally (The Hindu, 2019a). The new ministry was launched alongside a Jal Jeevan Mission to ensure piped water supply to all rural households by 2024, which it is expected to target through existing schemes (The Hindu, 2019b). The main water resource management policies of importance for off-grid solar pumps are summarized in Table 3.

**Table 3. Key water resource management policies: Central Government, Bihar and Rajasthan**

Policy	Objectives	Dates	Institution	Budget allocated
Central Government				
Atal Bhujal Yojana	Help recharge groundwater, create water storage and revive surface water bodies in seven water-stressed states	2018–2023	JS (previously, MoWR)	INR 3,000 central contribution, INR 3,000 World Bank (over 5 years)
National Water Policy, 2012	Sets high-level objectives for water management nationally, including sustainable use of groundwater	2012, not superseded	JS (previously, MoWR)	—
National Aquifer Mapping and Management Programme (NAQUIM)	Creating and disseminating data on groundwater resources	2012, ongoing	CGWB	n.d.
Master Plan for Artificial Recharge to Ground Water in India, 2013	Augment natural groundwater recharge with man-made techniques	2013–2023	JS (previously, MoWR) & CGWB	INR 79,178 crore (proposed, over 10 years)
Bihar				
Bihar Groundwater (Regulation and Control of Development and Management) Act, 2006	Establish a groundwater authority for Bihar	2006, not superseded	CGWB	—
Bihar Water Policy, 2014	Framework policy setting out principles for water management	2014, not superseded	DoWR-B	—
Rajasthan				
Rajasthan Farmers' Participation in Irrigation Management Act, 2000	Establishes legal basis for farmer's organizations to promote and secure distribution of water	2000, not superseded	Rajasthan State Legislature	—
Rajasthan Water Policy, 2010	Establishes combined bottom-up and top-down activities for integrated water resources management	2010, not superseded	DoWR-R	—
Water Resource Vision 2045	Highlights short- and long-term focus areas and actions to implement that State Water Policy and Plan	2000, not superseded	DoWR-R	—
Master Plan for Groundwater, 2013	Creates artificial recharge structures for groundwater	2013, not superseded	DoWR-R, CGWB	—
Mukhya Mantri Jal Swavlamban Abhiyan	A campaign to ensure effective and efficient water conservation and harvesting in rural areas	2016, ongoing	State Level Committee chaired by Chief Minister	INR 2,400 crore state contribution, further raised by crowdfunding

Notes: For further details about each policy or scheme and sources for the data in this table, see the [data file](#) that accompanies this paper. JS (previously MoWR) = Jal Shakti, previously the Ministry of Water Resources, River Development and Ganja Rejuvenation; CGWB = Central Ground Water Board; DoWR-B = Department of Water Resources of Bihar; DoWR-R = Department of Water Resources of Rajasthan; n.d. = no data on budget was identified.



At a central level, the National Water Policy sets high-level objectives for water management nationally, including the need to improve water-use efficiency for irrigation. The main initiative to address sustainable groundwater management is the Atal Bhujal Yojana, which is intended to operate with community participation in select water-stressed areas of seven states: Gujarat, Haryana, Karnataka, Madhya Pradesh, Maharashtra, Rajasthan and Uttar Pradesh. The scheme is to be implemented with World Bank funding and assistance. The objective is to recharge groundwater and create sufficient water storage for agricultural purposes. It also focuses on the revival of surface water bodies so that groundwater can be increased, especially in rural areas. This is complemented by a Master Plan for Groundwater Recharge and other policies that set high-level objectives for water resource management and a program (NAQUIM) that creates and disseminates data on the state of groundwater resources. The PMKSY—described in Section 4.2.2—also includes a watershed development program to promote effective management of runoff water and soil and moisture conservation (PMKSY, n.d.a).

At a state level in Bihar, the Groundwater (Regulation and Control of Development and Management) Act has, since 2006, established the legal existence and powers of the state groundwater authority, including powers to notify areas to regulate and control the development and management of groundwater; granting permits to extract and use groundwater in these notified areas; and registration of existing users in notified areas and registration of drilling agencies. The State Water Policy, 2014, which emphasizes access to safe and clean drinking water and sanitation as a right to life and pre-emptive over all other uses, broadly recognizes WEF linkages and promotes the development of various agricultural policies to overcome drought in the state. It calls for land, soil, energy and water management with scientific inputs from local, research and scientific institutions to evolve different agricultural strategies and improve soil and water productivity to manage droughts. It highlights increasing water-use efficiency in agriculture by adopting improved irrigation methods such as drip and sprinkler irrigation. It further stresses the risk of overdrawing groundwater for irrigation and the need to regulate electricity to manage extraction rates. There is, however, no comprehensive roadmap for implementing the policy or transparent mechanism for regular monitoring and feedback.

Rajasthan is characterized by harsh heat conditions during summers and an overexploited water table, so there is a substantial body of laws, policies and schemes on water management. A participatory approach to the management of water used for irrigation was established by the Farmer's Participation in Irrigation Management Act (2000), including a focus on improving irrigation efficiency in canal surface irrigation. This mandates the creation of farmers' organizations at different levels starting with a Water User Association consisting of all land owners as members. Also established in 2000, the Water Resources Vision 2045 set short-term (up to 2015) and long-term (up to 2045) focus areas and an action plan to successfully implement the State Water Policy. The key objective is water conservation and effective planning, touching upon different sectors of water use, involving community and private sector participation. It targets maximum use of irrigation potential and maximum crop production per unit of water used. However, the vision does not take into account renewable sources of energy like off-grid solar pumps.

The 2010 Rajasthan Water Policy adopts a unique combination of top-down and bottom-up approaches to community-based water management, adopting the principles of integrated water resources management and issuing certain benchmarks for water extraction. It provides for prioritizing different uses of water and especially mentions improving irrigation efficiency. In addition, it adopts methods to promote groundwater recharge, such as installing water meters in fields, promoting pressure irrigation instead of flood irrigation and mandating a legal framework for regulating groundwater extraction, among others. The Master Plan for Groundwater Recharge, 2013, following from an earlier 2002 Master Plan, aims to create artificial recharge structures for the replenishment of declining groundwater throughout the state. It identifies and demarcates areas where artificial recharge can be put in place.

Finally, a campaign known as Mukhyamantri Jal Swalamban Abhiyan, launched by the Government of Rajasthan in 2016, converges all the ongoing schemes aimed at rural water conservation and harvesting by



mobilizing financial resources through crowdfunding from various stakeholders such as governments, non-governmental organizations, private players, religious trusts and civil society, among others. The campaign adopts a holistic participatory approach at every level of planning and implementation to improve water use and efficiency. Priority is given to the villages that are particularly vulnerable, such as where drinking water is not potable, where there has been famine or deficit in the last five years or where 70 per cent of agricultural land is rainfed. Increasing the area under irrigation, cultivable area, crop production and groundwater levels is an important mandate of the campaign. As of July 2019, the project dashboard reported that 22,328 villages had been covered (Mukhyamantri Jal Swalamban Abhiyan, n.d.).

In comparison to well-resourced interventions on energy and food production, there appears to be relatively less emphasis by the Central Government on groundwater resource management, although this may change with the creation of Jal Shakti. This may also reflect the extent of state interventions to ensure water security. The establishment of Water User Associations in Bihar has helped look into Groundwater Act violations, created broad public awareness and led to a complete ban on the construction of new wells (both private and government) in notified overexploited and critical areas, except for human consumption. In Rajasthan, some challenges have been experienced, with the framework Farmers' Participation in Irrigation Management Act being focused on surface rather than groundwater and reported slow progress with the Plan for Groundwater Recharge. The focus on community groups has the potential to prevent overexploitation of groundwater in the long run and the Mukhya Mantri Jal Swavlamban Abhiyan campaign has been reported to have increased the level of the water table in certain areas. Nonetheless, nationally and in both states, there are still substantial concerns about the sustainability of groundwater extraction, suggesting that existing initiatives are not sufficiently addressing withdrawal rates in the light of future trends.

4.2.4 Production-Based Interventions to Increase Farmer Incomes

In the last few years, the Central Government has increased its focus on various aspects of agriculture. Its budget on agriculture totalled INR 56,700 crore (USD 8.2 billion) in 2018/19, almost double the budget of INR 27,049 crore (USD 3.9 billion) in 2013/14 (IndiaSpend, 2019; PIB, 2013). The main production-based interventions intended to increase farmer incomes are summarized in Table 4.


Table 4. Production-based interventions to increase farmer incomes: Central Government, Bihar and Rajasthan

Policy	Objectives	Dates	Institution	Budget allocated
Central Government				
Paramparagat Krishi Vikas Yojana (PKVY)	Promotes organic farming	FY 2015/16, ongoing	MoAFW	INR 109 crore (expenditure, FY 2015/16)
Income Support Scheme – Pradhan Mantri Kisan Samman Nidhi (PM-KISAN)	Assures income of INR 6,000 per year to small and marginal farmers	December 2018, ongoing	MoAFW	INR 87,000 crore (FY 2019/20)
Rashtriya Krishi Vikas Yojana—Remunerative Approaches for Agriculture and Allied Sector Rejuvenation (RKVY-RAFTAAR)	Supports state-determined plans to improve agricultural development and incomes	2007–2020	MoAFW	INR 3,370 crore (central contribution released, FY 2018/19)
Direct Benefit Transfer of Fertilizer Subsidy	Subsidy to companies who provide fertilizers for free to farmers through point-of-sale devices at retailers	FY 2017/18, ongoing	DoF	INR 79,000 crore (FY 2019/20)
Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA)	Provides unskilled manual work to every adult for at least 100 days in rural areas	2005, ongoing	MoRD	INR 60,000 crore (FY 2019/20)
Bihar				
Bihar Krishi Roadmap	Ensures food security, increases agricultural income and inclusive jobs, conserves resources	2009–2022, ongoing	DoA-B	INR 154,000 lakh crore (FY 2017/18 to FY 2021/22)
Diesel subsidy	Subsidizes fuel to reduce costs of diesel pumps during periods of drought	Ad hoc	DoA-B	INR 195 crore (kharif season, 2008)
Electricity subsidy	Electricity tariffs below the average cost of supply for farmers	Ad hoc	BERC	n.d.
Rajasthan				
Draft State Agriculture Policy, 2011	Ensures food security, increases agricultural income, saves water and increases productivity	2013, not superseded	DoA-R	—
Electricity subsidy	Electricity tariffs below the average cost of supply for farmers	Ad hoc	RERC	n.d.

Notes: For further details about each policy or scheme and sources for the data in this table, see the [data file](#) that accompanies this paper. MoAFW = Ministry of Agriculture & Farmers Welfare; DoF = Department of Fertilizer, Ministry of Chemicals and Fertilizers; MoRD = Ministry of Rural Development; DoA-B = Department of Agriculture of Bihar; BERC = Bihar Electricity Regulatory Commission; DoA-R = Department of Agriculture of Rajasthan; RERC = Rajasthan Electricity Regulatory Commission; n.d. = no data on budget was identified.



At the central level, a key framework policy is the government's target of doubling of farmers' income by 2022. A Central Government committee identified seven ways to achieve such a target: improvement in crop and livestock productivity; resource use efficiency; savings in the cost of production; increase in cropping intensity; diversification toward high-value crops; improvement in real prices received by farmers; and a shift from farm to non-farm occupations.

Aside from the PMKSY, which reduces the costs of production by directly assisting farmers with the costs of micro-irrigation systems—as described in Section 4.2.2—there are a number of central production-based schemes that may influence the affordability of irrigation systems and off-grid solar pumps indirectly by their influence on farmer incomes. This includes Paramparagat Krishi Vikas Yojana (PKVY), a component of the Soil Health Management scheme that promotes organic farming, giving farmers access to organic food markets and improving soil health (PIB, 2015); the Pradhan Mantri Kisan Samman Nidhi (PM-KISAN) Yojana, announced in the 2019/20 interim budget (Ministry of Finance, 2019b), which provides assured income support of INR 6,000 per year to most farmers (PIB, 2019b); RKVY-RAFTAAR, which supports state-determined plans to improve agricultural development and incomes; the Aadhaar-enabled Fertilizer Distribution System (AeFDS), which provides farmers with subsidized fertilizer; and the MGNREGA scheme that provides 100 days of guaranteed unskilled manual employment to people living in rural areas.

At a state level, Bihar initiated an agriculture road map known as Bihar Krishi Roadmap. It is divided into three phases: the First Agriculture Roadmap (2008–12); the Second Agriculture Roadmap (2012–17); and the Third Agriculture Roadmap (2017–22). Its objectives include food and nutrition security, increasing farmers' incomes, employment generation, control on migration of workers, an inclusive approach to agricultural development and extensive participation of women. The Third Agriculture Roadmap (ongoing) also aims to improve agricultural productivity by setting up an exclusive 1,500 MW power network for agriculture. The power network is expected to curb dependence on diesel for farming. It also includes innovative ideas for integrating solar power with agriculture and fisheries. Bihar's other major schemes that support farmer input costs are energy subsidies. In recent years, Bihar has provided substantial diesel subsidies during periods of drought to help farmers afford irrigation. In FY 2018/19, this was provided due to the delay in the launch of KUSUM, with a subsidy for five rounds of irrigation, as compared to three rounds earlier to protect crop productivity. Farmers were paid a subsidy of INR 50 (USD 0.73) per litre, and a farmer with one acre of land received a subsidy for 10 litres of diesel for each round of irrigation (Jayan & Mishra, 2019). Around 15.64 lakh farmers were supported, costing a total of INR 195 crore (USD 28.3 million) in the kharif season of 2018. The state has also provided farmers with low-cost electricity tariffs for many years, with private tube well operators paying a rate equal to only 82 per cent of the cost of supply in the tariff order for FY 2019/20 (Bihar Electricity Regulatory Commission, 2019).

The State of Rajasthan, despite having a strong dependence on agriculture for its economy, only formulated a draft Agriculture State Policy in 2010. Its main objective is to ensure food and nutritional security and highlights the importance of water productivity, agriculture productivity and improving farmers' incomes. It also intends to consider and harmonize recommendations from Rajasthan's State Water Policy, which addresses issues related to integrated water resource management, water resources infrastructure and optimum utilization of surface, ground- and rainwater. Interestingly, the policy prioritizes providing ample and reliable power supply to farmers and mentions the use of renewable energy sources such as solar and wind for this purpose. In doing so, it addresses off-grid solar pumps in a context that also promotes good agriculture practices such as micro-irrigation, conservation agriculture and use of certified seeds. Rajasthan also provides farmers with low-cost electricity tariffs. In the tariff order for FY 2018/19, the energy charge for agricultural supply was INR 4.75 per kWh despite an average cost of supply of INR 7.02 per kWh, a rate equal to only 68 per cent of the cost of supply (Rajasthan Electricity Regulatory Commission, 2018).



Delivering on government ambition to increase farmer incomes will be challenging, taking into account low productivity rates and weak year-on-year income growth of farmers. While many of the policies in this area are important for poverty reduction and development, energy subsidies in particular stand out as a policy tool that is costly and can have perverse impacts.

According to a study by NABARD and ICRIER, free electricity and other input subsidies play a major role in incentivizing water-intensive crops such as rice and sugarcane (Sharma et al., 2018). A study by Prayas has found that electricity DISCOM subsidies have significant impacts on DISCOM finances and that free or subsidized electricity has played a role in unsustainable groundwater extraction, though it noted that simply reducing electricity subsidies in the absence of other complementary measures is not a solution (Das et al., 2019; Dharmadhikary, Bhalerao, Dabadge, & Sreekumar, 2018). Below-cost conventional energy alternatives also undermine the viability of off-grid solar pumps. Some energy subsidies, however, such as Bihar’s diesel subsidy, are used on an irregular basis in response to drought conditions, and such interventions may need to continue until more sustainable approaches to addressing droughts have been developed. NABARD and ICRIER strongly back the shift away from input-based subsidies and toward direct cash transfers, such as PM-KISAN, to assist farmer incomes without distorting production incentives (Sharma et al., 2018).

4.2.5 Price Interventions, Instruments in Food Markets and Others

Price interventions in food markets are a final way in which government policy can interact in the WEF interrelationships of greatest importance for off-grid solar pumps. There are a very large number of policies in India that seek to ensure certain prices for producers and affordable goods for consumers. Under this theme, the mapping focused on identifying major schemes representative of the broad thrust of policy in this area but without attempting to be exhaustive. It also focused on schemes targeted more directly at influencing producer prices, as these were judged to be more influential on cropping decisions than final consumer prices administered through schemes such as the PDS. The main price-based interventions in food markets are summarized in Table 5.

Table 5. Price-based interventions in food markets: Central Government, Bihar and Rajasthan

Policy	Objectives	Dates	Institution	Budget allocated
Central Government				
Minimum support price (MSP)	Fixes a minimum price for 22 agricultural commodities. If market prices fall below this level, other schemes will procure them at the MSP (see below)	1960s, ongoing	CG, CACP	—
Pradhan Mantri Annadata Aay Sanrakshan Yojna (PM-AASHA)	Umbrella scheme aimed to ensure farmers receive cost-covering prices for goods, focused on pulses, oilseeds and copra	FY 2018/19, ongoing	MoAFW	INR 1,500 crore (FY 2019/20)
Price Support Scheme (PSS)	Part of PM-AASHA, procures oil seeds, pulses and cotton at MSP	n.d.	MoAFW	INR 3,000 crore (FY 2019/20)
Market Intervention Scheme	Protects growers of goods not covered by MSP if prices fall under production costs	FY 2011/12, ongoing	MoAFW	



Policy	Objectives	Dates	Institution	Budget allocated
Food Subsidy to Food Corporation of India (FCI) and the Decentralized Procurement (DCP) system	FCI procures wheat and paddy at MSP when market prices fall below MSP and sells it to consumers through other schemes at very low prices. The DCP reimburses state procurement agencies engaged in the same activities.	n.d.	FCI	INR 184,000 crore (FY 2019/20, budgeted)
Sugarcane Pricing Policy, Sugar Price (Control) Order and the Scheme for Assistance to Sugar Mills (SASM)	Establishes Fair and Remunerative Price (FRP) for sugarcane and introduces a minimum selling price for sugar at mills. The SASM extends price support to farmers when market prices fall below the FRP.	2009, 2018, ongoing	DoFPD	INR 400 crore (FY 2018/19) INR 100 crore (FY 2019/20)
National Agriculture Market or eNAM	Helps farmers identify highest bidder for goods	FY 2016/17, ongoing	MoAFW	
Kisan Credit Card scheme (KCC)	Credit cards to purchase inputs such as seeds, fertilizers and pesticides	1998, ongoing	MoF	
Bihar				
None identified				
Rajasthan				
None identified				

Notes: For further details about each policy or scheme and sources for the data in this table, see the [data file](#) that accompanies this paper. CG = Central Government; CACP = Commission for Agricultural Costs & Prices, Ministry of Agriculture & Farmers Welfare; MoAFW = Ministry of Agriculture & Farmers Welfare; FCI = Food Corporation of India; DoFPD = Department of Food & Public Distribution, Ministry of Consumer Affairs, Food & Public Distribution; MoF = Ministry of Finance; n.d. = no data on budget was identified.

Even though many food prices are determined by market forces, certain Central Government policies are designed to avoid extreme price oscillations both for consumers and producers. Each year, the Central Government establishes MSPs for 22 agricultural commodities and an FRP for sugarcane. If market prices fall below these levels, a number of schemes step in to procure goods at the fixed prices. Schemes include the Price Support Scheme (PSS), focused on oil seeds, pulses and cotton; the Food Corporation of India, which procures wheat and paddy; and the Scheme for Assistance to Sugar Mills; among others. In addition, the Market Intervention Scheme is an ad hoc scheme that covers horticultural commodities and other agricultural commodities that are perishable in nature and not covered under MSPs.

The National Agriculture Market scheme (eNAM) was introduced in FY 2016/17 to digitize agri-markets to enable better price discovery, transparency and fair competition so farmers receive better remuneration for their produce (PIB, 2018b). The government, through eNAM, has created a virtual market that provides a common platform to farmers, irrespective of their state, to sell their produce to the highest bidder, increasing the reach of farmers at a national scale. In two years, up until September 2018, 585 markets across 16 states and two union territories have been connected on eNAM with registrations of over 1 crore farmers and 1 lakh traders on the eNAM portal (Kapoor, 2018). The ability to discover better prices for their produce is intended to enhance the



well-being of farmers and may increase their ability to adopt better technologies for irrigation, including solar pumps (Kapoor, 2018).

Although the MSP has an important role in ensuring that farmers are protected from market volatility, it can also promote water-intensive production. A study by NABARD and ICRIER found that, alongside subsidies for production inputs, the MSP and related procurement policies have played a key role in encouraging farmers to cultivate rice and sugarcane despite farmers' concerns about its long-term sustainability (Sharma et al., 2018). It encourages the consideration of direct cash transfers to disconnect assistance to farmers from production decisions. A review of electricity, water and agriculture interlinkages by Prayas notes that MSPs and procurement policies could be formulated to encourage crops that are suitable for the climate in different agricultural areas, with different MSPs for different regions (Dharmadhikary et al., 2018).

4.3 Key Findings

A number of key findings stand out from this mapping exercise. First, while there are a number of energy and food policies and schemes that appear to be well-resourced and making progress at the central and state levels, there does not appear to be the same trajectory for policies on groundwater extraction. This may change with the announcement of the new Jal Shakti Ministry and the recently approved KUSUM scheme that, according to its draft policy design, will attempt to enable farmers to sell excess solar-generated electricity back to the grid. In theory, the revenue that can be earned from selling excess electricity back to the grid should create an incentive that prevents unnecessary water extraction, but it remains to be seen how this will affect farmers' behaviour in practice. Further, by definition, this type of sell-back scheme can only apply to grid-connected beneficiaries. It therefore does not apply to the component of KUSUM that is intended to promote off-grid solar pumps and would not influence the behaviour of these users.

Second is the fact that many policies do not formally recognize WEF linkages. Policies tend to be derived and managed by ministries or departments with a clear sectoral responsibility, and as a result, tend to focus on that sector primarily. Even KUSUM, which allows for the sale of excess solar-generated electricity to the grid, does not account for the risk that over-extraction may nonetheless take place and that additional measures may be necessary to conserve groundwater resources. This finding suggests a need for enhanced coordination and a better integration of anticipated future trends into current policy design. In this respect, a number of existing policies stand out as examples of good practice with respect to the multistakeholder representation of ministries and departments responsible for water, energy, renewable energy and agriculture. It also suggests a need to prioritize action on policies that are actively undermining WEF interrelationships, such as subsidized grid electricity—though noting that such reforms on their own are not a magic bullet and require a holistic approach to achieve their intended outcomes. These actions might include removing subsidies; improving the targeting of subsidies, so that their benefits are focused more narrowly on vulnerable populations most in need of assistance; and shifting from a direct benefits transfer approach to welfare that disconnects assistance from specific production incentives.

Third, a number of existing policies do, nonetheless, offer good examples or potential for coordination and integration of WEF issues. At a state level, in Bihar, the most notable of the policies and plans initiated by the state government in the context of the WEF nexus is the State Water Policy, which recognizes principles of integrated water management in agriculture to increase water-use efficiency and crop productivity. It calls for land, soil, energy and water management with scientific inputs from local, research and scientific communities to evolve different agricultural strategies and improve soil and water productivity to manage droughts. Similarly, in Rajasthan, the State Agriculture Policy effectively attempts to address the WEF nexus through promoting good agriculture and irrigation practices, while harmonizing with recommendations of the Rajasthan State Water Policy. However, this policy is still in the draft stage and thus needs political will for implementation. The Solar Pump Subsidy Scheme also recognizes WEF linkages by addressing the need to replace the expensive and



polluting diesel pumpsets, increase the productivity of irrigated areas, conserve water through efficient irrigation methods and enable farmers to diversify to remunerative high-value horticulture crops. Among policies with potential for greater integration of WEF linkages, the Minor Irrigation Fund could be harnessed to help promote sustainable irrigation practices, particularly in circumstances where solar pumps are being deployed. In Rajasthan, the involvement of the community through Water User Associations created under the Farmers' Participation in Irrigation Management Act in the context of surface water management can be customized and extended to groundwater irrigation management as well.

Fourth, it has been challenging in the course of this mapping to identify rigorous, empirical studies on the impact of many policies, particularly with respect to the social distribution of subsidies, groundwater extraction and policy implementation challenges. Some recent major policies in India, such as the Saubhagya electrification scheme and the Ujjwala liquefied petroleum gas connection scheme, have provided publicly available dashboards to help monitor progress. It is vital to have built-in, formal mechanisms to monitor the practical implementation of policies and address challenges, in addition to independent third-party studies. Such an approach will also aid in mid-course correction whenever there is a scope.



5.0 Recommendations

The mapping of policies of importance for solar irrigation suggests a number of key recommendations for different stakeholders.

Central Government

- **The MNRE is advised to establish a comprehensive monitoring, evaluating and learning system to track the impacts of the KUSUM scheme for off-grid solar pumps when it is finalized and launched.** This should go beyond simply tracking the number of solar pumps that are installed under the scheme and draw on some of the complex interrelationships identified by the causal loop diagram in this paper. This process should include assessing the extent to which the scheme influences farmer cropping behaviour, assists small-scale landholders, and affects irrigation practices and groundwater levels. It should be used as a mechanism for learning and adapting policy design and establishing how the program can best operate in different states and different ecologies. This should have representation from all key water–energy–food stakeholders, including the Ministry of Jal Shakti, the Ministry for Agriculture and Farmers’ Welfare and state-level stakeholders, to ensure that issues that arise can be addressed in a coordinated way.
- **The Ministry of Jal Shakti is recommended to upscale existing policies or establish additional plans and resources to ensure that groundwater extraction in the agricultural sector is sustainable, including from solar pumps.** The main schemes promoting micro-irrigation today are yet to have a significant impact nationally but progress in this area is vital to ensuring the sustainability of solar pump programs and groundwater resources in general. The Ministry of Jal Shakti can explore how existing micro-irrigation schemes and institutions and regulations for groundwater monitoring can be promoted in a way that is explicitly linked with the KUSUM scheme.
- **Better coordination is needed for policy interventions in the water–energy–food nexus, including but not limited to coordination between policies issued by the Ministry of Jal Shakti, the MNRE, the Ministry of Power and the Ministry of Agriculture and Farmers’ Welfare and coordination between central- and state-level policies.** Few of the policies identified in this review explicitly acknowledged water–energy–food interrelationships and specified practical steps for ensuring policy coherence. Few state-level policy schemes explicitly stated their relationship and interaction with central policies and schemes. Improving the degree of coordination will be important for successful attempts to promote off-grid solar pumps. This review has not conducted an investigation into existing structures for inter-ministerial and central–state government cooperation, so it cannot recommend a specific format for improvement, but the government can consider structures such as an inter-ministry, high-power policy committee and a multistakeholder technical working group. The use of multistakeholder advisory committees for policy implementation and the publication of relevant financial resource allocation data on key central water–energy–food schemes on an online platform such as data.gov.in may also be worth implementing more systematically.

Governments of Bihar and Rajasthan

- **State-level implementation of the KUSUM scheme and other off-grid solar pump programs should be aligned with state-level efforts to promote micro-irrigation and improved groundwater monitoring.** As with the Central Government, linking off-grid solar pumps and micro-irrigation schemes may be a powerful mechanism to ensure more sustainable outcomes. Previously in Rajasthan, the use of drip irrigation schemes has been made a prerequisite to qualify as a beneficiary for solar pump programs. While such policy design can successfully mitigate impacts on groundwater, it may also inhibit the social inclusion and benefits of solar pumps, given the limited distribution of micro-irrigation at the current time.
- **Shift resources away from energy subsidies for conventional pumps, particularly electricity subsidies, and swap them into converting irrigation to solar and promoting efficient irrigation**



methods and groundwater conservation and regulation. Energy subsidies stand out in this review as an element in the policy landscape that is particularly perverse, promoting unsustainable groundwater practices and wasting scarce resources that could be better used elsewhere. Simply removing subsidies may not promote more sustainable behaviour—rather, savings should be shifted into alternative policies that address sustainability in a holistic manner. Where diesel subsidies are used as an ad hoc measure to help cope with drought conditions, it may be necessary to establish alternative support measures before subsidies can be removed.

- **States like Bihar, which have enjoyed abundant water resources for many years, may be able to draw lessons from states like Rajasthan, which have been coping with water stress for many years.** This mapping found a significantly greater body of policy on water resource management in Rajasthan. Some policies—such as the Mukhya Mantri Jal Swavlamban Abhiyan campaign, which takes a community-based approach to good groundwater management and crowdsources contributions—may offer useful models to help address groundwater challenges early.
- **Better coordination is needed for policy interventions in the water–energy–food nexus, including but not limited to coordination between policies issued by departments responsible for water, agriculture, power and renewable energy.** This review found that many state-level policies of importance to off-grid solar pumps did not explicitly acknowledge water-energy-food interrelationships or specify any practical steps to ensure policy coherence. It also found it challenging to determine the exact relationships and resource-sharing between state-level policies and schemes that were linked to larger central-level policies and schemes.

Policy Researchers and International Development Institutions and Donors

- **More rigorous, independent policy analysis is needed to help complement formal government monitoring and evaluation systems in a number of key issue areas.** Some of the policies mapped in this review, such as the MSP, have been subject to extensive analysis and evaluation. In other cases, however, certain policies did not seem to have been rigorously studied and certain aspects of policy impacts were not captured in evaluations. This included evaluation of the extent to which central-level policy guidelines have helped foster the development of effective state-level policies and schemes; in general, adequate evaluation of state-level schemes, both in terms of immediate impacts and their subsequent social, economic and environmental impacts; evaluation of the ways in which solar pumps influence farmers' water extraction and cropping decisions; evaluation of efficiency schemes linked to pumps and irrigation; good state-level data on energy subsidies and total energy subsidy expenditure; the distribution of policy benefits from various schemes across income groups; and the environmental impacts of many schemes, particularly with respect to groundwater extraction. Independent third-party studies are a vital part of the policy ecosystem and often provide detailed, textured analysis that can help guide policy implementation and go beyond the more rigid scope of formal monitoring systems.



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