Food and Agriculture Organization of the United Nations

The benefits and risks of solar-powered irrigation - a global overview

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The benefits and risks of solar-powered irrigation - a global overview

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About Powering Agriculture: An Energy Grand Challenge for Development (PAEGC)

In 2012, the United States Agency for International Development (USAID), the Government of Sweden (SIDA), the Government of Germany (BMZ), Duke Energy Corporation and the United States Overseas Private Investment Corporation (OPIC (collectively, the "Founding Partners") combined resources to create the "Powering Agriculture: An Energy Grand Challenge for Development" (PAEGC) initiative. The objective of PAEGC is to support new and sustainable approaches to accelerate the development and deployment of clean energy solutions to increase agriculture productivity and/or value for farmers and agribusinesses in developing countries and emerging regions that lack access to reliable, affordable clean energy.

PAEGC utilizes the financial and technical resources of its Founding Partners to support its innovator cohort's implementation of clean energy technologies and business models that: (i) enhance agricultural yields/productivity; (ii) decrease post-harvest loss; (iii) improve farmer and agribusiness income-generating opportunities and revenues; and/or (iv) increase energy efficiency and associated savings within the operations of farms and agribusinesses – while stimulating low-carbon economic growth within the agriculture sector of developing countries and emerging regions.

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Foreword

In 2015, the Food and Agriculture Organization of the United Nations (FAO) and the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH hosted an exploratory workshop to better understand the potential of solar-powered irrigation systems (SPIS) for developing countries. During the workshop, representatives from nineteen countries shared their experiences and knowledge of solar pumping technologies, covering large to small-scale systems in tropical to arid climate zones, for vegetable gardens, orchards and livestock watering, using surface and groundwater.

SPIS are nothing new. The first solar-powered pumps were installed in the late 1970s. Nevertheless, it was not until 2009 when the price of solar panels started to decrease dramatically, making solar technologies affordable for agricultural purposes. Since then, there has been a race for the development of more powerful and efficient systems; every year, there are larger pumps on the market that can withdraw water from greater depths. The market potential for both small-scale and large-scale systems is great.. Prices continue to drop. The International Renewable Energy Agency (IRENA) is projecting a 59 percent cost reduction for electricity generated by solar PV by 2025 compared to 2015 prices.

SPIS have many advantages, providing a clean alternative to fossil fuels and enabling the development of low-carbon irrigated agriculture. In areas with no or unreliable access to energy, they contribute to rural electrification and reduce energy costs for irrigation. This improves the access to water of many farmers and can have knock-on effects on agricultural productivity and incomes.

Now in 2018, this report takes stock of the experiences with SPIS around the world. What are the real costs and benefits of SPIS compared with other technologies? What rules, regulations and policies are needed to manage the risks and realize the potential of such systems? What are viable business models? How can smallholders benefit? How can the risk of groundwater depletion be addressed effectively? How can SPIS help to empower women and promote gender equity? What types of capacity development programmes are needed to support farmers, extension workers, local private sectors and others? What are the opportunities for knowledge exchange and technology transfer?

Nevertheless, there are also challenges with the uptake and use of SPIS that this report explores. It finds that access to finance, especially for small-scale farmers, as well as the accessibility of good quality products and services remains an issue in many countries. Further capacity development activities are needed to ensure to users have a basic understanding of set-up and functions of the system, and can take care of the daily operation and maintenance. In line with this, FAO and GIZ have also developed a Toolbox on Solar-Powered irrigation Systems for advisors.

The report also stresses the importance of water resources assessments and planning to avoid increasing pressures on water resources. By reducing costs, SPIS can improve people's access to water. Nevertheless, without incentive to moderate water consumption, there is a strong risk of overexploitation, and even depletion of water resources. Coupling SPIS with efficient irrigation methods, such as drip irrigation, does not guarantee that water is saved. Water is simply reallocated to a greater area of land, more water-intensive crops, an additional cropping season, or to other uses. In some cases, water is sold to neighbours, generating an extra income for farmers and adding further pressure on water resources where they are scarce.

This report looks at how different countries work to create an enabling environment for SPIS technologies, while managing the risks and challenges that come with it. As such, it is a timely reflection of past and future trends and clearly highlights the interlinked nature of water, energy and agriculture.

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Abbreviations and acronyms

AC	Alternating Current
BMZ	Federal Ministry of Economic Cooperation and Development, Government of Germany
CAM	Crédit Agricole du Maroc
CONAGUA	National Water Commission of Mexico
COTA	Technical Committee for Groundwater, Mexico
CTA	Technical Centre for Agricultural and Rural Cooperation, Wageningen, The Netherlands
CWAC	California Water Action Cooperative
DC	Direct Current
DGPRE	Government Department for the Planning of Water Resources, Senegal
EMP	Environmental management plan
ESCO	Energy Services Company
EU	European Union
FAO	Food and Agricultural Organization of the United Nations
FBR	Fachvereinigung Betriebs- und Regenwassernutzung
FIT	Feed-In Tariff
GDP	Gross Domestic Product
GEF	Global Environment Facility
GHG	Greenhouse Gas
GIE	Groupement d'intérêt économique, economic interest group
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
GW	gigaWatt

ha	hectare
hp	horsepower
ICIMOD	International Centre for Integrated Mountain Development
IDCOL	Infrastructure Development Company Limited, Bangladesh
Int.	International
INR	Indian Rupees
IREDA	Indian Renewable Energy Development Agency
IRENA	The International Renewable Energy Agency
IRR	Internal Rate of Return
ITC	Investment Tax Credit, US
IWMI	International Water Management Institute
IWRM	Integrated Water Resources Management
KES	Kenyan shilling
KSSI	Kenya Smallholder Solar Irrigation
kW	kiloWatt
kWh	kiloWatt hour
kWp	kiloWatt peak
LAERFTE	Renewable Energy Law, Mexico
m	meter
MAD	Moroccan dirham
MASEN	Moroccan Agency for Sustainable Energy
MPPT	Maximum Power Point Tracking
MUS	Multiple Use System
MW	MegaWatt

NABARD	National Bank for Agriculture and Rural Development, India
NDMA	National Drought Management Authority, Kenya
NGO	Non-governmental organization
NRREP	National Rural and Renewable Energy Programme
O&M	Operation & Maintenance
OPIC	United States Overseas Private Investment Corporation
PAEGC	Powering Agriculture: An Energy Grand Challenge for Development
PNEEI	Programme National d'Economie d'Eau d'Irrigation (Morocco)
PV	Photovoltaic
PVC	Polyvinyl Chloride
REAP	Rural Energy for America Program, US
RET	Renewable Energy Technology
ROI	Return on Investment
RPO	Renewable Purchase Obligation
SAGARPA	Secretariat of Agriculture, Livestock, Rural Development, Fisheries and Food, Mexico's Agriculture Ministry
SCARDB	State Cooperative Agricultural Rural Development Bank
SDG	Sustainable Development Goals
SGMA	Sustainable Groundwater Management Act, US
SIDA	Swedish International Development Cooperation Agency
SEL	Sustainable Energy Lab, Columbia University (US)
Solar Generator	A collection of solar panels (or PV panels), wired in series or parallel, arranged to power a solar pump system
SPaRC	Solar Power as Remunerative Crop
SPICE	Solar Pump Irrigators' Cooperative Enterprise, India

SPIS	Solar Powered Irrigation Systems
SWP	Solar water pump
TAWS	Tufanganj Anwesha Welfare Society (Indian NGO)
UNDP	United Nations Development Programme
USAID	United States Agency for International Development
USDA	United States Department of Agriculture
V	Volt
WaPOR	(FAO) Water Productivity Open-access Portal

1. Introduction

1.1 BACKGROUND

Agriculture is the single largest employer in the world, sustaining the livelihoods of 40 percent of the world's population, many of whom continue to live in poverty (United Nations, 2015). Irrigation is among the measures that can improve yields, reduce vulnerability to changing rainfall patterns and enable multiple cropping practices (FAO, 2011). As such, irrigation is often seen as the engine that helps to ensure food security, generates incomes, provides jobs and drives rural development. Energy is a key input for irrigation services.

As investment costs for solar powered irrigation systems (SPIS) are coming down and subsidy schemes for SPIS are being rolled out, solar technologies are becoming a viable option for both large and small-scale farmers. SPIS provide reliable and affordable energy, potentially reducing energy costs for irrigation. In rural areas where diesel fuel is expensive or where reliable access to the electricity grid is lacking, they can provide a relatively flexible and climate-friendly alternative energy source. SPIS can be used in large-scale irrigation systems as well as for decentralized, small-scale irrigation.

Some countries are promoting SPIS in the framework of national action plans regarding climate change as a way to reduce emissions from agriculture. The operation of solar pumps does not produce any greenhouse gas (GHG) emissions. Life cycle assessments of SPIS, accounting for emissions in a cradle-to-grave scenario, indicate a potential reduction in GHG emissions per unit of energy used for water pumping (CO2-eq/kWh) of 95 to 97 percent as compared with pumps operated with grid electricity (global average energy mix) and 97 to 98 percent as compared with diesel pumps (GIZ, 2016).

Nevertheless, it is important to note that SPIS – if not adequately managed and regulated – bear the risk of supporting unsustainable water use. Once the systems are installed, there is no cost per unit of power and thus no financial incentive for farmers to save on fuel or electricity for water pumping. This can lead to wasteful water use, over-abstraction of groundwater, and low field application efficiency. In some cases, farmers sell water to their neighbours at a profit, increasing the overall water withdrawals. Recognizing the water-related risks and addressing those from the beginning – especially in the financing and design stages – will be crucial to ensure the sustainable use of SPIS technology.

In light of the rapid expansion of SPIS, there is an opportunity to not simply introduce a clean, climate-smart and innovative energy technology, but to think strategically about how this technology can be used to encourage more sustainable use of groundwater resources, to create more inclusive finance and management structures and to foster more integrated thinking about solutions around the water-energy-food nexus.

1.2 GROWING INTEREST IN SOLAR POWERED IRRIGATION SOLUTIONS

There is a growing interest in solar-powered irrigation solutions around the world, noticeable in the increasingly frequent requests from agricultural institutions in developing countries for installation, finance and training. In May 2015, the Food and Agriculture Organization of the

United Nations (FAO) and the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH hosted an exploratory workshop to better understand the potential of SPIS for developing countries. Representatives from 19 countries shared their experiences with solar pumping technologies – from large to small-scale, from tropical to arid climate zones, for vegetable gardens, orchards and livestock watering, using surface and groundwater.

It became clear that there was a need to synthesize these experiences and to respond to the issues, questions and needs that were raised during the workshop. What are the real costs and benefits of SPIS compared with other technologies? What rules, regulations and policies are needed to manage the risks and realize the potential of SPIS? What are viable business models for SPIS? How can smallholders benefit from SPIS technology? How can the risk of groundwater depletion be addressed effectively? How can SPIS help to empower women and promote gender equity? What types of capacity development programmes are needed to support farmers, extension workers, local private sectors and others? What are the opportunities for knowledge exchange and technology transfer?

FAO and GIZ decided to follow up on these questions with a global project that is part of the "Powering Agriculture: An Energy Grand Challenge for Development" (PAEGC) initiative. The overall aim of the project is to: (i) learn from good practices around the world; (ii) foster policy dialogue across sectors on topics such as finance, green jobs and groundwater management; and (iii) support the responsible use of SPIS through training and improved advisory services. This report is one of the outputs of this project.

Drawing on the experiences in different countries and projects, this report seeks to give a state-of-the art overview of historic and current trends in solar pumping technologies and to explore different approaches to promoting, regulating and managing SPIS. The report is based on an online survey, personal, telephone and Skype interviews, site visits to India, Kenya and Ethiopia, and an extensive literature review.

1.3 METHODOLOGY

1.3.1 Literature Research

A wealth of reports, case studies, product information, websites and published papers exists on solar-powered irrigation. A systematic overview was obtained and the most important information used is listed in the references. Several reports dating from several years back are no longer relevant, as the SPIS sector is changing rapidly due to increasing efficiency and decreasing investment costs in the last years. Different configurations of systems are now possible that were not considered previously, and many innovations and technical advances have been made.

1.3.2 Online survey

An online survey was developed to source information and to obtain a general overview of experiences with SPIS around the world. The survey was designed in English and French and made available on a dedicated website. It was structured in three parts:

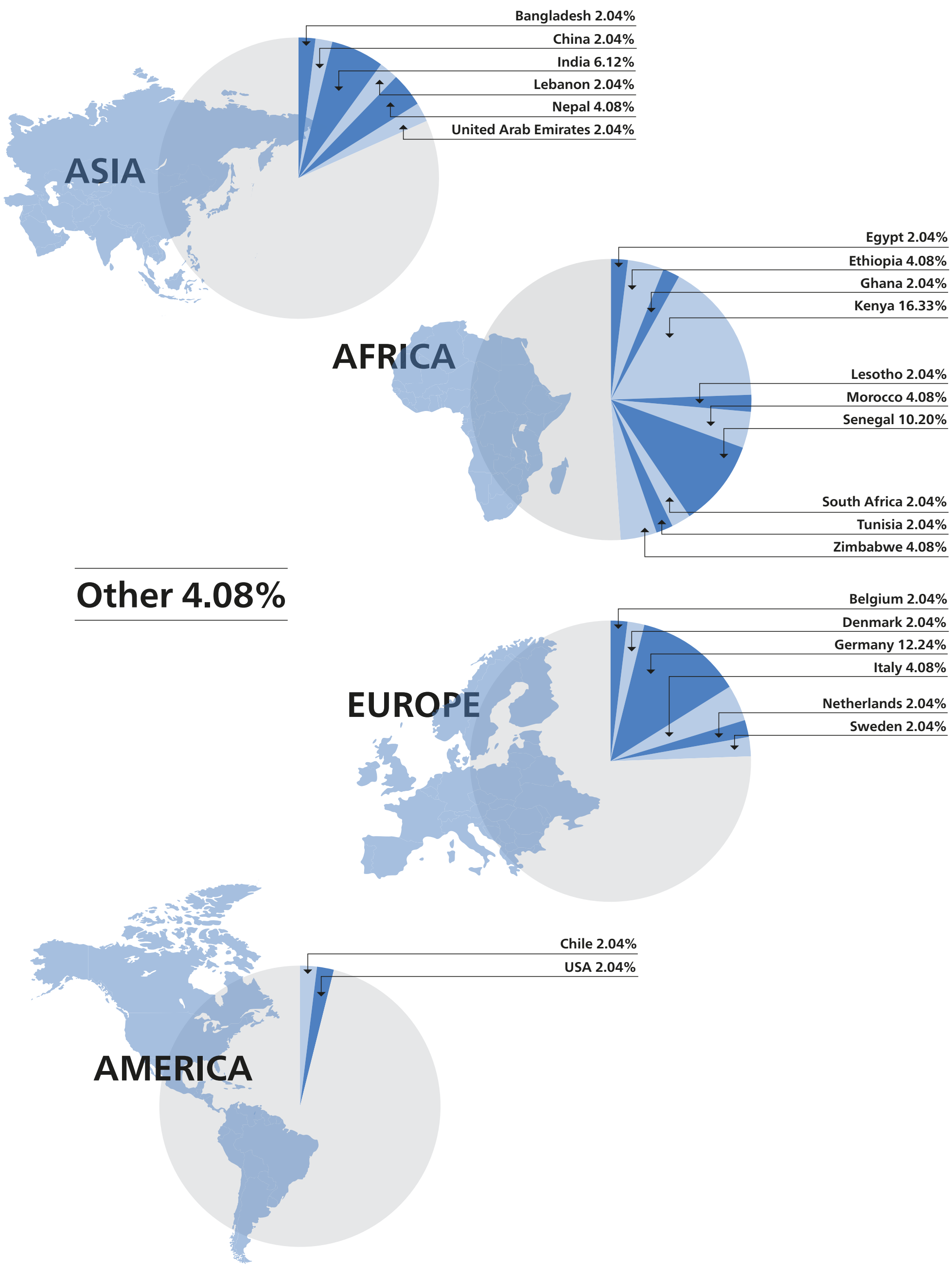
- Information on the person responding to the survey;
- Country-specific information on SPIS;
- Information on an SPIS case study.

The link to the survey was sent to 156 people by e-mail. The recipients were people already working with SPIS technologies, including government staff, private sector actors, non-governmental organizations (NGOs) and researchers. Among the people contacted were the participants in a FAO-GIZ workshop on the potential of solar-powered irrigation in May 2015. Other recipients were identified in relevant online forums and through intensive Internet research. The people contacted received a short explanation about the context, purpose and content of the survey and a link to the questionnaire. It was sent out on 5 April 2017 with an initial deadline of 24 April 2017, later extended to 1 May 1 2017.

Statistics on the background and responses of the survey participants can be found in Figure 2. Answers to the questionnaire varied in length and degree of completion. Participants were encouraged to reply to only the questions relevant to them. Overall, 54 individuals responded to the survey – i.e. 35 percent of those contacted.

FIGURE 1

Answers to the questionnaire were received from these countries



Relevant information was received from the questionnaire responses, coming from 25 countries. The sample is not (and was not intended to be) representative. Most of the people answering the survey were technical experts, technical advisors and trainers, as well as heads of departments and project managers; 15 percent of them were female.

- 73 percent confirmed that their respective countries had government programmes and policies to promote small-scale irrigation.
- 71 percent stated that their respective countries had programmes or policies on adapting agricultural water management to climate change.
- Only 46 percent said there were specific regulations limiting groundwater abstraction for irrigation purposes.

Regarding financial support for SPIS:

- 67 percent said that there are (financial) institutions that provide loans (and subsidies) for solar-powered irrigation.
- 53 percent described significant sector investments or public-private-partnerships for SPIS in their countries.

Regarding the experience with SPIS:

- 55 percent strongly agreed that the performance of the SPIS they were describing was good; 45 percent agreed.
- 52 percent strongly agreed that there were significant positive changes in agricultural productivity after the installation of SPIS; 48 percent agreed.
- 47 percent strongly agreed that changes in income were significant after the installation of SPIS; 43 percent agreed and 10 percent disagreed.

Servicing challenges for system repairs over the long term were seen by 31 percent; only 21 percent said that repair costs were high.

As expected, the degree of relevant and useable information varied. Those respondents who provided contact details were contacted to solicit missing information.

1.3.3 Interviews

Twenty-five people engaged in research, development and/or implementation of SPIS were interviewed in person or by Skype/phone. During visits to Kenya, Ethiopia and India, people working with SPIS were also interviewed. Two smallholder farms in Kenya with solar-powered irrigation and drip irrigation were visited, as well as a supplier of SPIS. This helped to put the results of the online survey, as well as the interviews and the literature research, into perspective. A training course at one of the solar pump manufacturers' development centres supported the better understanding of technological challenges as well as the significant advances made during the last years.

2. The evolution of Solar Powered Irrigation Systems (SPIS)

There is an increasing demand for irrigation due to the need for higher food production for a rising world population and decreasing supplies of freshwater in the context of a changing climate. High diesel and electricity costs and often unreliable energy services affect the pumping requirements for irrigation for small and large farmers. In many rural areas, grid electricity is not, or is only sporadically, available. Using solar energy for irrigation water pumping is a promising alternative to conventional electricity and diesel-based pumping systems. Solar water pumping is based on photovoltaic (PV) technology, which converts solar energy into electrical energy to run a direct current (DC) or alternating current (AC) motor-based water pump.

This chapter gives an overview of solar water pumping from its early days to present day uses and costs, as well as innovations and future trends. This brief history of solar water pumping shows that this technology goes back farther than most of us would expect. It draws attention to the complexity of the SPIS, taking into account variability in sunshine, clouds, rain and wind to which systems need to be adapted. Some rough cost estimations of SPIS components provide a first overview of the financial viability of such systems. The different configurations of SPIS are presented, followed by a discussion of key technological developments, which are already in use or slated to become important in the near future, ultimately making SPIS more sustainable and user-friendly (see also GIZ, 2018)

2.1 BRIEF HISTORY OF SOLAR WATER PUMPING

The first solar pumps were installed in the late 1970s. Since then, PV water pumping systems have shown significant advancements. The first-generation PV pumping systems used centrifugal pumps, usually driven by DC motors or variable frequency AC motors, with proven long-term reliability and hydraulic efficiency varying from 25 percent to 35 percent. The second-generation PV pumping systems introduced positive displacement pumps, progressive cavity pumps and diaphragm pumps for smaller water quantities, generally characterized by lower PV input power requirements, lower capital costs and higher hydraulic efficiencies (Chandel, 2015). This pioneering work was piloted in different countries around the world.

In the late 1970s and early 1980s, numerous problems were experienced in many of the pilot sites, as recorded in a World Bank/United Nations Development Programme (UNDP) project on solar pumping (Halcrow et al., 1981). These relatively minor problems included:

- Incorrect wiring;
- Terminals that did not readily provide good electrical connection;
- Failure of electronic circuitry (due either to overheating or to overload);
- Possibility of safety hazard due to dangerous DC voltages;
- Broken module cover glasses (both in transit and on-site);
- Suction pipework trapping air in cavities;
- Foot valves jamming or leaking;
- Inadequate packing for shipping.

FIGURE 2

A solar-powered irrigation system near Bamako, Mali, 1981

Photo: Hans Hartung

Most of these problems are now largely eliminated. The year 2009 - when the world was recovering from the global financial crisis - marked a turning point for solar-powered pumping. The price of solar panels decreased dramatically (see Fig. 2). This made larger solar pumping systems affordable for the agriculture sector. Since that time, there has been a race for the development of more powerful and efficient systems; every year, there are larger pumps on the market that can withdraw water from greater depths. The market potential for both small-scale and large-scale systems is great.

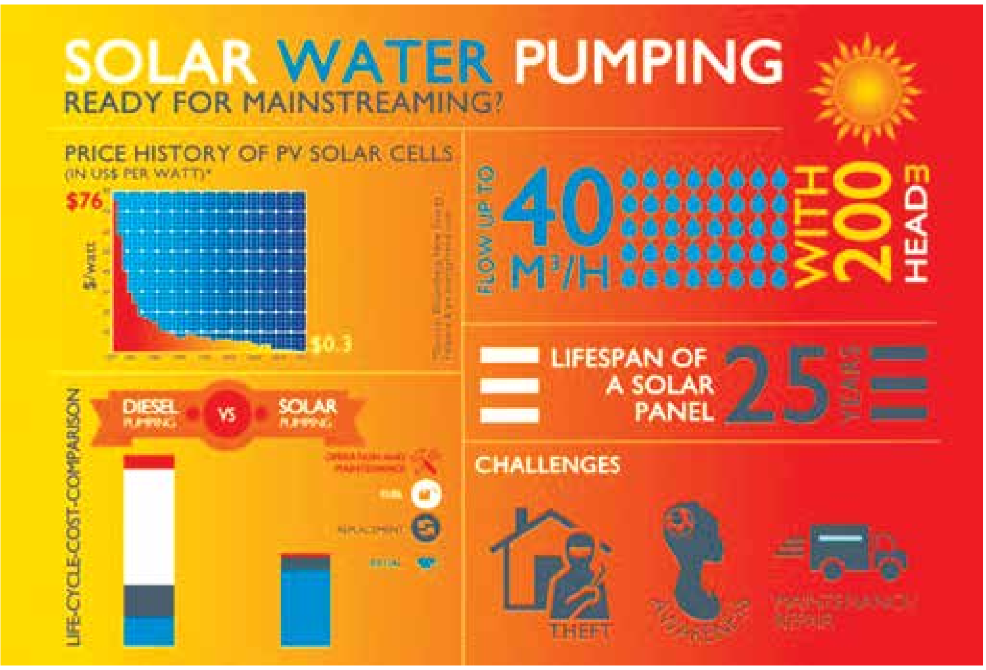
Current solar pumping technology uses electronic systems and intelligent software, which have further increased the output power, performance and overall efficiency of SPIS. The key device is now the electronic controller, which adapts the available power from the solar generator to the solar pump. Besides its controlling function, it provides inputs for real-time monitoring of various parameters, such as borehole water levels and storage tank levels, as well as pump speed. It uses Maximum Power Point Tracking (MPPT) technology to optimize the water output of the pumping system. Not only have prices for PV panels dropped, but also the prices for pumps and controllers – not as dramatically as the panels, but still a decrease of about 30 percent from the year 2009 to 2017 (information from manufacturers).

2.2 SOLAR POWERED IRRIGATION SYSTEMS PLANNING

SPIS refers to solar-powered pumps being used for irrigation. SPIS are relatively complex systems and their design requires not only a fit-for-purpose PV pump system and irrigation infrastructure (supply side), but also an assessment of water requirements and irrigation calendar (demand side), as well as skills and knowledge of the end user. Crop water requirements change with the weather and as the crop develops. Fig. 3 shows the various data to take into account when designing a complete SPIS. Weather, water, soil and crop data will determine the crop water requirement at the specific site, which also depends on the irrigation system used. Calculating crop water requirements is a complex task but with the help of useful software tools, such as CROPWAT, experienced agricultural extension workers are able to advise individual producers. CROPWAT is available from FAO after registration and is free of charge: www.fao.org/land-water/databases-and-software/cropwat/en/

FIGURE 3

A short summary of the potentials and the challenges of solar water pumping

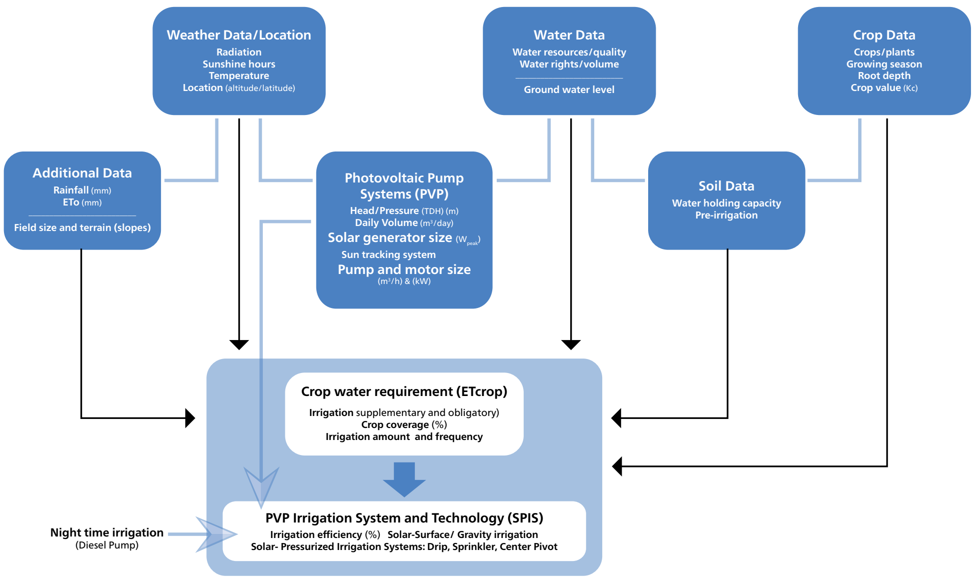


Source: World Bank (worldbank.org/en/news/infographic/2017/01/10/solar-water-pumping-ready-for-mainstreaming)

The crop water requirement will lead to the choice of a PV pump system, also based on the location, the water source and the specific weather data of the site. Larger solar pump companies have their own design software for determining an efficient system of solar generator, pump and irrigation technology for the specific site. There are also other uses for water to consider, such as livestock watering and domestic uses, including homestead gardening, cooking and washing.

FIGURE 4

SPIS data requirements for planning



Source: Bernward Hollemann, personal communication

2.3 SOLAR POWERED IRRIGATION SYSTEM CONFIGURATIONS

Using solar-powered pumps for irrigation allows for different configurations depending on the context of the application. The following short summary describes the most common configurations in use.

TABLE 1
Summary of SPIS configurations

Configuration	Description	Complexity	Adaptability	Remarks	Survey results
Direct pumping	PV panels and pump (with DC or AC motor) and controller with or without water storage (elevated) tank or reservoir and irrigation system (flood, sprinkler, micro-irrigation [drip], and irrigation machines). Maximum Power Point Tracking (MPPT) and other electronic/software features improve efficiency. Variable motor speed and pump volume during the solar day and cloud interfaces. Solar-irrigation controller uses volume meter (not timer).	Relatively simple	Adaptable to all sizes and irrigation methods as well as requirements. Fertigation (injection of fertilizers, soil amendments and other water-soluble products into an irrigation system) can easily be integrated, as well as water treatment and cleaning chemicals – e.g. for drip.	Most-used system across the world; water to wire efficiencies of more than 50% available from efficient systems. Should be used on volume basis. Needs speed control for irrigation machines.	27 out of 54 participants report that the water is used for other purposes than irrigation.
Multi-use systems (on-farm use)	Same as above plus other uses at times, when no pumping is required (milling, grinding, sawing, food processing, cooling, etc.)	Medium to complex	The controller is usually optimized for the pumping system – energy needs of other uses must logically follow the pump; the motors should have the same voltage as the pump motor and DC/ AC mode.	Use of batteries only with separate systems!	22 out of 54 participants report multi-use systems in their environ-ment.
Pumps in mini-grids (ommunity-based)	PV panels (generator) supply the power to various different uses (pumping, solar home systems, etc.)	More complex, technological solutions are being developed	Different uses can be accounted for (and paid for) – but important compromises on efficiency are necessary! Solar energy can feed into the grid as well and generate income, if not required for other uses.	Will the considerable loss of pump system efficiency make up for the advantages of a mini-grid?	
Hybrid systems	Solar pump systems work in parallel with the electrical grid and/or diesel pumps. Normal night-time use or energy blends at low radiation level for high season (water demand).Peak demand for solar generator size reduced.	Medium to complex	Various configurations exist, e.g. 1. Simple switching over to an external energy source when solar is not producing the required energy; 2. Supplementing the missing power (from solar) gradually as needed. Automatic and manual systems. Often used with old existing diesel pumps.	Often used to decrease electricity/ fuel charges. Feed into the electricity grid might be possible.	
Additional use (non-energy use)	"Lost space" under PV panels can be used for a range of high-value crops, (e.g. spinach, medicinal plants) or as shading for animals. Alternatively, the PV panels can be placed floating on water.Solar generator on roof of buildings or on top of water tanks.	Simple	Even sheds for animals can be constructed underneath the PV panels. Complex construction; no later extension possible.	Floating systems improve efficiency as they have a cooling effect on the panels (and decrease evaporation of the water body).	7 out of 54 participants report additional (non-energy) use.

Source: authors' compilation, based on material from GIZ, Toolbox on Solar Powered Irrigation Systems

2.4 COST OF SOLAR POWERED IRRIGATION SYSTEM COMPONENTS (FIGURES FROM MID-2017)

As mentioned earlier, the cost of PV panels has dramatically decreased during the last decade. The costs for solar pumps and configurations thereof have decreased as well, though not as much as PV panels. This is due to an already significant uptake of the technology worldwide. In some countries, unit costs are not determined by the open market but by large government capital subsidy programmes, leading to overpricing and a lesser decrease of unit costs than expected. The following Table gives a very rough estimation of costs of solar components to date. It is based on high-quality medium to large-sized installations, except the last three entries. It should be kept in mind that there are many suppliers of components as well as whole systems worldwide with different qualities, experience and designs.

TABLE 2

Cost estimation for SPIS components, mid-2017

Item	Description	Price range (average) in USD
PV panels	Installed at site	USD 1.25 to 2.00/Watt
Solar pump	International brand	Up to USD 1 000
Pump controller (*)	International brand	Up to USD 1 000
Electric cables	Depending on pump depth and distance to PV panels	USD 5.00 to 14.00/m
Pump installation	Manual up to 30 m	USD 200.00 to 400.00
	With crane	USD 750.00 to 1 000.00
Drip irrigation	Header with filter	USD 300.00 to 450.00
Drip lines (85% irrigated)	Depending on line thickness, quality of drippers, life expectancy	USD 600.00 to 1 000.00
Small-scale portable pump (Kenya)	Up to 12 000 l/day, with 80 W panel and 24-month labour and spare parts guarantee	USD 650.00
Small-scale submersible pump (Myanmar)	Up to 12 000 l/day, with 260 W panels and stand	USD 375.00
Small-scale complete system (Kenya)	Submersible pump, 300 W panels on secured 3 m high stand with controller, filters and 1 acre drip irrigation, with planning, installation and guarantees for pump, panels and drip lines	Starting from USD 2 400.00

(*) Pumps and Controller until app. 4kW

Source: average cost from different suppliers plus three examples of low-cost systems

2.5 CURRENT TRENDS AND DEVELOPMENTS IN SOLAR POWERED IRRIGATION SYSTEMS

2.5.1 Innovations in Technology and Services

SOLAR-POWERED DRIP IRRIGATION SYSTEMS

When appropriately sized, solar pumps can support drip, sprinkler, pivot or flood irrigation methods. Depending on the local conditions, a system can also include filtration or fertigation equipment. Solar pumps are often combined with low-pressure drip. The required pressure is typically achieved by pumping water into an elevated water tank and then releasing it through gravity. However, the tank presents an additional expense and is often more expensive than the pump itself. As pressure and flow rate of a solar pump vary with insolation, the direct connection of the drip system to the pump is problematic.

Solar trackers could help to maintain power output and therefore pressure for more hours during the day, but they are also expensive. Positioning solar panels not in north-south direction but split between east and west directions will also achieve more constant power/pressure for the irrigation system. Generally, the cost of additional panels will be less than the cost of a tracking system or an elevated tank.

FIGURE 5

Inspecting the drip-Irrigation system with a woman farmer outside Nairobi, Kenya

Photo: Hans Hartung

Irrigation is seldom done on a daily basis, depending on crop and soil types and climate conditions. Thus, the trade-offs between a storage tank and an oversized pumping system need to be considered. A storage tank, filled daily by a smaller pump, might be more cost-effective than a larger pump only operating once per week. The other alternative would be to maintain a rotating irrigation schedule.

FLOATING SOLAR SYSTEMS

Floating solar systems allow standard PV panels to be installed on large bodies of water, such as drinking water reservoirs, quarry lakes, irrigation canals or remediation and tailing ponds. No land resources are used in this case for the PV panels. Reduction of water evaporation, slower algae growth and higher efficiency of the solar panels due to the cooling effect of water on the panels are further benefits. Eco-friendly and easy-to-install systems are already tested and on the market (e.g. Hydrelio, 2017).

FIGURE 6

Floating solar system Ulu Sepri, Malaysia

Photo: Ciel & Terre

SOLAR-DRIVEN CENTRE PIVOT OR LATERAL MOVE IRRIGATION MACHINES

Up to now, centre pivots were (mainly) associated with large-scale irrigation. In a new development, solar pumps supply water to centre pivots. Nevertheless, most existing systems still need an external energy source for their operation, control and drive units, even if the water used is being delivered using solar energy. Developments are underway to run the entire operation on solar energy – preferably without using batteries. Smaller centre pivots (2 to 4 spans = 10-15 ha) are being tested at the moment. Larger systems will certainly follow. Solar-powered centre pivots (with batteries) are running in field tests along the Nile. This technology is driven by the irrigation and solar industry, satisfying a demand from large-scale farmers. Smallholder farmers could organise and share a centre pivot to irrigate nearby land (Hollemann, 2017).

OPPOSITE TRENDS: INTEGRATED, EFFICIENT SPIS VS. SPIS MADE UP OF COMPONENTS

Determining the right choice of solar generator, pump type and size, as well as irrigation technology, is complex, as illustrated in Fig. 3. The system has to be well adapted to the specific site conditions. Suppliers endeavour to supply the whole system, comprising the solar generator, pump, controller and accessories, plus the irrigation system. In addition, suppliers increasingly provide for technical (irrigation) support in order to satisfy end user needs. This is essential to optimize the use of the system and has many advantages, as described below. As a consequence, tenders should ask for estimates for complete systems rather than single components. In this way, the overall efficiency can be determined and compared among the submissions.

However, another trend goes in the opposite direction: PV panels, standard irrigation pumps and available controllers on the market are used and integrated into one unit with the irrigation system. This makes sense only for small systems, irrigating up to five hectares (ha), and the efficiency of these configurations is usually lower. Well-qualified professionals, who can understand pump curves and controller behaviour, are required to plan such a system. Only a detailed analysis can determine whether the lower price for such a system makes up for the loss of efficiency and greater difficulty obtaining after-sales service.

THE ONE-STOP-SHOP

There seems to be a general trend towards suppliers planning and designing the entire solar-powered irrigation system (including pump and irrigation equipment), installing it and offering service contracts for its operation. This is especially true for bigger systems, but there are also examples where this applies for smaller systems (e.g. several suppliers in Kenya). In this case, the One-Stop-Shop business may also act as financier of the system. Several solar-powered irrigation companies provide the layout and design of the whole system, including planning of agronomic aspects, and act as holistic service providers. This comprehensive view of the solar irrigation system gains importance if we consider other innovative developments described in the following paragraphs.

PERFORMANCE MONITORING

International solar pump suppliers offer monitoring equipment not only for operation of the water lifting system, but also for additional functions including data collection and monitoring – e.g. water level measurements and/or remote switching of the pump based on specific parameters (water needs, water source level, etc.) This concept has formerly been tested with observation wells. The new combined technology uses sensors, which are integrated into the production wells and the monitoring systems of the solar pumps. With this information, a groundwater monitoring programme can be developed and the pump capacity can be limited remotely to adapt to a predetermined water level in order to safeguard the aquifer. The individual farmer has no influence or control if the Ministry or another authority or institution – e.g. an irrigation association – switches off the pump.

With increased availability of Internet and communication technologies, pumps can be remotely accessed from anywhere in the world and their performance checked at any time. Time series of important data can be easily displayed. This allows the monitoring of groundwater and surface water levels of critical water resources and their control by governments or dedicated institutions. It supports reducing water abstraction in the case that water level decline is greater than the recharge rate. Large irrigation schemes are currently using these monitoring tools. They will be further introduced for smallholder farmers with plot sizes of only around ½ ha. This will give suppliers the chance to embark on innovative payment schemes that will allow them to switch off the whole scheme in case of non-compliance.

IOT PLATFORMS

IoT (Internet of Things) platforms will give SPIS (connected to the Internet, as described previously) the opportunity to receive additional services through this platform based on tracked sensors, flow meters and camera technology. For example, farmers can get a daily pump usage and weather report, along with crop management recommendations. This will no longer be limited to bigger systems. Solar energy will provide the power for data collection and transmission. For all the new technologies, however, intensive education and training will be required.

ELECTRICITY FEED-IN

If an electrical grid is available, the logical step will be to feed in electricity at times when irrigation is not needed. For single crops, irrigation for 70 to 120 days is necessary. For two cropping seasons per year, approximately 200 days are necessary. This means that there are times when energy is produced but not needed for irrigation. It makes sense to sell the generated electricity and feed it into the grid when the pumps are not used. Prerequisites for this strategy are sound institutional framework conditions such as technical standards for electrical and measuring equipment for connecting with the electricity grid and contracts with the relevant electricity company specifying conditions and the feed-in tariff. This may lead to bigger solar pump systems, supplying more than one farm, as only bigger systems (i.e. solar generators) fulfil the conditions for double use and are accepted for feed-in by the power companies. Examples in the United States of America (California, Nebraska and elsewhere) clearly display this trend. However, smaller systems can also be pooled through a micro-grid and supplied to the power company through a common evacuation point (Verma, 2017).

Another approach for using the otherwise unused electricity (when pumping is not required) consists of productive applications that provide additional income – e.g. the TAWS model in India, which is currently being tested by the GIZ Indo-German Energy Programme (Ghose, 2017). However, many technical details have to be solved to enable these productive applications (usually for on-farm equipment, such as threshing, harvesting, grading or grinding machines). SPIS suppliers may cancel their guarantees if their systems are used for applications other than pumping for irrigation.

FIGURE 7
Solar Powered Irrigation System with electricity feed-in, Proyecto Maripositas, Melipilla, Chile

Photo: Hans Hartung

2.5.2 Future trends

PLANNING SOFTWARE

Well-designed and easy-to-use software is available for solar pumping systems as well as for certain irrigation technologies. However, the integration of technology for solar pumps and irrigation is needed and is expected to be available in the future. A neutral effort and financing to support the integration of these technologies – i.e. without company bias – is urgently needed.

IRRIGATION MONITORING

The amount of irrigation water on the field will have to be monitored more precisely and regularly. As water becomes less available, this aspect will play an ever more important role. For this purpose, a differentiation should be made between monitoring water applied, which can be easily measured in pressurized systems with flow meters, and water transpired, which can be assessed through remote sensing technologies measuring evapotranspiration and biomass production. Modern technologies will become increasingly common – for example, monitoring of irrigated fields with drones and thermal imaging cameras. Satellite and thermal imagery is already used to calculate irrigation water demand (and to measure actual supply) for defined areas (e.g. fields, irrigation schemes, watersheds) and to charge farmers accordingly. An example of a global database is the FAO Water Productivity Open-access Portal (WaPOR) at 200m, 100m, and 30m resolution for certain countries.

SOLAR PUMP MANUFACTURERS' ASSOCIATION

It is expected that solar pump companies will create their own platform – i.e. a solar pump manufacturers' association. This will help to establish standards for the equipment and will allow comparison of data and information. When successful, smaller companies will probably join in order to benefit from the data-sharing and innovation potential of such an association. Many different industries have moved in this direction and their stakeholders have profited. A good example is Fachvereinigung Betriebs- und Regenwassernutzung (fbr), the Association for Rainwater Harvesting and Industrial Water Use in Germany, established in 1995. Rainwater harvesting equipment for housing and industrial buildings was not standardized in the 1980s and systems were not compatible. Bringing manufacturers, planners and users together in an association helped to promote the sector, to develop it further and to standardize and control the quality of equipment.

WEATHER STATIONS

Weather stations are becoming more important for an optimized irrigation regime and schedule. These stations can be expanded to become service centres for agricultural crop production as well. This will be possible if their databases are expanded to provide not only weather data, but also soil data, such as soil moisture, for the most important crops of the region. Forecasting for the upcoming few days could be made available, so that farmers know how much irrigation water has to be provided for each field and crop. This will require a closely linked network of extended weather stations.

BOX 1

In a nutshell

Solar pumps have been around for several decades. However, they were typically used in small-scale systems, as PV modules for large-scale systems were too costly. Prices have gone down significantly now and solar-powered irrigation technologies have become a reliable and viable option for many farmers, providing affordable energy and thus reducing energy costs for irrigation. A short overview of present-day costs (see section 3.4) confirms this.

Nevertheless, SPIS are relatively complex systems. Their design requires not only a fit-for-purpose PV pump system and irrigation infrastructure (supply side), but also an assessment of water requirements and irrigation calendar (demand side) as well as skills and knowledge of the end user.

Solar pumping systems are continuously evolving and improving, including configurations with drip irrigation, floating solar panels or purely solar-driven centre-pivot irrigation machines. Suppliers of SPIS are increasingly optimizing the whole system, including solar generator, pump, controller and accessories, plus the irrigation system. Additionally, suppliers now often provide technical support services to satisfy the needs of end users. Another trend goes in the opposite direction: individual components – PV panels, standard irrigation pumps and available controllers – are offered on the market and integrators provide services to connect these components into one irrigation system.

Moreover, online technologies will further improve SPIS and make it more versatile. Monitoring (e.g. groundwater), remote control and extended communication platforms can be expected to be part of even small-scale applications at minimal extra cost.

Possibilities exist for unused electricity (when pumping is not required) to be fed into the electricity grid or to be used for other on-farm productive applications, further increasing the economic viability of SPIS. However, this requires more research and development as well as specific policy and governance decisions to support such multiple use applications.

3. Current challenges

As mentioned in the Introduction, investment costs for SPIS are coming down. Subsidy and investments schemes for SPIS are being rolled out, making solar technologies a viable option for many farmers.

This chapter highlights some of the advantages and disadvantages of SPIS (Tables 3 and 4). While many of the challenges encountered with SPIS are context-specific, some common themes have emerged while preparing this report, including input from the questionnaire, interviews with practitioners, manufacturers, suppliers, consultants, governments and farmers in 13 countries, and field visits, as well as available literature.

The themes identified are:

- Economic viability;
- Access to finance;
- Installation, operation and maintenance;
- Standardization and quality control of products and services;
- Water management;
- Social justice.

3.1 ADVANTAGES AND DISADVANTAGES OF SOLAR-POWERED IRRIGATION

SPIS can provide significant environmental and socio-economic benefits, both at farm level and at national level.

At farm level, PV technology can constitute a reliable source of energy for pumping of irrigation water in remote areas, particularly in areas that are not connected to the electricity grid or where regular supply of liquid fuels and maintenance services is not guaranteed. Moreover, solar pumps can help to improve access to water. In countries with economic water scarcity, this can help to buffer the effects of drought and to overcome water stress during dry seasons, when groundwater is the only available water source, or when surface water has to be hauled over long distances. Through improved access to energy and water, SPIS can help to stabilize, increase and diversify production (e.g. vegetable production including during dry seasons to complement staple crops). Excess produce can be sold on markets and generate income. The increased availability of food can improve food security and nutritional intake, especially for small-scale farmers and their communities (Table 3).

Nevertheless, SPIS have a relatively high initial investment cost and need innovative financing models (or subsidies) to overcome this barrier to adoption, especially for small-scale farmers. Some technical knowledge or service infrastructure is needed to ensure that the systems run and are maintained effectively. Moreover, SPIS – if not adequately managed and regulated – bear the risk of fostering unsustainable water use as low energy costs can lead to wasteful water use, over-abstraction of groundwater, and low field application (Table 4).

At national level, reducing dependency on fuel is important and prospects for rural development are enhanced through improved access to water and energy. Overall, SPIS can play an important role in climate change mitigation, reducing GHG emissions in irrigated agriculture by replacing fossil fuels for power generation with a renewable energy source. Groundwater over-abstraction remains a critical issue that requires water accounting, smart water management and visionary policies across sectors.

TABLE 3
Advantages of solar-powered irrigation

Socio-economic advantages		Environmental advantages
Farm level	**National level**	
Financing and cost of solar panels continue to drop, making SPIS economically viable and competitive with other sources of energy.	Potential for job creation in the renewable energy sector (producers, suppliers, services).	No greenhouse gas emissions = climate mitigation.
Rural electrification and access to renewable energy, especially in remote areas and in humanitarian crisis situations.	Contribution to rural electrification and renewable energy targets.	Potential for adaptation to climate change by mobilizing groundwater resources when rains fail or rainfall patterns are erratic.
Independence from volatile fuel prices and unreliable and costly fuel supplies.	Reduced dependence on energy exports. Energy subsidies for fossil fuels can be reduced while offering an alternative to farmers and rural communities whose livelihoods would otherwise be negatively affected.	Potential for improving water quality through filtration and fertigation systems (more efficient application of less fertilizer overall).Less pollution resulting from inadequate fuel handling (diesel pumps).
Reduced cost for water pumping in the long run. If system is being modernized for pressurized irrigation, increases in energy costs are offset through the use of solar energy.		
Potential for increasing agricultural productivity and income due to improved access to water (additional cropping season, diversification of cropping pattern, higher value crops). Potentially more efficient use of water if combined with drip or other water- efficient irrigation technologies.	Food security may be improved if introduction of SPIS is accompanied by changes in irrigation technologies and agricultural practices.	
Potential for income diversification due to multiple uses of energy (e.g. feed-in to grid, lighting, cooling) and water (e.g. livestock watering, domestic uses).	Rural development through improved access to water and energy.	
Potential for new and innovative forms of financing and service models as well as organizational structures to finance and use SPIS (shared economy)		
Lower hourly yields, over more hours per day, which allow for gentler abstraction of sensitive ground water resources, reducing risk of borehole collapse.		
Potential time saving due to replacement of labour intensive manual irrigation, which can lead to other income-generating activities. Women and/or children might profit from time not spent on watering anymore.		

Source: authors' compilation, based on material from GIZ, Toolbox on Solar Powered Irrigation Systems

FIGURE 8

Demonstration of various solar pumping systems during a FAO workshop in Kigali, Rwanda

Photo: Hans Hartung

TABLE 4

Disadvantages of solar-powered irrigation

Socio-economic disadvantages/disabling framework conditions		Environmental disadvantages
Farm level	**National level**	
Still relatively high initial investment costs that smallholder farmers, especially, cannot afford or cannot tolerate the risk aligned with the investment.	Existing energy subsidies for fossil fuels and electricity that distort market; legislation and regulation of energy and agricultural markets may hinder the uptake and up-scaling of solar energy systems. Taxes on imported equipment that may distort (and artificially keep up) prices.	Production of PV panels requires some toxins and rare minerals; mining and production of these tends to produce environmentally harmful waste; panels need to be correctly disposed of to avoid environmental harm.
Finance is not accessible or affordable for all, especially for smallholder and tenant farmers.	High risk investment, especially if SPIS roll-out programmes do not adequately address onsite ownership.	Decentralized systems are difficult to regulate (however, SPIS often replace already decentralized systems); illegal pumping may increase.
	Lack of groundwater management/ institutional framework for abstraction.	Risk of groundwater over-abstraction, leading to depletion and degradation of groundwater resources.
Design needs to be fit-for-purpose and requires services (typically private sector) to advise farmers on best system; however, these are often not in place.	Lack of codes and standards to guarantee quality of SPIS.	
Optimal operation and maintenance of SPIS requires a certain degree of technical knowledge and skill, so farmers need to be trained and services (extension services or private service suppliers) need to be available.	Lack of systematic training schemes (e.g. vocational training); thus, lack of skilled personnel.	
SPIS are vulnerable to theft and hence often not covered by insurance as a prerequisite for loan finance.		
Lack of trust between farmers, utilities, service providers and government to try innovative forms of finance and of FITs; banks often perceive that SPIS have high risk, due to unfamiliarity with technology.		

Source: authors' compilation, based on material from GIZ, Toolbox on Solar Powered Irrigation Systems

3.2 ECONOMIC VIABILITY OF SOLAR-POWERED IRRIGATION

Although costs have decreased significantly in recent years, the economic viability of PV systems varies. Payback periods differ widely from country to country, depending on site conditions, crops and markets, as well as on energy sources, such as fuel (diesel, petrol or liquefied petroleum gas) and prices, which may be subsidized. Numerous site- or country-specific economic feasibility studies exist (see Prieseman, 2015), though they are often not relevant for general use as they look at specific configurations and socio-economic contexts (e.g. community-owned system vs. single farm use).

COMPARATIVE TECHNO-ECONOMIC FEASIBILITY

The key aspect that determines the economic viability of SPIS is how solar-powered systems compare with other forms of energy. Table 5 shows the advantages and disadvantages of PV pumps compared with diesel pumps. Generally, diesel pumps have low initial investment costs, but high operation and maintenance costs. In contrast, the investment costs of solar pumps are comparatively higher, but maintenance and operational costs are less significant.

TABLE 5
Overview of advantages and disadvantages of solar-powered and diesel-driven systems

Type	Advantages	Disadvantages
PV pump	Unattended operation	High investment costs
	Low maintenance costs	Water storage may be required as pump operates at sub-optimal levels when it is cloudy/rainy, and not at all during the night
	Long lifetime (low average yearly costs)	Repair often requires skilled technicians
Diesel pump	Fast and easy installation	Fuel supplies erratic and expensive High operational costs
	Low investment costs	High maintenance costs
		Short life expectancy
		Noise and air pollution

Source: based on Abu-Aligah, 2011

Various studies have compared pumps powered by solar energy with those powered by other sources of energy. Bolaños et al. (2014), for instance, chose to compare the techno-economic feasibility of PV technology vis-à-vis other sources of energy in Northern Colombia. They took into account irrigation water requirements, cropping patterns, irrigation methods and costs associated with different energy technologies (e.g. PV, wind, thermal) to assess which energy source provides the most appropriate and cost-effective solution to farmers.

Studies comparing solar and diesel pumps include, for example, Agrawal and Jain (2015), KPMG and Shakti Foundation in India (2014), as well as studies of the competitiveness of solar compared with other conventional options, such as the World Bank in Bangladesh (2015) or Magrath in Zimbabwe (2015). Noticeably, subsidies for electricity and fuel affect the competitiveness of solar solutions in almost all of these cases.

SOCIAL AND ECONOMIC VIABILITY

When assessing the economic viability of the use of solar pumps, it is important to take into account a broad range of parameters, including but not limited to: the size and configuration of the system (e.g. filtration, fertigation, water storage) and different pump types; the depth of the well; the remoteness of the area; the type of crop/soil to be irrigated; any other uses of the water (e.g. grassland restoration, livestock watering, domestic uses); and where the water will be used (e.g. greenhouses, open space). As early as 1978, Katzman and Matlin studied the economics of adopting solar energy systems for crop irrigation in the United States of America. They estimated the social and commercial profitability per acre of area irrigated using solar energy. The parameters applied included real fuel costs, discount rates for loans or credits, array costs and system support costs. They compared this with conventional energy systems for irrigation. The study indicated that SPIS can be commercially profitably in the United States of America, even without policy support.

More recently, Mukherji et al. (2017) conducted a comparative study in South Asia. Table 6 shows the price of SPIS in South Asia (for solar pumping systems), the amount of subsidy, the price that farmers paid to either buy the system or buy water from a solar pumping system, crops grown and energy costs for groundwater irrigation. This information was used to calculate financial payback periods under different financial models.

TABLE 6
Payback period for solar-powered irrigation pumps under different financial models

Location	Financing mechanism	Farmers' operational landholdings and major crops grown	Average cost of SPI system (per hp) in USD	Price paid by end user in USD	Annual savings in energy costs (per ha) in USD	Payback period (years) for the system (on subsidized price)	Payback period (years) for the system (on non-subsidized price)
Bihar, India .	Subsidy (100% of total cost)	8 ha (Paddy, Wheat, Maize, Lentils)	2 583	Irrigation charges of 9.50 per ha	102	0	19
Haryana, India	Subsidy (60% of total cost)	8 ha (Paddy, Wheat, Vegetables)	2 506	7 366 per system, post-subsidy	132	4	11
Rajasthan, India*	Subsidy (86% of total cost)	12 ha (Orchard crops)	2 723	1 252-1 324 per system post-subsidy	84	1	9
Bihar, India	Water seller	12 ha (Paddy, Wheat, Vegetables)	1 738	Irrigation charge of 1.20 per hour	94	10	10
West Bengal, India	Water seller	7 ha (Boro paddy Vegetables)	2 456	Irrigation charge of 1.70 per hour	91	8	8
Bangladesh	IDCOL model, (Water seller)	6 ha (Boro paddy)	4 660	Irrigation charge of 104 per hour	102	14	25
Pakistan	Market price	32 ha (Paddy, Wheat, Cotton)	2 696	2 696 per hp	219	6	6
Nepal	Subsidy (70% of total cost for woman farmer) and 15% loan	5 ha (Paddy, Wheat, Vegetables)	2 533	1 140 per system post-subsidy	96	2.5	8

Source: Mukherji et al. (2017), Solar powered irrigation pumps in South Asia: Challenges, opportunities and the way forward based on primary fieldwork conducted from Nov. 2014 to Febr. 2016 in Bangladesh, India, Pakistan and Nepal.

* *Calculations for Rajasthan are based on Kishore et al. (2014). Prices have been adjusted to 2016 using World Development Indicators data.*

The most significant finding from the small sample in this study is that the payback period for the full system cost is significantly shorter in Pakistan than in Bangladesh or India because of the higher (non-subsidized) cost of both diesel and electricity in Pakistan, as well as the larger size of farmers' landholdings. The long payback period in Bangladesh makes the system less attractive for private investors. The "fee for water service" model in Bangladesh and India, however, is very attractive for farmers. In West Bengal, farmers pay USD 1.03/hour for water from a solar-powered irrigation pump, whereas they used to pay USD 1.48/hour from a diesel pump (prices in mid-2016). This is also the most appropriate model for small and marginal farmers who can benefit from solar-powered irrigation pumps without having to invest in the technology.

In India, it can also be noted that SPIS are only economically viable under present subsidized farm power connection conditions in the country (approximately USD 1 500/kWp including pump, paid by 30-40% subsidy, 40-50% loan, with remainder as down payment) if the yearly utilization rate is above 200 days. This is very seldom the case, making SPIS in India not economically viable at the moment when competing with grid power. As of mid-2017, SPIS in India seem to be economically viable when replacing diesel pumps, when offering irrigation service for farmers not owning a pump, and in specific scenarios – for example, when growing very water-intensive crops, when groups of farmers grow crops in different cycles, or when very small marginal farmers shift from deficit irrigation (GIZ Indo-German Energy Programme, 2017; Verma, 2017).

Economic viability looks different in other parts of the world. For instance:

- Senegal: Payback periods for solar pumps in the belt between Dakar and St. Louis are given as 2 to 2.5 years (3 horticulture crops per year for city markets, 1 ha irrigation, 15% interest on equipment) (Hagenah, 2017).
- Chile: Payback period for solar pumps for small farmers (2-4 ha) in Northern Chile is around 4 years (3 horticulture crops, mainly tomatoes, paprika and green beans for the local and regional market) (Schmidt, 2017).
- Kenya: Suppliers of SPIS in Kenya claim a payback period of between 1 and 2 years, sometimes even less (at non-subsidized prices) for SPIS irrigating 1 2 ha fruits and vegetables (Ibrahim, 2017).

Assessing the economic viability of SPIS is a complex undertaking and should be done on a case-by-case basis. Financial advisors or extension workers, who are familiar with the local conditions, should support this process. The GIZ-FAO Toolbox on Solar-Powered Irrigation provides some useful tools for this: https://energypedia.info/wiki/SPIS_Invest

3.3 ACCESS TO FINANCE

Given the relatively high capital investment costs for solar-powered irrigation, access to finance and financial services is crucial. The "high" cost of SPIS technology often deters farmers, especially smallholder farmers without the needed capital, from investing in SPIS.

Banks often do not have specific credit lines for solar-powered irrigation and lack information on SPIS in order to design adequate credit lines. Typically, financial institutions consider it a high-risk investment, making it difficult to access loans. Many commercial and national banks lack core expertise in evaluating credit risk on these borrowers, although microfinance institutions are gradually stepping in to fill a critical funding gap. Nevertheless, the bankability of smallholders is low. They often produce low-value crops at little profit, further increasing payback periods. Information on subsidy and investment programmes, as well as other available financial products, is often difficult to find or unclear.

Finally, other energy sources for agriculture – including diesel, butane and electricity – are often subsidized, making investments in solar energy less attractive. However, some practices have been reported from different projects around the world that aim to address these issues.

IMPROVING FINANCIAL CONDITIONS FOR THE USER

1. It is possible to support financing institutions (such as microfinance institutions) that are already familiar to farmers. This can be done by:
    - Using social group guarantees and collateralizing the financed asset, providing additional insurance and technical assistance. An example comes from Juhudi Kilima (http://juhudikilimo.com) in Kenya, a microfinance institution for the agriculture sector that primarily provides loans for working capital to informal businesses, and finances specific agricultural assets that offer immediate and sustainable income for farmers.
    - Involving an intermediary. An example is provided by CoolCap in Kenya, a social capital organization designed to support smallholder farmers in Africa. It buys equipment from the vendors in bulk and sells it to the farmers at 10 percent interest, repayable at harvest. Farmers deliver their harvest to their buyers who deduct the farmers' payment from a portion of harvest proceeds and remit to CoolCap (https://coolcapfund.org).
    - Introducing an interest buy-down subsidy, which reduces monthly payments for the farmer. A similar programme for solar water heating equipment was tested in Tunisia (UNEP - Prosol, 2017) with much success. In this case the customer pays the monthly payments to the electricity company.
2. Local banks could augment their lines of credit to farmers so as to enable the adoption of new machinery (e.g. SPIS, mills, small stationary threshers). In many cases at present, lines of credit are only for seed and other supplies provided at the beginning of the growing season (Banerjee, 2017).
3. In order to upscale solar-powered irrigation, increasing access to credit is necessary not only for farmers, but also for local entrepreneurs. Multinational companies dominate the off-grid industry (Schuetzeichel, 2017); local and regional small and medium-sized enterprises need support. Small and medium enterprises are the main drivers for innovation, poverty reduction, employment generation and social integration. The lack of small and medium enterprises in developing countries is a significant obstacle, commonly referred to as "the missing middle."
4. Duty waiver for solar products (PV panels, controllers, pumps, etc.) can reduce the purchase price for the farmer, as seen in Kenya and many other countries.
5. Contractor models are another option, whereby payments are made to the contractor depending on the amount of water delivered from the pumps (WEF, 2015), using solar portable pumps to provide Pay-As-You-Go services (Energypedia Pay-Per-Use, 2017).

6. The company selling the equipment can also use Pay-As-You-Go models. Matching repayments with the cash flow of the farmer (paying small monthly instalments during the growing season and more after the harvest) will help the farmer to afford the equipment. Rent-To-Own is a similar model.

7. Non-formal credit can be provided by relatives, employers or the non-formal sector. In an example form Kenya, the employer provided the upfront loan and then deducted monthly payments from the recipient's salary.

DESIGNING SUBSIDIES STRATEGICALLY

1. Subsidies can be strategically designed to support change in water management, agricultural practices and even gender equity. The country case study of Nepal is a good example. The government in Nepal offers a grant model, whereby 60 percent (for women farmers, it is 70%) of the purchase price of the solar irrigation system is paid for. Such grants can be tied to conditions designed to avoid over-pumping or market distortion.

2. Further studies are needed to understand the distorting impact of direct subsidies for equipment, as this may affect market development and inflate prices. This has been experienced in India and led to a revision of the central government subsidy scheme in 2017.

3. It is important to make users, such as farmers, agricultural extension support services, and other public/private actors, aware of opportunities for financial support (and subsidies).

SUPPORTING THE DEVELOPMENT OF FINANCIAL TOOLS

REFINe (www.esd.worldbank.org/refine) is an interactive Web tool that helps users better understand experiences with financial instruments to scale up renewable energy technologies. The tool can be used to identify financial instruments that can be used to overcome user-specified project risks and barriers. REFINe is intended to assist policy-makers in low-income countries in identifying how to apply financial instruments funded from public and concessionary sources to support the scaling-up of commercially proven renewable energy technologies.

3.4 INSTALLATION OF THE SYSTEM, OPERATION AND MAINTENANCE

During field visits, interviews and in the online survey, a number of challenges with the installation, operation and maintenance of SPIS have been pointed out, including:

- Lack of awareness regarding SPIS potentials, risks and options;
- Lack of advisory services for farmers and other end users;
- Lack of technical skills, from planning to installation, operation and maintenance, at supplier and agricultural extension level;
- Initial teething issues during first months of operation;
- Lack of tailored solutions for farmers;
- Unavailability of spare parts;
- Service deficiencies, as services are often concentrated in the country's capital ;
- Sand and dirt, rodents and/or insects in the borehole or well;

- Termites and/or rats destroying the plastic of electrical cables and PVC pipes;
- Water quality (e.g. iron content);
- Theft and/or vandalism of panels and/or pump;
- Poor siting, with shading part of the day or wrong orientation of the PV panels

FIGURE 9

Elevated panels for a Solar Powered Irrigation System outside Nairobi, Kenya. Shading by trees is a problem

Photo: ***Hans Hartung***

All actors have to play their parts in the resolution to these challenges. Governments can support development of supplier and service infrastructure, while setting quality standards and rules for service provision. The private sector can ensure that high-quality products are expertly installed and provide support services after the installation. International organizations, NGOs and extension services can offer advisory tools and training to ensure that SPIS advisors and end users know how to respond to the challenges encountered.

PROVIDING BROAD HANDS-ON GUIDANCE TO END USERS, CLIENTS, POLICY-MAKERS AND FINANCIERS

GIZ Powering Agriculture, in partnership with FAO, is developing a Toolbox on Solar Powered Irrigation Systems (FAO & GIZ, 2017). The Toolbox on Solar Powered Irrigation Systems (SPIS) is designed to enable advisors, service providers and practitioners in the field of solar irrigation to provide broad hands-on guidance to end-users, policy-makers and financiers. Risks related to system efficiency, financial viability and the unsustainable use of water resources can thus be minimized.

The Toolbox comprises informative modules supplemented with user-friendly software tools (calculations sheets, checklists, guidelines). Modules and tools touch upon:

- assessing the water requirements
- comparing the financial viability
- determining farm profitability and payback of investment in SPIS,
- sustainably design and maintain a SPIS
- highlight critical workmanship quality aspects

- and many more

THE ONE-STOP-SHOP FOR SPIS

An increasing number of suppliers are providing whole system solutions for farmers. Cost-effective solar pumping technology is combined with a high-efficiency drip irrigation system (or other irrigation method) in the interest of making it cheaper and easier for smallholder farmers to grow high-quality fresh fruits and vegetables. An engineer first surveys the site and takes soil samples before a quote is made for a solar pumping system and/or drip irrigation (the engineers need about one day). At that time the farmer receives a first training on how the solar-powered irrigation system works and what it entails. System installation is also completed by the engineer (about one to two days) with the support of the farmer, who is trained on how to resolve technical problems as the installation progresses. Typically, the supplier company offers support services for a certain time after the installation (two to five years). Some companies also offer credit financing for the farmer and comprehensive training, as well as advisory services on other issues, such as seeds, fertilizer use and soil management.

THEFT PREVENTION

Theft is a frequently reported problem. Various strategies can help and have been proven successful, (see also FAO and GIZ, 2017):

- For small systems, panels and pump can be brought to the site in the early morning and taken back in the evening on a wheelbarrow or other suitable cart.
- Panels can be mounted on a high stand and/or protected in lockable steel frames; lock tie nuts can be used. Fencing and alarm systems help to inform on intruders. In some cases, it is worth hiring a watchman to ensure the panels are not stolen.
- Panels can be marked by engraving or spray painting (with epoxy-type paint) the owner's name to make them more difficult to resell if stolen.
- As PV panels get bigger and cheaper, they are not as easy to handle and not as attractive for thieves to sell on the second-hand market. As PV voltage increases (e.g. to 24V), their use for home systems gets more limited.

FIGURE 10
Very simple portable SPIS at an experimental stage, Cameroon

Photo: John DeMarco

3.5 STANDARDIZATION AND QUALITY CONTROL OF PRODUCTS AND SERVICES

The long-term sustainability of SPIS depends on well-designed products and quality of installation. If low-quality products are introduced to the market and fail, the credibility of solar PV as a reliable energy source can be seriously undermined.

Unfortunately, technical capacity is limited in many countries and competences are usually concentrated in the capital, far away from the end user. Solar-powered irrigation is a cross-cutting topic that requires not only expertise in solar energy (by planners and suppliers), but also in water management/irrigation and agriculture (by technical government staff, agricultural extension workers and farmers).

The lack of quality standards for equipment was mentioned several times in interviews and the online survey. Poor tender design is repeatedly reported (Bridge to India, 2016). Farmers feel insecure about what manufacturer, what configuration and what specifications are needed and where compromises between cost and quality considerations can be made, if any. If systems fail, farmers quickly lose trust in the technology and abandon it.

Another challenge is the bureaucracy, arbitrariness and sometimes corruption at customs clearance in many countries. Arbitrary application of tax exemptions for solar equipment, for example – despite official guarantees – can significantly increase costs of solar pumping systems. Uncertainty about long-term policies, such as feed-in tariffs, negatively affects investment climates.

In other to ensure quality control and standards of SPIS-related products and services, a number of good practices from different projects around the world can be considered.

QUALITY CONTROL OF SOLAR EQUIPMENT

The development and use of existing technical specifications and standards can support government authorities in the preparation of tender documents and help manufacturers to work towards common goals. When widely accepted, technical standards can contribute to lower production costs, reduce installation time and facilitate repair. Standards also foster fair and transparent competition, as all actors in the market must play by the same rules.

Government-funded programmes should ensure quality control of end consumer installations and training. Tenders should look at the water output for a defined solar irradiation and pumping head, not the power rating of the pump. Built-in water metering should be a standard requirement for tenders. Independent research and advisory bodies test pumps and related equipment, and can provide advice on quality standards and checks (see Nassem, 2016). User guidelines can be useful to understand the suitability and quality of products on the market; for example, the Silicon Solar Module Visual Inspection Guide (Sinclair, 2016) aids the visual inspection of solar panels to judge their quality. Irrigation associations have a role to play by informing themselves and advising their members.

CERTIFICATION OF SUPPLIERS/INSTALLERS IN-COUNTRY

A certification scheme could help to guide end users in choosing the most reliable product and service provider for their situation. Planning, design and installation should follow acceptable standards and after-sales service should be guaranteed – i.e. a service line for first-hand information when problems arise, as well as a guaranteed supply of spare parts or repair if needed. A certification scheme of suppliers could be a first step to create confidence and trust and weed out non-qualified suppliers. Mexico is one of the countries with such a certification scheme for SPIS suppliers and installers (Fillad, 2017).

STANDARDIZATION IN THE FIELD OF RENEWABLE ENERGY

Sound standardization processes can support innovation in renewable energy technologies by documenting and spreading information on state-of-the-art technologies, levelling the playing field for innovative products, allowing more focused research and development and closing the gap between research and development and marketable products. When well designed, standardization also provides an effective framework for the commercialization and diffusion of technologies by harmonizing information flow, understanding technical product design for interoperability of components, manufacturing and service requirements, as well as establishing common rules and quality requirements.

Benefits of standardization include decreasing product costs, reduced transaction costs through simplified contractual agreements and use of standardized components, a common language and understanding regarding what a product or service is or is not and increased levels of quality and safety for consumers (IRENA, 2013).

As a young industry, solar pump manufacturers and intergovernmental agencies have yet to make an effort to establish common rules or quality requirements or even a common language for components, parts and services.

3.6 WATER MANAGEMENT

One of the main risks of SPIS is the indiscriminate use of water resources. In many cases, energy prices have had a regulating effect on water withdrawals. With SPIS, this becomes less significant as there is no cost per unit of power once the system is installed.

The risk is that farmers will consume more water than they did before the introduction of SPIS, by: (i) applying more water in the field overall (for example, when shifting from deficit to optimal irrigation, or simply over-irrigating); (ii) expanding the area of land under irrigation; (iii) growing higher-value, but often more water-intensive, crops; (iv) selling water to neighbouring farmers and communities.

This is particularly an issue in areas where groundwater resources are already overexploited and recharge rates are slow. Globally, non-renewable groundwater abstraction contributes nearly 20 percent to gross irrigation water demand (Wada, 2012). In India, about 30 percent of aquifers are considered at critical status (Central Ground Water Board, 2014). Unrestricted pumping and pollution have led to threats to the sustainability of aquifers, and the allocation and use of groundwater have often been poorly aligned with society's goals for equity, sustainability and efficiency.

It is often argued that SPIS in combination with drip irrigation will ensure that water is efficiently used at field level. Drip and sprinkler systems allow farmers to improve the timing and distribution uniformity of irrigation, which can enhance crop yields, such that transpiration per hectare increases. The prospect of higher returns per hectare, however, will encourage some farmers to expand planted areas or to switch to higher-value, more water-intensive crops (Berbel, 2014). Assuming that drip irrigation will automatically lead to water savings at the farm level is a fallacy.

Water efficiency at field or farm level can also have implications at basin level. Water resource systems are highly integrated, and apparent gains (in terms of water use efficiency) in one part of the system can be offset by real losses in other parts of the system. Rainfall, surface water, groundwater, soil moisture and rates, and processes of evaporation from different land uses are all part of the same hydrological cycle and cannot be regarded as separate. Changes in water use in one domain may lead to unintended or undesirable consequences locally or downstream.

It is therefore important to systematically study the current status of and trends in water supply, demand, accessibility and use (FAO, 2016). This is called water accounting. By evaluating return flows, measuring both basin and field efficiencies, and distinguishing between consumptive and non-consumptive savings, water accounting helps to address such questions as: What are the underlying causes of imbalance in water supply (quantity and quality) and demand of different water users and uses? Is the current level of consumptive water use sustainable? What opportunities exist for making water use more equitable or sustainable?

When assessing the impacts of solar-powered irrigation on water use efficiency, it is important to distinguish between these different levels of analysis (field/farm/scheme/basin) and to carry out systematic water accounting to understand what options exist for optimizing water use overall.

These efforts need to be complemented by appropriate regulation and policies. Investment and incentive programmes may follow specific criteria (e.g. installations only in areas where groundwater is not overexploited) or encourage water savings. Tenders may set standards (e.g. groundwater metering and apps for monitoring as part of SPIS); regulations may restrict SPIS use at certain times or places.

Water governance in general, and groundwater governance in particular, is a complex issue that requires context-specific interventions. Some issues may be ubiquitous (e.g. intensive groundwater abstraction, pollution); others are confined to specific environments or regions (e.g. groundwater depletion, seawater intrusion, land subsidence, pollution by inadequate sanitation and wastewater treatment, pollution by industry and agriculture, inequitable allocation, inefficient use). Governance has to be tailored to the locally relevant issues and challenges. Nevertheless, there are some general themes that can be considered:

IMPROVING SYSTEM VIABILITY AT FARM LEVEL

1. At farm level, an integrated approach to water, soil, nutrient and energy management can help improve resource use efficiency and sustainability. In many cases, the introduction of solar pumps is coupled with measures to improve the efficiency of irrigation and on-farm water management methods (e.g. drip or sprinkler irrigation, rainwater harvesting) (see Salman, 2016) or agricultural practices (e.g. change of crops, organic fertilizer, polyhouses) to increase the viability of the system overall.

   Making optimal use of rainwater and soil moisture, knowing precisely where and when irrigation has to be applied, and then applying it accurately and uniformly, are fundamental to improving water use efficiency at the production site.

2. The option exists to use the solar energy produced on-farm for uses other than water pumping. The farmer then has a choice about whether to run the solar pump or to use the energy for other purposes, empowering him/her to make rational decisions about

water and energy use on the farm and increasing the overall economic viability of the system.

3. While further innovation and development are needed, possible on-farm applications powered by solar energy include solar-run pivot systems, harvesters, rice huskers, grinders and mills, cold storage and water purifiers. Such systems need to be designed to purpose in order to ensure optimal performance and cost-effectiveness.

SPECIFIC RULES FOR GROUNDWATER ABSTRACTION

Legal and regulatory frameworks for groundwater abstraction have often been inadequate and their application has proven problematic. In many countries, customary law has been applied to groundwater for generations and it is still significant — but only for small-scale abstractions in rural areas of developing countries, and this has been largely overtaken by the massive scale of abstractions.

Modern legislation on groundwater — and other laws affecting groundwater — are found in almost all countries. Laws typically cover ownership and use rights, protection from pollution, and institutional arrangements for management and regulation. The explosive growth of unregulated groundwater use and the resulting problems have prompted many countries to try to redefine groundwater ownership and use rights. Some options and considerations are as follows:

- Thorough water accounting is needed to make informed, evidence-based decisions about water allocation and management.
- Drilling permits for new boreholes should be given out and registered with a designated institution or government agency.
- Some countries consider thresholds for water abstraction beyond which water users have to pay a set fee. However, this is difficult to enforce unless new methods for monitoring, such as satellite imagery or drones, as well as flow meters in tubes like in municipal distribution systems, are used. Another option is a direct payment system that monitors groundwater abstractions at the controller of each installed pump and requires payments via IC-card, telephone or some other system when a given limit is exceeded (Leshan, 2017).
- In some countries, electric power supply to wells is rationed and restricted to certain hours per day to limit pumping. In high risk zones, new electricity connections to wells are restricted.
- Practicing sustainable groundwater use is in the self-interest of farmers and stakeholders of solar-powered agricultural development (FAO & GIZ, 2017). Aquifer management councils, like the Technical Committees for Groundwater (COTAS) in Mexico, consisting of groundwater users and the administration, have proven effective in managing aquifers in a participatory way.

CROSS-SECTORAL POLICIES, PROGRAMMES AND PLANS

Groundwater governance requires clearly defined goals, policies, principles and plans.

BOX 2

"Policies set goals — growth, sustainability, environmental protection, equity, poverty reduction, etc. and priorities — allocation to urban water supply as top priority, for example. Policies also incorporate principles to guide planning and management; for example IWRM principles of basin management, participation, subsidiarity, incentives reflecting scarcity, and integrated inter-sectoral management, together with the precautionary principle, and the 'polluter pays' principle. Other policy choices include: the balance between public and private roles and choices on the incentive structure — on the right balance between infrastructure, regulation or soft economic incentives like prices and subsidies. The quality and coverage of policies vary widely between countries, and policies may be proactive or — more commonly — reactive.

Resource management measures include technical interventions, generally readily accepted by local people, and non-technical measures to change stakeholder behaviour — these measures often encounter resistance."

FAO. 2016. Global Diagnostic on Groundwater Governance.

Different options exist for coupling subsidy and investment programmes with water management practices. These may include:

- Mandatory installation of groundwater metering along with solar pumps;
- Support for rainwater harvesting and conjunctive use of different water sources;
- Coupling of solar pumps with drip irrigation or other potentially water-efficient irrigation methods;
- Participating in user-based groundwater monitoring, using apps and IoT applications. This is of particular interest for countries with high Internet connectivity, such as India or Kenya.
- Capacity building for farmers, e.g. through public or private extension services or through SPIS suppliers or manufacturers (IFC, 2017).

Policy-makers may also look beyond sectoral silos and consider changes in agricultural and energy policies to affect change. The International Water Management Institute (IWMI) project on Solar Power as Remunerative Crop is often invoked in this context. The underlying idea is that farmers may be encouraged to reduce water pumping by offering them an alternative source of income through pooling and selling their surplus energy to the grid. The project seeks to demonstrate that farmers can "grow" and sell solar energy as a cash crop that has a ready buyer at an assured price. However, high capital investment and distorting energy subsidies can be deterrents (Shah, 2016). For this model to work, feed-in tariffs must incentivize farmers to sell the energy rather than pump water for their own use or for their neighbours. During dry seasons or drought, informal water prices often rise far above what farmers could get for selling electricity to the grid and they choose to sell water instead. Additional issues, particularly when thinking about up-scaling, are grid load management, licensing for electricity sales and establishing grid connections if they do not already exist.

It might be more effective to develop mini-grid and multiple use solutions for on-farm energy use instead, or to support service-based models run by private sector companies or NGOs, who buy solar pumps and sell water services to the farmer. This is especially attractive for small and marginal farmers (assuming that the price for water – or for electricity consumed by the pump – is affordable), as it avoids upfront capital costs for the pump (IDCOL, 2016). Water is pumped and delivered only as needed.

3.7 SOCIAL JUSTICE

SMALLHOLDER FARMERS

One key challenge of SPIS technologies is affordability for smallholder farmers. They are often overlooked in subsidy schemes or loan programmes, as some of the pre-conditions to obtaining a loan are proof of land ownership, farm registered with relevant Ministry, and collateral for loans. Yet, smallholder farmers among those that could benefit most from SPIS.

Sometimes, subsidy schemes are formulated and announced in a complicated and non-transparent way. Such schemes may not be known to smallholder farmers as they cannot access the relevant information channels. Corruption in the disbursement process ensures that, typically, large farmers that are well connected have access to the financial support offered.

The provision of the subsidy might be tied with other conditions, such as the need to have a registered land title or to make additional investments, such as constructing rainwater harvesting structures or investing in drip irrigation systems (see section 4.6) that small and marginal farmers cannot undertake unassisted. Also, smallholder farmers may not be able to afford the necessary upfront capital (Mukherji, 2017).

For these farmers, other finance and business models might be more attractive. These include:

- Contractor models, where the contractor owns the pump and sells water services to the farmer. This is attractive for small and marginal farmers (when the price for water – or for electricity consumed by the pump – is affordable), as it avoids upfront capital costs (Rahman, 2015).
- Pay-As-You-Go models, which are similar and avoid the capital payment by the user. Pay-As-You-Go is a digital financing technology that allows end users to pay for solar energy digitally, in small instalments. It is a pioneering credit system that removes the initial financial barrier to solar energy access by allowing consumers to make a series of modest payments to purchase, for example, a week's worth of solar energy rather than paying upfront for the entire solar system (adapted from energypedia.info/wiki).

GENDER EQUITY

Another challenge is inclusion of women in SPIS. Past experiences show that there are significant benefits of solar pumping solutions for women. SPIS are often used for crops traditionally grown by women, such as fruits and vegetables. For example, in the Sudano-Sahel area of northern Benin, SPIS (with low-pressure drip irrigation) were installed in vegetable gardens that were formerly watered with cans and hauled water. This allowed the women farmers to become net producers of vegetables, generate income from market sales and substantially increase their household nutrition intake and food security (Burney et al., 2009).

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 (IRENA, 2016).

There have been other examples in which SPIS projects were catalysts for the empowerment of women. In Nepal, for instance, financial support for SPIS by the government was linked to the gender of the beneficiary. Women farmers were given 10 percent additional discount, on the condition that the land on which the SPIS was installed was transferred to the woman beneficiary. This experiment generated encouraging results in that 77 percent of the demand (out of 65 SPIS that were demanded) came from women farmers and in all these cases land was transferred to them (Mukherji et al., 2017).

FIGURE 11
Women installing panels for a SPIS system, Nepal

Source: ICIMOD

It is important to understand the potential for small-scale technologies to empower women farmers and the best pathways to achieve that. Projects must make a greater effort to reach women with information, especially when it comes to financing and design options (e.g. identifying a convenient irrigation schedule and location of the SPIS system). Projects need to extend invitations to information-sharing events and meetings to women directly, and not rely on spouses or men in the community to inform women (Nigussie, 2017).

BOX 3

In a nutshell

The challenges for SPIS vary from country to country, including biophysical and climatic suitability, techno-economic feasibility, institutional arrangements, regulations and policy support, financing and economic viability of systems. Solar-powered irrigation presents an opportunity not just to introduce a clean-energy, climate-smart and relatively affordable technology, but to think strategically about how this technology can be used to regulate groundwater use and to provide energy access to rural areas so that small-scale farmers, women and youth can also benefit. How this is done, however, is highly context-specific.

The risk of groundwater depletion exists regardless of the energy source. However, there is a particular issue with solar-powered irrigation. Unlike other energy sources, solar-run systems have low operational costs, making it cheaper to pump water in the long run. Decision-makers across water, energy and agriculture sectors, as well as water users, need to be aware of the risks and need to be informed about options for managing risks posed for irrigated agriculture, and food security. Much can be done at the finance and design stage of SPIS – linking financial support to conditionalities, allowing for multiple use options, and integrating user-based monitoring systems. Nevertheless, sound surface and groundwater management is indispensable, requiring a holistic approach to water management at field and policy level.

Small-scale farmers could benefit greatly from SPIS but technical innovations and financial instruments specifically designed for smallholder farmers are needed to ensure inclusive and equitable access to SPIS. Kenya is one of the countries leading the way in SPIS innovations that are specifically designed and configured for application at small-scale farms. Nepal has shown that special incentives for women (gendered financial models) can have a great effect on the inclusion of women farmers.

4. How Different Countries Promote and Manage Solar Powered Irrigation

As discussed in Chapter 2, SPIS is not a new technology. However, it has only been in recent years that countries considered SPIS specifically in policies, legislation and strategic development plans. This Chapter will take a look at a number of selected country case studies – and in the cases of California, Rajasthan and Gujarat, case studies at state level. These case studies provide concrete examples of why and how governments and state authorities have promoted – and managed the risks of – SPIS, through policies, regulations and incentive structures. Not all have been successful, however, and there are also valuable lessons to be learned from what has been tried so far.

The countries referenced as case studies cover a wide geographic scope (Africa, Asia, North America and Latin America) and different contexts and challenges. In some countries, the issue is access to energy, while other countries struggle with access to water. Some countries seek to improve agricultural production; others use SPIS in humanitarian crisis situations when other sources of energy are not available.

The country cases are structured according to the following themes, which cover some of the most urgent policy-related issues regarding solar-powered irrigation:

- Green Economy, looking at the role of solar energy in achieving economic and environmental (especially climate) goals and targets;
- Finance, Investment & Business Models, exploring different subsidy schemes, investment programmes, innovative business models and other finance-related aspects of SPIS;
- Social Justice, examining how small-scale farmers, women and youth are being considered in SPIS-related policies, programmes and strategies;
- Groundwater Governance, showing how the country (or state) deals with the risks of groundwater depletion.

TABLE 7

Selected country/state profiles

Characteristics	United States: California	India		Kenya
		Rajasthan	Gujarat	
Agricultural area (1000 ha)[1]	408 204.7	179 600		27 630
Area equipped for irrigation (1000 ha) and %[2]	26 708 6.5 %	70 400 22.7 %		150.6 0.5 %
Three dominant crops with highest land use[3]	Maize, Soybeans, Wheat	Rice, Wheat, Seed cotton		Maize, Beans, Cowpeas
Agriculture value added, % of GDP[4]	-	17.4 %		35.6 %
Topic	Distributed generation/ air pollution	Solar-powered irrigation pioneers	Innovative solar cooperatives	Emphasis on smallholders
Entry point	Increasing energy prices	Mismatch between demand and supply of energy		Transforming small-scale farming into viable and sustainable agribusiness
Green economy	Laws call for half the energy generated by renewables	High targets of solar PV installations		National Drought Management Authority in Kenya (NDMA) is climate-proofing the country
Finance, Investment & Business Modelsr	Grants & loan guarantees (REAP program) &Investment Tax Credits (ITCs)	Grants & loans by specialized banks through government and state funding		Credit lines for SPIS by specialized banks & suppliers; informal arrangements
Groundwater Governance	The Sustainable Groundwater Management Act of 2014 and stakeholder platforms trying to tackle the problem	Free or subsidized agricultural power supply has depleted groundwater resources		Agricultural water policy well designed, but with deficits in implementation
		Holistic soil and water management might limit groundwater depletion	Solar cooperative provides water and sells excess energy to the grid	

Characteristics	Mexico	Morocco	Nepal	Senegal
Agricultural area (1000 ha)[1]	106 705	30 591.5	4 121	8 868
Area equipped for irrigation (1000 ha) and %[2]	6 500 6.1 %	1 530 5 %	1 368.9 33.2 %	120 1.4%
Three dominant crops with highest land use[3]	Maize, Sorghum, Beans	Wheat, Barley, Olives	Rice, Maize, Wheat	Groundnuts, Millet, Cowpeas
Agriculture value added, % of GDP[4]	3.8 %	13 %	33 %	18 %
Topic	Groundwater governance	Mitigating climate change	Women farmers' profit	Replacing diesel
Entry point	Water depletion due to excessive water extraction	Ambitious plans to reduce GHG emissions and pledges to generate a high percentage of electricity needs with renewables	High interest of women in SPIS	SPIS has high potential for smallholder irrigated horticulture
Green economy	Importance of renewable energy recognized, but grid power heavily subsidized	Actively pursuing a transition towards a green economy	Recent emphasis on SPIS by the Minister for Irrigation	SPIS not subsidized, but offer already now an economic advantage
Finance, Investment & Business Modelsr	Subsidies by the Ministry of Agriculture	Financing schemes supported by government; energy service companies	Grant model by NGO, supplier credits	No subsidies or financing models for SPIS
Social justice	Subsidies for poor areas – hardly used by the poor	Access to finance remains issue for small-scale farmers	High uptake of subsidy scheme by women	Successful programmes for women's market gardens
Groundwater Governance	Depletion of groundwater recognized. Self-monitoring by user committees less successful	Groundwater depletion a huge problem. Strong regulatory framework, problems with enacting it	Groundwater regulation tackled at present (2017)	No legislative protection for groundwater

[1,2,3] FAOSTAT, values for 2014

[4] World Development Indicators, World Bank Open Data

4.1 CALIFORNIA: DISTRIBUTED GENERATION

Farmers in California (United States of America) are faced with rising, volatile retail energy prices. In 2008 alone, prices for electricity for large agricultural users jumped by 14 percent. Though prices have adjusted somewhat, the installation of solar panel arrays offers a solution to the dilemma of rising electricity bills for many producers. New "distributed generation" facilities are being constructed all across the state at modest capital costs, low-to-zero fuel costs and in close proximity to consumers. At the same time, legal barriers are being removed, incentives for GHG emission reductions are given and an increasingly competitive marketplace is developing for solar energy. All these features are helping the cause of solar energy in the dry climates of high-energy-cost states like California (Western Farm Press, 2013).

Green Economy

The use of solar energy in California not only makes environmental sense – reducing air pollution – but also economic sense – supporting the state's solar economy and reducing energy costs for farmers.

Heavy air pollution is a key concern for many big cities in California, given their location and local weather conditions. Irrigation pumps are one of the causes of this air pollution. Already in 1998, California established a programme to fund the incremental cost of cleaner-than-required heavy-duty engines (average power rating of irrigation pumps in California was 184 hp or 137 kW in 2003 [California Environmental Protection Agency, 2006]). The California Environmental Protection Agency is closely monitoring emissions of irrigation pumps. Its Air Resources Board has been trying to transition growers from diesel to electricity with financial incentives, but high energy costs were and continue to be prohibitive. In 2015, Governor Jerry Brown into law that called for half of California's energy to be generated by renewable sources by 2030. The solar energy sector is also an important part of the state's economy; there are more than 2 300 solar companies in California and the industry employs over 75 000 residents (Notaro, 2016).

An estimated 70-75 percent of water resources in California and about 8-10 percent of its primary energy are used for irrigation. Pumps consume about 98 percent of the total energy use on farms. In addition to improvements in pumping efficiency, renewable energy can offer a more economic, emission-free alternative for farmers. When investing in a new pump, the shift to "smart pumps" with built-in intelligent functions to change source flow rate per required irrigation volume can help to further optimize agricultural water use. The farmer can set the required flow rate and volume per day based on crop type and irrigated area to help farmers avoid both over- and under-watering (Sultan, 2016).

Finance, Investment and Business Models

A number of policies and programmes promoting the adoption of solar energy technologies are available to farmers and ranchers. According to the United States Department of Agriculture (USDA)'s first On-Farm Energy Production Survey, the average financial support received for solar PV was 44 percent of the total system cost (2011). Federal incentive programmes such as the Rural Energy for America Program (REAP) or the Investment Tax Credit (ITC) are available to all farmers and ranchers; state policies and utility programmes differ by locality (USDA, 2011). REAP is an ongoing comprehensive programme supporting:

- Renewable energy system and energy efficiency improvement, on a continuing basis;
- Renewable energy system feasibility studies, energy audits and renewable energy development (SunPower, 2016)

California has its own "Energy in Agriculture Program" (California Energy Commission, 2017) which examines – among other topics – irrigation efficiency, with the Advanced Pumping Efficiency Program (http://www.pumpefficiency.org), administered by the Fresno Center for Irrigation Technology. The Modesto Irrigation District – like other Irrigation Districts in California – supports a Solar Photovoltaic Program parallel to the federal programmes (Modesto Irrigation District, 2017).

Groundwater Governance

According to Henry Vaux, a senior economist from the University of California, only 19 out of 431 groundwater basins in California are "actively managed." Groundwater management is passive in all other basins and essentially involves the use of federal government grants for building infrastructure to import surface water and supply it to groundwater users in lieu of pumping. In 412 basins, there are no regulations to limit groundwater abstractions.

With the Sustainable Groundwater Management Act (SGMA), established in 2014, the state government of California created a framework for sustainable, local groundwater management. SGMA requires groundwater-dependent regions to halt overdraft and bring basins into balanced levels of pumping and recharge. Following the SGMA, the Department of Water Resources launched the Sustainable Groundwater Management Program to implement the law and provide ongoing support to local agencies around the state. Information about Groundwater Sustainability Agencies, resources for the local agencies and the public, and the latest tools and guidance in managing groundwater basins sustainably are readily available (California Groundwater, 2017).

Projects on adapting agricultural water management to climate change are ongoing and are supported by a platform of stakeholders, called the California Water Action Collaborative (CWAC). It focuses on three areas: returning water to the system; building social capital to improve trust across sectors; and driving corporate water stewardship to align with the California Water Action Plan (http://cawateraction.org). The impacts of these extensive groundwater policies and regulations are yet to be determined.

4.2 INDIA: SOLAR-POWERED IRRIGATION PIONEER IN RAJASTHAN AND INNOVATIVE SOLAR COOPERATIVES IN GUJARAT

A complex set of factors, including global warming, competitive land use and lack of basic infrastructure, is creating new challenges for India's vast agrarian population. The ever-increasing mismatch between demand and supply of energy, and electricity in particular, is posing challenges, especially to farmers in remote areas. This reality, coupled with the increasing unreliability of monsoon rains, is forcing farmers to look at alternate fuels such as diesel for running irrigation pump sets. India used about 15 million grid-based electric pump sets and 6 million diesel/other irrigation pump sets (Irrigation Census, 2013-2014). Electric farm power connections receive either free or highly subsidized electricity, for which the bill is close to USD 12-14 billion per year (Verma, 2017). The high operational cost of diesel pump sets forces farmers to practice deficit irrigation of crops, considerably reducing their yield and income (GIZ India).

How this situation can be overcome is illustrated by Rajasthan, which has the highest solar radiation in India. Rajasthan has been pioneering the use of solar-powered irrigation and it has been one of the first states worldwide to develop a comprehensive subsidy scheme. After two years of successful tests, the state government launched an INR 515-crore (around USD 115 million at the time) scheme in 2011 to provide 10 000 subsidized solar PV pumping systems to farmers across the state. The scheme provided farmers with subsidies of up to 96 percent on the capital cost of the pump (Kishore, 2014). This has helped to address some of the issue of reliable access to energy and water for agriculture, and to a certain degree, the issue of agricultural productivity.

Solar pumps are seen as a potentially powerful solution to government shortcomings in providing energy grid connections for agriculture. The potential impact of solar pumps on excessive groundwater extraction is generally not seen as a major concern by policy-makers. Interestingly farmers are seeing solar pumps as both a pumping and an energy solution (Tewari, 2012).

Green Economy

The state government of Rajasthan set the overall target of 1 to 1.2 GW of solar PV installations by 2022, seeking to enhance energy security, create jobs in the solar manufacturing industry and become a main exporter of renewable power to third parties and neighbouring states. The target will be supported in multiple ways, including:

- Exemption of electricity duty for power producers;
- Incentive schemes for industry development;
- Solar power having guaranteed grid access under both the Indian Solar Mission and the Rajasthan Solar Policy;
- The Renewable Energy Infrastructure Development Fund;
- The Solar Research Centre for Excellence;
- Installation of solar thermal and solar PV (tender/direct sale auctions);
- Renewable Energy Certificates within the Indian Renewable Purchase Obligation (IRENA, 2011).

Renewable Purchase Obligation (RPO) compliance is mandatory for states in India, if they want to access funds for financial restructuring of their utilities. RPOs, put simply, are the minimum percentages of the total power that electricity distribution companies and some large power consumers need to purchase from renewable energy sources. RPO creates a minimum market for renewables in the absence of pricing externalities for conventional power generation.

With rapidly falling prices for PV cells, rising diesel prices, and dwindling hours and quality of farm power supply, solar pumps are likely to open a new chapter in India's irrigation economy in the years to come. Government subsidy programmes in different states have distributed more than 100 000 solar pump systems of varying capacities (Verma, 2017). The solar energy sector employs an estimated 103 000 people in grid-connected (31 000 jobs) and off-grid (72 000 jobs) applications (IRENA, 2016)

Finance, Investment and Business Models

Various banks provide financing for purchasing solar-powered pumps. These include the National Bank for Agriculture and Rural Development (NABARD), commercial banks, regional rural banks, state and district central cooperative banks and state cooperative agricultural rural development banks. They provide finance in form of grants and loans for the purchase of solar-powered pumps and their installation.

A government-run programme on solar pumping was started in India in 2012 and had installed around 14 000 solar pumps in the country by 2014. In 2014, the central government decided to introduce a more ambitious capital subsidy scheme for solar pumps. Customers can apply for a subsidy of INR 43 200 57 600 (equivalent to USD 670.00-893.00) per hp up to 5 hp capacity, along with a loan to cover the remaining costs. For capacities greater than 5 hp, it offers a fixed amount at INR 194 400 flat (around USD 3 013.00). This central government scheme was initially implemented by NABARD, but is now routed through the government's Indian Renewable Energy Development Agency (IREDA). The state governments complement it to varying degrees (GIZ, Frequently Asked Questions). In Rajasthan, a subsidy of up to 86 percent of the capital cost is available (as of 2016) through the Horticulture Department. In Gujarat, the subsidy amounts to 80 percent of the capital cost (as of 2016).

These high subsidies do not seem to reach the very poor as they are linked to specific requirements that small-scale farmers in India do not necessarily fulfil. In Rajasthan, for instance, it is expected that the farmer should: (i) own at least 0.5 ha of land; (ii) have a water storage structure on or near the land; and (iii) have installed a drip irrigation system (Kishore et al., 2014). As a result, the subsidy seems to mostly benefit farmers with bigger plots of land. A sample analysed by a recent IWMI study concludes that the average size farm in Rajasthan with SPIS is about 7.9 ha, while the average size farm in the state is 3.65 ha (Dekker, 2015).

Small and marginal farmers have received almost no direct or indirect benefits from subsidies on PV pumps in Rajasthan. The high subsidies limit the number of pumps that can be installed, discourage cost-cutting innovations, limit the emergence of an open market for solar pumps and could lead to diversion of solar panels from agriculture to other uses, where the subsidies are much lower (Kishore, 2014).

Several insurance schemes are available to cover the risks of theft, vandalism and other security issues related to solar-powered pumps. There are several prerequisites that need to be fulfilled in order to acquire such insurance, however. For example, some schemes require fencing around the installation (GIZ, Frequently Asked Questions).

Groundwater Governance

India's groundwater resources are in stark decline. As surface water availability decreases – or becomes increasingly sporadic – farmers turn to groundwater. Water stress is especially acute in north-western India, where agricultural outputs are declining and drinking water shortages are on the rise. In addition to scarce supply, water quality is seriously threatened. India's groundwater reserves are not only overexploited, but also contaminated by sewage, fluoride, arsenic and uranium. Incidence of arsenic contamination doubled between 2013 and 2016.

For over 40 years, perverse subsidies on farm power supply have not only made deep tubewell irrigation profitable for farmers but have, in fact, incentivized waste of energy and relentless depletion of aquifers. Data from the Fourth Minor Irrigation Census show that over 90 percent of India's electric tube wells and 80 percent of total groundwater use in irrigation are concentrated in ten western states, which offer free or subsidized farm power supply. Furthermore, 90 percent of withdrawn groundwater for agricultural purposes is applied through flood or furrow irrigation methods with low water use efficiency. How can India address its groundwater irrigation-energy nexus effectively, enabling farmers to benefit from a green technology while ensuring sustainable water use? Two experiences from Gujarat and Rajasthan shed some light:

BOX 4

Energy cropping: Diversifying incomes in Dhundi village in Gujarat

In the small village of Dhundi, in the state of Gujarat in western India, nine farmers have banded together to form a solar power cooperative that provides access to zero-carbon energy for agriculture and extra income from selling energy to the grid.

The farmers grow staple crops – such as pulses and spices – on their one-acre plots for either subsistence or selling to local markets. They mainly practice furrow irrigation.

Prior to switching over to solar energy in 2015, they used noisy, air-polluting and expensive diesel pumps, with negative impacts for health and climate. The relatively high costs for diesel added an extra strain on their already slender incomes. Dhundi is not a typical Indian village, as the farmers were not able to access electric farm power connections. Grid farmers are relatively better off and feel little pressure to shift to solar.

Now the Dhundi farmers have a total installed capacity of 71.3 kW AC solar water pumps, powering nine pumps that bring water up from a depth of up to 60 m, and they can sell excess energy to the grid. And more farmers are interested in shifting to solar energy.

They were assisted by the International Water Management Institute (IWMI) and financing through state and government subsidies, which paid roughly 20 percent of the price of the pumps.

Each farmer used to spend close to INR 20 000 rupees (USD 310) annually on diesel per pump for irrigation, running a total of 40 diesel pumps and one electric pump. The actual amount of CO2 emissions avoided by the solar project was estimated to be close to 55 tonnes.

The farmers have entered into an agreement with the local distribution utility (MGVCL) to buy back any excess power at the rate of INR 4.63/kWh. Each farmer could earn up to INR 40 000 rupees per year through this arrangement. However, this income is currently supplemented by an extra INR 2.5/kWh provided by IWMI.

The underlying idea is that farmers can make rational decisions about how to use the energy they produce: do they pump water or do they feed energy into the grid, thereby generating extra income? Ideally, this leads to an optimal use of water and energy resources, providing farmers with an incentive not to withdraw infinite amounts of water.

Nevertheless, even with the bonus paid by IWMI, the price at which farmers can sell energy to the grid is not yet competitive. "The rate fixed in the power purchase agreement is pretty low," says Parvin Parmar, a member of the cooperative.

During dry season, farmers can make more income by running their pumps, once their own irrigation needs have been met, and selling water to neighbouring farmers. This earns them up to INR 450 for four hours of sunshine, instead of the INR 93 they would make by selling this energy back to the grid. Such practices have led to an overall increase in water withdrawals.

The project has the potential to be rolled out across for the estimated 370 000 farmers in central Gujarat, bringing huge savings and climate benefits. For this to be successful, however, some teething problems need to be ironed out.

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The IWMI programme will eventually run out of funds to subsidize the feed-in tariffs. It is still unclear whether the energy utility or state government will continue the project in the future. IWMI's overall argument is that, instead of spending USD 12-14 billion per year to subsidize farm power (which creates perverse incentives to waste groundwater), the government should use some of that money to offer a feed-in supplement (which creates incentives to conserve groundwater).

One possible alternative is different uses of energy at the farm level, providing additional incentives for farmers to pump less water. If a significant number of farmers were to take this up, load management issues would also have to be considered.

FIGURE 12
Members of the Dhundi Solar Cooperative

Photo: Shilp Verma, IWMI India

BOX 5

Solar energy at the heart of holistic soil and water management in Rajasthan

An innovative Indian farmer has transformed his large farm outside of Jaipur, Rajasthan, by placing solar energy at the heart of a holistic soil, water, nutrient and energy management approach that is bringing him great benefits.

After a visit to Israel in 2012, Khema Ram transitioned to conservation agriculture, putting significant investments into a system that includes rainwater harvesting, polyhouses, solar pumps, drip and sprinkler irrigation, cow dung fertilizer, natural pest management, seedbeds and improved soil management.

A government subsidy scheme paid for a total of 82 solar panels and four pumps at a total capacity of 16 hp (official solar policy of Rajasthan only allows one pump and panels to a maximum of 3-5 kW). Ram has since installed an additional 25 kW system through his own investment, financed through a bank loan made possible by an increase in his income.

Now Ram can access water at any time, whereas previously energy to irrigate was only intermittently available. The solar system allowed him to shift from flood irrigation to sprinkler and drip irrigation in polyhouses and on open land.

Ram set up the polyhouses between 2013 and 2015. He would not have been able to take this step without the solar system, as the cost of running the fogger and cooling systems required for the polyhouses would have been prohibitive.

Most of the water is pumped from a rainwater harvesting pond, although groundwater is used as an additional source. As the groundwater is of lower quality than the rain (being high in minerals and fluoride), Ram installed a water filtration system at the same time as the solar pumps.

His production has refocused from traditional crops like gram, mustard, wheat and sorghum to horticulture crops (cucumber, broccoli, zucchini, fruit and spices).

Thanks to all the changes, the farm – in the village of Gurha Kumavatan – has increased from 4 000 m2 to 30 000 m2, including the rehabilitation of barren land. Ram now employees 40 people to keep the farm running, in addition to the family members who work there, bringing jobs to the local area.

The shift to near-organic production means higher-quality produce and more income: from up to INR 500 000 (USD 7 750) in 2010/11 to INR 10 million in 2016. Even with all the on-farm expenditures, Ram makes an annual profit of INR 5 million.

Ram is also turning the solar energy to other uses. He installed a large battery in 2017, which means he can power his home and now takes zero energy from the grid for his farming activities and household use. Service teams support him in case of problems with the system, with a maximum response time of 48 hours. The pump performance is monitored by smartphone.

Issues remain: market access – for example, to hotels – is controlled by local committees, requiring Ram to maintain good relationships and pay a portion of his income to ensure he can sell his produce. The cold chain also needs to be further developed to reduce losses.

Ram is now passing on his knowledge by training others to replicate his success. While progress has been accelerated by good soils and higher incomes than in other areas, his farm serves as a good model for the many benefits of holistic management and solar power.

4.3 KENYA: FOCUS ON SMALLHOLDERS

In Kenya, the agriculture sector contributes about 30 percent of gross domestic product (GDP) and accounts for 80 percent of national employment, mainly in rural areas. Cross-country estimates also show that GDP growth originating from agriculture is at least twice as effective in reducing poverty as GDP originating from outside agriculture (Ndunga, 2016).

Small-scale farming is largely rain-fed and thus highly vulnerable to climate change impacts such as unreliable rainfall and frequent episodes of drought. This results in lower and highly unpredictable income streams for the typical small-scale farmer in rural Kenya. For such small-scale farmers, farming is a manual and laborious activity with limited opportunities for improving efficiency, value addition and achieving scale – attributes essential for transforming small-scale farming into a viable and sustainable agribusiness in rural Africa (Solar Energy Foundation, 2017).

Green Economy

Solar-powered irrigation is becoming a niche in Kenya's economy, with many small and medium-sized companies developing supply chains and services around SPIS. There are now several companies in Kenya that will: provide or arrange for an appropriate financial payment system; give advice, surveying the site to make a reliable offer; install, train on-site and provide after-sales support through phone or a visit. These solutions are targeted at Kenya's diverse and fragmented agriculture sector, and especially smallholders.

It is estimated that there are around 2 000 solar borehole pumps and around 1 000 solar surface pumps (under 2.5 kW) in operation in Kenya (estimation by a solar pump distribution company). A growing number of technicians and engineers are being employed by the companies cited above, although these companies usually have to train their personnel themselves.

The government is also focused on supporting smallholder farmers. Several support programmes, including the Agricultural Sector Development Support Programme, have been set up by the Government of Kenya and six development partners. These programmes aim to strengthen the role of smallholder farmers in Kenya's agriculture sector.

The Kenyan government is refraining from charging value-added tax on solar kits in order to make these kits more affordable. The country's draft National Irrigation Policy proposes more incentives for farmers to buy such devices, including lower import taxes.

Nevertheless, the government has also been criticized for hampering the drive for more renewable energy and mini-grid solutions through unrealistic target-setting, legal barriers, complicated procurement procedures and lack of standards. Unattractive feed-in tariffs discourage private developers frominvesting in medium- to large-scale renewable energy plants.

Finance, Investment & Business Models

Banks, such as Equity Bank, and microfinance institutions, such as Juhudi Kilimo (owned by farmers), offer credit lines for solar-powered irrigation. Different options for loan prerequisites and repayments are offered – for example, harvest cycle repayments. There are also equipment suppliers for solar-powered irrigation that offer credit lines for their customers. This has been described in Chapter 4.4 as One-Stop-Shop.

Alternative financing methods in Kenya include:

- The "merry-go-round" (an informal cooperative society that is normally used to pool and invest savings by multiple people);
- A "check-off system" (a hire/purchase arrangement whereby products are sold and monthly repayments recovered from the customer's salary by his or her employer).

Groundwater Governance

Kenya has a well-designed water management framework, as well as a draft National Irrigation Policy (Republic of Kenya, 2015). Accordingly, water use is regulated through permits defining water use, volume authorized for abstraction and the duration of the permit. The National Irrigation Policy asks that "irrigation development will be informed by stakeholder participation and multiple-use water systems. Irrigation developments will adopt integrated water resources management (IWRM) to reduce water conflicts and concurrently comply with the environment management plans (EMPs) as integral services to beneficiaries and ecosystems."

Nevertheless, the implementation of these laws, policies and regulations is ad hoc at best. Water is commonly perceived as a private resource belonging to the owner of the land and is typically exploited for short-term gain, ignoring the long-term consequences of unregulated use. Groundwater management decision-making is sector-based and, on the whole, ad hoc; there is no mechanism for coordination or for fostering cross-sector linkages. Consequently, the management of groundwater resources has continued to be carried out in isolation from the management of land and other land-based resources, with the inevitable consequence that the implications of management decisions in critical areas such as physical planning, land use planning and agricultural activities have often been overlooked.

BOX 6

Solar water pump return on investment at Homa Bay County, Kenya

The Kenya Smallholder Solar Irrigation (KSSI) project is working to accelerate commercial sales of solar water pumps to small farmers. KSSI staff met Ms. Lilian Akinyi, who rents a farm in Homa Bay County near Luala Kambuya village. She was using a diesel pump to transfer water from a canal fed by the Sondu Miriu River. She paid KES 5 500 per season to hire a diesel pump one day a week. She irrigated 0.75 acre of tomatoes with the diesel pump and 0.25 acre of kale with a watering can.

In September 2016, Ms. Akinyi purchased a "Futurepump" Solar Water Pump (SWP) for KES 75 000, which included a 80 Wp solar panel and a 12 metre pipe, through Futurepump's Pay-As-You-Go programme. She made a down payment of KES 20 000 and will make a monthly loan payment of KES 2 500 for 22 months. She stopped using the diesel pump as soon as she purchased the solar water pump.

Ms. Akinyi no longer has diesel pump rental, fuel and transport costs. She has increased her irrigated area from 1 to 1.25 acres, and is irrigating more frequently than before. Using conservative estimates, her gross profit is projected to increase by 350 percent after she pays off the loan. The Table in the next page shows the return on investment (ROI) analysis of the farm of Lilian Akinyi:

TABLE 8
Return on investment (ROI) analysis of the farm of Lilian Akinyi

Farmer profit and loss statement (KES)	Year 1 Actual (still with Diesel pump)		Year 2 Actual	Year 3 Projected
	Season 1 (Pre-SWP)	Season 2 (Post-SWP)	Season 2	Season 2 (Post-loan)
Acreage planted	Tomatoes 0.75 Kale 0.25	Tomatoes 0.25 Kale 0.25 Maize 0.25	Tomatoes 0.5 Kale 0.5 Maize 0.5	Tomatoes 0.5 Kale 0.5 Maize 0.5
Total yeld (kg)	2 517	3 683	6 300	6 900
Yeld change (%)	-	46%	71%	10%
Total revenues	**99 200**	**144 890**	**250 600**	**282 800**
Revenue growth (%)	-	46%	73%	13%
Operating costs	**29 530**	**3 063**	**50 246**	**52 700**
Pump fuel and transport	2 500	1 000	-	-
Pump hire and maintenance	3 000	3 700	1 500	1 800
Total operating costs	**35 030**	**42 763**	**51 746**	**54 500**
Gross profit	**64 170**	**102 127**	**198 854**	**228 300**
Gross profit margin (%)	65%	70%	79%	81%
Loan + interest payment (six months)	-	15 000	15 000	-
Earnings before taxes	**64 170**	**87 127**	**183 854**	**228 300**
Debt coverage and investment returns				
SWP total upfront investment	78 600	5-year Return On Investment (ROI)		18.14
Financed by own savings	23 600	5-years Internal Rate of Return (IRR)		197%
Financed by vendor loan (10% two years)	55 000	Incremental gross profit/initial investment		2,56x

**Exchange rate: KES 100 = USD 1; rental value of land and imputed value of family labour not counted*
Source: Winrock International

FIGURE 13
Lilian Akinyi with her 0.75 acre Maize crop

Source: Winrock International

4.4 MEXICO: GROUNDWATER GOVERNANCE

Mexico's agriculture sector is divided into modern farms, which are highly technological and integrated in world markets, on one hand, and small-scale and subsistence farmers, which constitute the majority and are mostly marginalized and food-insecure, on the other (FAO Mexico, 2016). At the same time, groundwater depletion due to over-abstraction is a critical issue; the main user being the agriculture sector.

The government subsidizes electricity for pump systems for agriculture, which is one reason for over-pumping, along with weak enforcement of water management. CONAGUA (the National Water Commission) is the institution responsible for water resource management in the country. Mexico adopted three sets of tools – regulatory, economic and participatory – for groundwater reforms. Responses to the reforms are mixed. The large water users (agribusinesses, industrial and commercial users) quickly applied for concessions and paid water fees. The real challenge, however, is registering the water rights of the many, dispersed agricultural users – who together account for at least 80 percent of the total volume pumped – and monitoring their withdrawals (Shah, 2014).

Green Economy

Mexico is blessed with sunshine, particularly in the northern and western areas of the country, in the states of Baja California, Sonora and Chihuahua, which have insolation values of 7 kWh/d per m2. In recent years the Mexican government and the public have begun to recognize the importance of renewable energy – especially solar – and energy efficiency. In 2005, the federal tax law was amended to allow for 100 percent depreciation of the capital expenses for renewable energy investments in its first year. Two years later, in 2007, a model interconnection agreement was developed for renewable energy projects to facilitate their connection to the electricity grid. A renewable energy law (LAERFTE) and the Law on the Sustainable Use of Energy followed. These new laws help pave the way to eliminate barriers for new projects and technologies and encourage growth in the installation and development of new projects.

Large-scale solar pump systems for irrigation in Mexico are few, as grid power is reliable and heavily subsidized (tariff 9CU: 0.033 USD/kWh and tariff 9N: 0.016 USD/KWh), making it more cost-effective to run electricity pumps. In more remote, rural areas and for decentralized, small-scale farms, solar pumps may provide a viable alternative.

Finance, Investment and Business Models

Two different schemes are supporting solar-powered irrigation at present, both administered through the Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación (SAGARPA), Mexico's Ministry of Agriculture.

- The support programme for renewable energies in the agriculture sector is designed for highly productive provinces and subsidizes SPIS at 50 percent, up to a maximum amount of USD 6 000.
- Through the support programme for rural arid areas, farmers can get up to 70 percent subsidy for solar-powered irrigation, up to a total amount of USD 22 000 (!)

Both programmes are restricted to specific areas. These areas and attached conditionalities are changing every year. The programme is now administered directly by the decentralized offices of SAGARPA in the provinces. However, the conditions for the programmes are rather complicated. Farmers have to apply and produce a business plan, which needs to be validated by SAGARPA. A specific emphasis is placed on assessing water sources to be used for the irrigation system. The decentralized offices of SAGARPA are often not aware of all the different support programmes and farmers generally do not know about them either. The best channel for communication seems to be that solar equipment suppliers inform farmers and help them to apply and fill out the forms. Banks are currently not providing loans for solar irrigation projects. The bank credit available for solar panels is "CIBanco" but it applies only for on-grid installations for consumers with high electricity tariffs (Fillad, 2017).

Social Justice

The support programme for rural arid areas by SAGARPA focuses on areas with high poverty rates and a strong degree of marginalization. Subsidies can be as high as 70 percent of the total cost of the irrigation system, as described above. However, SPIS technology is unknown to most of the farmers, due to the very low number of installed solar pump systems relative to the size of the country. Small farmers are not used to applying for subsidies and often do not fulfil the criteria for approval. Getting permission for a new well is nearly impossible for a small farmer.

Groundwater Governance

Even with an ambitious water law, Mexico is grappling with basic groundwater management issues, such as registering wells and issuing water use permits (Shah, 2014). CONAGUA helped establish technical committees for groundwater (COTAs) as user-based groundwater management organizations. The idea was to transfer responsibility for managing aquifers to the users. Nevertheless, there were no further rights or budget allocated to the COTAs, making them financially dependent on support from the federal or state governments and in dire need of technical support. Self-monitoring of groundwater abstraction may seem utopian in some contexts; nevertheless, the high-quality public education and awareness programmes of the COTAs do seem to be bearing fruit (Fillad, 2017).

4.5 MOROCCO: MITIGATING CLIMATE CHANGE

Climate change mitigation and adaptation is a key priority for the Kingdom of Morocco. It has laid out an ambitious plan to reduce GHG emissions and pledged to generate 52 percent of its electricity needs from renewable energy by 2030. As a consequence, Morocco has lifted all subsidies on diesel, gasoline and heavy fuel oil to encourage more efficient use of energy and to free up resources to invest in the transition to a green economy.

At the same time, Morocco has introduced the Plan Vert, among other measures, to incentivize farmers to use water more efficiently through modern irrigation techniques, such as drip irrigation. It also seeks to provide farmers with reliable access to water, so that they can cope with changing climate patterns and drought. Solar-powered irrigation represents a confluence of these efforts, providing a zero-emission technology to farmers that can be coupled with a potentially water use-efficient irrigation method. Both mitigation of and adaptation to climate change are thus possible.

Green Economy

Morocco is actively pursuing a transition towards a green economy. This has implications for the energy and agriculture sectors, which in turn affect the viability and uptake of solar-powered irrigation technologies.

In the energy sector, the Moroccan government is phasing out subsidies for both diesel and butane. Currently, the only energy subsidy provided is for domestically used butane, fixing its price for the next ten years at around MAD 42 for a bottle of 12 kg, compared to MAD 90 on the world market (GIZ 2016). Given these artificially low prices, the illicit use of butane for other uses than domestic can be observed across the country. Butane remains the most commonly used energy source for irrigation with which solar energy technologies need to compete.

Nonetheless, the government is pushing forward its renewable energy agenda, promoting solar technologies and seeking ways to cushion the negative effects of the removal of subsidies for small-scale farmers. In 2013, the Moroccan Ministry of Agriculture, the Ministry of Energy and the Ministry of Finance jointly prepared a law to roll out a subsidy scheme, together with the government-owned bank, Crédit Agricole, helping farmers to afford the transition from conventional to renewable energies. It was solidified in 2017 with a budget of USD 220 million. The subsidy would provide 50 percent of the capital cost of the solar panels and 80-100 percent for drip irrigation installation (AgriMaroc, 2017). There are already other financing options for farmers by national banks and financing institutions in Morocco. The UNDP/GEF project, "Promoting the development of photovoltaic pumping systems for irrigation" (2016 2019), will invest USD 73.5 million (with 96.5% national co-financing), aiming to promote the adoption of PV-powered drip irrigation pumping systems in Morocco by creating a conducive framework for the implementation of the national renewable energy programme.

Both the energy and agriculture sectors are key engines for job creation and employment in Morocco. Thirty-nine percent of the country's workforce is employed in the agriculture sector (as of 2014), which accounts for 13 percent of Morocco's GDP (as of 2016). Meanwhile, the renewable energy sector is growing and renewable energy production could soon have a positive impact on the GDP in the range of 1.2 to 2 percent, with a full-time equivalent employment effect of 270 000 to 500 000 jobs (Arce, 2012). Investments in solar projects, such as NOOR, also stimulate local manufacturing, as sourcing is focused on local products (IRENA, 2016b). These developments make the uptake of solar technologies in Morocco more likely.

Finance, Investment and Business Models

In Morocco, SPIS are economically viable. UNDP-GEF compared the costs of solar, butane, diesel and electricity pumps and concluded that the PV pumps were comparatively cheaper, even when considering different plot sizes and depth of aquifers from which water is withdrawn. While the government-supported subsidy programme is not yet in place, there are a number of other financing schemes available for SPIS in Morocco at present. They are listed in Table 9

TABLE 9
Existing financial models, advantages and disadvantages

Financial model	Target group	Advantages	Disadvantages
CAM (Crédit Agricole du Maroc)	Farms with high energy consumption	Fast process	Requires collateral
Tamwil El Fellah	Farms with a bankable record	"Soft" collateral sufficient	High interest rate
Ardi / Al Amana/ Al Baraka	Agricultural or non-agricultural micro-enterprises	"Soft" collateral sufficient	Loan ceiling
Banque populaire/ Attijari / BMCI	Enterprises or private individuals	No loan cap	Collateral
MorSEFF	Registered enterprises only	Subsidy of 10%	The farm must be registered as an enterprise and must be improved by the involved banks, namely BMCE and BP

Source: GIZ Maroc, 2017

Nevertheless, not all farmers can make use of such schemes as they require that farms are registered as enterprises, land ownership is certified and collateral is available. Also, they often involve significant paperwork, which presents a barrier for many farmers. Extended family will often give loans without interest or with low interest, making informal ways of financing more attractive for some.

There are a few examples of Energy Services Companies (ESCOs) in Morocco that provide an alternative business model for solar-powered irrigation. Essentially, the ESCO signs a performance contract with the farmer, taking over engineering, supply, financing, installation and maintenance of the solar-powered irrigation equipment. The farmer pays for the energy delivered (or the irrigation water). In Morocco, ESCOs have been set up in the context of introducing renewable energies in mosques, creating jobs and working with imams to educate people about solar technologies.

Another business model that has been considered in Morocco is micro-leasing (Microfinance Gateway, 2017). This is a mechanism whereby solar-powered irrigation equipment is rented to the small farmer by a financial institution (e.g. credit and savings cooperative, microfinance institution or commercial bank). Additional services, such as insurance on the equipment and training in operation and maintenance of the equipment to be rented, are also available to support the farmer. This model does not yet exist in Morocco and would need further refinement in how and when services can be delivered (GIZ Maroc, 2017).

Social Justice

There are different customer groups for SPIS systems: small, medium-size and large farmers, cooperatives and GIEs (Economic Interest Groups) in Morocco. As can be seen in Table 9, more than 40 percent of farms are in the smallholder category (1-3 ha). UNDP-GEF note that savings in pumping costs are particularly noticeable for farmers with small plots, as water and energy use efficiency already tends to be higher on larger farms.

TABLE 10
Number of farms vs. plot siz

Plot size (in ha)	Number of farms
[1-3]	162 983
[3-5]	81 737
[5-10]	86 064
[10-20]	40 980
[20-50]	16 837
[50-100]	3 297
+100 ha	1 602
Total	**393 500**

Source: IRENA, 2016b

Nevertheless, access to finance remains a significant issue for small-scale farmers. Morocco's National Energy Strategy is primarily focused on large-scale investments and pays less attention to small-scale, distributed renewable energy solutions. The planned subsidy scheme indicates a break from this approach. However, the scheme is yet to be rolled out and it has been noted that smallholders with plot sizes of 1-3 ha do not benefit much from existing finance schemes. This is because they often do not fulfil the requirements (e.g. registered land ownership, registered enterprise) for loans and financial support as discussed in the previous section.

There is a need to further investigate the socio-economic impacts of SPIS for small-scale farms, and to study how women and marginalized groups can gain access to SPIS technologies.

Groundwater Governance

Groundwater depletion in Morocco is a huge problem. Much more water is being pumped from the ground than is naturally recharged, and aquifers have been declining. The government has revised law 10-95 on water to create a stronger regulatory framework for water management. Moreover, the government has invested in capturing more surface water and directing it to recharge aquifers. It is promoting regional aquifer plans ("contrat de nappe") and deploying a water police force to control new well drilling and illegal pumping.

The government is also implementing the Programme National d'Economie d'Eau d'Irrigation (PNEEI, National Irrigation Savings Plan) under the Plan Maroc Vert, which seeks to increase 38 percent of the current area under drip irrigation to about 550 000 ha, or 49 percent of irrigated land (surface and/or sprinkler) between 2010 and 2020, and to double the value added per m3 of water by the end of the programme. The PNEEI ultimately aims to convert surface and sprinkler irrigation to drip irrigation over an area of 920 000 ha by 2030, resulting in water savings of 2.4 billion m3/year (FAO & EBRD, 2016).

From a technical viewpoint, the coupling of solar pumps and drip irrigation is an optimal solution, potentially resulting in increased field application efficiency. Nevertheless, to address the risks (or actual problems) of groundwater depletion, drip irrigation is not enough.

4.6 NEPAL: WOMEN FARMERS BENEFIT FROM SPIS

Although hydropower development is currently a priority issue in Nepal, solar technologies have great transformative potential in a country with very remote and difficult-to-reach areas.

Green Economy

The Government of Nepal has repeatedly indicated a commitment to renewable energies. Under its National Rural and Renewable Energy Programme (NRREP), Nepal aims to install 600 000 solar home systems. The Ministry of Population and Environment has an Alternative Energy Promotion Centre that seeks to make renewable energy a mainstream resource. The World Bank is funding a programme on Grid Solar and Energy Efficiency, which will support the construction and operation and maintenance of a grid- connected 20 MW solar farm near the Kathmandu Valley.

Despite the support for solar energy, significant market challenges remain for SPIS in Nepal, including limited options for manufacturing, relatively few suppliers and limited access to finance. At the same time, information and understanding about SPIS among farmers is inadequate, as they hesitate to change farming practices.

With a wide range of prices and no performance or safety standards, solar energy has become a risky investment. However, by embedding the technology in value chain productive-use projects that support farmers to increase income by growing and selling off-season produce, there are increased opportunities to demonstrate financial benefits. Current commercialization barriers are overcome through public-private partnerships that emphasize quality systems, education and demonstrations, linkages with innovative microfinance institutions and partnerships with technology providers (Foster, 2015).

Finance, Investment and Business Models

In mid-2017, the Minister for Irrigation gave orders to promote SPIS. The next fiscal year will see further funding for SPIS, especially for groups of farmers who want to apply for government grants (The Rising Nepal, 2017). Meanwhile, the International Centre for Integrated Mountain Development (ICIMOD) has offered farmers three financial models for SPIS support:

- A grant model, covering around 60 percent of total investment costs;
- A grant-loan model with a grant component as well as an additional 20 percent loan at a 5 percent interest rate per annum;
- A grant pay-as-you-go model, where farmers pay a monthly rental fee for use.

An additional 10 percent subsidy was offered to female farmers, provided they owned the land on which the SPIS was installed. This was done in consideration of low land ownership of women, who own only 3 percent of land in Saptari, the district in which the project was implemented. Of the 65 applications received for SPIS finance, 20 percent were for a grant model, 46 percent for the grant-loan model and 34 percent for the grant pay-as-you-go model. Access to finance is also provided by the NGO "SunFarmer," which has partnered with existing local cooperatives to offer affordable solar water pumping to farmers. They install durable solar water pumps for irrigation, provide affordable rent-to-own financing with three-year terms, and monitor and maintain the systems. The cooperatives, in return, identify farms and collect monthly repayments on behalf of SunFarmer, retaining a fee for collection. Market-based models, such as those of SunFarmer and ICIMOD, work for all those farmers who have already invested in irrigated agriculture and want to reduce the long-term costs of irrigation (Mukherji et al., 2017b).

Social Justice

In Nepal, women cultivate most of the land, as men migrate in search of jobs in cities and other countries. Nevertheless, female land ownership is very low. In the Saptari district, only 3 percent of land is owned by women. ICIMOD sought to address this issue by offering an additional 10 percent for SPIS grants if the application was submitted by a woman and provided she owned the land on which the SPIS would be used. The results were significant. Out of 65 applications, 77 percent were from women. In most cases, land had already been transferred to them. This shows that the need to transfer legal ownership of land to women was not seen as an impediment to availing the additional discount. It also demonstrates that the structural inequities can be reduced through innovative public policy interventions (Mukherji, 2017).

Once SPIS are installed, they can serve multiple uses, making water supply more cost-effective and efficient. Multiple-use systems can be highly efficient and allow for improved management of limited water resources. This is especially important for many of the disadvantaged communities, which require a system that allows them to maximize the productive output of highly constrained resources (Int. MUS Conference, 2016)

Groundwater Governance

In Nepal's Terai plains, abundant groundwater resources close to the surface and high replenish rates are juxtaposed with high costs of groundwater extraction due to low electrification rates and high diesel costs. This leads to low agricultural growth rates and high rural poverty (Mukherji, 2012).

The Water Resources Act 2049 BS (1992) is an umbrella act that was designed to regulate all forms of water resources in the country for their rational utilization, conservation and management. Beneficial use and equity in access are the important principles adopted by this Act in the allocation and re-allocation of water resources in the country. Water right is confined

BOX 7

Giving women loans to buy solar panels for irrigation – and access to land – can help them build resilience to climate change

Amrica Devi Yadav, a farmer from the Terai region in Nepal, is not alone in her struggle to grow food. "I cannot grow many vegetables with just watering cans. But in our village, we do not have many options for irrigation. Electricity is not reliable and diesel pumps are too expensive for us," she explains. Yadav lives on a 1-ha farm with her husband and two children in the village of Rayapur, in the Saptari district. During the long dry season, like many others, she finds it hard to cope with her workload, juggling household chores, child care and watering her vegetable plot.

Terai is Nepal's food basket, with 71 percent of paddy rice, 64 percent of wheat and 58 percent of total vegetable production coming from the region. Yet the crop productivity in the many small farms of this region (on average 0.7 ha) is low, partly due to the difficulty of accessing irrigation. Led by ICIMOD, in collaboration with the local NGO, Sabal Nepal, and the social enterprise SunFarmer, which specializes in affordable solar energy technologies, a project was initiated that aimed to demonstrate the potential of low-cost SPIS as an irrigation alternative. Three pilot solar pump sets were installed in the Saptari district, one of them for the women farmers' association in Rayapur village, of which Yadav is a member.

Yadav particularly appreciates the eased workload. "This solar pump has made irrigation physically easier for me," she says. "We were able to irrigate cash crops like eggplant, potato, chilli, garlic, coriander, onion seed, green leafy vegetables and pointed gourd during the dry season and get a good income." Further down the line, it will be interesting to evaluate whether solar pumping succeeds in boosting women's empowerment in a region where irrigation is seen as a male domain.

"This season, I have tried new vegetables, like broccoli, which is in high demand in the local market. The solar pump system is easy to operate and thanks to it, I will continue grow more cash crops," says Yadav. With continued government support and the right financial models, it is hoped that the benefits of solar irrigation will reach other Terai villages.

Source: http://news.trust.org/item/20170321102609-5y7no/?source=spotlight

to the "right to utilize water resource" (Kansakar, 2011). However, when it comes to irrigation, there is still no strong institution that handles the planning, investment, oversight, monitoring and evaluation of the irrigation sector (Pradhan, 2012).

Groundwater regulation is needed. A plan currently exists (as of 2017) that seeks to regulate the extraction of groundwater over certain limits through appropriate regulation and standards (The Himalayan, 2017); however, this plan is yet to be approved and implemented.

4.7 SENEGAL: SOLAR PUMPS REPLACING DIESEL PUMPS

Green Economy

In Senegal, natural resources play a decisive role in the country's economic performance, but continued pressure on these resources is reaching a point where the country's economic security is being jeopardized. Under current damaging practices, the country's environmental sustainability and economic growth appear to be mutually exclusive. Transitioning towards a green economy can help Senegal (and other countries) to receive significant benefits in terms of preserving the ecosystems that support the supply and renewal of these much-needed resources for the country on the one hand, and ensuring that the country is on track in promoting human development and social equity on the other (UNEP, 2015).

Nearly 90 percent of agricultural lands in Senegal are used by small-scale, family-run farms engaged in subsistence agriculture. Smallholder, irrigated horticulture, with a large range of vegetables, mainly onion and tomatoes, accounts for a large part of the country's irrigation sector (Paglietti, 2016). There are an estimated 10 000 smallholders irrigating mostly with small diesel pumps near the coast north of Dakar up to St. Louis. They grow horticultural crops in three seasons per year on areas of between 1 and 2 ha.

These diesel pumps are not very economical, as they last only two to three years and monthly expenses for diesel fuel and interest for loans make it hard to survive. Solar pumps can offer relief to strained farmers, bringing about real economic benefits. Operational costs are significantly lower for solar pumps over a 2-3 year period. Solar pumps also offer an opportunity to gradually introduce more efficient irrigation methods and lower input rates for fertilizers and pesticides. As of the beginning of 2017, in Senegal there were an estimated (from the online survey):

- 100+ small-scale mobile solar irrigation systems (panels and pump can be removed overnight);
- 100+ small multi-use solar irrigation systems that also use the energy for lighting and battery- charging.

Suppliers of solar pump systems who are capable of correctly planning, installing and servicing them are still rare in Senegal. No certification for tested suppliers exists. Subsidies for SPIS do not exist and are not necessary, as they already offer an economic advantage compared with diesel/petrol pumps.

Finance, Investment and Business Models

Financial institutions in Senegal are still hesitant to finance solar pump systems. The systems are new in the country and not well understood. Farmers can seldom provide collateral and the banks do not yet accept the pumping system as collateral. There is at present no market for used solar pumps.

Sometimes farmers' associations can guarantee on behalf of their members. There are credit schemes for grinding mills, which may be used as a reference in the future. Payback periods for solar pumps in the belt between Dakar and St. Louis (3 crops per year, 1 ha irrigation, 15 percent interest) are 2 to 2.5 years (Hagenah, 2017).

Special mini-grids for decentralized irrigation are realized in Senegal by SEL, Columbia University's Sustainable Engineering Lab. Electricity is generated centrally by a single, solar PV array. A custom-made, battery-less AC system controls and monitors pump function for 7+ farmers. Electricity is sold by a micro-utility to farmers, who use a prepaid credit system similar to cell phone scratch card systems, paying only for what they consume. Thus farmers retain autonomy of their individual wells and pumps (The Earth Institute, 2015). However, the pumps are less efficient than optimized pumps directly coupled with PV panels.

Social Justice

Groups of women in Lower Casamance in the south of Senegal are farming small plots of market garden crops. The drop in precipitation over the last 30 years has brought about a decrease in rice production and progressive development of market garden crops. Solar pumps make it

BOX 8

Twelve solar pumps in market gardens in Senegal (Energie Solidarité Senegal)

Crop irrigation is still recent in the region of Ziguinchor in Casamance, Senegal. Rain-supplied rice cultivation was traditionally practiced in this area, but the drop in precipitation over the last 30 years or so has brought about a decrease in rice production and progressive development of market garden crops. Women have grouped together to farm market-crop plots. In addition to making it possible for them to provide for the needs of their families in terms of food, it also offers them a framework and context for social exchange and encounters. But without any pumping or irrigation system, the work of these women, who have to draw and transport the needed water in pails, is hard and long.

Twelve farm areas, located in the Department of Bignona, were finally selected. They include 25 to 85 women active in market gardening operations; their water needs were estimated at between 20 and 50 m3 per day. Once technical studies were completed, it was decided to orient the project toward water-raising systems composed of a solar generator and a submersible centrifugal pump. Depending on the farmed plot, required solar generator capacities were evaluated at between 530 and 1100 Watt peak. Installation layout is similar for all of the sites: the pump, which is immersed in a well, supplies a main discharge basin, and the water is then distributed to different plots of the farmed area by means of several secondary basins.

Each group now has documentation containing this same information and a daily logbook in which the site manager has to record everything that is done. In order to take care of maintenance and equipment replacement, a fund was constituted by each of the beneficiary groups through an initial payment of 300 000 CFA francs (USD 550.00). This contribution, which was paid before equipment installation, is a significant sign of the group's commitment towards the installation and its sustainability. Annual fees of an identical amount are added to this sum, which is placed in a bank account. It's now a fact that solar energy has made a remarkable breakthrough in Lower Casamance.

possible for the women to work in better conditions – not having to carry water for irrigation, they can develop their market garden activities and improve the nutritional balance of food served in their homes (Energie Solidarité Sénégal, 2006).

Groundwater Governance

Groundwater and surface water management in Senegal, including water policy, are the responsibility of the Direction de la Gestion et de la Planification des Ressources en Eau (DGPRE). Permits are required for drilling and water abstraction. Currently, there is no legislative protection for groundwater in vulnerable areas and water disposal is not controlled.

Although Senegal has significant groundwater resources, the distribution of availability and demand do not match. This means that some groundwater systems are overexploited, leading to groundwater depletion (British Geological Service). Solar pumps can be equipped with water level sensors to monitor groundwater depletion. Current planning of such a monitoring system is ongoing in the PERACOD programme (www.peeracod.sn).

BOX 9

FAO experience on women vegetable gardens in The Gambia using SPIS)

Eight vegetable gardens of various sizes (4 to 8 ha) for women in eight different villages have been fenced, equipped with boreholes, SPIS, overhead tanks and water distribution networks. This was planned and implemented by FAO Gambia between 2013 and 2016 within the framework of the European Union project, "Improving Food Security through Crop Production Intensification and School Feeding Programs," to improve household food security and the income of participating farmers

Through a bidding process, contracts were awarded to companies for the implementation of the different components of the project such as:

- Garden fencing;
- Borehole drilling;
- Supply and installation of solar water pumping systems comprising submersible pump and accessories, solar panels and overhead tanks;
- Construction of reticulation network for water application on plots (4 ground reservoirs per ha, drip irrigation).

Vegetable production

More than 2 500 women are currently farming on these eight gardens, each woman having a plot size from 30 to 200 m2 (see Table 10 below). Input from the women led to the building of an overhead tank with a capacity of 20 m3 for gravity feed, and a reticulation system; drip irrigation can be connected in the future. At the same time, the women made clear that they need further water storage in form of ground reservoirs (4 per ha with a capacity of 4 m3), as irrigation times and pumping times do not overlap. Usually the women irrigate the vegetable gardens for four hours per day (during dry season), while the time they have available to operate the pumps is much less. With the added storage, the women can be more flexible with the irrigation times. When interviewed, the women were very happy with systems; their men and children appreciate the rich and varied food they can now enjoy. They also claim that diseases have decreased significantly.

TABLE 11

Land distribution of the gardens in The Gambia

Vegetable garden information								
Village/Site	**Area (ha)**	**Participants 2015 season**		**Total participants 2015 cropping season**	**# of beds**	**Av. beds per farmer 2015**	**Av. bed size (m^2)**	**Actual targeted beneficiaries**
		Male	**Female**					
Njoben	5.0	9	500	509	1 360	2.7	10	518
Sutukung	5.0	21	358	379	893	2.4	10	418
Jappineh	5.0	6	178	184	908	4.9	10	420
Madina Lamin Kanteh	5.0	3	117	120	1 795	15.0	5	106
Darsilami	3.5	8	57	65	2 400	36.9	5	165
Dampha Kunda	5.0	0	65	65	1 285	19.8	5	536
Nuimi Lamin	8.0	25	335	360	2 029	56.4	3	200
Konteh Kunda Nigii	5.0	2	156	158	6 258	39.6	5	225

Source: Evaluation report, Samaké, 2017

FIGURE 14

Solar Powered Irrigation System at Niumi Lamin

Photo: FAO

5. Recommendations

The following chapter makes recommendations regarding the following areas of work on SPIS:

- Research and Development, including proposals for further studies, assessments, planning tools and technological developments;
- Capacity Development and vocational training to create local jobs and technical competence;
- Structural Support to create an enabling environment for solar-powered irrigation that helps realize the potential and manage the risks.

5.1 RESEARCH AND DEVELOPMENT

INITIATE FEASIBILITY STUDIES FOR SPIS IN WELL-DEFINED GEOGRAPHIC AREAS

Feasibility studies for the potential use of SPIS in specified districts or regions are necessary. They should be based on GIS information, taking into consideration parameters like weather and soil data, slope of the terrain, crop requirements, water availability and distance, economic analysis, and government plans and policies. Water data are often lacking or outdated, making water accounting of both surface and groundwater resources an essential exercise. Guidance on how to conduct water accounting can be found in FAO Sourcebook on Water Accounting and Water Auditing (FAO, 2016). Socio-economic aspects of the area (e.g. appropriate business models) must be considered, which could be done in the form of livelihood mapping. This can help to establish criteria for areas where solar-powered irrigation is feasible and advisable. These studies would also serve as market assessment studies and can thus prompt SPIS suppliers into action where attractive markets have been identified.

PROMOTE THE DEVELOPMENT OF A HOLISTIC PLANNING TOOL FOR SPIS

Comprehensive planning tools that consider the interlinkages between energy, water and agricultural production as well as finance, technology and policy are needed.

Many manufacturers and suppliers provide tools to understand the feasibility and design of SPIS. Planning software and impact assessments for irrigation methods and technologies also exist, and usually they are well-designed and easy to use. However, the integration of these systems (solar pump and irrigation technology) is necessary.

The GIZ programme on "Sustainable Energy for Food – Powering Agriculture," in partnership with FAO, is currently developing a Toolbox for Solar Powered Irrigation Systems (SPIS), designed to enable advisors and practitioners in the field of solar irrigation to provide broad hands-on guidance to end users, policy-makers and financiers. The aim is to guide technical government staff, agricultural extension workers and other advisors on how to design, set up and maintain SPIS in the most sustainable way possible, thereby avoiding risks related to system efficiency, financial viability and the unsustainable use of water resources (see Energypedia, Toolbox). This Toolbox is constantly evolving; further contributions and refinements are needed.

CONDUCT IMPACT ASSESSMENTS OF SOLAR-POWERED IRRIGATION

More information is needed on: the impacts of solar-powered irrigation on water use, agricultural productivity and yields; changes in agricultural practices – e.g. cropping patterns, irrigation scheduling and methods; expansion of irrigated land; socio-economic aspects, such as job creation and income generation; as well as climate change mitigation and adaptation potential. This is important for future planning and advisory services for subsistence, smallholder, and commercial farmers.

Farmers need more site-specific information. This can be obtained through decentralized test fields, where different irrigation technologies are tested for standard crops of the area. These test fields are ideal locations for training and advisory services, including for SPIS. Weather stations can provide not only weather data, but also data like soil moisture for the most important crops of the region. Weather and soil data collection can be associated with such test fields. The results should be made public and be available in a timely fashion. Nearby farmers can make best use of the information regarding irrigation needs and timing for different crops.

FIGURE 15
Measuring solar irradiance in Melipilla, Chile

Photo: Hans Hartung

EXPLORE ADDITIONAL PRODUCTIVE USES OF SPIS

Two of the key challenges of SPIS are the economic viability of the system and the risks it poses to groundwater resources. This is paradoxical, as the pump should run as long and often as possible to make the greatest productive use of it, while from a water perspective, it would be better to abstract as little water as possible. What if the solar energy produced by the system could be used not only for pumping? What if multiple uses for the energy were possible? This would allow for both the optimal use of the solar panels as well as empowering farmers to make rational decisions about their water and energy use on-farm.

Mini-grids and multiple-use solar applications – such as rice huskers, processors and cold storage – already exist. However, to ensure that the solar pump is coupled effectively with other on-farm applications, new products and developments are needed. SPIS have the potential of improving access to water and energy in rural areas with significant impacts for food security and farm incomes.

5.2 CAPACITY DEVELOPMENT

RAISE AWARENESS ON SOLAR-POWERED IRRIGATION

Solar-powered irrigation has potential for rural development through improving access to electricity and water, and can generate new job opportunities (see Chapter 5.1). It can help reduce dependency on energy imports and contribute to climate change mitigation. There is great potential for innovative forms of finance, organization of stakeholders and technical applications that go far beyond basic energy and water supply. At the same time, there are risks for SPIS to fail due to lack of access to finance, overexploitation of water resources and limited technical knowledge about how to design, set up and maintain the systems.

Awareness of SPIS technologies as well as their adaptability for different farm systems, sizes and crops is limited by lack of training for consultants and agricultural officers. Targeted training measures can help to make better use of the great potential of SPIS and manage its risks; for example, through:

- Awareness campaigns on SPIS in agricultural colleges and any other educational institutions that teach agriculture, water and energy-related subjects or rural development;
- Inclusion of solar-powered irrigation in curricula for agricultural extension services, irrigation managers, technicians and technical government staff;
- Public-private partnerships to organize trainings by private sector companies or national institutions to sensitize farmers to the benefits and risks of SPIS and to train them on more water-efficient irrigation methods, cropping patterns and soil management.

SUPPORT CAPACITY DEVELOPMENT AT ALL LEVELS

Universities and higher education centres in most of the countries mentioned in this report teach about SPIS, but are seldom engaged in the practical training, use and management of SPIS. At the same time, private sector companies and governments note the lack of qualified solar technicians for planning, installation, operation and maintenance of SPIS. Companies resort to in-house training of their personnel as they cannot find suitable candidates on the market. Rather than posing a barrier to SPIS, this could become an opportunity for job creation. Some suggestions are:

- Encourage universities/irrigation institutions to promote research and development of country- or region-specific irrigation topics, such as:

FIGURE 16
Participants of the FAO workshop: "Solar powered irrigation in Eastern Africa: from technology to up-scaling", Nov. 2017, Kigali, Rwanda

Photo: Hans Hartung

1 Optimizing irrigation for different crops. This includes training on improved irrigation techniques as well as crop selection, cropping calendars and farming methods. On-farm water management is an opportunity to reduce fertilizer and pesticide use, lower energy bills and ensure adaptation to climate change and growing competition over resources.

2 Training on water accounting at field, scheme and basin level. Water efficiency at field or farm level can also have implications at basin level. Water resource systems are highly integrated, and apparent gains (in terms of water use efficiency) in one part of the system can be offset by real losses in other parts of the system. Rainfall, surface water, groundwater, soil moisture, and rates and processes of evaporation from different land uses are all part of the same hydrological cycle and cannot be regarded as separate. Changes in water use in one domain may lead to unintended or undesirable consequences locally or downstream.

3 Water accounting can help in understanding the current status and trends in water supply, demand, accessibility and use. By evaluating return flows, measuring both basin and field efficiencies, and distinguishing between consumptive and non-consumptive savings, water accounting helps to address such questions as: What are the underlying causes of imbalances in water supply (quantity and quality) and demand of different water users and uses? Is the current level of consumptive water use sustainable? What opportunities exist for making water use more equitable or sustainable?

- Look at the whole irrigation system, not just optimizing one component (e.g. the solar pump system), but the entire system. Does the design of the pump meet the water needs of the farmer's irrigation schedule? What kinds of crops can best be grown in the soil and with the water available? What are the actual water requirements? How could the management scheme be improved?
- Install training-of-trainers courses for polytechnic lecturers/secondary school teachers/ vocational training centres on solar applications of PV systems, with an emphasis on solar-powered irrigation. E-learning can supplement face-to-face courses.

- Establish and implement specialized training courses on installation, operation and maintenance for students of the above-mentioned centres.
- Conduct awareness campaigns for farmers' associations and agricultural extension workers on the basics of solar-powered irrigation (advantages, disadvantages, choice of system, financial implications, choice of crops, etc.) – for example, at the test field mentioned above.

Specific programmes to promote SPIS for small-scale irrigation and/or intensification and diversification of crops do exist in several countries. There are also other programmes to support the adaptation of agricultural water management to climate change. Staff members of these programmes need training on realistic and practical use of SPIS, covering advantages and disadvantages, technologies, financial implications and water management.

5.3 STRUCTURAL SUPPORT

ENSURE NO WATER ABSTRACTION WITHOUT APPROPRIATE WATER MANAGEMENT

Modern irrigation technology can help to apply water more efficiently. It also has other benefits for the farmer: it saves labour; fertilizers and chemicals can be precisely and economically applied; leaching of nitrates and other pollutants is minimized; pumping costs may be reduced; and energy can be saved. The farmer may be able to diversify into higher-value crops. It allows some combination of increased irrigated area, increased quantity of production and increased value of production.

There is, however, evidence that modern irrigation technology does not necessarily lead to water savings. To the contrary, in many cases an increase in water consumption is observed due to an expansion of irrigated area, changes in cropping patterns and higher yields per hectare. This phenomenon is not specific to solar-powered irrigation. It is important to take note and think about alternative ways to reduce water consumption. While the following recommendations are key to sustainable water use, it is important to realize that groundwater (and agriculture) economies remain largely informal in a developing country context.

- First, establish a water accounting system (Batchelor, 2016) that provides quantitative estimates of the physical water balance (sources, diversions and withdrawals, consumption, return flows, changes to storage, etc.)
- Second, set limits to water allocations (designed, based on the current water balance, to reduce consumption to sustainable levels). Monitoring the allocations is crucial – e.g. by using water meters as an obligation for all users under a water rights regime. Check subsidies so that they do not work against the allocations.
- Third, encourage and support all users to maximize the net benefit of allocated water. In this context, introduction of all possible measures, such as high-tech irrigation (e.g. solar-powered irrigation) will find an appropriate place (Perry, 2017).

Current technology allows combining the control of SPIS with data management of water sources. An official body may be established for their sustainable use. The effect of water abstraction can be monitored in time; trends in water level changes can be detected. Corrective measures can thus be introduced, such as a maximum daily water volume.

STRENGTHEN WATER USER ASSOCIATIONS

Farmers' cooperatives, water user associations, irrigation associations and similar organizations for water distribution have a long-standing history in many countries with an irrigation history. In some countries, these have stopped operating, but in others, they have proven to be stable, respected and innovative in adapting to new challenges. A greater effort to support such structures will be helpful to create bottom-up user organization and to engage representatives of irrigation water users in decision-making processes. As water resources are becoming increasingly scarce, the fair and equitable distribution of allocated water is crucial. Irrigation organizations can be very beneficial in schemes in which farmers do not own individual pumps but are rather part of a group that shares SPIS. In order to come to sustainable solutions, these associations have to go beyond their direct purpose and reach out to form partnerships with the private sector (financiers, suppliers and service providers) and water authorities (e.g. to guarantee groundwater monitoring).

ENGAGE WITH IRRIGATION DEPARTMENTS

In most countries, the Irrigation Department is the government-level counterpart of water user organizations. It is important that these Departments are well informed about new developments, such as solar pumps, modern irrigation technologies and mini-grids. They play a crucial role in advising farmers on these issues, developing policies to support farmers, especially smallholders and marginalized groups, and promoting sensible technological developments. There are great opportunities for improving (ground)water monitoring through solar pumps coupled with online data management systems and mobile applications, but these opportunities need to be seized by Irrigation Departments or other official bodies.

ENCOURAGE STANDARDIZATION OF EQUIPMENT AND CERTIFICATION OF SUPPLIERS

The increasing number of suppliers for solar-powered irrigation equipment makes it difficult for consumers to select the appropriate and reliable product. A structured local supply industry with standardized equipment (at least in the data supplied to the customer) will help consumers, as will a certification scheme for national suppliers, who would have to undergo a transparent qualification procedure to become certified.

Tender documents should include minimal efficiencies of the main components and an overall efficiency rating "from wire to water." Neutral institutions should analyse and control the data given by the manufacturer or supplier in the form of public test results.

ESTABLISH "GREEN SUBSIDIES" (INSTEAD OF "BLACK SUBSIDIES")

Subsidies on fuel (diesel, petrol, butane) or grid electricity for agricultural use have led to over-abstraction of water bodies in places like California, Morocco and Mexico. These subsidies are very costly for governments (e.g. 6 percent of the GDP in Morocco), promote inefficient water use and often only benefit a few large agricultural producers. They run the risk of distorting markets and inflating prices and they often hinder the introduction of new technologies such as solar pumps, etc. Points to consider:

- Solar pumps can compete with fuel pumps and often with grid electricity-powered pumps as well, if the subsidies described above are reduced and eventually eliminated.

- Subsidies and other financial incentives for the introduction of solar irrigation systems can be combined with the obligatory use of highly efficient irrigation systems, as well as (ground) water monitoring. The emphasis of subsidies and financial incentives must be adapted to the specific situation and stimulate green growth.

CONSIDER SOCIAL JUSTICE

Subsidies and loans tend not to reach small and marginal farmers, women and other vulnerable groups, as they are often tied to conditions that are hard to fulfil. They are often formulated in complicated language, not easy to understand. The applicant may need proof of land ownership, be registered as an enterprise or have collateral, which a small farmer often does not have.

It is important to design subsidies, financial support programmes and financial products for SPIS solar powered irrigation systems with vulnerable groups in mind. Suggested steps:

- An assessment of vulnerable groups and their specific needs should be carried out, so that interventions can be designed in an inclusive manner. This should address questions, such as: how can small and marginal farmers take advantage of the subsidies? How can women? How can young farmers? What financial products are needed to make SPIS available for poor and marginal farmers? Can there be group guarantees for loans? Is it possible to collateralize the asset (e.g. solar pump system) to obtain a loan? Can repayments for loans be matched with cash flow patterns on the farm? How can Pay-As-You-Go models (paying a service provider for water or electricity used) be realized?

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The benefits and risks of solar-powered irrigation - a global overview

The report gives a state-of-the-art overview of policies, regulations and incentives for the sustainable use of solar-powered irrigation technologies (SPIS) around the world. SPIS offer a viable, low-tech energy solution for irrigated agriculture, providing a reliable source of energy in remote areas, contributing to rural electrification, reducing energy costs for irrigation and enabling low emission agriculture. Nevertheless, SPIS have a significant initial investment cost and require innovative financing models to overcome this barrier to adoption, especially for small-scale farmers. Technical knowledge and service infrastructure is needed to ensure that the systems run effectively. Moreover, SPIS – if not adequately managed - bear the risk of fostering unsustainable water use as lower energy costs may lead to over-abstraction of groundwater. This report looks at how different countries work to create an enabling environment for SPIS technologies, while managing the risks that come with it.

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