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Research Report

172

Agricultural Water Management – Making a Business Case for Smallholders

Business Model Scenarios and Suitability: Smallholder Solar Pump-based Irrigation in Ethiopia

Miriam Otoo, Nicole Lefore, Petra Schmitter, Jennie Barron and Gebrehaweria Gebregziabher

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Front cover photograph shows the use of solar-powered pumps for small-scale irrigation in Ethiopia (*photo:* Petra Schmitter, IWMI).

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Acronyms and Abbreviations

ACSI	Amhara Credit and Saving Institution
AEMFI	Association of Ethiopian Microfinance Institutions
AfDB	African Development Bank
AWM	Agricultural Water Management
BADEA	Arab Bank for Economic Development in Africa
BCR	Benefit-Cost Ratio
BGS	British Geological Survey
CAADP	Comprehensive Africa Agriculture Development Programme
CDM	Clean Development Mechanism
CIF	Cost, insurance and freight
CO_2	Carbon dioxide
CRGE	Climate-Resilient Green Economy
DBE	Development Bank of Ethiopia
DECSI	Dedebit Credit and Saving Institution
DEM	Digital Elevation Model
ECAE	Ethiopian Conformity Assessment Enterprise
EEA	Ethiopian Energy Authority
EEP	Ethiopian Electric Power
EEU	Ethiopian Electric Utility
EIB	European Investment Bank
EnDev	Energising Development
ERA	Ethiopian Roads Authority
EREDPC	Ethiopian Rural Energy Development and Promotion Center
ETB	Ethiopian Birr
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
FiT	Feed-in Tariff
GEF	Global Environment Facility
GHG	Greenhouse Gas
GIS	Geographic Information System
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
GoE	Government of Ethiopia
GRASS	Geographic Resources Analysis Support System
GTP	Growth and Transformation Plan
ICT	Information and Communications Technologies
IFC	International Finance Corporation
IGAD	Intergovernmental Authority on Development

ILSSI	Innovation Lab for Small-Scale Irrigation
ISRIC	International Soil Reference and Information Centre
IUCN	International Union for Conservation of Nature
LIVES	Livestock and Irrigation Value chains for Ethiopian Smallholders
METEC	Metals and Engineering Corporation
MFI	Microfinance Institution
MODIS	Moderate Resolution Imaging Spectroradiometer
MoEFCC	Ministry of Environment, Forest and Climate Change
MoWIE	Ministry of Water, Irrigation and Electricity
NGO	Nongovernmental organization
NPV	Net Present Value
OCSSCO	Oromia Credit and Saving Share Company
OMFI	Omo Micro-Finance Institution
ORDA	Organization for Rehabilitation and Development in Amhara
OSHO	Oromo Self-Help Organization
PV	Photovoltaic
REF	Rural Electrification Fund
RoI	Return on Investment
RUSACCO	Rural Savings and Credit Cooperative
Sida	Swedish International Development Cooperation Agency
SNNPR	Southern Nations, Nationalities, and People's Region
SRTM	Shuttle Radar Topography Mission
SSA	Sub-Saharan Africa
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
USAID	United States Agency for International Development
USD	United States Dollar
VAT	Value-Added Tax
WUA	Water User Association

Summary

This report outlines a business model approach to assessing the feasibility and for encouraging investment in smallholder solar pump irrigation. It also proposes a new methodology for mapping the suitability of solar energy-based irrigation pumps. The proposed business model framework and the methodology for suitability mapping are applied to Ethiopia as a case study, based on data from existing case studies and reports. A brief analysis outlines the regulatory and institutional context for investment in solar pump irrigation, and the ways in which it both constrains and attempts to support investment. The report identifies and outlines three business model scenarios that present opportunities for investing in smallholder solar pump-based irrigation, which would contribute towards sustainable intensification for food and nutrition security. The business model scenarios are based on the value proposition of supplying water to smallholder farmers for irrigated agricultural production. Analysis of potential gains and benefits suggests that direct purchase of solar pumps by farmers is feasible, and that out-grower schemes and pump supplier options with bundled financing offer promising solutions. The potential constraints that different investors may face in up-scaling the business models are also discussed, particularly within institutional, regulatory and financial contexts. The report provides development actors and investors with evidence-based information on the suitability and sustainability of solar pump irrigation in Ethiopia, as well as suggestions for helping to enable smallholders to invest in individually-owned, smallholder photovoltaic (PV) solar pumps.

Business Model Scenarios and Suitability: Smallholder Solar Pump-based Irrigation in Ethiopia

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Introduction

This is the first report in a series on business investment opportunities in agricultural water management (AWM). The series identifies promising investment opportunities that can increase the sustainability of AWM technologies and practices without the need for continued public funding. Improving AWM on small farms in developing countries is critical to increasing and ensuring food security and improved nutrition, particularly given expected growing food demands and climate variability. Past research has identified technologies and practices with a high potential to enhance AWM in various value chains, but the actual supply chains to ensure delivery of the technologies, services and expertise have yet to be developed. Investors face myriad challenges in developing AWM technology markets, despite the evidence that such markets are emerging. The series bases its conclusions on an adapted business model framework that considers returns for profit and socioeconomic development.

The framework includes business model components that can help private and public sector investors understand entry points for strengthening and sustaining market development in the AWM sector. A business model outlines how an entity or a firm should operate to generate a positive return on investment (RoI) and to meet its objectives. It identifies ways to build on strengths, mitigate threats or risks, and ultimately capture the benefits from an opportunity in a particular context. Since development initiatives have multiple goals, including goals beyond profit, the business models presented in this report and throughout the series have been adapted to include interrelated components relevant to socioeconomic and environmental sustainability in agricultural water management, such as biophysical suitability, economic sustainability, finance, institutional and regulatory context, technology, market supply chains and environmental sustainability. These components reflect the institutional objectives of various potential investors, both non-profit and for-profit, and the drivers that can incentivize investments.

This report focuses on the case for solar energy-based irrigation pumps in Ethiopia. Building on data from existing literature and case studies, it outlines the regulatory and institutional context for investment in solar pump irrigation, and describes how institutions both constrain and attempt to support investment. The report identifies three business model scenarios that present opportunities for investing in smallholder solar pump irrigation. Each of these will be profitable for farmers and contribute to sustainable intensification for food and nutrition security. In doing so, the report provides development actors and private investors with evidence-based information on the suitability and sustainability of solar pump irrigation, suggesting potential market size and niches, as well as suggestions for assisting smallholders to invest in individually owned, smallholder photovoltaic (PV) solar pumps.

Background on Solar Pump Irrigation in Africa

Development partners, researchers and policymakers are proposing PV solar energy-based pumps as a 'cost-effective' and 'clean' approach to irrigation in developing countries (FAO and GIZ 2015). They hold that solar energy-based pumps offer an inexpensive alternative to electric or fuel-based irrigation pumps (IRENA 2015). At the same time, the potential for irrigation development to reduce poverty and enable economic growth in sub-Saharan Africa (SSA) (Woodhouse et al. 2017) has been emphasized by policy bodies ranging from the Comprehensive Africa Agriculture Development Programme (CAADP) (NEPAD 2003) to national and subnational programs. In the past, the major focus was on investment in large-scale irrigation schemes (World Bank 2008), but this is changing. Research now suggests that there is significant potential for expanding small-scale irrigation to contribute to local and national food security, improved nutrition (Domènech 2015) and income generation (Namara et al. 2010; Dillon 2011; Burney and Naylor 2012). One study proposed the scope for expanding small-scale irrigation in Africa to be 7.3 million hectares (Mha), with internal rates of return much larger for small-scale than for large-scale, dam-based irrigation (You et al. 2010), an argument supported by Fujiie et al. (2011).

Farmers are ahead of studies and policy, and adopt individually-owned and operated irrigation technologies, often using small, motorized pumps, to increase production (Giordano and de Fraiture 2014). New investments in motorized pumps could benefit 185 million farmers and generate net revenues in the range of USD 22 billion per year (Giordano et al. 2012). These individual, distributed systems offer potential benefits, such as a more sustainable means to use shallow groundwater (MacDonald et al. 2012), and options for multiple use that more equitably benefit both women and men (Burney et al. 2013). You et al. (2010) concluded that it is only through such lower-cost technologies that irrigation can develop extensively in SSA.

The scope to expand and benefit from investment in small-scale irrigation in SSA appears significant, but it is also constrained. One key limiting factor is the access of farmers to energy sources for pumping water. According to FAO (2000), evidence links improved productivity in the agriculture sector in industrialized countries with access to 'modern' energy. Mechanized agriculture, including irrigation technologies such as pumps, increases commercial energy use per hectare as compared with manual labor methods (Kendall and Pimentel 1994). Electricity is often the least expensive and most efficient form of energy for pumping water in most countries, but it may not be available to farmers on small, dispersed plots. SSA has the lowest electrification access in the world: only 290 million out of 915 million people have access to electricity, with a minority of those having a grid connection that is unreliable and electricity tariffs that are among the highest in the world (OECD and IEA 2014). OECD and IEA (2014) predicted that by 2040, more than half a billion people in SSA, mostly rural, will still be without electricity. Therefore, farmers rely on diesel or petrol pumps for lifting both surface water and shallow groundwater. However, high fuel costs and limited access to fuels limit expansion, particularly for farmers located far away from markets. Assessments suggest that solar PV systems are cheaper for smallholder farmers than diesel over time (Bonsa 2013). Thus, small, solar-powered pumps provide a means for farmers to overcome energy-related access and cost constraints to adopting and benefiting from irrigation.

Solar pumps have been used in agriculture since the late 1970s (Parker 1991), but PV-powered water pumps are increasingly seen as the "harbinger of a new era in water provision for rural and developing communities" (Short and Thompson 2003). Solar-powered pumps exist in three main categories: concentrated solar, solar thermal and PV. Solar PV systems are more commonly available than concentrated solar and solar thermal pumps, which account for only a small share of the global solar-powered pump market. Complete PV systems are complex, consisting of a PV array, inverter, motor, pump and a water storage tank or a battery to store energy (Odeh et al. 2006). SSA accounts for only 9% of the world's PV systems, despite the fact that most countries in SSA receive, on average, between 4 and 6 kWh/m²/day of solar energy in most months of the year. This would allow a square meter of solar panel to generate 4 to 6 kW of electricity (Hare and Ancygier 2016). Given the above conditions and the increase in the adoption of pumps by individual farmers, more solar pump manufacturers and suppliers are seeking to expand markets in African countries.

The potential for solar pumps to enable agricultural intensification and improve incomes, as well as the interest of the private sector in developing solar pump markets, have led the agenda for a number of initiatives in SSA. Development donors and nongovernmental organizations (NGOs), as well as a few private sector actors, have piloted projects in a limited number of countries. In 2000, the Food and Agriculture Organization of the United Nations (FAO) advocated for integrating solar energy into agriculture and rural development projects, particularly as packages of energy services that include irrigation, citing a community-based garden project in Senegal, among others (van Campen et al. 2000). Attention has become more concentrated recently. A multi-donor initiative, *Powering Agriculture: An Energy Grand Challenge for Development*, is providing funding for renewable energy pilots in agriculture, for example, in Kenya and Southern Africa (Ensor 2016). The United States Agency for International Development (USAID) is also investing in a smallholder solar irrigation project in Kenya, which claims to improve incomes for participating farmers close to Nairobi (Winrock International n.d.). A Swedish International Development Cooperation Agency (Sida) - Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) solar irrigation project sought to improve food self-sufficiency in two communities in drought-prone areas of Kenya. The agriculture and irrigation social enterprise, iDE, is also testing solar pumps in different countries in Africa. Malawi intends to develop over 500 hectares (ha) using solar-powered irrigation through a government program funded by the African Development Bank (AfDB) (Kazembe 2015). The Government of Ethiopia (GoE) and donors are also investing in solar pump irrigation in multiple sites in Ethiopia, as described below. Donors and development implementers plan more such projects.

The implementers of projects on smallholder solar irrigation are ahead of research in the field, having carried out studies focused on potential markets for solar pumps. The International Finance Corporation (IFC) has conducted three market assessments of solar-powered irrigation in Morocco, South Africa and Yemen, which show large market potential under a subsidy for solar pumping systems (IFC 2015). Energising Development (EnDev) has conducted a case study on investment in solar pump irrigation in Ghana, which proposes different financing models, including a 'pay as you go' system based on mobile money (EnDev 2016). Private sector actors also undertake such studies. Forster Irrigation carried out a case study on using solar pump irrigation in Zimbabwe, which noted both the challenges to market development and the benefits, particularly with regard to using solar pumps in multiple household applications (Forster 2016). Other regions offer business models that suggest opportunities, e.g., preferred finance models for solar pumps in Nepal (Mukherji et al. 2017).

A few studies to assess the economics of solar irrigation pumps for countries in SSA all found positive impact. Stanford University published a study on solar-powered drip irrigation in Benin, which argued that the intervention had a positive impact on household income, food security and nutrition, particularly for women. However, the study compared the outcome of the project to the baseline of rainfed subsistence production, so may not provide clear outcomes attributable to solar pump irrigation compared to another form of irrigation (Burney et al. 2013). An assessment of the Sida-GIZ project in Kenya provided valuable information on adapting solar irrigation projects to the biophysical and social context, such as the need for capacity strengthening and strong links between actors in the value chain. A review of a project in Zimbabwe, which used solar pumps to fill a dam and localized storage tanks for commercial vegetable gardens, showed increased cropping seasons per year, resulting in increased incomes ranging from 47% to 286% and improved dietary diversity through nutritious crops (McGrath 2015). FAO also published a report on investment in solar pump irrigation in Zambia (Mendes et al. 2014). However, few rigorous impact assessments exist and there is no analysis of the potential for replicating such projects from one region or country to other countries in SSA.

IRENA (2016) argued that solar pump irrigation 'disproportionately' benefits women farmers. The argument was based on case studies that found that the pumps can be used to grow fruits and vegetables cost-effectively. These crops are traditionally grown by women and mostly used to feed the family. A study conducted by the International Water Management Institute (IWMI) in Ethiopia (Nigussie et al. 2017) found that women preferred solar pumps to other technologies when the pumps are located near the household and can be used for multiple purposes, including irrigating homestead gardens and supplying domestic water. However, the number of studies that systematically assess the suitability of solar pump irrigation and its benefits for women farmers are limited. Also, these studies do not compare across agro-climatic and economic contexts to enable well-founded conclusions or recommendations on how to target both men and women irrigators.

Research on negative environmental impacts remains a notable gap in studies on the use of solar pumps for irrigation. Some have argued that solar pumps lower emissions by reducing the use of fossil fuels in pumps (IRENA 2016). In that regard, some development banks provide funding for solar pumps under their climate facilities, such as the World Bank in Bangladesh and the Nordic Development Fund in Benin. In addition, some people suggest that solar pumps could reduce groundwater pumping in comparison to electric or diesel pumps, because solar pumps have limited power that limits the amount of water that is extracted. However, pumps and contexts vary, and no studies have systematically assessed such trade-offs. Rather, some studies suggested that the introduction of solar pumps could pose additional risks for over-extraction: increased water wastage has been reported following extensive solar pumping in parts of India and China, for example (IRENA 2015). It is critical to add an environmental component to research on solar pumps, particularly alongside any increase in demand.

Participants at an international workshop on solar irrigation called for more evidence on its potential benefits for smallholders and large-scale farmers, financing mechanisms, business plans, technology assessments, 'smart' subsidies for solar irrigation, governance arrangements, and models for taking solar irrigation to scale (FAO-GIZ 2015). Many of these knowledge gaps apply to small-scale irrigation generally, meaning that the use of solar pumps is just one more dimension. For example, a relatively high capital cost for solar pump systems requires that farmers have access to affordable credit or other forms of financial support (Setiawan et al. 2015). However, the credit market for irrigation inputs is generally undeveloped in SSA for rural smallholders. Knowledge is also lacking on opportunities for solar pumps within value chains and the existence of enabling factors, such as policies and other institutional arrangements. Researchers and practitioners need to fill such knowledge gaps to support efficient and sustainable investments in solar pump irrigation that benefit both men and women smallholders.

Solar Pump Irrigation in Ethiopia: Role for Business Models

This report uses Ethiopia as a case study for assessing the potential and suitability of PV solar pumps for smallholder irrigation. About 1.4 million farmers are engaged in small-scale irrigated agriculture in Ethiopia, between 210,000 to 400,000 of whom use motor pumps[1] (FAO 2012). Mendes and Paglietti (2015) estimated the annual value of imported motor pumps in Ethiopia in 2012 to be USD 10 million, an important subset of the USD 70 million spent on imported irrigation equipment. The authors predicted that this value could increase tenfold if Ethiopia achieves its 2020 targets for irrigated agriculture. Limited access to electricity is a key constraint to expanded irrigation: only 14% of the population is connected to the electricity grid due to poor grid coverage and the dispersed nature of settlements in rural areas (Mendes and Paglietti 2015; World Bank 2012). The government recognizes that the Rural Electrification Fund – established in 2003 – has not managed to scale up off-grid solar energy technologies. The Carbon Development Initiative, administered by the Development Bank of Ethiopia (DBE) with the World Bank as trustee, includes new efforts in renewable energy. The government's strategy is to transition existing motor pump users to solar, while also introducing new solar pump irrigation to those not currently irrigating. Given the number of existing and potential pump users, the scope for expanding the solar pump market for irrigation appears significant.

The Clean Development Mechanism (CDM) program aims to extend the use of solar irrigation pumps to enhance farming productivity, while enabling savings from fuel costs for diesel irrigation pumps and offsetting carbon emissions (UNFCCC 2016). At the same time, the program seeks to strengthen private sector involvement in renewable energy access, by assisting this sector to become instrumental in the widespread sales of household- and community-level renewable energy technologies. The Ministry of Agriculture has the task of developing financing models for households to purchase solar pumps for irrigation, and raising awareness about the opportunity to acquire solar pump technologies, possibly with private sector enterprise support. At the same time, the DBE is supposed to raise awareness among microfinance institutions (MFIs) about possibilities for acquiring financing to enable onward lending to households for solar technologies. This would require the MFIs to register with the DBE for loan management, and increase reporting to the government on loans to households for solar pump technologies. The initiative maintains key roles for the government and state enterprises, despite aims for private sector engagement.

To date, federal and regional state government institutions have driven the market for solar power in Ethiopia. Solar power is mainly used for rural electrification and, on a much smaller scale, for solar pumps to supply rural water and sanitation needs and water for irrigation. A number of public and donor institutions plan to provide support for solar pump irrigation projects in the coming years. For the 2016/2017 budget year, the Rural Electrification Fund includes renewable energy interventions, including solar power (see Table 1). The anticipated cost of the plan for 2016/2017 is ETB 1.6 billion (or approximately USD 70,645,000).[2] This is primarily for procurement and installation or distribution of solar home systems and solar lanterns, but there is a small line for solar pumps. Loans (66%), grants (33%) and the government budget (1.2%) should finance the solar-related expenses. The strategy for implementation includes collaboration between technicians from solar companies, local microenterprises and finance institutions on loans to small and medium enterprises, manufacturers, suppliers and distributors.

[1] Fifteen percent (15%) of all smallholder farmers practicing irrigated agriculture use motor pumps (FAO 2012).

[2] Based on the December 2016 exchange rate.

TABLE 1. Rural Electrification Fund, Growth and Transformation Plan II (GTP II) (2015-2020): Activity plan and budget for solar expansion.

No.	Description	Quantity per year				
		2015/2016	2016/2017	2017/2018	2018/2019	2019/2020
1	Solar lanterns	400,000	500,000	700,000	1,000,000	1,000,000
2	Solar home systems	50,000	50,000	100,000	100,000	100,000
3	Institutional PV systems	500	500	800	800	1,000
4	Solar thermal	500	750	1,000	1,250	1,500
5	Solar cookers	200	400	500	1,000	1,500
6	Solar mini-grid	15	25	40	70	100
7	Solar water pump	5	8	10	12	15
8	Training for Technical and Vocational Education and Training (TVET) graduates	200	300	300	300	400
9	Wind power water pumping	20	40	60	80	100
10	Microhydropower development	9	13	22	26	35
11	Wind-powered electrification study and development		3	4	5	6

Source: MoWIE 2016.

As indicated in budget line 7 in Table 1, the government plans a small number of large-scale, solar pump irrigation projects to be implemented in three regional states: Afar, Amhara and Somali. According to interviews with stakeholders, the Somali Regional State is entering into an agreement with a state enterprise, the Metals and Engineering Corporation (METEC), to develop systems at Kulen (2,000 ha) and Harewe (2,000 ha). A similar agreement is being signed with the Afar Regional State to provide solar pumps for the Serdo (1,443 ha) and Sunata (2,000 ha) irrigation projects for smallholders. The Kobo Integrated Irrigation Development Project, which will use 20 solar pumps, is another planned large-scale solar irrigation project in Amhara Regional State. In addition, six irrigation dams are under construction in the Tigray Regional State, with plans to introduce a hybrid system of microhydropower and solar power for domestic and irrigation purposes. The Fentale project In Oromia Regional State receives its water supply from the Awash River, mainly due to gravity, but large diesel pumps must supply the 2,000 ha of land not suitable for gravity-fed irrigation. The pilot initiative aims to supplement and then replace these pumps with a hybrid solar system. The Japanese government is funding the project and the manufacturing company Kyocera is providing technology and expertise. The Koga irrigation project is a large scheme whose discharge wells remain idle due to power shortages. Recently, a comparative advantage study of solar, diesel and hydropower electric pumps showed solar to be feasible. As a result, the Koga irrigation project office intends to purchase and install 20 large discharge solar pumps (Alemayehu 2016).

The Ministry of Water, Irrigation and Electricity (MoWIE) administers procurement and funding for irrigation projects, but regional water bureaus own the schemes. According to policy, regional states should cover the full cost of large-scale irrigation projects. However, interviews conducted suggest that farmers will be required to cover partial or full costs of some of the projects after they begin harvesting. Regional states have limited funds available for irrigation investments and lack the capacity to respond to demand,

and lack sufficient expertise about solar pump irrigation systems to determine the type of system needed with technical specifications, cost, etc. Experts in the irrigation subsector clearly identified a general knowledge gap around solar-powered pumps. Engineers and planners have stated that they avoid addressing requests for solar pumps, fearing failure and rejection by decision makers and end users (Alemayehu 2016).

In brief, public and development sector actors believe there is huge scope for solar pumps, and GoE has plans for a few projects, but the public sector is unable to meet the full demand for solar irrigation. Moving away from conventional donor-funded and publicly-funded development requires market-driven mechanisms to catalyze the scaling up of solar irrigation pumps. However, the private sector supply of solar pumps has not developed sufficiently to serve the potential market. Broadly, stakeholders observe a number of factors constraining private sector market expansion: affordability (cost of the technology relative to farmer income levels), awareness (knowledge about the technology), accessibility (options for obtaining the technology), and lack of customization (capacity to match farmer needs with technological solutions). Economically viable business models could offer direction for the private sector development of the solar pump market, and thereby contribute significantly to the growth of the solar pump-based irrigation sector. Innovative business models enable assessment of the likely yield from different approaches to taking the technology to market (Chesbrough 2010). The current context points to the need for smart business models that do not require sustained donor input, but present opportunities for private, market chain actor investment that could lead to sustained benefits. This report uses a business model framework for mapping the suitability of solar energy-based irrigation pumps in the case of Ethiopia.

Methodology: Business Model and Suitability Mapping Approaches

This section outlines the methodological framework used for mapping the suitability of solar energy-based irrigation pumps and subsequently developing economically viable business models.

Adapted Business Model Framework for Solar Pump Irrigation

In the past couple of decades, academics and business practitioners, and to a lesser extent development partners and public investors, have given increasing attention to the business model concept (Magretta 2002; Osterwalder et al. 2005; Shafer et al. 2005; Zott et al. 2011). This report defines a business model as the blueprint for how an entity creates, delivers and captures value (Osterwalder and Pigneur 2010). Put another way, a business model describes how an entity operates to generate a positive RoI, either in monetary and/or non-monetary terms, and ensures its competitiveness. Different business models offer various value propositions to ensure that the entity's objectives are met (Osterwalder and Pigneur 2010). Generally, all seeking to achieve an objective have a business model, whether explicit or not (Chesbrough 2007). Business models provide a framework to address a critical need or to perform a job that the existing market or system is not addressing.

In order to understand and operationalize the business model concept, Osterwalder and Pigneur (2010) described four core elements that create and deliver value when considered together. These core elements describe a firm's: (i) value proposition, which distinguishes it from other entities through the products and services it offers; (ii) customer segment(s) the firm is targeting, the channels a firm uses to deliver its value proposition and the customer relationship strategy; (iii) infrastructure, i.e., the key activities, resources and the partnership network that are necessary to create value for the customer; and (iv) financial aspects, which ultimately determine a firm's ability to profit from its activities. These factors enable entities to explicitly visualize the processes underlying their business model, and identify ways to boost their strengths, mitigate their weaknesses and threats, and explore and capture the benefits from existing opportunities.

This study employs an adapted version of the business model concept. It considers the main elements of the business model canvas, including the following:

- Value proposition (the product or service being offered).
- Resources needed for proper functioning of the system that would enable realization of the value proposition (e.g., natural resources, financing).
- Activities in which the business entity has competitive advantage and should engage or does not and should outsource.
- Partnerships needed to facilitate access to financing and other resources.
- Cost and revenue model to ensure economic viability.
- Markets and channels through which the products and services are delivered.

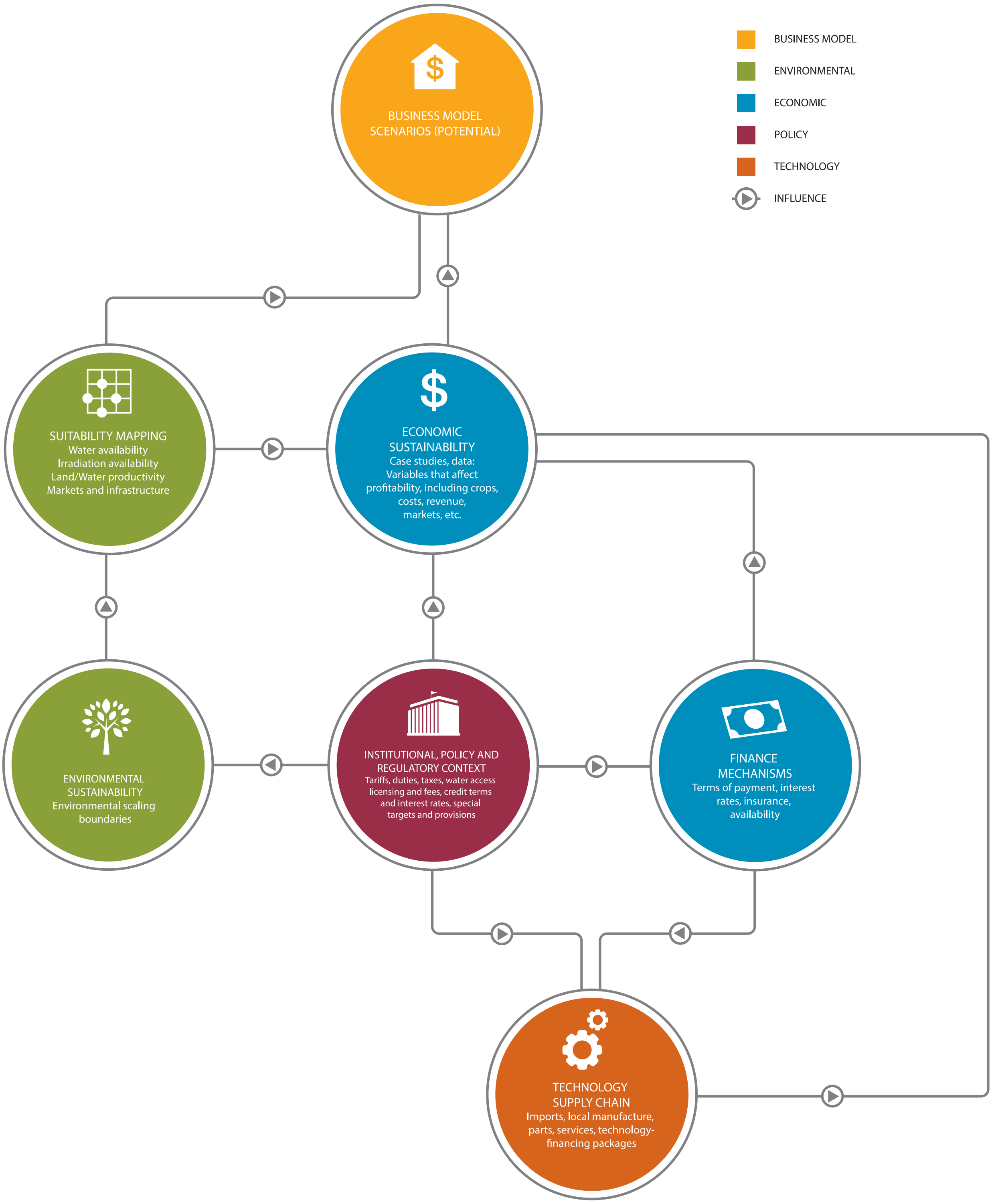
In the context of socioeconomic development with multiple goals, sustainable business models for solar-powered pump irrigation require consideration of biophysical suitability and environmental factors. We have categorized these factors into the interrelated components depicted in Figure 1, which together form the basis for the report's business model analysis, as follows:

1. Suitability mapping (biophysical factors, water availability, infrastructure).
2. Environmental sustainability.
3. Institutional, policy and regulatory context.
4. Finance mechanisms.
5. Technology supply chain.
6. Economic sustainability.

As shown in Figure 1, each of the components are interrelated and contribute toward a goal to achieve social, economic and environmentally sustainable business investments. The key criterion underpinning this framework is the *suitability mapping* of biophysical resources, as non-functionality of the solar irrigation pump technology due to limited bioresources would mean that there can be no solar pump irrigation in an area and therefore no derivation of economic value. Solar pump irrigation requires adequate solar energy, and access to land and water sources suitable to irrigated agriculture, as well as physical market infrastructure, such as roads and market places (see Schmitter et al. 2018 for a full report on suitability mapping). The suitability of an area for a water-lifting technology is an important parameter for developing situation-specific business models, as it helps to estimate the potential market size and boundaries. The method employed for this study was an open source geographic information system (GIS) interface (Quantum Geographic Information System [QGIS] with Geographic Resources Analysis Support System [GRASS] GIS) and various input maps, and included two steps: constraint analysis and suitability assessment. The constraint analysis excluded unsuitable areas for any of the given input parameters (e.g., specific land use, such as forests; solar radiation lower than 1,300 kWh m^{-2} y^{-1}). Different input maps were overlaid to identify potentially suitable regions for solar irrigation development. Suitability measures included appropriate land and water resources, and market and road infrastructure.

The consideration of *environmental sustainability* is particularly important in the context of solar-powered irrigation. Cheaper and increasingly more powerful solar-powered water pumps can result in significant environmental costs related to groundwater extraction and water quality.

FIGURE 1. Framework for the development of business models for solar-powered irrigation.



There is growing evidence, for example, that the low operational cost and available energy of solar-powered water pumping systems contribute to excessive extraction of groundwater, decreasing water tables and poor water quality (IRENA 2015; Shah and Kishore 2012). The promotion and scaling up of any business model for solar pumps needs to consider the scaling boundaries for small-scale individual systems and medium- to large-scale cooperative systems, in order to identify and mitigate any potential negative impacts. This report's suitability mapping did not include an in-depth environmental impact assessment. However, it does outline and briefly review the potential unintended negative and positive environmental consequences of solar pump irrigation, particularly with regard to water quantity, greenhouse gas (GHG) emissions, nutrient management and salinity, and intensified agrochemical use in relation to water quality and biodiversity. The report suggests mitigation measures for addressing potential negative environmental impacts. The environmental impact of solar pump use is (or could be) influenced by the institutional and regulatory environment. This depends on the policies and regulations adopted to monitor and limit the negative environmental impacts of solar pump use, so these components are also linked.

The *institutional, policy and regulatory context* shapes the macroeconomic factors that influence credit terms, interest rates, low-cost financing, tax exemptions and import duties, as well as subsidies or other forms of special support. These have significant implications for the economic/financial viability of a business. Policies and institutions also determine natural resource and environmental regulations, which can affect sustainability. The development of sustainable business models for solar pumps requires understanding the following:

- The institutional landscape, which comprises the organizational and institutional arrangements[3] that have the potential to affect a proposed business model. This includes key actors, and the existence or potential of incentives for mutually beneficial partnerships that can sustain the business and reduce business risk.
- The regulatory and administrative contexts, particularly related to existing regulations and their implications for technology, location and viability of the business.
- The economic and financial climate, which influences the probability of private sector engagement. This is particularly important in Ethiopia where the market is not well developed.
- Social barriers or opportunities embedded within institutions, policies and regulations; access to water and land; and gender issues that might favor or hinder investments by particular groups of people.

The framework includes *finance mechanisms* as a component, recognizing that the institutional, policy and regulatory context influences financing, but also that finance mechanisms affect supply chain development. Financing deserves close analysis as it is essential to catalyze the scaling up of small-scale irrigation technologies, including solar pumps. Therefore, the effects of financial drivers are considered in the analysis and include: (i) financing mechanism options available and suitable for key actors in the value chain; (ii) level of awareness about the technology and market among financial institutions; (iii) interest rates; (iv) terms of payment; and (v) insurance availability, among others. Different finance mechanisms can include national direct and indirect support programs, such as credit guarantee funds, value chain financing and price smoothing, to name a few. The investment climate functions within an institutional and regulatory environment in which there are existing policies, and formal and informal rules of operations.

The institutional, policy and regulatory context, including institutional and political

[3] 'Organizational' refers to both formal organizations and groups of people or stakeholders; 'institutional' refers to their formal or informal rules of operation, e.g., mandates or customary practices.

history and financing, shape the *technology supply chain* on the input side of the solar pump market. This includes key economic actors in the sector, their roles, the activities in which they engage, market inefficiencies, market structure and level of competition, and supportive mechanisms/policies available to actors along the value chain. The value chain approach used here assumes multiple interactions with different industry stakeholders, including pump and panel manufacturers (external or domestic), system integrators, dealers and financing organizations, service providers (installers, repair and maintenance services) and consumers. In some cases, the supply chain actors might include financial products with the provision of a technology or service, so the framework recognizes that the supply chain is both influenced by and can influence financial mechanisms.

Any responsible investor will base an investment decision on a positive long-term RoI, whether it is an international finance agency, private financial investor, a government or an individual farmer. As such, the framework component on *economic sustainability* evaluates the economic and financial viability of the proposed solar pump business model. In the economic and social development space, however, the financial viability of solar pump irrigation does not necessarily imply profit maximization, but depends on the objective of the business implementer. Private sector financiers or technology supply companies, for example, are often interested in the financial rate of return and, therefore, the profitability of the investment. In addition, public or donor investors may seek an increase in economic benefit, such as improved livelihoods for smallholder farmers, improved health and nutrition, or reduced agricultural GHG emissions. Stated otherwise, public and donor investors may take a ‘triple bottom line’ approach that measures economic, social and environmental performance over time (Elkington 1997; Gillis and James 2015). Donors such as the Bill & Melinda Gates Foundation and the Rockefeller Foundation reflect these values in their development programs. Potential investors systematically evaluate their investment initiatives against their institutional objectives. To provide an overview useful to different types of investors, this report outlines the cost-benefit analysis, and provides basic operational and financial information. The financial cost and revenue model is linked to the financing, and institutional and regulatory components, because of the importance of related information on market and financial drivers (e.g., interest rates, insurance, payment schedules, licensing fees, taxes, etc.).

In sum, the methodological approach taken in this report ensures that business models for solar pumps are sustainable, both environmentally (with minimal negative externalities) and economically (without continuous external financial support), and operate within existing institutional and regulatory guidelines. The models also consider potential financing mechanisms that could enhance equity, particularly important since gender and social fairness can affect the sustainability of a development investment. This report suggests business models, based on different value propositions, which can directly or indirectly lead to: (i) optimizing economic benefits to farmers, and (ii) addressing failures in the input (supply) market environment.

Data and Sources of Information for Business Model Development

The development of the business models described in this report drew on a broad range of information sources, including published and grey literature, key informant interviews, focus group discussions, secondary quantitative data and recently collected data. The information emerged from a study – commissioned by IWMI (Alemayehu 2016) – to collect data from the private sector, relevant government officials, individual farmers using solar pumps for irrigation/drinking water, non-profit and research organizations implementing solar pump programs, and civil society organizations promoting renewable energy and/or agriculture. In addition, the report used data from a 2015-2016 field pilot case study of solar irrigation pumps with men and women farmers, which was conducted through the Livestock and Irrigation Value chains for Ethiopian Smallholders (LIVES) and the Africa Research in Sustainable Intensification for the Next Generation (Africa RISING) projects (Gebregziabher at al. 2016). Finally, data to support biophysical and infrastructure analyses for suitability mapping came from national and international maps (see Table 2). Open access geospatial maps were used whenever possible (e.g., groundwater resources from the British Geological Survey [BGS], Digital Elevation Model [DEM] and solar radiation).

Background Analysis for Solar Pump Irrigation Business Models

Based on the methodology outlined in the section *Adapted Business Model Framework for Solar Pump Irrigation*, this section presents the underlying analyses carried out for mapping the suitability of solar energy-based irrigation pumps and developing economically viable business models.

Suitability Mapping of High Potential Areas for Solar Pumps

Identification of Unsuitable Areas: Constraint Analysis

The variables outlined in Table 3 are considered to be constraints or restrictions to feasible solar pump irrigation, based on previous research. These criteria were used to exclude unsuitable areas in the first step of the process. For example, slope is an important factor in irrigated agriculture, because slopes higher than 8% are not recommended for irrigation given the erodibility of several soil types. Some high-tech solutions (e.g., pressurized drip systems) would allow for slopes greater than 15%. In this study, the slope limit for sustainable gravitational irrigation was set at 8%. The constraints were merged to derive one constraint data layer, which revealed potentially suitable regions for developing solar energy-supported irrigation. Those areas were considered in the suitability analysis, where further constraints were applied (labeled criteria in Table 3). These criteria were used to develop different scenarios, depending on a specific threshold value (e.g., solar pump types that cannot pump beyond 7 m or 25 m).

Identification of Suitable Areas: Reclassification and Suitability Analysis

In total, four scenarios were developed to assess the suitability of solar pumps for groundwater and surface water (see Table 4). Scenarios 1 and 2 use groundwater[4]: scenario 1 - shallow groundwater up to 25 m divided into two classes (0-7 m, 7.1-25 m), and scenario 2 - very shallow groundwater (0-7 m) levels only. Scenario 3 uses surface water based on proximity to rivers and small reservoirs. Scenario 4 portrays the potential for using (a) groundwater, and (b) surface water.

Prior to developing the weighting factors for the various input maps, the maps were reclassified, and models were subsequently developed using the weighting factors derived from a pair-wise comparison. Isolated pixels and very small suitability areas were removed based on a threshold of 100 ha.

[4] Various solar pumps with different suction head capacity are on the market. Two types were considered in the suitability mapping: (i) suction heads up to 10 m, and (ii) suction heads up to 30 m. Given the classification of the groundwater level map, this corresponded to a cutoff at class I (0-7 m) and class I and class II up to 25 m.

TABLE 2. Overview of the spatial data used in the assessment.

Data	Spatial resolution (m)	Provider	Year
Original maps used			
Elevation	30	Shuttle Radar Topography Mission (SRTM) 30 m DEM 1 arc-second	2016
Rainfall	900	WorldClim (http://www.worldclim.org/)	2005
Groundwater level	5,000	BGS (http://www.bgs.ac.uk/research/groundwater/international/africangroundwater/mapsDownload.html)	2012
Aquifer productivity	5,000	BGS (http://www.bgs.ac.uk/research/groundwater/international/africangroundwater/mapsDownload.html)	2012
Water storage	5,000	BGS (http://www.bgs.ac.uk/research/groundwater/international/africangroundwater/mapsDownload.html)	2012
Land use and land cover	30	Woody Biomass Inventory and Strategic Planning Project (origin: LANDSAT) (Ministry of Agriculture and Rural Development 2005)	2004
Irrigated land	250	IWMI (origin: Moderate Resolution Imaging Spectroradiometer [MODIS]) (available upon request) (http://waterdata.iwmi.org/applications/irri_area/)	2014
Depth to bedrock	250	International Soil Reference and Information Centre (ISRIC) (Hengl et al. 2015)	2017
Town population	Point layer	Ethiopia Woody Biomass Project (1987 census data). Used to derive proximity to town	2004
Road	Vector	Ethiopian Roads Authority (ERA)	2010-2011
River	Vector	Ministry of Water Resources, GoE	2007-2008
National park	Vector	International Union for Conservation of Nature (IUCN) database	2010
Suitability for affordable lifting devices (small pumps)	Vector	FAO (http://awm-solutions.iwmi.org/databases.aspx) (available upon request)	2012
Suitability for small reservoirs	Vector	FAO (http://awm-solutions.iwmi.org/databases.aspx) (available upon request)	2012
Derived maps	Spatial resolution (m)	Source	
Slope	30	Derived in this study from SRTM 30 m DEM	2017
Aspect	30	Derived in this study from SRTM 30 m DEM	2017
Irradiation	30	Derived from elevation, slope and aspect	2017
Proximity to town	30	Derived from town population	2017

Source: Schmitter et al. 2018.

TABLE 3. Criteria for excluding unsuitable areas for solar pump irrigation.

Constraint factor	Range of values within the constraint factor
Protected areas	National parks, wildlife conservation areas (e.g., sanctuary), forests, wetlands, lakes and dams
Land cover	Land cover other than agriculture, grassland, shrubland and bare land
Elevation[1]	Elevation below 500 meters above sea level (masl) and higher than 3,200 masl
Rainfall[1]	Annual precipitation lower than 900 mm
Depth to bedrock	Depth to bedrock < 30 cm
Slope	Slope greater than 8%
Irradiation	Regions with a solar irradiation lower than 1,300 kWh $m^{-2} y^{-1}$
Groundwater depth	Groundwater depth of 7 m, with 25 m as a maximum limit
Groundwater storage	Low groundwater storage
Aquifer productivity	Less than 0.1 liters per second

Source: Schmitter et al. 2018.

Note: [1] Elevation and rainfall were merged to create the constraint layer named agroecology.

TABLE 4. Overview of reclassified maps used in groundwater, surface water and combined scenarios.

Data	Groundwater		Surface water	Groundwater and surface water	
	Scenario 1	Scenario 2	Scenario 3	Scenario 4	
				a	b
Solar irradiation (KWh m^{-2})	✓	✓	✓	✓	✓
Slope (%)	✓	✓	✓	✓	✓
Distance to roads (m)[a]	✓	✓	✓	✓	✓
Groundwater depth (0-7 m) I		✓		✓	
Groundwater depth (0-7, 7.1-25 m) II	✓				✓
Aquifer productivity (liters/second)	✓	✓		✓	✓
Groundwater storage (mm)	✓	✓		✓	✓
Proximity to river (m)			✓	✓	✓
Proximity to small reservoirs			✓	✓	✓
Proximity to town (population-dependent)[b]	✓	✓	✓	✓	✓

Source: Schmitter et al. 2018.

Notes: [a] Distance to roads is a proxy for market access.

[b] This is a proxy for market access.

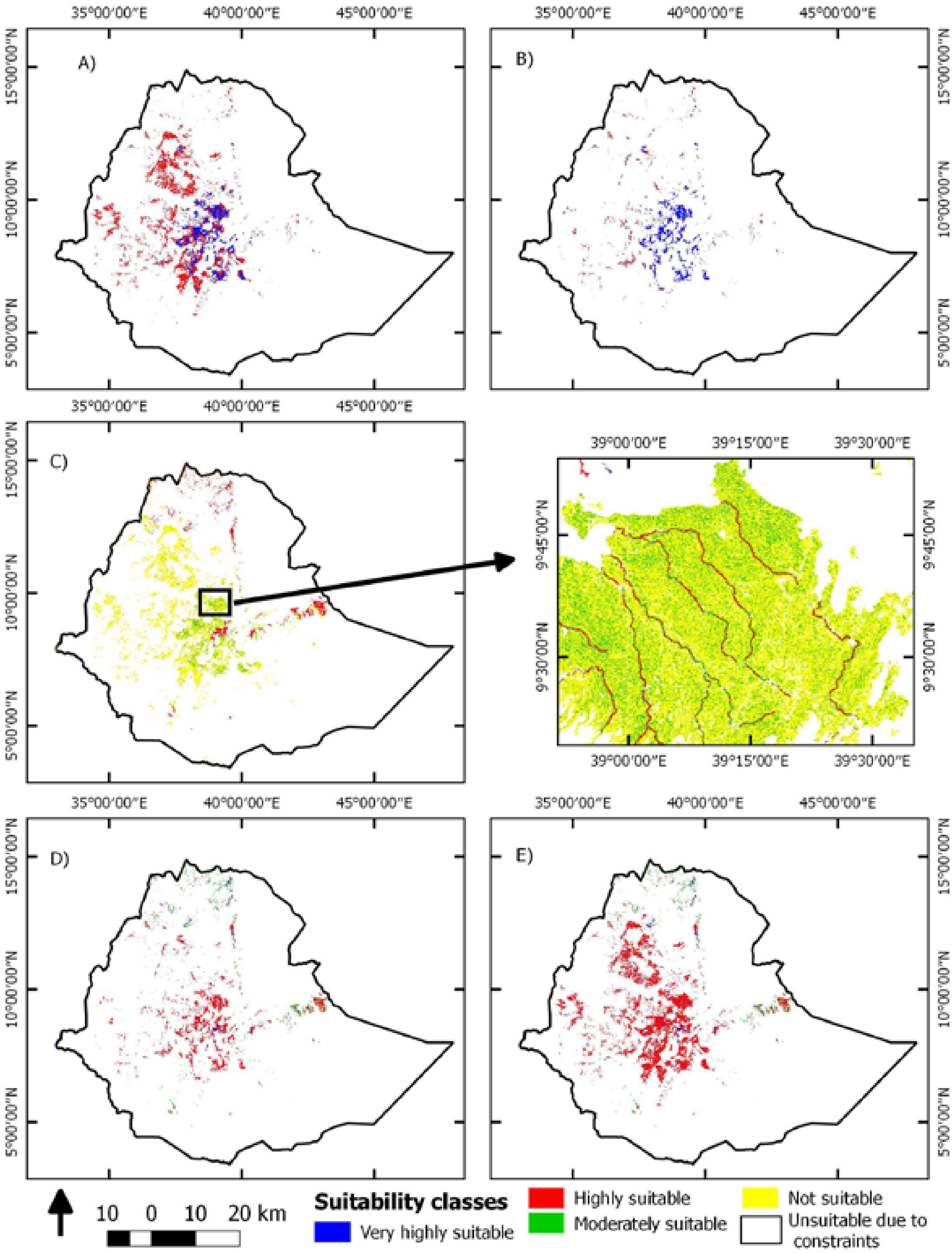
The maps in Figure 2 show suitable areas for solar pump irrigation with a resolution of 120 m. Available ground-truthing data[5] were used to evaluate the outputs of Figure 2. The data on well depths were very limited, thus well data from two regions (three districts and three *kebeles*) were used to check whether the feasibility observed in the field matched the feasibility derived by Scenarios 1, 2 and 4.[6] According to the assessment, 73% of the 127 wells used for irrigation fit the suitability classification, whereas 23% were identified as unsuitable according to the various groundwater-based models.

[5] Model output for the area around Lake Tana can be compared with irrigation information available from the IWMI water data portal, as well as data from the ongoing Feed the Future Innovation Lab for Small-Scale Irrigation (ILSSI) project (http://ilssi.tamu.edu/). The output results corresponded with the irrigation information.

[6] Recently, well depths throughout Ethiopia were obtained from MoWIE. Data are currently being organized and can be used to further check the robustness of the suitability maps based on groundwater information (i.e., Scenarios 1, 2 and 4).

FIGURE 2. Suitability scenario maps.

(A) Scenario 1 with groundwater depth up to 25 m (two classes: 0-7 m and 7.1-25 m); (B) Scenario 2 with groundwater depth up to 7 m; (C) Scenario 3 using proximity to rivers, and the potential map of small reservoir implementation with a zoom-in frame of the suitability in the north of Addis Ababa; (D) Scenario 4a combining both groundwater depth up to 7 m, rivers and small reservoirs; and (E) Scenario 4b combining groundwater depth up to 25 m, rivers and potential of small reservoirs.



Source: Schmitter et al. 2018.

The feasibility of using solar-based pumps to extract water from both groundwater and surface water was calculated for the various regions in Ethiopia (see Table 5).

Depending on the water source and the technical constraints of the solar pump (i.e., size of suction heads), the suitability ranges from 1.1 Mha (Scenario 3) to 6.3 Mha (Scenario 1). Combining surface water and groundwater resources (with groundwater up to 25 m), the estimated potential could be around 6.8 Mha. The analysis shows the suitability of solar pump technologies with a capacity to withdraw water not deeper than 25 m is highest in Oromia followed by the Amhara region. According to interviews conducted, large areas in those regions are known to have shallow groundwater (e.g., around Lake Ziway and Lake Tana).

TABLE 5. Summary of the total potential suitable area (x 1,000 ha) for solar water-lifting devices in various regions in Ethiopia.

Region	Area (1,000 ha)				
	Scenario 1	Scenario 2	Scenario 3	Scenario 4a	Scenario 4b
Addis Ababa	2	0.6	0.2	0.7	2
Afar	8	8	2	8	8
Amhara	1,776	371	202	446	1,834
Beneshangul Gumuz	21	5	0.5	5	21
Gambella	16	8	0.4	9	16
Harar	0.4	0.4	0.8	0.7	0.7
Oromia	3,337	1,443	463	1,716	3,569
SNNPR[1]	1,077	282	41	298	1,087
Somali	10	8	154	125	125
Tigray	57	51	272	143	147
Total	6,304	2,177	1,136	2,751	6,810

Source: Schmitter et al. 2018.

Note: [1] Southern Nations, Nationalities, and People’s Region.

Environmental Sustainability

The previous section shows that there is great potential for solar pump irrigation. However, determining the environmental sustainability of intensifying irrigation using solar pumps requires an assessment of available water resources both in terms of quality and quantity, and the identification of indicators to determine whether water could be negatively impacted beyond an acceptable threshold. Increasing the use of water resources for sustainable intensification of smallholder agriculture can have different and undesirable impacts at farm and landscape scales, and can affect basin environment and ecosystem services. These impacts need to be understood in relation to each business model, since the potential for scaling varies, and each agro-environmental context has different opportunities to mitigate or absorb changes. This section will discuss four environmental factors related to solar pump irrigation development: water quantity, GHG emissions, nutrient management and salinity, and intensified agrochemical use in relation to water quality and biodiversity. The report draws on the current state of knowledge to support mitigation options for various business cases, and offers general suggestions for environmental sustainability when scaling up proposed business models. Local and national stakeholders should consider any unintended negative environmental impacts of the models alongside social and economic gains, and in relation to policies and laws.

The suitability assessment presented in the section *Suitability Mapping of High Potential Areas for Solar Pumps* used distance to rivers, depth of groundwater and aquifer productivity and storage, and soil depth to identify suitable locations for solar pump usage. However, this does not consider other water use requirements or estimated groundwater recharge. It is important to quantify the water needed for other activities (e.g., drinking water, sanitation, industry) and recharge estimates to prevent over-extraction of groundwater for agriculture. This would help to define the maximum land area and the number of solar pumps in a specific location to ensure that the extracted groundwater does not exceed the sustainable threshold (Closas and Rap 2017).

The development of solar pump irrigation can affect landscape water withdrawals for other uses, and can undermine water flows, storage and recharge, depending on local agro-hydrometeorological conditions and the number of pump users. A number of studies have made specific assessments of groundwater withdrawals in Ethiopia to determine the potential for sustainable irrigation development based on conservative estimates of recharge. For example, the implications of water quantity withdrawals for smallholder irrigation development with motorized diesel and petrol pumps have been presented by Xie et al. (2014)[7], indicating a potential increase to $6.5 * 10^9\ m^3y^{-1}$ water withdrawals assuming that smallholder farmers adopt motorized pumps. This is more than a threefold increase over current estimated withdrawals for smallholder farming irrigation of $1.8 * 10^9\ m^3y^{-1}$, but constitutes only about 5% of the total annual freshwater recharge of Ethiopia (FAO AQUASTAT database[8]). Therefore, on a country level, even with an elevated adoption of solar pump irrigation, the expected withdrawals are minor relative to available annual renewable freshwater resources.

Altchenko and Villholth (2015) have suggested that Ethiopia can increase the irrigated area to 3 Mha, assuming a recharge rate of 50%, while maintaining environmentally sustainable withdrawals. This may be considered in relation to recent work carried out by the ILSSI project, which suggests that only 8% of the suitable land in Ethiopia can be irrigated with groundwater alone. However, supplementing surface water resources for irrigation is a viable option and could bring the irrigation potential to 6 Mha (Worqlul et al. 2017).

Overall, the studies suggest significant scope for expanding small-scale irrigation in Ethiopia. However, withdrawals for crop irrigation are likely to occur in highly water-contested landscapes, sub-basins and watersheds. Therefore, a regional and local water withdrawal and availability assessment should be undertaken in the regions and watersheds where rapid change is taking place (Dessalegn and Merrey 2014; de Bruin et al. 2010). Ideally, such an approach should incorporate monitoring and evaluation processes to guide management, avoid conflict between users, and avoid undermining water-dependent habitats and ecosystem services in the medium or long term. At the farm level, there is also scope to emphasize the efficient use of irrigation water through best practices in the scheduling of irrigation applications (Stirzaker et al. 2017; Schmitter et al. Forthcoming) to avoid both over- and under-irrigation, which may pose risks of either leaching or salinization. This would have the benefit of reducing aggregated water appropriation through solar pumping. Ultimately, such practices contribute to changing water-use efficiency in the agriculture sector and to reducing overall water stress.

Solar pump irrigation development can also increase the risk of water quality deterioration, as can any agricultural intensification practice (Mateo-Sagasta et al. 2017). Solar pump water withdrawals tend to be used for high-value crops, which are often subjected to higher applications

[7] A simplified modelling approach to scaling up various agricultural water management technologies for smallholder sustainable intensification in Ethiopia can be accessed from the Agwater Solutions project investment visualizer (http://investmentvisualizer.agwater.org/).

[8] FAO AQUASTAT Ethiopia annual freshwater recharge $122{,}000 * 10^6\ m^3y^{-1} = 122 * 10^9$. FAO AQUASTAT Ethiopia summary is available at http://www.fao.org/nr/water/aquastat/countries_regions/ETH/ (accessed on September 11, 2017).

of agrochemicals such as fertilizers, pesticides, insecticides, herbicides and fungicides. Gedfew et al. (2017) found that the application of such agrochemicals by smallholders is inconsistent and often inappropriate, with cases of excessive use leading to the pollution of downstream water sources. Recent household studies suggest that 30% of smallholder farmers in Ethiopia apply different agrochemicals for pest, insect, weed and/or fungi control, and about 55% apply inorganic fertilizer (Sheahan and Barrett 2017). However, there have been no comprehensive assessments of the efficiency and potential risks to water quality and human health arising from the use of agrochemicals in irrigation. At present, data suggest that smallholder farmers in Ethiopia generally underfertilize their crops. However, there is no disaggregated information about organic and/or inorganic fertilizer rates on rainfed versus irrigated crops. Thus, it would be inappropriate to scale specific cases to the national potential. Forecasting water quality risks to the environment and human health due to solar pump irrigation requires more information on agrochemical use by smallholder farmers.

Intensified cropping and irrigation with water pumps, including solar pumps, can lead to salinization when water is managed inappropriately; this ultimately affects land productivity and degradation. There may be a risk of salinity accumulation in the root zone, if too little irrigation is applied (i.e., insufficient leaching) where soils have inherent salinity characteristics. Salinization does not appear to be a major risk in cropland areas with potential for solar pump irrigation (ATA 2013). First, most high potential land is subject to inter- and intra-annual surplus rainfall, leaching salts beyond the root zone. Second, Ethiopian cropland is not inherently affected by alkaline and salinity-prone soils.

Mapping of soil salinity by Asfaw et al. (2016) suggests that most areas suitable for solar pump irrigation have non-saline or slightly to moderately saline soils. Although Gebrehiwot (2017) suggested that some lowland areas in the Awash Basin have poor drainage and suffer from salinization, these tend to be zones with large-scale irrigation schemes in the Rift Valley. Therefore, solar pump irrigation development in suitable areas should be combined with good site-specific and crop-specific irrigation scheduling to avoid the risk of salt accumulation, as salinity concerns can be very localized. The maps in Figure 2 do not include soil type, salinity or drainage issues, as the aim was to determine the potential for solar pump irrigation and not the potential for irrigable land.

A major issue in the sustainable intensification of agriculture and irrigation development is the increase in carbon dioxide (CO_2) emissions that may occur when shifting from manual to mechanized water lifting. Studies in India and China have shown that aggregated irrigation mechanization in smallholder farming systems, in relation to pumps in particular, can contribute substantially to country-level carbon emissions. For example, in India, Shah (2009) suggested that diesel- and electricity-driven pumping for irrigation purposes contributes to 4-6% of the country's total carbon footprint, and the decrease in groundwater levels exponentially affects carbon emissions. A study mixing empirical and statistical methods in China by Wang et al. (2012) suggested that the emission from groundwater pumping alone constitutes 0.5% of the country's total CO_2 emissions to produce 70% of its food, which is equivalent to New Zealand's full annual CO_2 emissions. Ethiopia still has limited expansion of motorized pumps, but there are estimates on the potential carbon footprint through the scaling up of smallholder irrigation. Sugden (2010) suggested that a rapid uptake of small motorized pumps could exponentially increase the CO_2 emissions until 2025. In this regard, solar pump development offers the scope to reduce the carbon footprint in sustainable intensification. However, the uncertainty in estimates of the current number of pumps and the rate of uptake by smallholder farmers suggests the need for new assessments to get a better handle on the mitigation opportunity that solar pumps can offer for smallholder sustainable intensification.

Little scientific evidence is available on the impacts of smallholder irrigation development on landscape and aquatic biodiversity in Ethiopia.

Elsewhere, research suggests that irrigation development can reduce biodiversity and valuable habitats, particularly in water-scarce landscapes as a consequence of water quantity withdrawals and potential water quality impacts (e.g., Terrado et al. 2016; Arthur et al. 2011). There is a particular risk for species-rich habitats, such as wetlands and riverine corridors, which can be affected by irrigation with mechanized pumps, including solar-driven pumps (Galbraith et al. 2005). However, there are also examples of sustainable irrigation development that can co-exist with habitat creation and species diversity through natural resource management. This includes recreating (artificial) wetlands, sparing riverine corridors, and developing farm/community ponds and dams for irrigation water storage (Brainwood and Burgin 2009). To obtain higher plant, insect and animal species diversity around water points, farmers often need support in the sustainable management of agrochemical and fertilizer use in agricultural development through solar pump irrigation development. Given the relative absence of data on biodiversity and habitat changes in smallholder irrigation development, this is another opportunity to develop more information in view of the current drive to support solar pump uptake in Ethiopia.

In summary, there is significant scope for smallholder irrigation development to sustainably improve total production, productivity and income from an environmental perspective in Ethiopia. Most notably, solar pump irrigation offers the environmental benefit of mitigating agricultural GHG emissions and can thereby contribute to cleaner, mechanized smallholder farming systems. The other three environmental aspects - water quantity, nutrient management and salinity, and intensified agrochemical use in relation to water quality and biodiversity - apply to scaling of irrigation more generally. As a precautionary principle, measures should be taken to avoid or mitigate unintended negative impacts. Such measures can be outlined as follows:

- Introduce irrigation management tools and practices to smallholder farmers alongside solar pumps to reduce the risk of inefficient water abstraction and nutrient leaching.
- Ensure that women and men farmers have equitable and extensive access to the best knowledge and practices in fertilizer and agrochemical use to support efficient and effective conservation practices in sustainable intensification.
- Invest in collecting data on irrigation and environmental impacts within an overall monitoring and evaluation framework with clear guidance to support policy around sustainable intensification of solar pump irrigation, in particular, around quantity appropriation, water quality, biodiversity and land sparing at the watershed scale.

Institutional, Policy and Regulatory Context for Solar Irrigation Pumps

The adoption and spread of solar pump irrigation in Ethiopia must occur within the applicable institutional and regulatory environment. Many policies, strategies, regulatory instruments and laws are relevant to solar pump investments, but these may not be easy for an investor or potential financier to navigate (see Annex 1 for a list of relevant institutions and Annex 2 for a summary of regulations and instruments).

Institutional Context for Solar Pump Irrigation in Ethiopia

GoE’s commitment to increasing irrigation is accompanied by complementary policies and initiatives. The national ministries have overall responsibility for land, water resources, agriculture and irrigation, but the regional states administer land and related resources within their boundaries. In 1975, the government reformed land rights, and currently the country’s land policy is enshrined in Article 40 of the Constitution, according to which ownership is vested in the state and held by the people. The state acquires and redistributes agricultural land to people who wish to farm. Officially, land cannot be sold, exchanged or mortgaged, but farmers enter into rental agreements, notably in irrigated areas. However, landholdings are small: about 55.7% of farming households cultivate less than 0.5 ha and the average holding is 0.81 ha (Alemu 2011).

Studies on the links between land tenure and agricultural production levels in Ethiopia are inconclusive: some suggest that the land tenure system discourages investment by smallholder farmers (Gebreselassie 2006), provides (sometimes negative) openings for foreign investment (Alemu 2011), or is conducive to smallholder investment when farmers have credit and market access (Pender et al. 2001). Water access, in turn, is inseparable from land rights and access: land targeted for agricultural development generally includes water (GWP 2015). In Ethiopia, water access nominally entails a user fee. While limited studies suggest that enforcement is currently unfeasible, consistent application of the user fee could constrain access to water and reduce profitability for irrigated production, particularly for smallholder farmers (Ayana et al. 2015).

This report considers irrigation institutions and policies from a gender perspective, because institutional constraints may determine whether or not women invest in solar pump irrigation. The national land policy in Ethiopia aims to promote joint ownership of land by husbands and wives, which some argue has had a positive impact on women by improving their landownership (Amare 1994). However, other case studies suggest that women farmers still do not have equal access to farmland. Ogato et al. (2009) studied one district, finding that women farmers had limited access to land, and even when they did have access, it was to smaller areas of land. In addition, recent studies note that the gender-sensitive reform of land rights has not been sufficient to catalyze investment behavior that improves gender equality and resilience. This has been attributed to gender gaps in knowledge about the reforms, particularly related to tenure security, land transferability and gender rights (Kumar and Quisumbing 2015). The authors find that, while awareness of Ethiopia's land registration program can result in greater economic benefits through the adoption of improved soil conservation technologies and sustainable farming techniques, women were less likely than men to be aware of the land registration process. This suggests that formal land rights are not sufficient to ensure increased investment in agricultural technologies that benefit women, thus effective measures to close gender gaps in access to information will be critical for impact (Quisumbing and Kumar 2014).

Women's limited access to land also extends to water. Local gender norms and water control practices shape water rights (Boelens and Hoogendam 2002), which in turn influence women's and men's rights to access and use water for different purposes, including irrigation. Ethiopian policies and institutions do not deny women the right to water, but they have limited decision-making power over water. Women tend to have the right at the household level to control water related to domestic or reproductive activities, but they have significantly less control over water for productive purposes, such as irrigation (Nigussie et al. 2017). This is reflected in the study conducted by Ogato et al. (2009), which showed that 70% of women farmers depend on rainfall as compared to 58.4% of men farmers, and that fewer women than men can rely on a diversified income from rainfed *and* irrigated agriculture. Moreover, women farmers have significantly less access to agricultural extension than men farmers, which limits their capacity to receive the information they need to access credit, make decisions about technology adoption, and strengthen their capacity in irrigated agronomic practices. The gendered structural differences in access to land, water and information are institutionalized at national, local and household levels, potentially reducing women's access to, adoption of and ability to benefit from the use of solar pump technologies.

Policies for Renewable and Solar Energy in Ethiopia

The public utility company generally dominates the energy sector, but GoE formulated the 1998 Investment Code (No116/1998) to promote private sector participation in the power generation business. The foreign private sector can, however, only participate in the manufacturing of electrical equipment, such as transformers, cables and other supplies. The Investment Code reserves the transmission and supply of electrical energy through the Integrated National Grid System exclusively for the government. The private sector can participate in electricity generation from any source and without any limit on capacity, but cannot supply to the grid. This limits options for gaining revenue from both energy supply and irrigation through solar pumps.

The GoE issued a National Energy Policy in 1994, a Water Management and Environmental Policy in 1999, and the Conservation Strategy of Ethiopia in 1989. These three policies directly support the development of renewable energy resources. The National Energy Policy promotes the following principles: (i) ensure a gradual shift from traditional energy to modern energy; (ii) ensure a reliable supply of energy at affordable prices; (iii) streamline the development and use of energy resources; (iv) give priority to indigenous energy resources to attain self-sufficiency; (v) increase energy efficiency; and (vi) ensure environmental sustainability. The policy also promotes export-oriented growth and a zero-carbon emission plan. In view of the fact that more than 85% of GHG emissions in Ethiopia come from forestry and agriculture, the policy proposes that solar and other renewable energy sources shall be used to generate electricity or other energy services once those technologies become economically feasible. The new Energy Proclamation 810/2013 entered into force in January 2014; it expands upon previous policies, including aims for independent Power Purchase Agreements for fully off-grid systems and on-grid energy efficiency.

To further support its national energy policies, the government initiated the Climate-Resilient Green Economy (CRGE) initiative to protect the country against the adverse effects of climate change, and to build a green economy that will help realize its ambition of reaching middle-income status before 2025 (Ministry of Water and Energy 2012). Ethiopia has set targets for renewable energy in its Growth and Transformation Plans (GTP I and GTP II) and Power System Expansion Master Plan Study. The GTP set a target of 10 gigawatts (GW) for hydropower by 2014/2015, and the expansion plan set a target of 5 GW for geothermal, 1.5 GW for wind, 0.3 GW for solar and 12.4 GW for hydropower by 2037. These targets reinforce the aims of the Ethiopia Off-grid Renewable Energy Program, which is under the CDM of the Kyoto Protocol of 2007. A related credit line from the World Bank will enable lending to private sector enterprises and microfinance institutions that supply technologies and finance products related to the CDM program of activities.

Regulatory Provisions

Existing incentives and provisions in the laws and regulations support the development of renewable energy resources, as well as providing other concessions for the agriculture sector. For example, there is a draft feed-in tariff law[9], government support for rural electrification, and duty-free import of machinery and equipment, particularly related to both energy and agriculture. Annex 3 lists some additional interventions by the government to enhance the expansion of renewable energy.

The government has taken steps to reduce the customs duty rate from 60% to 0% in order to support inward investment and private sector enterprises. According to the reduced rate, the minimum customs duty rate is zero (0) and the maximum is 35% of the cost, insurance and freight (CIF). Capital goods imported into the country for establishing power generation or transportation facilities are exempt from duties. However, the importer is required to provide authentication from the Ethiopian Investment

[9] This report excludes the potential of mini-grid solar systems that could simultaneously provide electricity for localized irrigation, domestic and commercial needs, and potentially improve the viability of solar irrigation pump business models. Therefore, regulations related to feed-in tariffs and government support for rural electrification were not addressed in this report.

Authority or related government bodies that the imported items are not to be directly used for commercial purposes (Marge and Econoler 2011). Although Directive No. 23/2009 also targets and benefits charity/aid organizations, this could discourage private sector investment in the market if it gives advantages to the non-profit sector over private companies.

Solar pumps and other modern off-grid energy products are now exempt from duty tax, excise tax and surtax. Initially, solar pumps and other modern off-grid energy products were not exempted from duty, value-added tax (VAT) and surtax, if not powered by renewable sources or identified as energy efficient. In the past couple of years, the importation of solar pumps has been included in the list of items that are exempt from 15% VAT and 2% withholding tax on the condition that the inputs are not directly used for commercial purposes. The Council of Ministers Regulation No. 270/2012 denotes additional areas of investment eligible for incentives; these can be found in Annex 4.

There are incentives for engaging in the solar pump sector through various government initiatives; these include access to finance, and duty and tax exemptions. However, the incentives and special support exist across numerous directives, proclamations and programs, as well as through special funds. Furthermore, the supporting mechanisms are spread across various government ministries, departments and agencies. Investors, importers, manufacturers and service providers face a complex bureaucracy, which challenges their ability to understand opportunities and to realize any benefit. For example, duty-free privileges for solar equipment are available to importers, but they face lengthy custom clearance processes particularly related to acquiring duty-exempt certificates from the Ethiopian Conformity Assessment Enterprise (ECAE). In addition, some of the incentives primarily target public and aid/donor entities, and are less attractive for private sector participation/investment, particularly non-domestic investors. Other incentives encourage local investors to invest in other sectors, particularly given the lack of rural finance, which reduces farmer access to financing for irrigation investments. Further constraints to investment include foreign exchange market regulations and limitations: interviews conducted suggest that importers (including non-profit organizations) feel hindered by their limited access to foreign exchange. Different types of investors need to pay particular attention to these challenges and to identify avenues to mitigate associated business risks in the development of business models for solar pumps.

Finance Mechanisms

Access to financing continues to be a major challenge to scaling up agricultural technologies. There are different financing options for developing the solar power market in Ethiopia. These include government funding, international finance agency funding, loans from microcredit and rural banks, the International Carbon Finance Mechanism, private investment and self-financing by users. It is important to note that different financing schemes are applicable at different levels and for different stakeholders and investors; some options are already in use and others have been identified as having potential (Hagos et al. 2017).

Under GTP I, financial support has been provided for rural electrification through the Universal Access Program; this is expected to continue through GTP II. Funds will also be available through mainstreaming Green Economy initiatives into existing development programs. The Ethiopia Off-Grid Renewable Energy Program specifically targets farmers in drought-prone regions, for example, in the Somali and Afar states, where there is no MFI presence. Amhara, Oromia, Tigray and SNNPR have budgets for developing irrigation schemes and hydropower, and may benefit from a subsidy or credit from the federal and local governments for solar power generation. This could be through a credit line from the World Bank for lending to private sector enterprises and MFIs that act as suppliers of technologies and finance products (DBE 2016). That said, it is unclear if irrigation is included in the program, whose final registration is underway with the United Nations Framework

Convention on Climate Change (UNFCCC). In addition, some incentives are available to private entities for investing, but the details are not widely known because the Ministry of Finance and Economic Development sometimes issues provisions via a letter of notification to a limited group of institutions and organizations rather than as regulations (Alemayehu 2016).

International finance agencies, such as the World Bank, AfDB, the Arab Bank for Economic Development in Africa (BADEA) and the European Investment Bank (EIB), are helping to finance solar development at the national level. The agencies provide these funds as budget support, investment in revolving funds, and credit facilitation with microcredit institutions or banks. Initiatives undertaken through the European Union (EU)-financed Intergovernmental Authority on Development (IGAD) PV project, the Global Environment Facility (GEF)-supported off-grid rural electrification project and the United Nations Environment Programme (UNEP)/ GEF PV commercialization project proved to be successful in removing some local barriers, such as awareness, skills training and finance. The World Bank has been the main international finance agency in the energy sector working closely with the government. The World Bank's role is likely to continue with renewable energies, particularly as it is the trustee for funds related to the CDM program of activities. The majority of initiatives have, however, focused on rural electrification (e.g., ensuring affordability to poor customers by offering 5-year loans to cover the costs of connection to the energy source) and, to date, have paid only limited attention to solar energy for irrigation.

To scale up solar pump irrigation, it is imperative that key actors along the value chain can access the various financing mechanisms available. Rural MFIs may be the most suitable financiers/credit sources for farmers looking to invest in household-level irrigation technologies. However, the MFIs do not reach the Somali and Afar regional states, where public investors plan solar pump irrigation expansion. Furthermore, financial institutions, such as DBE, even at its lowest limit, lend at an interest rate of 12% per annum for priority areas. Even at these rates, the loans do not address the financial needs of the rural poor. Reaching rural areas is difficult, given high transaction costs and the risks involved in serving poor households. To fill the gap, MFIs have started to provide financial services to the rural poor households, mainly in the form of agricultural loans for irrigation and modern agricultural inputs. However, the terms of repayment for irrigation technologies are often not favorable and tend to target rainfed agricultural inputs. The interest rates of MFIs in Ethiopia are relatively high, in the order of 15% to 24% per annum for poor rural farmers (see Table 6), although the rates are still relatively lower than in several other SSA countries (Wiedmaier-Pfister et al. 2008). In addition, some MFIs have either an informal or formal maximum loan amount that is lower than the cost of a solar pump (Hagos et al. 2017).

Since 1993, more than 29 MFIs have registered and operated under Proclamation No. 40/1996 with supervision and monitoring from the National Bank of Ethiopia. In 1999, the four largest MFIs formed an umbrella organization, the Association of Ethiopian Microfinance Institutions (AEMFI). The network seeks to promote best practices among its member MFIs. The five largest MFIs in Ethiopia are regional government-affiliated and operate as non-profit institutions; it is possible that political objectives could influence the lending operations and priorities. These five institutions constitute 83.8% of the total capital and 90.4% of the total assets of MFIs with a market share of 80%. In addition, MFIs and savings organizations have only introduced individual lending recently, as most of their products have traditionally been savings plans and lending to groups. Commonly, MFIs require a 10% to 40% savings deposit of the total loan amount.

Cooperatives can also provide loans for equipment and services, and 75% of agricultural credit currently comes from cooperatives (Minot and Mekonnen 2012). Savings and credit cooperatives, known commonly as Rural Savings and Credit Cooperatives (RUSACCOs), represent 19% of all cooperatives. Likewise, 26% of unions offer savings and credit plans, though these only operate in the four largest regional states. Cooperatives and unions receive a 100% regional government credit guarantee, but are constrained by regional government budgets, low liquidity and high default rates, often because borrowers see loans as government funds and have little incentive to repay them. A more recent report has suggested that the government tends toward partial guarantees complemented by risk insurance (Alemayehu 2016). Regardless of the constraints, however, cooperatives and unions are the main sources of financing available to farmers for small water-lifting technologies.

Most MFI and cooperative loans cover the following: (i) agriculture, (ii) non-agriculture-based businesses, and (iii) rural petty trade and small investments (these can also be used for solar pump purchases). As can be seen in Table 6, the loans available for agriculture are quite small. An average small solar irrigation pump costs ETB 10,000, which implies that farmers have to acquire multiple loans from multiple sources in order to be able to purchase a solar pump and other agricultural inputs. This is often a significant deterrent for farmers. Some MFIs provide a wider loan range to individual farmers, cooperatives or water user associations (WUAs). However, large loans to purchase deep-well solar irrigation at a cost of around ETB 250,000 is unlikely for the majority of small-scale, individual farmers and small WUAs.

World Bank funds are available to enable MFIs to provide loans from a renewable energy fund, as noted above. However, one of the top five MFIs, the Oromia Credit and Saving Share Company (OCSSCO), has only accessed 50% of the total ETB 100 million available, and no loans have been given (or requested) for solar pumps. However, OCSSCO now states that it would be ready to provide funding for solar pump systems in highly productive areas, on the condition that the regional government provides a guarantee fund. Experience from other countries suggests that economic feasibility for small farmers may require credit subsidies (Closas and Rap 2017).

MFIs can play a significant role in scaling up solar pump irrigation, but different financing mechanism arrangements will be required. Matching revolving funds from donor agencies or government funding can help bridge the gap between MFIs' offerings and farmers' capital investment needs. Government-affiliated NGOs, such as Oromo Self-Help Organization (OSHO) and the Organization for Rehabilitation and Development in Amhara (ORDA), have expressed their willingness to work with MFIs to facilitate loan processes and solicit matching funds to provide sufficient financing for individual farmers and associations. They are also willing to partner with the private sector and other institutions to create demand, and test and promote the irrigation technology. iDE's experience in financing self-supply wells can be taken as a model for partnership. In the past, iDE has successfully facilitated the loan process between farmers and MFIs, particularly by negotiating for repayment terms at dry-season harvest that are favorable to farmers. However, such practices are generally not continued after an intermediary or an NGO no longer facilitates them. According to interviews conducted, farmers view MFIs in Ethiopia as benevolent institutions and thereby often do not repay their loans. This can cause financing agencies to be hesitant about investing in supportive mechanisms, such as matching revolving funds.

Apart from MFIs and cooperatives, suppliers of solar irrigation pumps can provide financing to farmers through various financing and credit instruments. No suppliers currently use this approach in Ethiopia, examples are found elsewhere, notably in Kenya: (i) lease-to-own, (ii) pay-as-you-go, and (iii) buy-as-you-use (Futurepump 2016). The business model described below will consider these market-based financing mechanisms.

TABLE 6. Description of potential financial sources for rural smallholder farmers by MFIs and the rate of interest charged.

Name of MFI	Loan size (ETB)			Grace period (years)	Interest rate (%)	Region
	Agriculture	Non-agriculture (business, asset)	Petty trade, small investment			
Dedebit Credit and Saving Institution (S.C.) (DECSI)	200-30,000	15,000-5,000,000	200-30,000	2	15	Tigray
Amhara Credit and Saving Institution (S.C.) (ACSI)		5,001-10,000,000	1,000-15,000	3	18	Amhara
Omo Micro-Finance Institution (S.C.) (OMFI)	2,000-50,000	2,000-50,000	2,000-50,000	1	18	SNNPR
Oromia Credit and Saving Share Company (OCSSCO)	1,900-5,000		1,900-5,000	1	14.5	Oromia
Buusaa Gonofaa Microfinance Share Company			5,000	2	24	Oromia
Addis Credit and Saving Institution (S.C.)	700-250,000	700-1,000,000				

Source: Wiedmaier-Pfister et al. 2008.

Technology (Solar Pump) Supply Chain

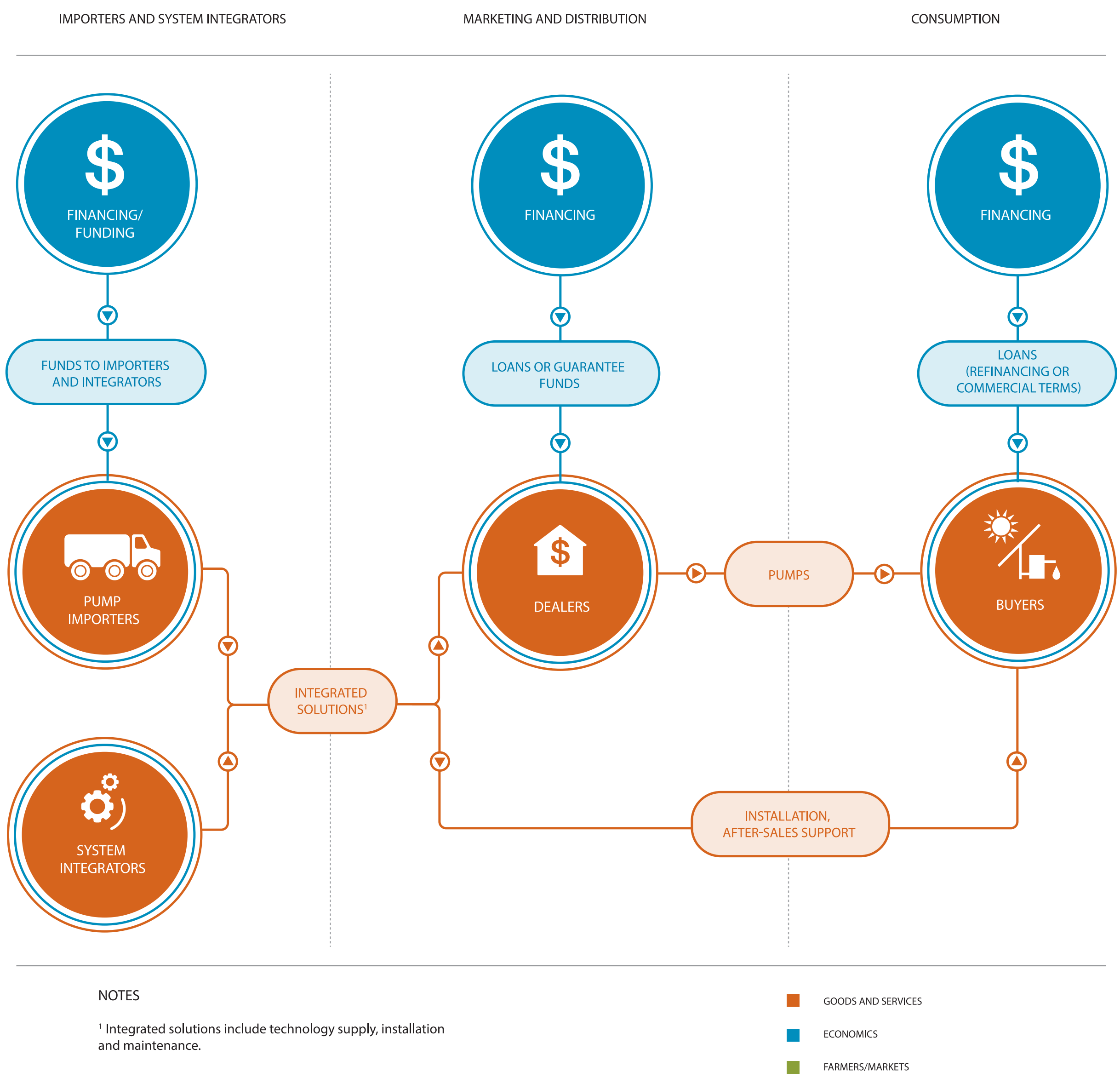
There is a growing demand for solar pump irrigation in Ethiopia. Smallholder women and men farmers express their preference for solar pumps over other water-lifting technologies in areas where they have observed or tested the technology (Nigussie et al. 2017). This preference appears to be based on the multi-purpose functionality of the technology when installed near homes. That said, farmers currently using solar pumps express the need to include energy storage (batteries) to extend the use of the pumps beyond peak radiation periods, and to enable additional income from charging cell phone batteries; this could increase costs for individual or institutional investors (Abu-Aligah 2011). Many farmers in Ethiopia continue to perceive solar technology as expensive and technically difficult to manage, but those with exposure or awareness of solar pumps express strong interest (Alemayehu 2016).

Potential investors at different levels need to understand both the input market for solar pumps and technologies (solar pump market) and the output market for agricultural produce, which together influence profitability. In particular, the functioning of the solar pump market, for example, price differentials due to market competition and the types of incentives available can significantly influence the financial feasibility of investment in solar pump irrigation. In general. there is only limited information available to enable a comprehensive assessment of the solar pump market in Ethiopia, although key actors are identified as suppliers (importers), retailers, installers and regulatory institutions, with little to no manufacturing being done domestically (see Figure 3 and Annex 5 for the list of identified market chain actors as of January 2017).

Importers, System Integrators and Suppliers

The Ethiopian Energy Authority has issued three private investment licenses and three assembly plants for solar technologies currently functioning in Ethiopia, although these are primarily concerned with home systems. The Sendafa Solar Energy Equipment Production Factory is the only solar panel manufacturing facility in Ethiopia with significant scope for production. Local manufacturers and assembly factories produce PV panels and submersible pumps as separate components. However, no actors currently manufacture products, such as inverters,

FIGURE 3. Overview of supply chain framework of the solar pump market in Ethiopia.



control boxes, storage options and suitable batteries, which would be needed to assemble packaged solar pump systems for irrigation.

Various actors in Ethiopia import packaged solar pump technologies. Importation is mostly by specific order and direct supply, as opposed to local stock for distribution. According to interviews conducted with supply chain actors, NGOs or development agencies placed most of the orders for solar pumps. Local companies act as local distributors for international manufacturers. The key distributors of solar pumps in Ethiopia are Davis & Shirtliff, Lydetco, RET Energy Engineering, and Yandulux. Davis & Shirtliff currently has the largest share of the market due to its strategic partnerships with the world's leading solar pump manufacturers, including LORENTZ, Grundfos, Pedrollo, Davey, and Shurflo. Its market extends to most of Eastern Africa (branches in Kenya, Zambia, Ethiopia, Uganda, Tanzania, Rwanda, South Sudan and the Republic of the Congo), allowing the company to benefit from economies of scale (Alemayehu 2016). According to interviews conducted, the buyers of solar pumps are typically institutions with irrigation or community drinking water needs (Alemayehu 2016).

A limited number of importers can have a significant impact on the pricing structure for retail sales to farmers: retail sellers with limited competition sometimes set higher prices, which could in turn negatively influence farm-level RoI for solar pumps. In the case of Ethiopia, private sector importers tend to also play the roles of system integrators and distributors. In this context, a system integrator would be an organization or private company that coordinates and links the components of the solar pump supply chain to prevent gaps in supplies and services. However, the lack of regulatory interventions to prevent the dominance of single companies as suppliers and integrators could create a risk for narrow control across the value chain, resulting in price setting for products and maintenance fees by one or a small number of private actors. One option to mitigate the effects of high market concentration is to increase participation of public enterprises in the manufacturing and/or import and supply of solar pumps.

The government has mandated certain public enterprises to import and manufacture water-related goods at federal and regional levels in order to fill gaps in water works and related activities. Public enterprises in Amhara and Oromia have established factories for manufacturing water-related goods, and these can be strategic partners for the government, user community and foreign investors. The partnership between Oromia Water Works Construction Enterprise and Boshan Pumps of China is one such example. The enterprise imported 100,000 surface and submersible pumps for distribution to the farmers in Oromia on a full cost recovery basis. The regional states of Amhara and Somali have implemented similar initiatives. Regional governments provide financial support in the form of revolving funds for these programs based on full cost recovery; the programs include providing solar pumps to smallholders (Alemayehu 2016).

Solar pump markets could also be stimulated by promoting them in particular commodity markets. Interviews conducted indicated that coffee could be one entry point for expanding the solar pump market chain (Alemayehu 2016). Climate variability and an interest in introducing new varieties of coffee to the regions may be pulling coffee farmers toward supplemental irrigation: adequate water during the flowering period is critical to achieving satisfactory yields. FAO notes the positive context for investing in irrigation, including for coffee. Coffee marketing is more organized and formalized than it is for some other crops, providing a mechanism for introducing credit and finance products to farmers to acquire solar pumps. Coffee cooperatives are very active in terms of facilitating credit to farmers, while irrigation cooperatives are weak. Additional roles for the cooperatives are to supply technology, machinery, equipment and services. Coffee production involves the use of water for purposes other than irrigation, so solar pumps can also offer multiple services to coffee farmers and cooperatives in remote areas. Interview respondents did not mention other high potential commodities, but a range of commodities can be explored for suitability and market potential.

Dealers, Retailers and Service Providers

There are numerous solar equipment dealers or retailers registered in Ethiopia (see Annex 5 for a list of solar market actors), and this helps to develop awareness, capacity and markets for solar energy products generally. However, most sell home systems or lights; it is estimated that fewer than 10 dealers import solar pumps for irrigation into Ethiopia. Broader business engagement between retailers and importers is very limited. Most retailers in the solar pump market are engaged in pilot and promotional initiatives through NGOs, international financial institutions and government agencies. Retailers do not stock solar pumps. They typically give buyers a two-year guarantee for pumps and five-year guarantee for solar modules. Importers (often also system integrators) typically provide integrated solutions to their customers, including installation and maintenance.

The lack of service providers for solar pumps is also a concern in relation to expanding the market in Ethiopia. Two key challenges for the solar pump market are: (a) delays in the provision of maintenance and after-sales service, such as untimely delivery of some replacement parts and equipment; and (b) a lack of qualified personnel for maintenance of systems. The lack of timely maintenance and repair is critical, because irrigation is time-bound and delays can result in pumps not being available for one or more irrigation seasons, rendering them economically unfeasible. Existing information on the availability of technical support and training on solar pump technologies is ambiguous. On the one hand, the ability to provide technical support is important to large importers/distributors, such as Davis & Shirtliff and Lydetco, who have fully equipped workshops with testing bays and are backed by a team of experienced and qualified master technicians capable of repairing their whole range of products. On the other hand, interviews conducted at all levels indicated that low capacity in the technology hinders the promotion of solar pumps in Ethiopia, particularly in remote areas; farmers or communities tend to abandon malfunctioning systems unless there are trained personnel to manage repairs.

One testing and training center for solar panels is located in Addis Ababa: the Knowledge and Sustainable Environment and Conservation for Humanity of the Mothers and Children Multisectoral Development Organization. Foundation Electric de France donated flexible solar panels and accessories to the testing and training center, as well as technical assistance, in collaboration with the NGO Blue Energy France. The organization targets remote communities that use solar pumps for domestic, hygiene and health services. At present, it appears to be the only known training center concerned with installing and maintaining solar pumps for women and young technicians. Tertiary and technical education on solar technology and specifically on solar irrigation pumping lags behind the demand for solar-based irrigation.

Economic Sustainability and Financial Viability of Solar Pumps for Irrigation

Potential investors, whether an international finance agency, a government or an individual farmer, expect long-term sustainability and an economic RoI. The economic feasibility of solar pumps for irrigation can be projected at different scales depending on the desired objective of the investor. For the case of smallholder farmers, investments in solar pumps for irrigation will be based purely on the potential for increased financial profitability. A financial feasibility assessment provides key information on a farmer's cash flow, profit margins and returns, which are good indicators of: (i) credit worthiness (ability to repay depending on regularity of income streams), and (ii) the most suitable financing arrangement (i.e., fees to be charged, loan repayment structure) for the farmer. From the farmer's perspective, information on the required cost of factors of production (e.g., labor requirements, minimum area required to be cultivated, fertilizers, etc.) will be important in assessing their cost and revenue model.

The focus of this report is on individually-owned, smallholder pumps that use PV technology. The results presented here are based on a pilot study conducted by the East Africa and Nile Basin subregional office of IWMI, through the LIVES (https://lives-ethiopia.org/) and AfricaRISING (https://africa-rising.net/tag/usaid/) projects (Gebregziabher et al. 2016). The projects piloted eight solar pumps for smallholder irrigation in selected farm households in Oromia and SNNPR. The solar pump that was tested is a suction version (up to 7 m) with a maximum capacity of 13 m^3/day when lifting from 4 m, and 4 m^3/day when lifting from 20 m. The pump has the potential to irrigate an area up to 2,500 m^2 (0.25 ha), if pumped from a 4-m deep shallow well. Adding a second solar panel can increase the capacity of the pump, which costs USD 650. A single panel solar pump, costing ETB 8,000 and with an expected life span of 10 years, was considered in this study. The feasibility assessment considered multiple scenarios on demonstration plots whose size varied between 50 and 200 m^2, including: (i) solar pump use with three water application methods (i.e., drip, furrow and overhead); and (ii) three different crops (pepper, carrot and head cabbage).

Results of the financial feasibility assessment suggest that investments in solar irrigation pumps can be profitable for smallholder farmers, depending on crop type, type of water delivery system and cultivated area. Table 7 shows that the use of the solar pump in combination with a drip irrigation technology significantly increases the irrigable land capacity compared to using the pump with the furrow or overhead water application methods. The solar pump can abstract between 1,800 and 2,500 liters/hour (depending on the depth of the water table) to irrigate about 2,000 m^2 of land using the furrow irrigation method. However, the size of the irrigable land area increases significantly to 2,797 m^2 and 4,431 m^2 with the overhead and drip irrigation systems, respectively.

In addition, labor requirements and related costs are significantly lower when the solar pump is used in combination with the drip irrigation system, as can be seen in Table 8. Labor costs become the key driver of total production costs, with the other input costs relatively similar across the three water delivery systems. This implies that investment in a solar pump for smallholder irrigation will be more profitable and effective when used in combination with a drip irrigation system, although non-labor costs are highest under this water delivery system. Labor costs were estimated based on an average daily rate of ETB 75/day. The non-labor costs include: (i) a fixed-cost component comprising the costs of a solar pump and water tank, the drip water delivery system, a drip kit and installation fees for the drip system; and (ii) a variable cost component comprising seeds, fertilizer, pesticides, transport costs, etc. The yields for the crops used in the estimation of *value of production* was based on the following: yields for pepper ranged between 175 and 275 kg using the drip system, furrow and overhead systems on 200 m^2 of cultivated land; and yields for carrots and cabbage ranged between 130 and 150 kg and 150 and 170 kg, respectively, on 200 m^2 of cultivated land using the overhead system. It is noted that output prices are volatile (e.g., prices for pepper ranged between ETB 10 and 20/kg in this study) and can vary significantly across markets and regions, invariably affecting profitability levels and the benefit-cost ratio (BCR). Thus, output price-related market risk needs to be accounted for prior to investment in solar irrigation pumps. It is important to note that the estimated BCR is based on discounted benefits and costs over a ten-year period.

TABLE 7. Descriptive statistics of water use and the size of the irrigated area by water application method.

	Water delivery system			
Crop type	Drip Pepper	Furrow Pepper	Overhead Pepper	Overhead Cabbage, carrot, fodder
Demonstration plot (m^2)	200	200	100	68
Amount of water used (m^3/demonstration plot)	52	105.3	41.2	27.4
Per-hectare equivalent water used (m^3/ha)	2,600	5,266.1	4,118.5	4,028.1
Discharging capacity (liters/second)	0.5	0.5	0.5	0.24
Total discharge (m^3/day)	14.4	14.4	14.4	6.9
Cropping season (days)	80	80	80	131
Total discharge (m^3/season)	1,152	1,152	1,152	905.5
Potential irrigable land (m^2)	**4,431**	**2,188**	**2,797**	**2,248**

Source: Gebregziabher et al. 2016.

TABLE 8. Labor use, input cost and production per hectare by water delivery system.[a]

Variables	Drip-Pepper	Furrow-Pepper	Overhead-Pepper	Overhead-Cabbage, carrot, fodder
Total labor hours/hectare	2,385	3,431	3,932	4,365
Labor cost per hectare (ETB)	22,366	32,168	36,867	40,925
Non-labor input cost per hectare (ETB)	42,969	38,793.5	13,150	9,822
Total cost per hectare (ETB)	65,335	70,961.5	50,017	50,747
Value of production per hectare (ETB)	195,000	126,175	116,350	87,842
Benefit-cost ratio	2.985	1.778	2.326	1.731

Source: Gebregziabher et al. 2016.

Note: [a] In the pilot study, one cropping season was used for the cultivation of all crops.

Importantly, a minimum area of cultivated land is required to ensure an economic RoI from solar irrigation pumps. A negative net present value (NPV) for a plot size of 100 m^2 (overhead system) and 200 m^2 (drip and furrow system) indicates that the size of the demonstration plot used was smaller than the minimum required plot size for a viable investment. Table 9 shows that, when pepper is grown under the drip irrigation system, the minimum plot size required for financial feasibility ranges between 710 and 950 m^2, but this also depends on the interest rate used. It is clear that the plot size required for economic feasibility increases with increasing interest rates. Given that the average cultivated land size in Ethiopia is about 0.25 ha (2,500 m^2), Table 9 shows that the average Ethiopian farmer could invest in the solar irrigation technology for a positive return when growing peppers. Moreover, the case study suggests that farmers can generate significant profits, if they are able to negotiate lower interest rates for inputs and cultivate their crops on land double the required minimum size.

As indicated in Table 10 and Figure 4, NPV estimates based on potential irrigable land size indicate a positive economic RoI, even at a discount rate of 24%. A comparison of profitability based on crop type (pepper production with cabbage, carrot or fodder production under the overhead system) suggests that pepper production yields the highest benefit.[10] Table 10 indicates that the drip irrigation system yields (using pepper production as the crop type baseline) the highest benefits to farmers for their investment in solar irrigation technologies, followed by the furrow system, which generates marginally higher benefits than the overhead irrigation system.

The feasibility analyses also show that, while crop type, water delivery system and minimum land area cultivated have an impact on the benefits generated by using solar irrigation pumps, differences in NPV estimates across different sites showed that the level of feasibility of the technology can be influenced by factors such as access to markets for produce and labor and input cost, among others. More detailed analyses would be needed to account for market proximity (cost and product price implications), multiple cropping seasons with variable yield and price, different financing mechanisms, land availability and tenure systems, among other factors; some of the factors could then be added to the suitability mapping. In addition, the analysis of gender-disaggregated data is needed to assess whether solar pumps favor women farmers more than men, or offer them greater benefits than other water-lifting technologies.

[10] This assumes a price for pepper at a set point in time. Prices may vary across the irrigation season and by market.

TABLE 9. Minimum required land size for pepper cultivation by discount rate.

Water application system	Minimum required plot size (m^2)		
	15%	18%	24%
Drip	710	790	950
Furrow	1,510	1,690	2,070
Overhead	830	930	1,125

Source: Gebregziabher et al. 2016.

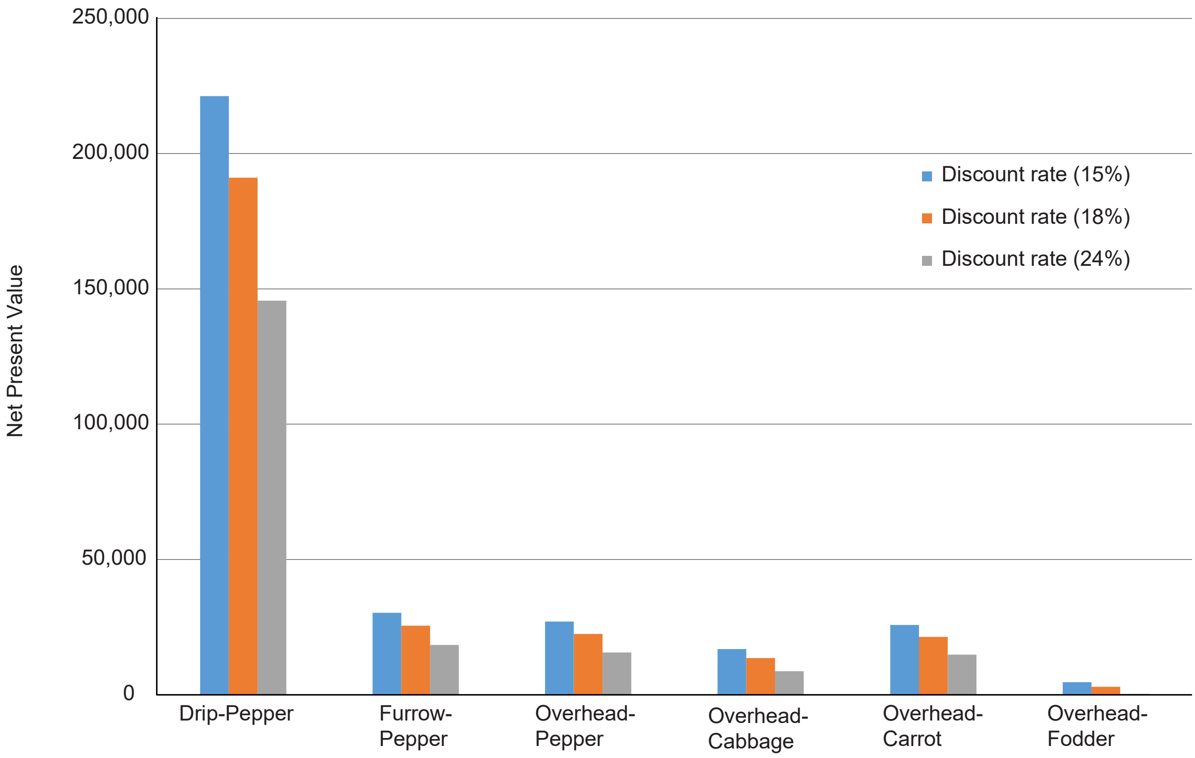
TABLE 10. Benefits of investment in solar irrigation pumps: NPV estimates by crop type, water application method and interest rates (in ETB)[a]

Crop type by water application method	Discount rate (15%)	Discount rate (18%)	Discount rate (24%)
Drip-Pepper	221,294	191,100	145,670
Furrow-Pepper	30,323	25,532	18,375
Overhead-Pepper	27,061	22,464	15,619
Overhead-Cabbage	16,889	13,587	8,698
Overhead-Carrot	25,817	21,378	14,772
Overhead-Fodder	4,626	2,885	354

Source: Gebregziabher et al. 2016.

Note: [a] A ten-year life span of the pump was used in the estimation of NPV.

FIGURE 4. Profitability estimates (as measured by NPV) of the solar irrigation pump technology in combination with different water delivery systems.



Source: Gebregziabher et al. 2016.

Business Model Scenarios for Potential Up-scaling of Solar Pumps in Ethiopia

The acceleration of the solar pump market in Ethiopia can be facilitated by creating enabling frameworks that include a supportive institutional and regulatory environment, innovative financing schemes, phased exemptions from VAT and import taxes, and viable market-driven mechanisms. This section identifies potential opportunities, using business model scenarios, for investing in smallholder solar pump irrigation that will be profitable for farmers within such a framework. The models consider avenues to mitigate the effects of identified constraints to the use of individually-owned, smallholder pumps that use PV technology. Potential investors can consider value propositions for both '*increasing access to water for agricultural purposes'* and *'increasing access to energy service'*, as described below. However, the business models presented in this report focus on the value proposition related to irrigation.

❋ ***Value proposition 1: Increased access to irrigation water***

The value proposition for '*increased access to irrigation water'* is based on a need to increase water supply to smallholder farmers for irrigated agricultural production. The business models can be viewed from the perspective of an individual farmer (or group of farmers) or a supplier (e.g., solar pump service provider). We present the following models:

- *Business Model 1:* Individual purchase
- *Business Model 2:* Out-grower or insurer scheme
- *Business Model 3:* Supplier model with bundled financing

Under the third model, whereby a solar company sells or leases pumps to farmers, several alternative financing scenarios can be considered, including: (i) lease-to-own; (ii) pay-as-you-go; (iii) harvesting cycle financing; and (iv) solar pump solution bundled with financing (e.g., direct financing – a percentage down payment and periodic payments). Scenarios (i) and (iv) are explained in this report.

❋ ***Value proposition 2: Increased access to energy services***

Increasing access to energy, particularly for rural households, is a growing economic opportunity, with companies providing off-grid (i.e., solar lanterns or solar home systems) or micro-grid (localized, small-scale generation, typically serving residential loads) solutions. This value proposition is based on the concept of using the solar pump technology for the dual purpose of irrigation and energy generation. A business model derived from this concept can be viewed from the perspective of an individual farmer (depending on the solar pump technology used), a group of farmers or a supplier that uses the solar pump for water abstraction as well as to serve as an anchor load in a micro-grid. A business entity comprising individual farmers or a group of farmers or cooperative sells the energy generated to: (i) the grid (e.g., via a subsidy through a fixed-wheeling or support price model); and/or (ii) households, depending on the policy environment within which they operate. At present, the policies in Ethiopia do not allow private provision of energy into a grid system, although the direct sale of energy for small services, such as cell phone charging, is allowed.

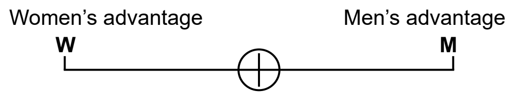
Business Models for Solar-Powered Irrigated Agriculture

Business Model 1: Individual Purchase

A. Key characteristics

The key characteristics of this business model are shown in Table 11.

TABLE 11. Business Model 1.

Model name	Individual purchase
Value proposition	Increased access to water for irrigation throughout the cropping season
Biophysically suitable regions	Areas in regions listed under scenarios 2, 3 and 4a in Table 5
Minimum land size required[a]	710-950 m^2 (drip irrigation system); 1,510-2,070 m^2 (furrow system) and 265-2,070 m^2 (overhead irrigation system). Maximum benefits are accrued, if estimated with the use of the upper limit of potential irrigable land size, i.e., 2,118 m^2 (furrow), 2,797 m^2 (overhead) and 4,431 m^2 (drip)
Potential market reach	Assuming a 50% adoption rate, between 105,000-200,000 solar PV pump users[b]
Objective of entity	Profit maximization
Business entity	Individual farmer or farmer groups (cooperatives or other type of user group)
Investment cost range	USD 450-850, depending on additional investments in water delivery system, water storage technologies and installation cost
Type of financing needed	Microfinancing
NPV[c] - measure of financial viability	Based on maximum potential irrigable land size (dependent on geographical sites, interest rates for financing, crop type):[d] NPV: USD 17.7-1,353 (overhead) NPV: USD 919-1,516 (furrow) NPV: USD 7,284-11,065 (drip)
Environmental impact	Significant environmental benefits from reduced fossil fuel consumption and reduced GHG emissions, depending on the rate of adoption and the number of existing fossil fuel pumps that are replaced. Increased water withdrawals and agricultural intensification can lead to water quantity and quality deterioration.
Socioeconomic impact	Increased farmer access to water during dry seasons can improve livelihoods through potential nutrition and health improvements, as well as increased incomes from higher agricultural production (assuming stable market prices for produce). Negative environmental impacts in terms of decreased water availability and quality could also have health and livelihood implications for downstream users of surface water or other users of a groundwater aquifer.
Gender dimension	Technology has no demonstrated (dis)advantage for any gender.[e] 

Notes:

[a] The estimated land size requirements for an economically feasible investment in solar irrigation pumps depend on the type of crop cultivated and water delivery system used. The range provided here is based on different interest rates used in the calculations as reported in Table 6.

[b] Based on the estimated number of farmers (210,000 or up to 400,000) using motor pumps (FAO 2012).

[c] NPV is the present value of net cash flows generated by smallholder farmers from agricultural production activities using solar pump-based smallholder irrigation.

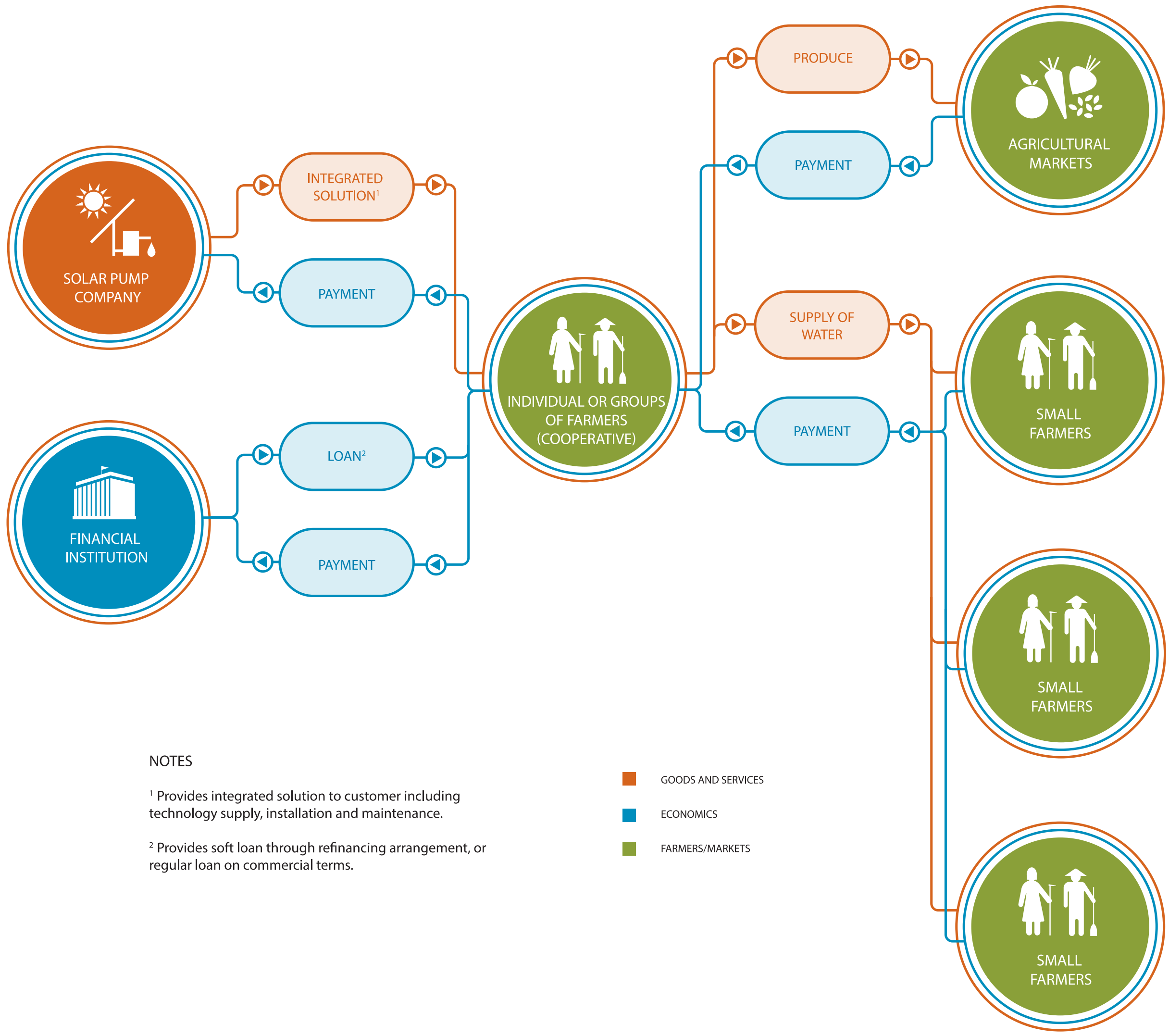
[d] A ten-year life span of the pump was used to estimate NPV; applicable to all the models.

[e] No systematic studies exist to show that women or men farmers benefit more or less from using solar pumps for irrigation, although women may lack rights to access land, water and the information that would support adoption, use and realization of benefits.

B. Business model concept

Business Model 1 rests on the notion that there is great potential for farmers to use a solar pump to address the challenge of limited access to water for dry-season irrigation (see Table 11). The business model is designed for a standalone private enterprise (i.e., a farmer) that invests in a solar irrigation pump for agricultural production (see Figure 5). The model is suitable for all selected regions under the suitability mapping scenario analyses. There are potentially 2.1 Mha of agricultural land irrigable with solar pumps in the Oromia region and SNNPR alone. A scenario where groundwater levels are less than or equal to 7 m and proximity to rivers/small reservoirs is considered. In Ethiopia, 70% of the farmers in Oromia and SNNPR depend solely on rainfed staple crops, while 30% can earn additional income from irrigated agriculture (FAO 2012).

FIGURE 5. Business model 1: Value chain schematic.



The model assumes that farmers will be motivated to invest in solar irrigation technology, if the RoI is positive and that they will find ways to mitigate costs in the business process and/or create multiple revenue generation streams. The model is based purely on profit maximization[11] (cost minimization). From a profit-motive perspective, economic estimates indicate that this business model can be profitable for an individual farmer who cultivates a minimum area of 710-950 m^2, 1,510-2,070 m^2 and 265-2,070 m^2 in combination with drip, furrow and overhead irrigation systems, respectively (see Table 11).[12] Increasing the cultivated area to a range between 0.2 and 0.4 ha significantly improves profitability from 15% to 200%, depending on the crops cultivated, geographic location, water delivery system used and interest rates on capital investment (Gebregziabher et al. 2016). Farmers could increase their incomes significantly, if variables such as interest rates are favorable. BCR estimates indicate that solar irrigation in combination with a drip system generates the highest benefits compared to the combined use with furrow or overhead irrigation system.[13]

In addition to generating income from crop sales, farmers can consider selling excess water to neighboring farmers. Since water for irrigation is only needed for a certain number of hours per day, using the solar pump to abstract additional water for sale could be a way to increase the use of the solar panels. One estimate has the utilization factor of solar pumps at only 15%, i.e., the time spent actually using the asset versus the time it could be used (Shakthi Foundation and KPMG 2014). Thus, instead of matching the amount of solar power generated to meet the maximum ('peak') irrigation pumping needs, the solar power generation could match the demand of nearby farmers or households. An economic assessment accounting for variables, including pump proximity to buyers of excess water, water pricing, water storage costs, water delivery system costs, transport costs and additional investment costs, is required to justify the viability of such a model. That assessment is not carried out in this report.

In this model, an additional means to minimize cost to smallholder farmers is through financing mechanisms. Rural MFIs seem to be the most suitable financiers/credit sources for farmers seeking to invest in individual irrigation technologies. MFI interest rates are relatively high in Ethiopia – between 13% and 24% per annum. Financial institutions, such as the DBE, even at its lowest limit, lends at an interest rate of 12% per annum in priority areas. Policies to set lower interest rate ceilings would reduce farmers' capital investment costs and likely catalyze the adoption of solar pump irrigation. This is evident from our analyses, which indicate that greater benefits accrue to farmers with financing at lower interest rates. That said, in SNNPR, the Omo Micro-Finance Institution (OMFI) usually offers loans ranging between ETB 2,000 and 50,000 for agricultural producers at an interest rate of 18%, and the analysis suggests that farmers could still gain a positive RoI in such a scenario (although the level of profitability will depend on crop type). Different financing mechanisms, such as matching revolving funds, credit guarantees from development entities or government funding to help bridge the gap between the MFIs' offerings and farmers' capital investment needs, require consideration and further research.

Suppliers of solar irrigation pumps can also provide alternative avenues for financing directly to farmers. This can take the form of different market approaches, such as: (a) lease-to-own (regular payments and farmer owns pump after full payment); (b) pay-as-you-go (farmers pay for use[14] and supplier retains ownership and

[11] Ongoing studies suggest other benefits to farmers from solar pump use, such as improved social status in the community and availability of water for other purposes, particularly domestic use, which reduces labor requirements (Nigussie et al. 2017). These benefits are not considered as part of the value proposition here.

[12] The estimated land size required for an economically feasible investment in solar irrigation pumps depends on the type of crop cultivated and water delivery system used. The range provided here is based on different interest rates used in the calculations.

[13] As noted above, estimates are based on pepper production in the Oromia region and SNNPR in the 2016 cropping season.

[14] Use is measured by the units of water pumped or the period of time the pump is in use.

responsibility for maintenance); and (c) buy-as-you-use (farmers pay for use[15] and maintenance service, and obtain ownership of the pump after paying a set amount). Some of these mechanisms rely on information and communications technologies (ICT) linked to usage meters; their feasibility may be limited by lack of access to internet and other infrastructure. Additional analyses are needed of such market-based, supplier-managed financing mechanisms.

The business model of a single farmer purchasing a solar pump to meet irrigation needs is scalable given the farmer's profitability objective. However, success will depend on a number of external factors related to infrastructure, and supportive policies for financing and input (technology) markets. From the input market perspective, solar pump technologies are largely imported to Ethiopia through an oligopolistic market. This suggests that farmers will be price-takers and may face significant mark-ups, translating into increased investment costs. Mitigation of these market failures lies outside the control of the farmers, and requires public sector intervention to create a more competitive market in the manufacturing and/or importation and supply of solar pumps. With a mandate to build a green economy, the GoE has an incentive to help accelerate the solar irrigation pump market. An example of where the government can intervene is in the solar pump supply chain. Public enterprises can engage in strategic partnerships with international manufacturers, and facilitate financing, tax incentives or directly market and service solar pumps in the local market. In addition, the public sector can support financing and the capacity of high-value commodity cooperatives to create a more stable and regular market for importers and distributors.

C. Alternate scenarios – Cost-sharing model

To address the capital investment challenge faced by most smallholder farmers, the business model can adapt to a cost-sharing model where a group of farmers pool their funds to invest in a solar irrigation pump (either as a group or a cooperative). Commonly, MFIs require a 10% to 40% savings deposit of the total loan amount. The inherent sustainability driver for a cost-sharing model is mitigated investment risk for individuals. Joint partnership investments allow smallholder farmers to pool their collateral and negotiate for lower interest rate loans from MFIs or traditional financial institutions (e.g., commercial or rural banks). As seen in the economic analyses above, higher benefits accrue to farmers at lower interest rates regardless of the crop they grow and/or the water application method they use with solar pumps.

While this scenario of the model offers an avenue to reduce investment costs, other issues may limit its success, including: (i) logistical restrictions on pump installation (i.e., lack of mobility of solar PV pumps) may limit the number of farmers in the group (i.e., proximity of adjacent farmlands has to be considered); and (b) cost implications, if water needs to be transported to other (often non-contiguous) farms. In the latter case, the entity bearing the transportation cost and the location for pump installation (i.e., on which farmer's land) would need to be taken into account, in view of the implications for the economic feasibility assessment of the model. Experience with the cost-sharing model in farmer groups is mixed, with some success found in India (Tiwary 2012) but not in Nepal (Mukherji et al. 2017).

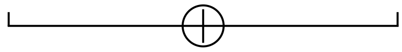
[15] Use is measured by the units of water pumped or the period of time the pump is in use.

Business Model 2: Out-grower or Insurer Scheme

A. Key characteristics

The key characteristics of this business model are shown in Table 12.

TABLE 12. Business Model 2.

Model name	Out-grower or insurer scheme
Value proposition	Increased access to water for irrigation throughout the cropping season
Biophysically suitable regions	Area in regions listed under scenarios 2, 3 and 4a in Table 5. Potential irrigable area = 3,165,418 ha
Minimum land size required[a]	Varies significantly across crop type, especially for exported agricultural products. Maximum benefits can be accrued, if estimated upper limit of potentially irrigable land size is used
Potential market reach	Assuming a 50% adoption rate, between 105,000 and 200,000 solar PV pump users
Objective of entity	Profit maximization (decreased risk of crop failure and resulting payouts to farmers)
Business entity	Out-growers/agricultural food exporters; insurers
Investment cost range	USD 450-850 per pump depending on additional investment in water delivery system, water storage technologies and installation cost
Type of financing needed	Commercial loans, microfinancing for farmers (if partial capital investment is required)
Environmental impact	Depending on the rate of adoption, significant environmental benefits can accrue from reduced diesel consumption and GHG emissions. Increased water withdrawals and agricultural intensification can lead to water quantity and quality deterioration.
Socioeconomic impact	Increased farmers' access to water during dry seasons can have health and nutrition benefits, as well as increase household income. Negative environmental impacts in terms of decreased water availability and quality could also have health and livelihood implications for downstream users of surface water or other users of a groundwater aquifer.
Gender dimension	Technology-wise, no particular (dis)advantage for any gender — Women's advantage **W**  **M** Men's advantage

Note: [a] The estimated land size requirements for an economically feasible investment in solar irrigation pumps depend on the type of crop cultivated and water delivery system used. The range provided here is based on the different interest rates used in the calculations.

B. Business model concept

This business model is based on the notion that the savings that contracting companies can make from the use of solar pumps would outweigh the costs of investing in them (see Table 12). In Ethiopia, commercial agribusinesses, particularly those involved in out-grower schemes, might be interested in investing in solar irrigation pumps for farmers. This could reduce the risk of crop failure and enable a steadier supply of agricultural products and thus higher profit margins. The model proposes that the companies would provide the solar pumps to contracted farmers, as they do with other agricultural inputs, as well as technical support to strengthen capacity in operating and maintaining the solar pump (see Figure 6). The companies can decide to: (a) have the contracted farmers pay for the solar pump with a flexible financing mechanism (e.g., payment at harvest, deduction from source); or (b) give contracted farmers the solar pumps for 'free', depending on whether the increase in agricultural yields/production justifies the investment. This model mitigates the capital investment risk that farmers face, either entirely or partially, depending on the terms of the contractual agreement. If the companies purchase the solar pumps for their contracted farmers, the model becomes commercially viable, if and only if it fulfills the following parameters:

(1) The price of the solar pump is sufficiently low for the contracting companies to be willing to invest.

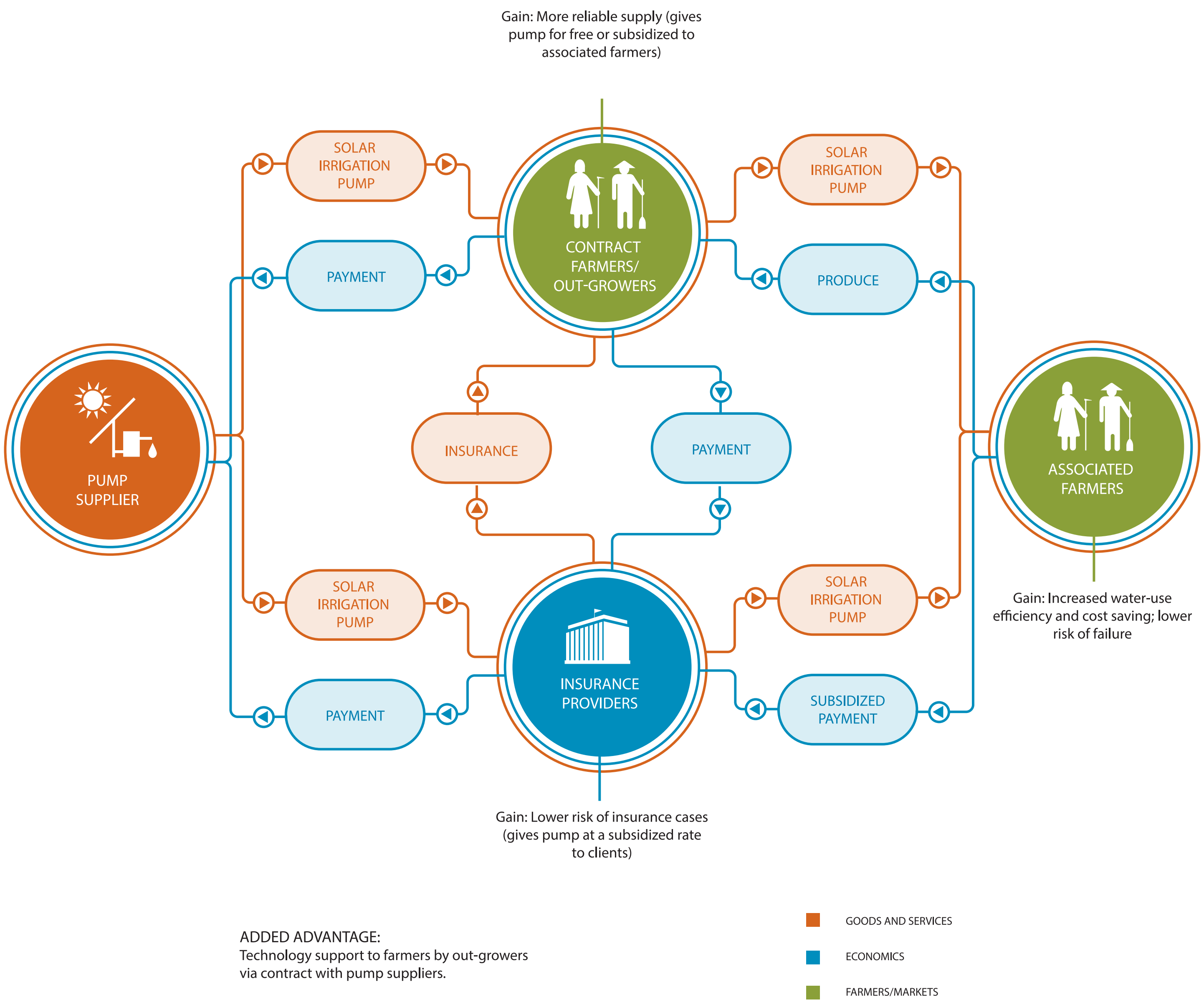
(2) The price of the solar pump is sufficiently low that contracting companies will gain on the purchase, based on reliable and increased crop production from their contracted farmers.

(3) The price of the solar pump is sufficiently high for the model to be commercially viable for pump suppliers to sell to contracting companies.

Detailed business model analyses are required to assess whether this model is viable from the perspective of both the contracting company and the farmers (see Figure 6). In particular, numerous individual contractual agreements come with high transaction costs, which can be a deterrent to the companies. An assessment of the minimum number of farmers and the related transaction costs (including direct and indirect costs) required for profitability from the perspective of the contracting companies (essentially, a positive RoI) will determine whether or not they adopt the out-grower model. Additionally, individual farmers still risk being price-takers, with a larger share of the consumer surplus going to the contracting company. Farmer cooperatives offer an opportunity to mitigate the negative effects of price-taking, as they typically have a stronger bargaining power and such an arrangement can accrue greater benefits to the farmers, although it is important to note that the effectiveness and success of cooperatives have been known to vary widely in SSA. Business entities engaged in contract farming are known to working with farmers' cooperatives, as it helps them to achieve the production scale they need and mitigates farmers failing to uphold a contractual agreement, typically if market prices are higher than contracted prices (Bernard et al. 2010; Prowse 2012).

As an alternative to the contracting agribusiness, other business entities such as crop insurers may be interested in investing in solar irrigation pumps for smallholder farmers, because they can reduce the risk and size of damage claims (assuming cost savings outweigh investment) and realize a higher profit margin increase (see Figure 6). Researchers have observed that farmers are paying into small-scale crop insurance plans (e.g., weather index-based crop insurance) to deal with the worsening impacts of climate change in Ethiopia. Three farmers' cooperatives and 1,870 households in the Oromia Region were found to have paid for crop insurance in 2013; by the end of 2014, those numbers had increased to five cooperatives and 5,720 households (Gebreselassie 2015). Based on the net return on their investments in solar pumps, crop insurers can offer solar pumps to farmers: (i) for free, (ii) at a subsidized rate, or (iii) at full cost in combination with flexible financing. An option for full cost recovery through financing can be modelled as part of the insurance premium paid by the farmers. Further research is needed to evaluate the economic feasibility of this model, in particular, to estimate the net benefits to the insurers in view of subsidized or full cost recovery financing.

FIGURE 6. Business model 2: Value chain schematic.

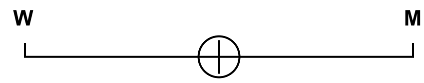


Business Model 3: Supplier Model with Bundled Financing

A. Key characteristics

The key characteristics of this business model are shown in Table 13.

TABLE 13. Business Model 3.

Model name	Technology supplier model
Value proposition	Increased access to water for irrigation throughout the cropping season and mitigated investment capital risk
Biophysically suitable regions	Area in regions noted under scenarios 2, 3 and 4a in Table 5. Potential irrigable area = 3,165,418 ha
Minimum land size required[a]	Varies significantly across crop type, especially for exported agricultural products. Maximum benefits can be accrued, if estimated upper limit of potential irrigable land size is used
Potential market reach	Assuming a 50% adoption rate, between 105,000 and 200,000 solar PV pump users[b]
Objective of entity	Profit maximization
Business entity	Technology supplier
Investment cost range	USD 450-850, depending on additional investment in water delivery system, water storage technologies and installation cost
Type of financing needed	Microfinancing, commercial loans
Environmental impact	Significant environmental benefits can accrue from reduced fossil fuel consumption and related reduced GHG emissions, depending on the rate of adoption and the number of existing fossil fuel pumps replaced. Increased water withdrawals and agricultural intensification can lead to water quantity and quality deterioration.
Socioeconomic impact	Increased farmers' access to water during dry seasons can improve livelihoods through potential nutrition and health improvements, as well as improved income. Negative environmental impacts in terms of decreased water availability and quality could also have health and livelihood implications for downstream users of surface water or other users of a groundwater aquifer.
Gender dimension	Technology-wise, no particular (dis)advantage for any gender; Women's advantage – Men's advantage 

Notes:

[a] The estimated land size requirements for an economically feasible investment in solar irrigation pumps depend on the type of crop cultivated and water delivery system used. The range provided here is based on different interest rates used in the calculations.

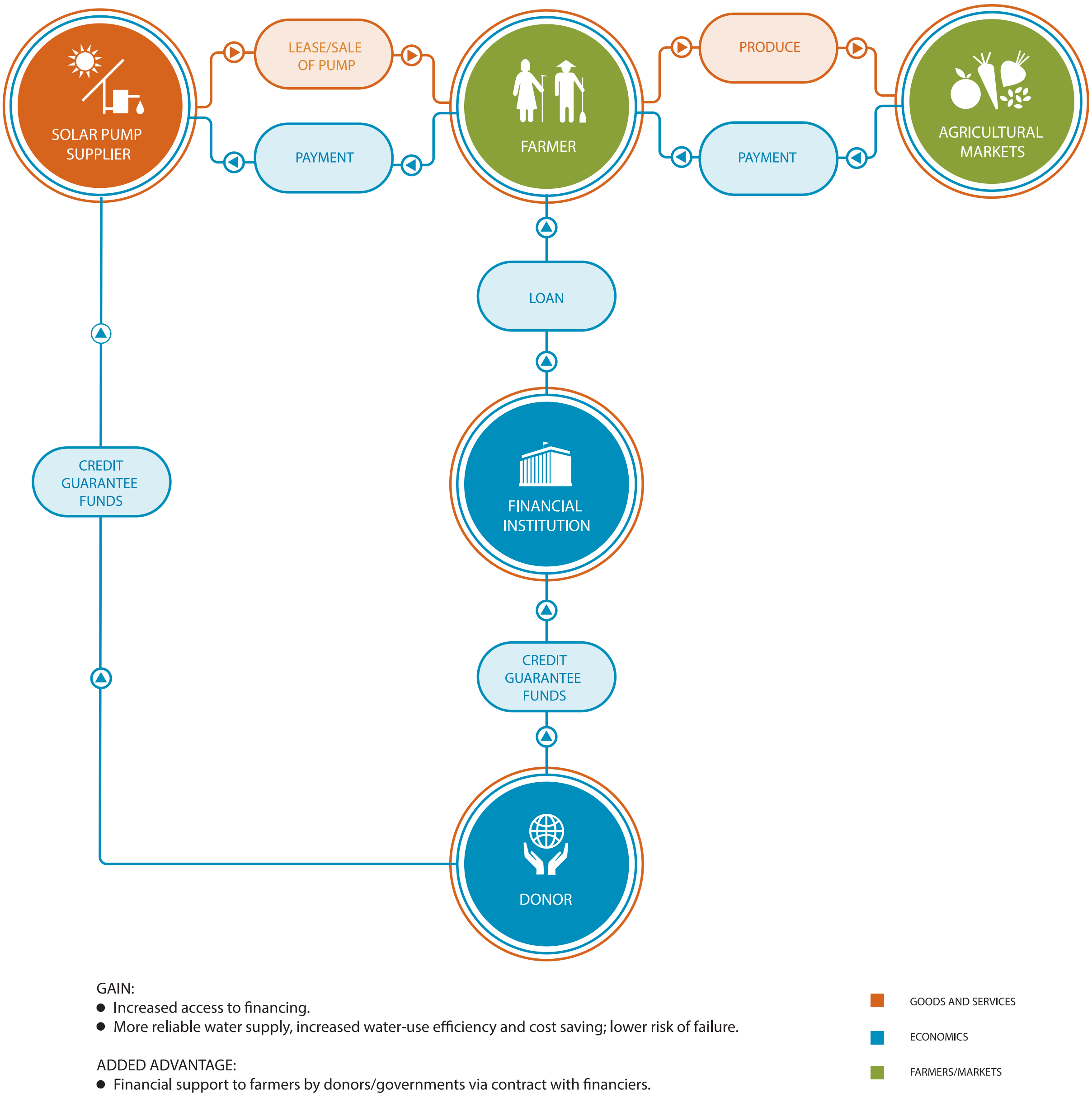
[b] Based on the estimated number of farmers (210,000 or up to 400,000) using motor pumps (FAO 2012).

B. Business model concept

Increasing access to financing for farmers willing to invest in solar irrigation will increase the benefits of dry-season irrigation and lower the risk of crop failure. The business model considered here is intended to facilitate farmers' access to financing and is viewed mainly from the perspective of the solar irrigation pump supplier (see Table 13). There are several financing scenarios as well as market-based approaches that can be considered under this model (see Figure 7). These include the following:

a) Providing ***direct financing*** to the farmer: In this model, the solar irrigation pump suppliers (and service providers) cooperate with local financing institutions

FIGURE 7. Business model 3: Value chain schematic.



(MFIs, cooperatives, banks) to offer the solar pump coupled with financing to smallholder farmers (i.e., their client base). This replicates a model similar to that used by MFIs where the farmer makes a percentage down payment and periodic payments. The approval of each farmer's application is based on a range of criteria that is relevant to their specific circumstances (e.g., primary sources of income generation, harvest cycle financing), and the loan size and terms are tailored to the farmers' needs. Bundled financing mechanisms are an option for increasing farmers' incentive for technology use. However, this often comes at a higher risk to the technology supplier, in the instance where farmers are unable to pay back the loans. An alternative avenue to mitigate this risk and still increase access to credit for farmers is for the government and/or to establish credit guarantee fund mechanisms to encourage MFIs and even commercial banks to lend money to smallholder farmers.

b) ***Credit guarantee fund***: In Ethiopia, there is a possibility of receiving subsidy support from the government (federal and regional) for solar power generation. However, the mechanisms for determining fund allocation, direct beneficiaries and terms, as well as for the process of acquisition of such funds are unclear. While some incentive provisions are available, private entities in particular remain unaware of them, as noted above. Credit guarantee funds allow the government (potentially via donors or international funding mechanisms) to provide guarantees on loans granted by banks for the purpose of purchasing solar irrigation pumps, essentially acting as a partial substitute for conventional collateral. This provides third-party credit risk mitigation to lenders as the government absorbs a portion of the lender's losses on the loans in case of default. There are several successful examples of off-take in rural markets as a result of bundling agricultural technologies with finance (Shakthi Foundation and KPMG 2014; World Bank 2015; IFAD 2016).

   Credit guarantee schemes need to be commercially viable and sustainable, even though the subsidy requirement from the government is significantly reduced, even at commercial lending rates (World Bank 2015). Funded schemes operated by independent entities (some may be owned and managed by governments) are preferable to non-funded schemes for the scaling up of solar irrigation in Ethiopia. Governments tend to own and operate non-funded schemes that fully take on any liability from the issued guarantees. This often results in 'moral hazard' behavior among lenders and borrowers: lenders are aware that, if farmers default, the scheme will bear the risk; borrowers are aware that, if their agricultural business fails, the financial lender and the scheme will bear the loss. In this situation, the potential benefits from the scheme are cancelled out and, in turn, the government carries an economic burden equivalent to or even greater than it would in a 'direct subsidy' program. A sustainable credit guarantee scheme requires that risk is distributed among the scheme (the government or independent entity), lender and the borrower, such that default and claim rates are kept at a minimum. Partial guarantee funding is a way to assign a percentage of the risk to the lender; the borrower carries some risk by making an upfront payment on the cost of the investment. Loan recovery is one of the key success factors for the model, so it is imperative that financiers tailor repayment schedules to farmers' specific circumstances. Furthermore, sustainability of a funded credit guarantee scheme for solar irrigation requires revenue-generating streams. In the Ethiopian case, this can come from the investment of capital funds, processing fees and annual premium payments charged on outstanding loans.

c) ***Lease-to-own***: The lease-to-own approach helps to address the prohibitive upfront costs that farmers face in purchasing the solar pump. The sale of solar irrigation pumps on a hire-purchase basis allows farmers to acquire and repay both the asset and the financing through payment schedules tailored to their income streams. In this case, the farmer has the choice to renew the lease on a periodic (e.g., weekly or monthly) basis by making renewal payments, or to terminate the agreement with no further obligation by returning the solar pump. Although not required, the farmer can also choose to continue making interval payments on the pump for a pre-specified time period, after which they would own the equipment. One of the key benefits of this model for smallholder farmers is that it does not require group financing or collateral, unlike commercial banks and MFIs. This mitigates the challenge that farmers face with capital investment risk (e.g., loss of collateral with delayed payment) and minimizes their upfront payment requirements.

MFIs or cooperatives should base their approval of each farmer's application on a range of criteria relevant to the farm situation (e.g., primary sources of income).

As noted above, rural markets have witnessed several successful examples of market off-take as a result of bundling agricultural technologies with finance (RTO Africa 2016). However, farmers can potentially face higher costs in the long run with lease-to-own contracts as compared to traditional loans provided by MFIs. Conversely, the provision of additional services such as installation, assembly, service and repair by the supplier, when factored into the higher assessed value and corresponding price charged, may actually make such a lease-to-own model comparatively more affordable for farmers than traditional financing options.

As with Business model 1, suppliers of solar irrigation pumps can provide alternative avenues for financing directly to farmers. In addition to the lease-to-own mechanism described above, suppliers might also consider using a pay-as-you-go (where farmers pay for use[16], and the supplier retains ownership and responsibility for maintenance) or a buy-as-you-use (where farmers pay for use[17] and maintenance service, and obtain ownership of the asset after payment of a set amount) approach. Some of these mechanisms rely on ICT linked to usage meters; and the feasibility may be limited by access to the internet and other infrastructure. Also, as noted above, analyses would be needed on these market-based, supplier-managed financing mechanisms in the Ethiopian context.

Conclusion and Further Research

This report proposes three business model scenarios based on the value proposition to supply water to smallholder farmers for irrigated agricultural production. It describes the benefits to be gained from the different scenarios, noting that direct farmer purchase of solar pumps is feasible, but out-grower schemes and pump supplier options with bundled financing offer promising alternatives. At the same time, the analysis acknowledges potential constraints that different investors may face in up-scaling these business models, particularly given the institutional, regulatory and financial contexts. The business model scenarios should be analyzed further to consider context-specific viability. This will require additional data for the various components of the framework. Moreover, the scenarios should be piloted to collect detailed data and test their feasibility. Finally, the suitability mapping would be enhanced with more data and ground-truthing. The combination of the solar suitability map with soil and water quality information would allow an assessment of overall environmental sustainability. A more detailed analysis of the areas with the highest potential for solar pump implementation and economic feasibility would foster sustainable intensification of agriculture through solar pump irrigation.

The present analysis excludes larger pumps and clusters of high-powered, solar-based pumps that can be used for communal irrigation schemes. It also excludes the potential of mini-

[16] Use is measured by the units of water pumped or the period of time the pump is in use.

[17] Use is measured by the units of water pumped or the period of time the pump is in use.

grid solar systems, which could simultaneously provide electricity for localized irrigation, and for domestic and commercial needs. Furthermore, it does not include the possibility of selling electricity to the grid: the study assumes a rural context without electricity infrastructure and uses the current policy context that limits sales to the grid. There is potential for these and other scenarios, but they require more exploration and piloting.

The report points to further areas requiring more research as solar pump irrigation becomes more accessible, affordable, and of interest to public and private investors. Data and analysis are needed for incorporating environmental implications into suitability mapping and monitoring, e.g., on climate variability, groundwater recharge rates and impacts from up-scaling at landscape scale. In addition, different management options need to be assessed in relation to various contexts and objectives. As the solar pump technology is adapted to become mobile, there could be potential for group ownership, but the few cases available from other regions and countries show highly varied outcomes for that approach. Also, the potential expansion of solar pumps requires new approaches to water resource governance: the dispersed nature of individual solar pump use does not lend itself easily to shared monitoring and management of shallow groundwater resources. Finally, a few case studies have proposed that women farmers may particularly benefit from solar pump irrigation. However, in-depth assessments are needed on suitability and the distribution of benefits to women farmers, including possible financial models that reach women and contribute to transforming gender relations. At present, farmers, governments, private sector actors and development investors show much interest in solar pump irrigation as a solution to improving food security and resilience. That interest needs to be matched with systematic study and business models that support the expected outcomes.

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Annex 1. Solar Pump Irrigation in Ethiopia: Relevant Institutions.

Institution	Role	Responsibilities related to solar energy
Ministry of Water, Irrigation and Electricity (MoWIE)	Regulatory policy and decision making, energy operations, implementation, and supervising other governmental agencies and enterprises. Plans, leads, coordinates and monitors overall energy development. It is also responsible for capacity building in the sector, research, development, and the dissemination of renewable energy technologies and improved energy technologies.	GTP II targets for implementation
Ministry of Environment, Forest and Climate Change (MoEFCC)	Responsible for regulatory policy and decision making, environmental, climate-related operations, climate change mitigation and scaling up the use of improved cooking stoves.	International Carbon Financing Mechanism
Ministry of Agriculture and Natural Resources	Facilitator between farmers, credit organizations and technology suppliers to support access for farmers.	CDM program facilitator
Ethiopian Energy Authority (EEA)	Regulates energy efficiency and conservation; regulates the electricity sector; issues technical code standards and directives; commissions programs and projects on energy efficiency.	Licensing, promotion, certification
Ethiopian Electric Utility (EEU)	Engages in the construction and maintenance of electricity distribution networks; purchases bulk electric power; sells electrical energy to customers; initiates electric tariff amendment approval.	Purchase of bulk solar electric power from mega plants
Ethiopian Electric Power (EEP)	Undertakes feasibility studies; designs and surveys electricity generation; undertakes transmission and substation construction and upgrading; handles electricity generation and transmission operation and maintenance activities; leases electricity transmission lines; sells bulk electric power and undertakes universal electricity access work; carries out any other related activities.	Introducing reliable PV system proposals and requests for support from foreign countries. Specifies appropriate sites for megasolar plants. Preferable treatment for megasolar development such as the Feed-in Tariff (FiT) bill
Ethiopian Rural Energy Development and Promotion Center (EREDPC)	Carries out national energy resource studies; data collection and analysis; rural energy policy formulation; technology research and development; promotes appropriate renewable energy technologies in rural areas; serves as the executive arm of the Rural Electrification Fund (REF).	Testing and promoting solar technology
Rural Electrification Fund (REF)	Works to enable private and cooperative engagement in rural electrification activities through loan-based finance and technical support; prepares an off-grid rural electrification master plan which will be updated annually; conducts feasibility studies to identify suitable rural electrification projects, which will be implemented by the private sector.	Avail loan for investment
Development Bank of Ethiopia (DBE)	Administrator of the CDM program and related financial mechanism	Management of CDM and related funds in partnership with the World Bank as trustee
Federal region institutions	Supports and executes energy-related activities at regional level; regional bureaus related to water, mines, agriculture, irrigation, energy.	Utilization of electricity generated for irrigation and water supply; specifies appropriate sites and funding mechanisms for solar

Annex 2. Solar Irrigation Pumps in Ethiopia: Relevant Policies and Regulatory Instruments.

Institution or instrument	Year	Relevance to solar power and irrigation
National Energy Policy	1994	Promotes the following principles: (i) ensure a gradual shift from traditional energy to modern energy; (ii) ensure reliable supply of energy at affordable prices; (iii) streamline the development and utilization of energy resources; (iv) give priority to indigenous energy resources to attain self-sufficiency; (v) increase energy efficiency; and (vi) ensure environmental sustainability. The policy also promotes export-oriented growth and a zero-carbon emission plan. As long as the economic potential is realized, solar and other renewable energy sources shall be used to generate electricity or other energy services.
Environmental Policy	1999	Improve energy efficiency in agriculture, industry and at household level; develop/adapt alternative energy resources.
Proclamation No. 285/2002	2002	Outlines goods exempted from VAT, which do not include solar pumps and renewable energy products. Import of agricultural inputs, such as fertilizers, seeds of superior quality and insecticides, are exempt from VAT.
Directive 79/2005	2005	Duty-free status for goods and spare parts for development projects registered by NGOs and Associations Agency. Grants income tax exemption on the manufacture of some products related to irrigation for 4 or 5 years depending on location. Pumps have exemptions of 5 and 6 years based on location. According to Regulation 270/2012, this applies to domestic investors.
Directive No. 23/2009	2009	Grants non-profit organizations exemption from certain duties and/or taxes on capital goods.
Council of Ministers Regulation No. 270/2012	2012	Specifies areas eligible for investment incentives, as related to duties and taxes on imports and domestic investments. It also outlines income tax exemptions for 1 to 6 years, notably for the production of agricultural products and energy.
Growth and Transformation Plan I (GTP I)	2010-2015	Sets a target of 0.3 GW for solar by 2037, increase to 80% of households supplied with some type of renewable energy source technology, including solar lanterns, during the GTP I period.
Climate-Resilient Green Economy (CRGE) Initiative: Green economy Strategy	2011	Aims to protect the country against the adverse effects of climate change and to build a green economy that will help realize its ambition that Ethiopia reaches middle-income status before 2025. Four pillars include the following: 1. Improve crop and livestock production practices for higher food security and farmer income while reducing emissions. 2. Protect and reestablish forests for their economic and ecosystem services, including as carbon stocks. 3. Expand electricity generation from renewable sources of energy for domestic and regional markets. 4. Leapfrog to modern and energy-efficient technologies in transport, industrial sectors and building.
Energy Law, Proclamation 810/2013	2014	Expands earlier policies and instruments. Aims for independent power purchase agreements for fully off-grid systems and on-grid energy efficiency. Sets standards.

(Continued)

Institution or instrument	Year	Relevance to solar power and irrigation
Ethiopia Off-grid Renewable Energy Program	2014-2042	Expands activities related to renewable energy technologies, including solar pump irrigation. Includes financing arrangements for technology and service suppliers, rural banks and MFIs. Seeks to expand renewable energy use in irrigation to offset carbon emissions from diesel fuel pumps, and to increase the use of groundwater in irrigation.
Growth and Transformation Plan II (GTP II)	2015-2020	Increases irrigation-based agriculture to 4.1 Mha (smallholder schemes) and 954,000 ha (medium and large schemes), including alternative energy sources. Promotes off-grid energy supply, including solar.

Annex 3. Supportive Measures for Renewable Energy Development in Ethiopia.

Beneficiary	Supportive measures	Entity providing the support	Time period
Renewable project developer	- 95% loan with zero interest - 20-30% capital subsidy of the investment costs to project developers on a reimbursement basis	DBE with GoE and World Bank oversight	N/A
Private sector investor	- FiT and power purchase agreements enable direct private sector delivery of technologies (although not necessarily energy-related) - Competitive tariff rates for distributed energy generation for private sector investment - Special provisions and credit access to importers and manufacturers in relation to expanding and strengthening transmission and distribution infrastructure	GoE, DBE	N/A
New investors	- Manufacturing, agro-processing or the production of certain agricultural products, where at least 50% is exported or at least 75% is supplied to an exporter as production inputs; these are exempt from income tax for a limited period[a] - Investors who expand or upgrade existing enterprises and export at least 50% of their output or increase production by 25% are eligible for income tax exemption	GoE	2 to 5 years

Notes: N/A = Not available

[a] The time period for exemption depends on the geographical location of the productive activity.

Annex 4. Tax-related Incentives for Renewable Energy and/or Agricultural Capital Goods.

These represent additional areas of investment eligible for incentives as per The Council of Ministers Regulation No. 270/2012.

Tax concession	Purpose of investment	Status of investor
Customs duty exemptions: 100% exemption from duties and other taxes on imports;	Agriculture, agro-industries, generation-transmission-supply of electrical energy	Domestic and foreign; New enterprises or expansion projects
Spare parts up to 15% of total value of imported investment capital, if those goods are also exempt		
Customs duty exemptions	Manufacturing of electrical products, generation, off-grid transmission and supply of electrical energy, and technical and vocational training service	Domestic and foreign
Income tax exemption for 1 to 6 years (varies by sector and geographical area of investment and/or manufacturing and assembly)	agro-processing; production of agricultural products; generation, transmission and supply of electrical energy; and information and communication technology development	New enterprises

Annex 5. Solar Irrigation Pump Market in Ethiopia: Key Actors.

Company	Main activity	Contact information	
		Telephone	E-mail
Fosera Manufacturing PLC	Manufacturer	+251 91 037 2072	http://www.fosera.com| thomas.koepke@fosera.com
Metals and Engineering Corporation (METEC)	Manufacturer		
Carlo	Manufacturer		
Selam Technical and Vocational Center	Manufacturer and testing	+251 11 462956/42	selamtvc@telecom.net.et
Tehadiso Ethiopia	Manufacturer and retailer	+251 92 43653	
RET Energy Engineering	Manufacturer and retailer	+251 91 250 1796	
EMU General Importer PLC	Importer	+251 11 5523131 +251 91 120 5176	emu@ethionet.et, emugenpk@gmail.com
SOLAR23 Development PLC	Importer	+251 92 217 2069	
Solar and Information Technology plc (SIT)	Importer	+251 14 163449	
Eternum Energy Ventures	Importer and supplier	+251 92 156 3060	http://www.dungoenergy.com
Solar Woman	Importer and supplier	+251 11 3200021	www:solarwomanethiopia.com
Equatorial Business Group PLC	Wholesaler and retailer	+251 11 4424955	ebg@ethionet.et
Maty Trade / Mara Solar	Wholesaler and retailer	+251 91 325 6064 +251 91 263 5132	
Lydetco Plc.	Supplier and installer	+251 11 4667153 +251 11 4663189 +251 11 4660267	lydetco@ethionet.et, info@lydetco.com.et
Davis and Shirtliff Trading Ethiopia PLC	Supplier and distributor	+251 11 5159341 +251 11 5159344 +251 91 306 0711	ethiopia@dayliff.com www.davisandshirtliff.com
TENSAE International Business Enterprise Plc.	Supplier and installer	+251 11 8501458 +251 93 601 0793	Biruk.tensae@gmail.com www.tensaeinternational.com
Geosynthetics Industrial Works Plc.	Supplier and installer	+251 11 4395285 +251 92 072 7226	gizawberehan@gmial.com
Bruh Tesfa Irrigation and Water Technology Plc.	Supplier and distributor	+251 11 5157622 +251 91 020 0153	Bruht-aa@ethionet.et Asfaw1977@yaho.com
Green Power Africa Plc.	Supplier and distributor	+251 11 6632357 | +251 93 000 3968	www.greenpowerafrica.com
Admas Solar	Supplier and distributor	+251 91 130 6530	yetema45@yahoo.com
Auto Truck	Supplier and distributor	+251 91 120 6362	autotruck-plc@hotmail.com
Direct Solar Energy	Supplier and distributor	+251 11 5529178 +251 11 5538248	
Ever Bright	Supplier and distributor	+251 11 4420028 +251 11 4401251	
Mara Trade	Supplier and distributor	+251 91 325 6064	mymara00@gmail.com
RET Energy Engineering	Supplier and distributor	+251 91 250 1796	retenergyengineering@ gmail.com

(Continued)

Company	Main activity	Contact information	
		Telephone	E-mail
Sat Solar Engineering	Supplier and distributor	+251 11 5545861 +251 11 4669815	
Sky Solar	Supplier and distributor	+251 11 1239927	
SOLSolar 23 Development	Supplier and distributor	+251 91 164 61 20 +251 11 5507770	
Solar Light Energy Africa	Supplier and distributor	+251 11 5516025 +251 11 5513678	
Solar Woman (Tigist Tadesse)	Supplier and distributor	+251 13 200021 +251 13 200026	solartech_eth@yahoo.com
Suntransfer Tech	Supplier and distributor	+251 91 168 9292	yonas@suntransfer.com
Vizzer Viorino	Supplier and distributor	+251 11 6293412	
Vonall Com	Supplier and distributor	+251 11 5511659 +251 11 5511647	info@vonall.com www.vonall.com
Wonderwheel Business	Supplier and distributor	+251 91 120 7227	seife@orchidbg.com
Electric World P.L.C.	Supplier and distributor	+251 11 1565838 +251 11 1111887	
Biselex Ethiopia P.L.C.	Supplier and distributor	+251 11 6628600/01/02 *+251 91 121 6164*	*biselexet@biselexgroup.com* *www.biselexgroup.com*
MEGEN Power (MGP) Ltd.	Consulting company and trainer	+251 91 120 3097 +251 11 6297818	

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