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Solar pumping for irrigation:

Improving livelihoods and sustainability

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About IRENA

The International Renewable Energy Agency (IRENA) is an intergovernmental organisation that supports countries in their transition to a sustainable energy future, and serves as the principal platform for international co-operation, a centre of excellence, and a repository of policy, technology, resource and financial knowledge on renewable energy. IRENA promotes the widespread adoption and sustainable use of all forms of renewable energy, including bioenergy, geothermal, hydropower, ocean, solar and wind energy, in the pursuit of sustainable development, energy access, energy security and low-carbon economic growth and prosperity. www.IRENA.org

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Contents


Photograph: Oxfam/John Magrath

A farmer from the Mazuru market garden in Zimbabwe

Introduction

The agriculture sector is the single largest employer in the world, sustaining the livelihood of 40% of the population, many of whom live in poverty (United Nations, 2015). Increasing productivity in the agriculture sector is widely recognised as one of the most effective ways to fight poverty and stimulate socio-economic development. In fact, for every 10% increase in farm yield, there has been an estimated 7% reduction in poverty in Africa and more than 5% in Asia (United Nations Environment Programme (UNEP), 2012).

Irrigation is among the measures that can improve yields, reduce vulnerability to changing rainfall patterns, and enable multiple cropping practices (Food and Agriculture Organization (FAO), 2011). Although expanding, land area under irrigation nevertheless represents a marginal share of total cultivated area, especially in sub-Saharan Africa, where only 5% of farmland is irrigated (International Water Management Institute (IWMI), 2010). Affordable, reliable and environmentally sustainable energy is a vital input for delivering irrigation services.

Solar-based solutions can provide reliable, cost-effective and environmentally sustainable energy for decentralised irrigation services in a growing number of settings. When deployed, the benefits include improved livelihoods (increased productivity and incomes, and food security), increased social welfare (poverty alleviation, emissions reduction) and reduced spending on fossil fuel subsidies and centralised infrastructure. In an effort to contribute to a number of Sustainable Development Goals, these solutions are becoming increasingly widespread, as demonstrated by the initiatives of a growing number of governments, development agencies, and the private sector.

The decision-making on "energy options for irrigation" lies at the heart of the water, energy and food nexus. This warrants a cross-sector examination of effective ways to deploy solar pumping technology for irrigation and maximise the benefits. This policy brief analyses the key drivers behind the adoption of solar pumping technology and brings to the forefront the cross-sector aspects that should be considered in programme design and implementation.

IRENA'S WORK ON RENEWABLE ENERGY AND THE WATER, ENERGY AND FOOD NEXUS

This policy brief is part of a broader work stream in IRENA focusing on renewable energy opportunities in the agriculture and water sector. It began with the publication of a comprehensive report, *Renewable energy in the water, energy and food nexus* (2015), which analysed the key interactions of renewables across the three sectors. IRENA has since developed in-depth empirical analysis on renewable energy applications and their wider cross-sector impacts. These include, *Water Use in China's Power Sector: Impact of Renewables and Cooling Technologies to 2030* (2016), the "In-focus" chapter on desalination in *Renewable Energy Market Analysis: GCC* (2016) and the present policy brief, *Solar Pumping for Irrigation: Improving livelihoods and sustainability*. The work stream builds on continuing support for an integrated approach to renewable energy development and contributes to IRENA's growing body of work on the socio-economic benefits of renewable energy.

1. The Water-Energy-Food Nexus in the Context of Irrigation

Worldwide, food is produced mainly on rainfed land. Approximately 95% of farmed land in sub-Saharan Africa and 60% in South Asia rely on seasonal rains to meet water needs (IWMI, 2010). Productivity on these farms can be particularly low, resulting in food insecurity and poverty for many of the subsistence and smallholder farmers. The challenges they face are further exacerbated by increasing climate variability that brings unpredictable, insufficient or too much rainfall. In order to overcome some of these challenges, irrigation can be increased by exploiting the ground or surface water that is available.[1] Land that is irrigated tends to give greater yields of crops than that which is rainfed. Therefore, while irrigated agriculture represents only 20% of the total cultivated area, it provides 40% of total food produced globally (FAO, n.d.). To increase yields and cope with rising demand for food, the land area under irrigation will need to expand, but this would translate into increased use of water as well as energy. Around 56% of irrigated land already requires energy and that figure is growing (FAO and Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), 2015).[2]

SOURCE TO FIELD: ENERGY NEEDED FOR WATER TRANSPORT

Water for irrigation purposes can either be drawn from surface reservoirs (*e.g.* canals, streams, lakes) or from aquifers.[3] Energy needs can vary depending on the vertical and horizontal distances the water travels. An analysis of energy needs for irrigation requires a distinction between two main settings:

i. ***Access***, when pumps are energised, but a change in energy source is desired to improve reliability, reduce costs and minimise environmental impacts; or

ii. ***Non-access***, when different energy sources (*e.g.* diesel, biomass, solar) are explored to bring additional water - more than is naturally supplied through agro-climatic conditions to increase yields and reduce vulnerability.

To stimulate agricultural productivity, many agrarian economies have supported the accelerated development of irrigation infrastructure, in particular, groundwater structures (wells and tube wells). In India, for instance, the number of agriculture connections has increased from 13 million to around 19 million between 2001 and 2015 (Agrawal and Jain, 2015; Panda, 2007). This has substantially increased productivity and contributed to food security objectives. It has, however, also set in motion a perpetual cycle of increasing water and energy use. In some parts of the country, the water table is

OPTIONS FOR POWERED IRRIGATION

Conventional: Electricity grid-connection, diesel or petrol-based

Renewable: Solar, wind, biogas, or small hydropower schemes

Hybrid: Grid with diesel/solar/biogas, or diesel with solar/wind

[1] *Attention must also be given to more effective rainwater harvesting which would represent a freshwater source (even if increasingly vari able) that could be used for supplemental and small-scale irrigation (IWMI, 2010).*

[2] *Not all irrigated land consumes energy, since a substantial proportion relies on flood irrigation.*

[3] *Around two-thirds of global water supplies used for irrigation are drawn from aquifers. Water can also be procured from non-conventional sources, such as treated wastewater, desalination or drainage water. Such sources, although energy-intensive, provide for a small proportion of the irrigation water and are thus not the focus of this case study.*

receding by 0.3 metres per annum, thus requiring even more energy for pumping purposes (Casey, 2013). Over 18% of total electricity consumption and over 5% of total diesel consumption in India is already used for irrigation purposes (Central Electricity Authority (CEA), 2015; Neilsen, 2013).

Even as farmers increasingly gain access to modern energy for pumping through grid electricity or diesel fuel, a large proportion continue to rely on seasonal rains for irrigation. In this non-access context, farmers are expected to invest in pumping systems to obtain access to groundwater or surface water. The main challenges they face are access to finance and the right technology, as well as the capacity to operate and maintain the systems. Fuel-based solutions can be cumbersome, especially in remote areas where the cost of transportation can be inhibitive. More importantly, a substantial proportion of earnings would need to be reinvested into procurement of fuel for subsequent crop cycles.

WATER PUMPING: A MAJOR ENERGY CONSUMER

Globally, electric irrigation pumps consume around 62 terawatt-hours per annum – equivalent to Singapore's annual electricity consumption in 2014 (United Nations Educational, Scientific and Cultural Organization (UNESCO), 2014). Many farmers also continue to rely on diesel for their water pumping needs. In Bangladesh, peak electricity demand during the irrigation season increases by almost a quarter, and over 25% of annual diesel use is linked to agriculture (Bangladesh Petroleum Corporation (BPC), 2014). Similarly, in Iran, groundwater pumping consumes 20.5 billion kilowatt-hours (kWh) (or 11% of total electricity) and 2 billion litres of diesel annually (Karimi *et al.*, 2012). The tremendous growth in energy usage for irrigation is a consequence of the efforts of several countries at the beginning of the 1950s - especially those in the South Asian region - to aggressively expand irrigation by helping to finance electric interconnections and pumping equipment, along with low-cost fuel. Some have even asserted that the "green revolution is more a tube well revolution than a wheat revolution." (Repetto, 1994; Shah et al., 2007). With the land area under irrigation expanding, water tables have dropped and deeper aquifers and more distant freshwater sources are being tapped into. This poses major challenges for the energy sector:

i. The fiscal burden on public budgets is reaching an unsustainable level, since energy inputs (electricity or fuels such as diesel or petrol[4]) for irrigation are often subsidised.[5] The spillover effects include the following:

    » Low-cost or free electricity for pumping can prevent cost recovery for utilities/distribution companies, thus negatively impacting their ability to invest in infrastructure development and to act as bankable off-takers for new power projects (on-grid and off-grid).

    » Non-cost reflective pricing provides little incentive to address inefficient water and energy practices in the agriculture sector.

ii. The grid infrastructure in developing countries fails to reach many rural areas or is inadequately equipped to handle an increasing pumping load. In many rural areas, the lead time for a grid connection is long and farmers must, in the interim, resort to fuel-based options. Where electricity supply is available, it is often unreliable and experiences limited and unpredictable supply and voltage fluctuations. Moreover, increased seasonal agricultural demands can aggravate the pressures borne on electricity networks.

iii. The environmental impact of the current stock of pumping solutions is considerable. As energy usage for pumping has burgeoned, so have the

[4] *Small petrol engine-driven pumps are, at present, the preferred option for smallholder irrigation. These pump sets are relatively inexpensive, are available in most regional capitals and maintenance can be assured by rural mechanics. The small size and weight of these devices enables farmers to take them home, thus avoiding the risk of theft. The disadvantages, however, are their short life span and the potentially high fuel and maintenance costs (SNV, 2014).*

[5] *There is a substantial body of literature that analyses input subsidies in relation to the agriculture sector. The focus of this particular study is neither to discuss the effectiveness nor the need for such subsidies; rather, the aim is to highlight the implications of such an environment for the introduction and long-term sustainability of new technology solutions.*

associated greenhouse gas emissions. Fuel-powered groundwater pumping is responsible for 8%-12% of all greenhouse gas emissions in India (Shah, 2009). In China, energy use for irrigation amounts to approximately 45 metric tonnes of CO_2eq, or 50%-70% of total emissions from energy activities in the agriculture sector (Xou, 2015).

IMPROVING ACCESS TO, AND SUSTAINABILITY OF, IRRIGATION SERVICES

Governments, development agencies and the private sector are exploring and implementing solutions to improve access to, and sustainability of, irrigation services. The principle is to increase productivity across all scales of farming, and water and energy-use efficiency (more crop per drop and per kilowatt-hour) in order to reduce the pressure on relevant sectors, including on land and the environment. The solutions that are available vary from technology intervention at the farm level (*e.g.* improved management of water and soil moisture; promotion of drip irrigation, displacement or hybridisation of grid/diesel-based pumping with renewable energy, improvement of pumps and efficient distribution) or at the energy system level (*e.g.* feeder segregation programmes, time-of-day metering, energy/water price reforms). The appropriateness of a solution depends on the local conditions, such as the crops grown, the demand for water (quantity and frequency), source (depth, distance and geology), land holding patterns (acreage and ownership), existing irrigation practices, access to grid infrastructure and availability of on-site alternate energy resources.

SOLAR-POWERED IRRIGATION COMES TO THE FORE

Within the broad spectrum of solutions, solar-powered irrigation has gained prominence lately. While solar pumping technology has been deployed for decades, recent cost reductions and increasing awareness of the potential benefits of this technology, has compelled a growing number of countries to launch programmes to accelerate its deployment. For example, Bangladesh has set a target to deploy 50 000 solar pumps by 2025; India, 100 000 by 2020; and Morocco, 100 000 by 2022. In Malawi, over 500 hectares of farm land are expected to benefit from solar-powered irrigation through a government programme, funded by the African Development Bank (Kazembe, 2015).

The private sector is showing a keen interest with several local enterprises developing, marketing and retailing solar pumping solutions. While other renewable energy options are also being adopted, such as biogas-fuelled pumping in Pakistan or micro-hydro systems in Zimbabwe, the application of solar-based power is emerging as the preferred solution due to its predictability in supply, scalability and zero-fuel input.

Photograph: IWMI/Prashanth Vishwanathan

Raman Parmar at the International Water Management Institute's pilot solar pump on his farm in India

2. Solar-Powered Irrigation Systems: An Opportunity

Powering irrigation systems with solar energy is a reliable and environmentally sustainable option in a growing number of contexts. Solar-based irrigation systems can be scaled to meet diverse energy demands and can contribute to a decoupling of growth in irrigated land areas from fossil fuel use, while improving livelihoods. Building on case studies from different projects, this section discusses the key socio-economic and environmental benefits of solar-powered irrigation systems. Throughout the case study, important cross-sector aspects are also discussed with the objective of promoting an integrated approach to the deployment of these systems (Box 1).

UNDERSTANDING THE ECONOMICS OF SOLAR PUMPING

How solar irrigation solutions compare with conventional solutions depends on a number of factors, including (i) initial capital costs (type and size of system, cost of shipping and installation); (ii) recurring costs (*e.g.* costs relating to operation and maintenance, labour and fuel); (iii) ensuing economic benefits (*e.g.* fuel savings, yield increases); and (iv) current energy expenditure.

A number of studies have assessed the economics of solar irrigation solutions. The comparability of results is limited due to differing contexts, methodologies and cost assumptions. Across the literature, however, there is emerging consensus that solar-based irrigation offers substantial economic benefits. In India, several studies point to the competitiveness of solar solutions compared to diesel under many conditions (Agrawal and Jain, 2015; KPMG and Shakti Foundation, 2014; GIZ, 2013; Self Employed Women's Association (SEWA) and Natural Resources Defense Council (NRDC), 2015; Prayas, 2015). Evidence also exists in Bangladesh, Benin, Chile, Egypt, Kenya, Zambia and Zimbabwe of the competitiveness of solar solutions compared to conventional options (World Bank, 2015; Dean, 2010; SELF, 2015; PV Insider, 2014; Egypt Network for Integrated Development (ENID), 2013; Crowe, 2014; FAO, 2014; Magrath, 2015). Indeed, subsidies offered for electricity and fuel affect the competitiveness of such solutions. When considering the economics of solar irrigation solutions, two key aspects should be examined:

i. Costs and benefits for farmers as well as government should be considered (Figure 1). In the case of grid-connected pumps, in particular, non-cost-reflective power tariffs distort the attractiveness of solar pumping solutions for farmers, although governments are increasingly recognising the long-term economic benefits that can be gained from switching existing or new grid-connections for agriculture pumps to solar.

ii. Different scales of farming (commercial, smallholder[6] and subsistence) and existing irrigation practices (grid-connected, fuel-based and rainfed) need to be considered. The competitiveness of solar irrigation solutions could vary as farmers with smaller landholdings may adopt smaller, less capital-intensive irrigation options, such as petrol-/diesel-based pumps or they may opt to pay for irrigation services (SNV, 2014).[7]

[6] *Smallholders are small-scale farmers who manage areas that vary from less than 1 hectare to 10 hectares. The characteristics of smallholders also include family-focused motives, such as favouring the stability of the farm household system, using mainly family labour for production and using part of the produce for family consumption. Eighty percent of the farmland in sub-Saharan Africa and Asia is managed by smallholders, providing up to 80% of the food supply (FAO, 2012).*

[7] *Small-holder and subsistence farmers often rely on a third-party to deliver water for irrigation paying a service fee that is either on a per-land-area basis or a seasonal basis. The third party may be a larger-scale farmer or a local private operator. Such a "water-as-a-service" approach allows small-scale farmers to benefit from irrigation even though on-farm water demand is insufficient to justify investments in dedicated irrigation infrastructure.*

BOX 1: SOLAR PUMPING SOLUTIONS: ADOPTING A NEXUS APPROACH

Decision-making in terms of irrigation has spillover effects on the water, energy and food sectors. These sectors have different end-goals (*i.e.* to maximise security of supply) and, therefore, the challenge is to seek solutions that converge with sector-specific objectives. In the case of irrigation, the convergence point is where irrigation systems can deliver the needed volume of water in a timely manner, maximise water-use efficiency and utilise energy sources that will minimise costs and environmental impacts. In a growing number of contexts, solar-powered irrigation systems are able to meet many of those cross-sector objectives, although some long-term concerns have been raised.

One issue is the risk of excessive water withdrawal. Solar pumps do not require fuel and have a very low operation cost compared to diesel (or even grid-based) pumps. Early experience - especially with solar pumps that are used for non-irrigation purposes - highlights the risk of over-withdrawal of water. At present, the capital-intensive nature of the technology, and the fact that government programmes generally support pumps with low capacity, limits this risk to a great extent. Nevertheless, concerns continue with rapidly decreasing costs and a growing number of countries announcing large-scale deployment plans. This risk can, however, be mitigated by adopting a cross-sector view during programme design, as well as appropriate regulatory measures such as those that would limit the size of pumps; promote water-use efficiency; allow grid interconnection and integration with other rural electricity loads.

The risk is also context-specific. There is, for example, a stark difference between West India and East India. In the West, where groundwater is over-exploited and there are large solar pumping programmes (*e.g.* state of Maharashtra), the risk of over-extraction can be managed through the regulatory measures previously mentioned. To the East, in fact, solar pumps mostly displace diesel-based pumps in the Ganga Brahmaputra River Basin, which has a high groundwater table, and brings the added benefit of better management and use of shallow groundwater systems. Since it is a flood-prone region, increased pumping of shallow groundwater would create room in the vast porous alluvial aquifers of the Ganga Basin to receive more recharge and reduce intensity of flooding further east. Solar pumping programmes targeted in these areas, therefore, have to be tailored accordingly. Cross-sector aspects such as these are discussed in greater detail throughout this case study, which concludes with a summary of key nexus considerations for governments and implementing agencies when designing solar pumping programmes.

Photograph: IDCOL

Solar irrigation pump in Bangladesh

While solar-based irrigation solutions can be competitive on a life-cycle basis, they are a capital-intensive technology with front-loaded investments that pay back over time. System costs continue to fall as a result of the dramatic reduction in solar photovoltaic costs – approximately 80% between 2012 and 2015. Unit costs can vary quite dramatically though, depending on the scale, location of the project and what is included in the cost (*e.g.* after sales service). A recent large-scale public procurement of over 8 900 solar pumps in the state of Maharashtra in India yielded costs in the region of USD 8 100 for systems ranging from 3 to 7.5 horsepower (Jain, 2015).[8]

Similar figures emerge from Bangladesh, where a 4 kilowatt peak of solar irrigation system comes in at around USD 8 400, with an estimated return payment of five years on account of diesel savings and yield improvements (Infrastructure Development Company Ltd. (IDCOL), 2015). Given that the systems can be downsized substantially, solar pumping solutions are also available starting from USD 1 600 (Nichols, 2016). Pilot/individual projects experience higher costs, given the lack of scale and additional resource needed for market and ecosystem development. The high upfront cost of the systems is a key barrier.

In order to make solar irrigation systems accessible to farmers, instruments are needed to either improve access to credit and/or bring down the capital cost of systems to affordable levels. These instruments should be tailored to farmers' cash flows, which are often linked to crop cycles with a substantial proportion of their income often reinvested in the next harvest cycle (further discussed later). It must also be noted that the preference of farmers for solar, electric or diesel pumps is affected by other aspects, such as the reliability and quality of energy supply, waiting time for new electric connection, cost of repair and maintenance, and general perception of technology, as well as the existence of trusted service providers. Looking beyond the energy sector, coupling the introduction of solar

Figure 1: Benefits of Solar Pumping Solutions for Farmers and Governments

Farmers

- Supply of energy and improved access to water for irrigation
- Improved crop yields and increased incomes
- Reduced manual work and improved expenditure of time
- Enhanced crop resilience and food security
- More income generating opportunities by complementing staple foods with high-value crops
- Additional benefits for health, education and poverty alleviation

Governments

- Reduction in electricity and fuel use
- Subsidy savings
- Reduced fuel imports
- Creation of small businesses/employment across the value chain
- Improved reliability of power systems
- Increased agricultural economic output
- Emissions reductions

[8] *The tender for 8 959 solar pumps is the first pilot phase of the world's largest solar agri-pump project for 500 000 pumps, launched by the government of Maharashtra in India. Under this phase, pump sets of 3.0, 5.0 and 7.5 horsepower capacity, comprising of 4 559 alternating current and 4 400 direct current pumps, will be installed depending on the farmer's water requirement, crop pattern and land availability, among others. The beneficiaries will include small and marginal farmers, who are based in drought affected areas, and traditional farmers who do not have access to electricity. The tender is expected to be serviced in 6 to 12 months, with further operational and maintenance support to the farmers for the following five years.*

pumps with measures to improve the efficiency of irrigation practices and tap into dual productivity gains, could further improve the viability of such systems.

ASSESSING THE IMPACT ON LIVELIHOODS

Solar-based pumping solutions can provide reliable, predictable and affordable energy inputs for irrigation. Depending on the context, this can have several impacts: (i) for grid-connected farmers, such solutions can help overcome erratic and low-quality grid supply; (ii) where fuel-based pumping is used, solar-based irrigation solutions can almost entirely eliminate the need - as well as the cost incurred - to purchase fuel, thus insulating farmers from market fluctuations (Box 2); and (iii) for rainfed areas, reliable energy access for pumping can translate into increased crop yields (Box 3), as well as potential for cropping multiple times in one year, including high-value cash crops. In each case, these solutions can have a direct economic impact on farmers, with derived benefits ranging from increased and sustained income to reduced hardships to improved livelihoods.

The benefits of solar pumping solutions, especially in the non-access context, include a strong gender dimension, since a large number of women are engaged in rainfed agriculture and they produce two-thirds of the food in most developing countries. It is women, predominantly, who fetch the water for food production - a laborious and time-consuming activity. In the market gardens of Mazuru, Zimbabwe, each woman walks nearly 4 kilometres or more each day to carry buckets of water

BOX 2: REDUCING DIESEL EXPENSE: INDIA

Nearly 70% of India's salt is made in Little Rann of Kutch in Gujarat. The majority of the 43 000 salt pan farmers use inefficient diesel-powered water pumps to extract brine from the ground as part of the salt harvesting process. As a result, diesel accounts for a significant proportion of farmers' production costs. In fact, farmers spend up to 40% of their annual revenue buying diesel for the next production season, thus reducing disposable income.

Two pilot projects, carried out by the Self Employed Women's Association, have demonstrated that powering pumps with solar energy can reduce production costs, as well as increase reliability, efficiency and salt harvest outputs, resulting in improved rural livelihoods. Annual savings for a farmer rose to USD 1 277 (INR 83 000) – a 161% increase when compared to those using diesel-powered pumps - with additional benefits including reduced air pollution. Across the Kutch, replacing diesel water pumps with solar and hybrid solar/diesel ones could potentially reduce CO_2 emissions by 115 000 tonnes. The multi-functional nature of solar panels also increases its value, particularly for off-grid villages, enabling complementary uses such as powering households. Interestingly, some salt traders - who usually loan salt-pan-worker money to purchase diesel for irrigation - have now acquired solar pumps and are leasing them out to salt pan workers on an annual basis. In this manner, they are able to recover their investment in three years, while making the technology accessible for salt pan workers who now need not incur the capital costs of the system.

Photograph: SEWA

Solar pumps reduce production costs for Gujarat saltpan farmers in India

Source: SEWA and NRDC (2015).

BOX 3: INCREASING YIELDS AND INCOMES: ZIMBABWE

The transformational impact of irrigation is evident in Oxfam's Ruti Dam Irrigation Scheme, where solar pumps were used to expand the coverage of the scheme from 40 to 60 hectares. Two-thirds of the Ruti scheme is based on gravity-fed irrigation, and additional solar booster pumps have been deployed to pump water into a storage reservoir. Nearly 270 smallholder farmers, who were previously growing little more than subsistence crops of maize, can now feed themselves, earn income and benefit their neighbours. Farm yields have increased to an average of 4 tonnes to 5 tonnes of maize per hectare. Irrigation enables farmers to grow three crops per annum and rotate crops to grow a diversity of nutritious and cash crops, such as potatoes and sugar beans. The Ruti scheme also hosts an energy kiosk that is powered by solar rooftop panels, which provides cold storage with solar charging.

A project evaluation by Oxfam of the scheme shows that household incomes increased by 286% for the very poor, 173% for the poor and 47% for the middle income groups. Furthermore, employment creation increased as farmers no longer had to target large-scale farm employment in exchange for food, producing instead food and new job opportunities on their own land.

Photograph: Oxfam/John Magrath

Ruti solar irrigation site in Zimbabwe

Source: Magrath (2015).

from the dam site to irrigate their gardens, which grow spinach, cabbage, beans, tomatoes, and other crops (Magrath, 2015). Watering can take a gruelling six hours, leaving little time for other essential work, such as hoeing, weeding and tending to the plants, in addition to household chores. A diesel pump used to provide water to the garden but the women couldn't afford the rising fuel costs, and eventually the pump broke down. Market garden members, from their community fund, have bought a solar water pump so that the women in the community can now fill their tanks each day at mid-day to water their gardens - taking no more than an hour or two. This experience also relates to Benin, described in Box 4.

These experiences illustrate the disproportionately greater benefits of solar pumping solutions for women. Energy for pumping can affect the economic activities of a man and a woman in different aspects, especially in relation to whether or not the water used is for "*men's crops*" or "*women's crops*". Solar energy can be particularly useful and cost effective to grow the types of crops that women traditionally grow the most – fruit and vegetables, much of which goes directly back to feeding the family, thus improving health and nutrition. As has been the case in the deployment of many rural energy solutions, gender characteristics play an important role in terms of energy decision-making.

BOX 4: IMPROVING FOOD SECURITY AND REDUCING HARDSHIPS: BENIN

To address the challenges of food security, the Solar Electric Light Fund installed three Solar Market Gardens in the Kalale district of northern Benin in 2007. Each garden is about half a hectare, equipped with a solar-powered drip-irrigation system and farmed by a co-operative composed of 35-45 women. Usually, each woman farms one full plant bed, the produce from which she brings home to her family, gives away, or sells. Members pay a weekly membership fee as a contribution to a fund for the amortisation of the systems. During the dry season, in particular, the irrigation system provides a safety net for farmers, reducing their daily task to a weekly or bi-weekly activity. It takes only a few minutes to water each plant bed, saving each woman up to four hours a day.

The gardens produced an average of 2 tonnes of produce each month. In the 2013-2014 dry season, the Solar Market Gardens yielded 27.7 metric tonnes of produce, valued at USD 40 000. The additional earnings and the more reliable anticipated income flows ensure the ability of women to feed, educate and provide medical care to their families - choices they can now more independently make. The success of this pilot project has led to the replication of eight new Small Market Gardens, estimated to directly benefit 3 352 individuals, with another 66 000 gaining high-quality produce from these gardens.

Photograph: SELF

Farmer in Kalale district in Benin

Source: SELF (2015); United Nations Framework Convention on Climate Change (UNFCCC, 2015)

Further advantages from solar irrigation solutions exist in the larger context of rural electrification. Solar irrigation systems could be integrated into rural electrification strategies to meet electricity demands for water treatment and supply, agro-processing and household electrification.[9] Solar pumps are generally designed to meet a peak water requirement for only 30%-40% of the total season (SNV, 2014), thus allowing the systems to be utilised for other applications to improve capacity utilisation and economic viability. Policy and regulatory measures, such as allowing excess generation to be fed into the grid, are also being considered and piloted in several countries so as to increase the utilisation of grid-connected solar pumps, diversify incomes for farmers and reduce the risks associated with water over-withdrawal (Shah and Verma 2014; Shah *et al.*, 2014).

[9] *Synergies between different end-uses in rural areas have been effectively tapped into in the past. Improved water mills in Nepal, for instance, have been used to grind grain, such as corn and rice, during the day and to generate electricity for household lighting at night (Shakya, 2014).*

RECOGNISING THE ENVIRONMENTAL IMPACT

Solar irrigation pumping solutions have a substantially lower environmental footprint compared to traditional options. The potential environmental advantages from solar pumping, compared to conventional methods, is impressive. In India, it is estimated that 5 million solar pumps can save 23 billion kilowatt-hours of electricity, or 10 billion litres of diesel. This translates into an emissions reduction of nearly 26 million tonnes of CO_2 (World Wildlife Fund (WWF) and Council of Energy, Environment and Water (CEEW), 2013). Installing 50 000 solar irrigation pumps in Bangladesh could save the country 450 million litres of diesel and reduce emissions by a million tonnes of CO_2 per annum (IDCOL, 2015).

The opportunity offered by solar irrigation for sustainable development, emissions reduction and climate resilience makes it a preferred contender for climate financing. Bangladesh's IDCOL solar irrigation programme, for instance, is supported by the World Bank under the Bangladesh Climate Change Resilience Fund (World Bank, 2013). Meanwhile, the Nordic Climate Facility has provided funding for solar powered irrigation to farmers in Benin (Nordic Development Fund (NDF) and Nordic Environment, Finance Corporation (NEFCO), 2015). Looking forward, the global solar pump market is expected to reach over 1.5 million units by 2022 compared to approximately 120 000 units in 2014, representing a 12-fold increase in market size (Grand View Research, 2015). Reaching such a scale of deployment will require substantial efforts to develop an enabling environment to support market development.

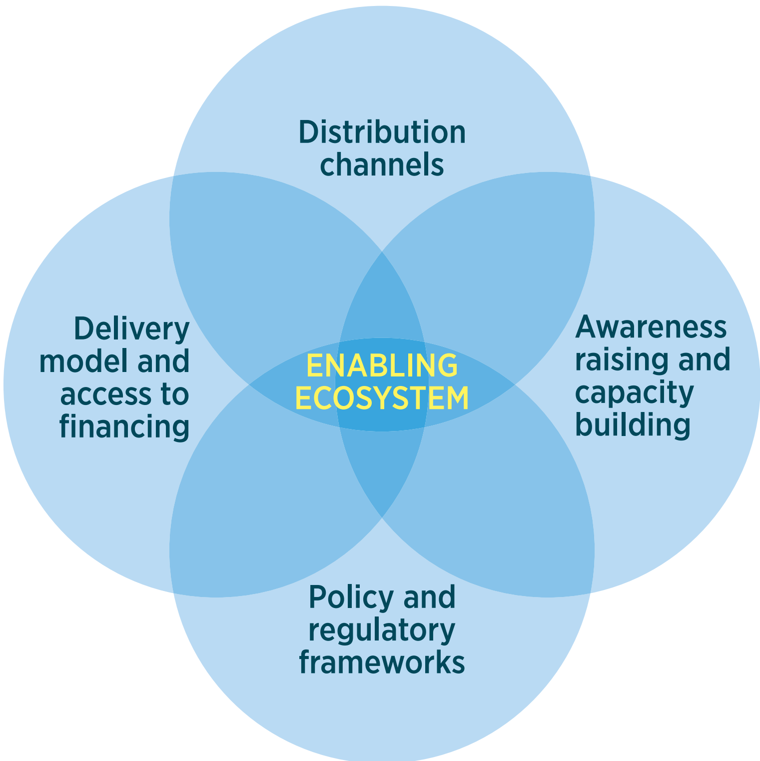
3. Scaling-Up Deployment: The Enabling Environment

The case for solar-based irrigation solutions is a compelling one. Introduced for decades on a project-by-project basis, it now requires continued market-building efforts to exploit their full potential. Several parallels can be drawn from the market penetration efforts of other off-grid renewable energy technologies, such as solar home systems and mini-grids. Decades of experience have shown that the introduction of new technologies into rural markets requires prudent consideration of, at least, the following key aspects: (i) distribution channels; (ii) delivery model and access to finance; (iii) policy and regulatory frameworks; and (iv) awareness raising and capacity building (Figure 2). In the specific case of irrigation, additional aspects include, for example, access to markets for food commodities so that farmers can realise income from increased yields to pay back the cost of the system.

ESTABLISHING APPROPRIATE DISTRIBUTION CHANNELS

Solar irrigation solutions are on-farm, decentralised interventions. As with any new market product, this means that distribution channels and service networks should be established to ensure technology access and the continuity of operations. Despite evident shortcomings, conventional fuel-based pumping systems have the advantage of an established rural distribution network that includes the skills necessary to undertake general operation and maintenance activities. A key challenge for many suppliers/service providers has been to establish a similar distribution channel for solar pumping. Furthermore, last-mile suppliers/service providers need the right environment and the incentives to spearhead product

Figure 2: Building Blocks of an Ecosystem to Support Solar Irrigation Solutions



development and applied research, and to develop and deploy solutions customised for all farmer categories. Unlike other off-grid solutions where capacity can be augmented, irrigation systems should be carefully calibrated at the design stage to optimise yield. For example, replacing a grid-connected 5 horsepower system would require an oversizing of solar panels by 1.5 times to 1.8 times if the objective is to ensure that the farmer can pump at the same rate as previously (Verma, 2016). In addition, the availability of spare parts and skilled technicians are essential in the face of a potential crop failure due to a system's downtime (SNV, 2014). Early adopters will face challenges, but as deployment grows, the distribution channels will develop.

IDENTIFYING DELIVERY MODELS AND FACILITATING ACCESS TO FINANCE

The delivery (or business) model is a key determinant for how accessible solar pumping technologies can be for farmers, whether they are subsistence, smallholder or commercial. The high upfront capital cost of solar pumps (compared to diesel or petrol pumps) inhibits off-the-shelf purchasing. Various approaches are being tested in an effort to adapt business and financing models to strengthen access and maximise the socio-economic impact. These generally involve promoting ownership of pumps as well as advancing *water-as-a-service* model to reach smallholders and subsistence farmers.

Subsistence and smallholder farmers usually have constrained cash flows that are closely linked to the cropping season(s), thus limiting surplus capital to invest in capital-intensive technologies. Commercial and large-scale farmers may be more equipped economically to afford solar-based irrigation methods and they are more likely to own a dedicated water extraction and pumping infrastructure (*e.g.* borewells). This does not imply, however, that solar pumping has no relevance to smallholder or subsistence farmers. Smallholder farmers are known to organise themselves into co-operatives to jointly procure the necessary systems or secure *water-as-a-service* from farms within the vicinity or from mobile pump operators. The case evidence of Zimbabwe, Benin and India (Tiwary, 2012) demonstrate that community models have been rather effective. Indeed, to achieve a scale-up by way of such an approach will require a careful examination of socio-cultural norms, existing water user associations, ownership, operation and management, and financing aspects of the system (Mitra *et al.*, 2014).

Small farmers, in fact, are more enthusiastic participants in the irrigation service market, since they have surplus pump capacity to spare and they are under pressure to recover investments by earning additional income from the sale of irrigation services. In some cases, entrepreneurs are procuring systems on an annual lease - as in the case of the salt pan workers in Kutch, India - and delivering irrigation services. Such a service market need not be monopolistic; several small entrepreneurs working in the same village/command area can compete with each other to ensure competitive pricing, as well as provide quality services.

A suitable delivery model should closely resemble local conditions, often requiring multiple approaches to cater to different market segments, as experienced in Bangladesh (Box 5). From a cross-sector perspective, the delivery model adopted should be able to address some of the risks of solar pumping, such as water over-extraction. An incentive for the optimum utilisation of water resources may be more effective with a *water-as-a-service* model, wherein operators would be inclined to service more farmers with available water resources while, being restricted by the transportation distances for delivery.

Financial support is often necessary to overcome the initial capital cost barrier that is associated with solar irrigation systems. This often includes capital subsidies (or grants), long-term credit and tax incentives. In Bangladesh, as shown in Box 5, a combination of equity, credit and grants (15%, 35% and 50%, respectively) is adopted to lower the capital cost of the systems. Many jurisdictions offer capital subsidies that amount to as much as 90% of system costs. These subsidies may be economically justified in some cases - based on the benefits associated with reduced fossil fuel subsidy payments and saved generation capacity - and that they

BOX 5: OWNERSHIP AND WATER-AS-A-SERVICE MODELS FOR SOLAR IRRIGATION PUMPING: BANGLADESH

The Infrastructure Development Company Ltd. (IDCOL) in Bangladesh has set itself a target to deploy 50 000 solar irrigation systems by 2025. The implementation arrangement for solar irrigation pumps builds on the successful solar home system programme which reaches almost 20 million people by way of nearly 4 million systems deployed as of March 2016. IDCOL's tried and tested ownership model - wherein microfinance has been used as a tool to enhance rural household's ability to afford capital-intensive solar home systems - is being applied to solar pumping solutions. Under the proposed arrangement, IDCOL provides a combination of grant and credit to partner organisations to install and operate the pumps.


Photograph: IDCOL

Bangladesh aims for 50 000 solar pumps by 2025

Under the ownership model, farmers may select to have the pump on their own land and, in some cases, sell water to nearby farmers. One of the key challenges has been that most farmers do not own irrigation infrastructure; instead, they rely on service providers that use mobile, fuel-based pumps and charge on a per-unit/ irrigated-area basis. In general, farmlands that are not flooded during the rainy season – and therefore are suitable for three crops per annum – are ideal for solar pumps, providing power for about 20 acres of land and three annual crop irrigations. Given Bangladesh's fragmented land ownership situation, a group of 20-25 farmers are able to form an association to buy water from one irrigation pump. Adapting to the local conditions, IDCOL is pursuing a *fee-for-service* model whereby partner organisations can install and operate the pumps and sell the water to the farmers. A total of 168 pumps are now operating, benefiting more than 3 500 farmers, with another 277 pumps projected for installation. So far, IDCOL has also explored an ownership model with smaller-sized pumps, whereby a combination of grants and credit will be extended to farmers who would be able to purchase the pumps in instalments rather than buy water from partner organisations. This will overcome the need for small farmers to seek suitable sites that require sufficiently large land area for larger-sized pumps under the fee-for-service model.

Source: IDCOL (2015); World Bank (2015).

can have an immediate effect on deployment. They can, however, be designed to be smarter and more results-based to ensure cost-effectiveness, quality and after-sales service. When markets are reasonably large, public procurement programmes for solar pumping systems could offer the opportunity to further reduce costs by tapping into economies of scale potential and ensuring timely delivery and sustainable operation.[10]

[10] Centralised procurement programmes, organised by public bodies or non-governmental development agencies, can be designed to procure a large number of solar irrigation systems from potential suppliers, instead of each end-user identifying a supplier and accessing financial support on an individual basis. A centralised programme can help reduce system-level cost (for farmers and the government), and more effectively ensure quality and after-sales service. These programmes could procure systems (wherein the specific system configurations and specifications, such as power rating of pumps, is pre-defined) or services (wherein the end-services are defined such as supply of certain litres of water per day). An end-service approach may be more relevant in cases where water demand is more predictable and can be more easily estimated and standardised such as in the case of procuring solar pumping solutions for the supply of drinking water.

Uptake is often seen to remain limited despite high capital subsidies being offered. This usually reflects a lack of financing options for the remainder of the capital cost. Capital subsidies, therefore, often need to be complemented by enhanced credit access, as has happened in Bangladesh. In India, recent efforts to scale-up solar pump deployment have focused on obtaining exemptions from rural and commercial banks on the collateral requirements (*e.g.* land mortages). Such exemptions would apply to loans under INR 500 000 (about USD 7 500) for solar pumps, with the pump systems also being regarded as assets (MNRE, 2016).

Furthermore, such support can be supplemented with incentives, such as tax exemptions, which could have a further impact on reducing the installed system costs. Country experience demonstrates that while each of these instruments has advantages and shortcomings (summarised in Table 1), a combination of these could be effective in meeting deployment and development goals.

TABLE 1: Advantages and Shortcomings of Various Financial Support Instruments

INSTRUMENTS	ADVANTAGES	SHORTCOMINGS
Capital subsidies	» Directly address high upfront capital costs and could potentially reach all types of farmers » Ease of implementation and low transaction costs from a government perspective without the need for continued operating subsidy » Potential for immediate impact on deployment	» High subsidy burden for each pump deployment » Size of market limited by, and vulnerable to, subsidy budget » Lack of incentive to reliably operate system for the long term » Market loses incentive to become more efficient and competitive » Transaction costs for end-users in accessing subsidies » Possibility of not reaching the targeted economic group
Long-term credit	» Design can be tailored to local economic conditions (*e.g.* down payment and payback options) » Incentive to continue operating the systems until costs are fully recovered » Deployment may be slower but supports sustainable market development » Can be combined with efforts to increase financial inclusion of farmers	» Spreads risk of capital recovery over a longer time period » Long-term budgetary commitment » Requires access to financial institutions » May require inhibiting collateral requirements and, hence, possibility of not reaching the targeted economic group » Transaction costs associated with collection and risk of defaults
Fiscal incentives (*e.g.* value added tax, customs duty exemptions)	» Directly impacts high upfront capital cost » Potential for immediate impact on deployment » Supports suppliers (bulk procurers) to achieve economies of scale	» May not be sufficient to address the affordability challenge » Exemptions usually restricted to specific components (*e.g.* modules) alone » Markets are vulnerable to changes in fiscal policy usually not controlled by energy or agriculture ministries. » Under the purview of non-energy insittutions.

BOX 6: RENT-TO-OWN CONSUMER FINANCE MODEL FOR SOLAR IRRIGATION

Unlike traditional microfinance, which provides monetary loans for working capital to informal businesses, a rent-to-own model involves loaning productive assets or equipment to viable small- and medium-sized enterprises and small-scale entrepreneurs in rural areas, especially farmers. The asset itself acts as a form of collateral to help in reducing the client's chance of spiralling into debt and further poverty. The customer pays a (minimum) fixed monthly or quarterly fee. Interest is charged, on a monthly basis, on the declining principal balance. After the balance is paid in full, the customer owns the equipment. The rent-to-own business model focuses on providing equipment with a set of services and advantages for the renters:

- Repairs: If the rented property is in need of repair, service is typically included at no charge.
- Down payment: Most agreements do not require a down payment, so the buyer has access to the property without making a large upfront payment.
- Ownership trial: The business model allows the renter to take temporary ownership of the property with the option of backing out of the transaction if he/she is dissatisfied.
- Fixed payments: If the cost of the property (or the value of the home) increases, the renter is protected from monthly payment increases.
- Price protection: Contracts will state the purchase price of the goods, thereby allowing the renter to lock in the price paid for the property.

A form of the rent-to-own model is being adopted by SunFarmer in Nepal, where affordable financing at three-year terms is provided to farmers. The model works closely with cooperatives which, in fact, identify the farms and collect monthly payments on behalf of SunFarmer.

Source: Zahner (2015); SunFarmer (2015).

Besides the three common instruments, consumer finance models such as leasing and rent-to-own are also being implemented (Box 6). In general, and irrespective of which instrument (or a combination thereof) is adopted, emphasis should be laid on reducing the transaction costs that are associated with accessing support and facilitating market development.

PUTTING IN PLACE ENABLING POLICY AND REGULATORY FRAMEWORKS

The potential benefits that solar pumping solutions offer should be recognised within sector-specific strategies. Greater coordination between ministries and the public entities that are responsible for water, agriculture and energy can ensure that solutions are tailored to local conditions and can address the cross-sector challenges. As noted earlier, support policies will be necessary to level the playing field for solar solutions vis-à-vis conventional options. Such policies need to be oriented towards creating sustainable markets and allowing innovation in terms of delivery models and technology configurations. While the time and cost of importing equipment is to be minimised, adequate quality control and standards need to be in place to avoid the dumping of cheap, sub-optimum systems on the market.

The regulatory regime also needs to be conducive to market development and natural resource considerations such as water extraction rates. Several programmes and initiatives consider solar irrigation pumping systems as an energy generation infrastructure that could feed into the grid when not being utilised for irrigation. This approach could increase system utilisation, strengthen tail-end grid supply, diversify income avenues for farmers and reduce the risks associated with the over-pumping of water from zero-marginal-cost solar systems (Box 7).

BOX 7: SOLAR PUMPS AS CASH CROPS: HARNESSING THE SUN TO PRODUCE FOOD, GENERATE ELECTRICITY AND INCREASE INCOMES

Solar water pumps have a near zero marginal cost of operation, thus raising concerns of water over-withdrawal. Several programmes, therefore, offer packaged drip-irrigation or micro-irrigation options, while simultaneously placing a cap on the pump capacity receiving public support. These measures - although potentially effective in the short term - will be difficult to enforce as costs decrease and unsubsidised markets develop. One of the solutions proposed is that solar pumps export surplus generation to the grid. This would incentivise water- and energy-use efficiency and augment the incomes of farmers.

Photograph: IWMI/Prashanth Vishwanathan

Farmer Raman Parmar carries out routine panel cleaning

In 2014, the state of Karnataka in India launched a scheme to deploy solar-powered irrigation pumps on a net metering basis. The scheme document noted that "*The excess solar generation available…will add generation capacity to the grid and can be a source of revenue of the farmer, thus encouraging farming and same time giving a solution for energy crisis*" (KREDL, 2014; Shah *et al.* 2014). A pilot project, implemented in the state of Gujarat under the Solar Power as a Remunerative Crop programme initiative of the International Water Management Institute, has showcased the effectiveness of such a solution. A grid-tied solar system of 8 kilowatt per hour was allowed to export surplus power to the grid at INR 5 per unit (USD 0.078). In June 2015, the farmer received INR 7 500 (USD 118) as compensation for electricity fed into the grid over a period of four months. If the same energy had been used to pump water, an estimated 8 million litres of groundwater would have been extracted.

Purchasing surplus power from each individual farmer involves high transaction costs for the electricity utility. In Dhundi village in Gujarat, the second field pilot project of the International Water Management Institute has organised six solar pump irrigators into a Solar Pump Irrigators' Cooperative Enterprise. These solar farmers are connected through a mini-grid which will pool their surplus power and evacuate it at a single point (Nair, 2015). The informal cooperative will be responsible for the operation and maintenance and will also distribute the earnings among the farmer members. Further aggregation can be made at the feeder level wherein solar capacity (1-2 megawatts) is developed feeding directly into the rural distribution network. Combining efforts to replace all pumps with energy efficient ones would ensure optimum utilisation of capacity, bring down costs and ensure a reliable supply. Such an aggregated approach could be more cost effective and manageable, and could open private sector opportunities for public-private partnership alliances with local distribution companies (Prayas, 2015). A challenge to this approach is the lack of incentives for farmers to become energy and water efficient, which would result in their boosting pumping with the operator wishing to maximise evacuation. In addition, the tariffs set under pump-level net metring schemes need to be carefully calibrated to disincentivise over-withdrawal and not become the primary source of income for farmers.

Source: IWMI (2015); Indian Express (2015).

RAISING AWARENESS AND UNDERTAKING CAPACITY BUILDING

In a number of markets, where substantial financial support has been proposed for solar pumping, uptake has been rather slow due to a reluctance to embrace new technologies, in general. A key component to developing the market for solar pumping in rural areas is to raise awareness and demonstrate the viability and reliability of the technology. Such efforts can increase awareness on the technology options that are available, the financial support on offer and the economic benefits that can accrue over time. In addition, it is essential to take into account capacity building to ensure long-term operability, as well as to target the various stakeholders that cover the entire value chain, including those involved in policy and programme formulation; design and installation of solar pumping and complementary technologies (*e.g.* drip irrigation); financing; and operation and maintenance. Past experience has shown that the solar panel itself is highly reliable and the system failures that may occur are largely due to balance of system components (*e.g.* inverters, pumps) and distribution infrastructure (*e.g.* piping) (IRENA, 2013). Solar pumping programmes packaged to include drip irrigation - require relatively advanced technical skills to design, install and operate - and further capital investment. For farmers, support should extend to accessing agrifood markets and assessing market opportunities to realise increased incomes, including cash crops in the dry season. There are several ongoing efforts to provide technology practitioners and service providers the tools to assess the feasibility and design of solar pumping systems. GIZ, for instance, is in the process of preparing a comprehensive manual and toolbox for solar pumping irrigation solutions, specifically targeting practitioners (GIZ, 2016).

4. Key Policy Messages: Adopting a Nexus Approach

Energy for irrigation is a typical example of the nexus between water, energy and food. The linkage defines the source of energy that is utilised to deliver water to fields - or lack thereof - and the spillover effects on water supply and, in turn, on food production and security. Therefore, these effects should be adequately taken into account in the design of policies and programmes that aim to support solar pumping to ensure that sustainability is maximised across these sectors. In this context, decision makers are encouraged to consider the following:

» **Foster innovation and flexibility when delivering solar pumping solutions.** Country experience has shown that tailor-made delivery models will be necessary to reach subsistence, smallholders and commercial farmers so that they can reap the full socio-economic benefits that the technology has to offer. Existing practices should be closely examined to identify the most suitable entry points for solar pumping - whether through ownership or by way of a *water-as-a-service* approach. Where rainfed agriculture is predominant and access to modern energy is limited, pilot projects can play an important role in identifying which delivery model is most suitable. Partnerships between governments, international development agencies, financial institutions and the private sector are critical vehicles, not only for undertaking applied research and development, but also for supporting policy, financing and technical innovation to sustainably deploy these solutions under complex circumstances.

» **Take into account target groups and the long-term sustainability of markets when considering financial instruments to support solar pumping.** The cycle of increased energy consumption and rising fiscal costs can be broken by linking financial support to the generation asset rather than to that of fuel. The choice of financial support, however, should take into account the long-term sustainability of the market. A combination of incentives, such as grants, long-term credit and tax exemptions, can play an important role in making these solutions more affordable while, at the same time, leave scope for market development. Depending on local contexts, these can be integrated into existing rural financing networks (*e.g.* MFIs) and community organisation structures (*e.g.* cooperatives). Additionally, linking financial

Photograph: Raghav Agarwal

Solar water pump in India

Photograph: SELF

Produce in Solar Market Gardens in Benin

support with pre-conditions, such as existence of drip irrigation, can help mitigate the water-energy nexus challenge, but could also undermine the ability of farmers to access solar pumping technology.

» **Focus on after-sales support and capacity building.** Solar pumping programmes need to be designed to ensure that the operators have access to after-sales support for regular operation and maintenance, as well as in the event of system breakdown. The provision for this support, both in terms of earmarking responsibility as well as ensuring adequate human and financial capacity, should be an integral part of the programme design and system procurement process. Local technical capacity building can be an effective tool to minimise response times, undertake periodic maintainence locally and contribute to the overall sustainability of system operation.

» **Package energy and water-efficient solutions in water-stressed areas.** Shifting to drip irrigation, in particular for smallholders, requires a substantial behavioural change. Drip systems are often expensive and difficult to manage, and require advanced skill sets. In addition, over-pumping and salinity may actually result in reducing the efficiency of the system if the network is not adequately cleaned and maintained. Therefore, the technology should be customised to adapt to local conditions, especially with respect to capacity building across the value chain. It is also essential to note that the adoption of technologies, such as drip irrigation, may increase water and energy use efficiency, but might increase overall consumption owing to an expansion in irrigated areas and/or an increase in the intensity of cropping and irrigation.

» **Assess the direct and indirect impacts on water resources**. Large-scale solar pumping programmes need to integrate some form of water accounting as part of the programme design and monitoring process. This will ensure that improvements in the reliability and affordability of energy services do not further aggravate the depletion of aquifer. Some programmes limit the capacity of the pump to act as a mechanism in regulating water withdrawal - a limitation that should be carefully examined. When less than

Photograph: World Bank

Solar water pump in Bangladesh

optimal, farmers tend to use solar pumps as a supplementary irrigation method to conventional pumps. It is not uncommon for them to use solar pumps that have been procured through government programmes in tandem with existing diesel and electric-pumps. Moreover, increases in irrigated land areas, which can indirectly impact absolute water use, should also be taken into account.

» **Monitor performance and gather data**. The evidence base on the impacts of solar pumping interventions on cropping patterns, yields, irrigation methods and cost savings over time is limited. Datasets are crucial for demonstrating the business case for intervention, and they are useful for informing the development of delivery models for various scales of farming. The data also can contribute to approaches with regard to the large-scale deployment of solar pumps, including over-withdrawal of water. Stakeholders involved in the development of pilot projects should be encouraged to put in place adequate data-gathering measures to build on the knowledge base of post-deployment impacts of solar pumping solutions. These measures should be mainstreamed into relevant policies and programmes in an effort to standardise data gathering, and to make data available and accessible.

» **Consider the influence of availability and cost of energy on the choice of crops grown**. The first green revolution - most evident in South Asia - is a testament to the enabling role that affordable energy can play in increasing yields through irrigation. Except for its impact on groundwater resources, it also demonstrates how access to energy has positively influenced the transition towards water-intensive wheat and paddy crops in terms of food production. Solar pumps provide an affordable and reliable energy that may influence the cropping decisions of subsistence, smallholders and commercial farmers. These dynamics need to be closely considered when planning for large-scale deployment of solar pumping solutions.

Photograph: IDCOL

Grameen Shakti solar irrigation pump in Sapahar Noagoan in Bangladesh

» **Adopt an integrated approach to programme design**. Solar pumps have the potential to act as anchor loads to improve access to electricity for surrounding communities. An integrated assessment of unmet demand (basic and productive) near irrigated areas would be useful when designing systems with a view to trigger wider socio-economic development through improved energy access. Given the cross-sector nature of intervention, solar pumping programmes should include the three sectors of water, energy and agriculture to enable the mitigation of potential trade-offs. When effectively designed and implemented, these programmes have the potential to contribute to multiple Sustainable Development Goals.

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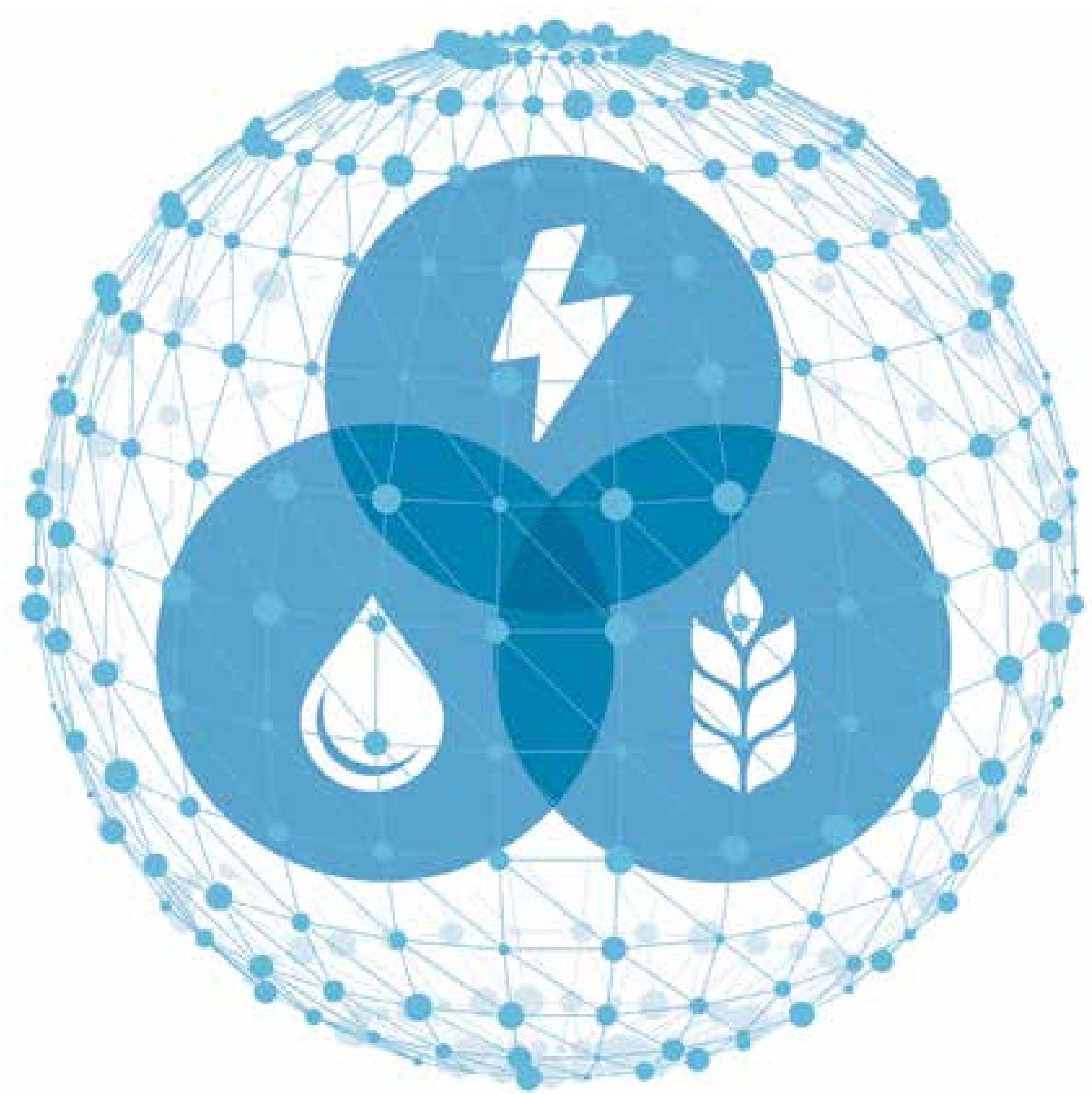

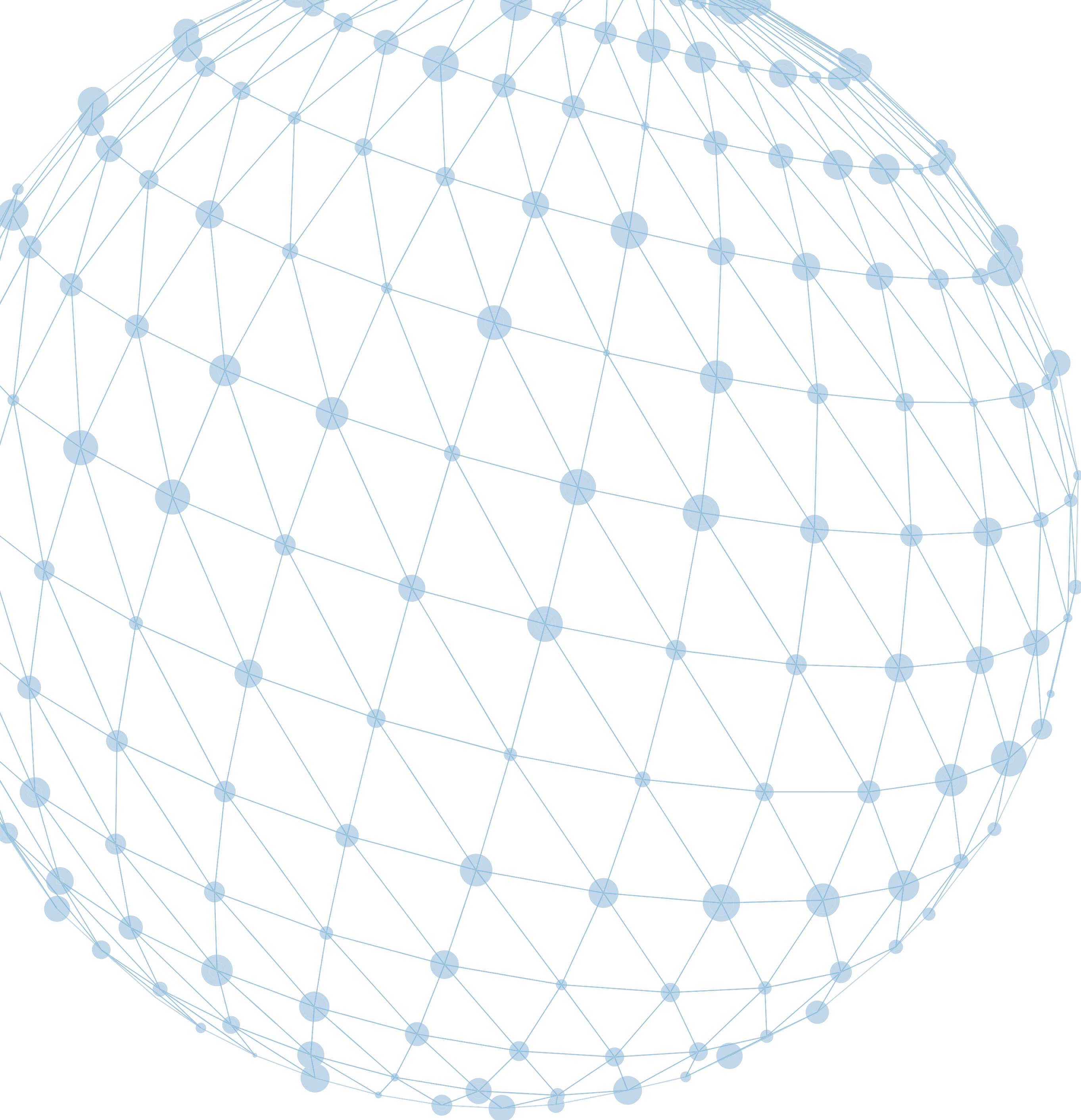

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