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Solar irrigation market analysis in Ethiopia

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LIST OF ABBREVIATIONS

AAU	Addis Ababa University
AEEP	Africa-EU Energy Partnership
AGP	Agricultural Growth Program
AREI	African Renewable Energy Initiative
ATA	Agricultural Transformation Agency
BGS	British Geological Survey
BIT	Bahirdar University Institute of Technology
BMZ	Federal Ministry for Economic Cooperation and Development
BoWE	Bureau of Water and Energy
CSA	Central Statistics Agency
DBE	Development Bank of Ethiopia
EFCCC	Environment, Forest and Climate Change Commission
EIAR	Ethiopian Institute of Agricultural Research
EnDev	Energising Development(GIZ initiative)
ESEDA	Solar Energy Development Association
ETB	Ethiopian Birr (currency)
EUEI	EU Energy Partnership for Poverty Eradication and Sustainable Development
EVI	Enhanced Vegetation Index
FAO	Food and Agriculture Organization
FLID	Farmer-led irrigation development
GDP	Gross Domestic Product
GIZ	German Corporation for International Cooperation
GLCM	Gray-level co-occurrence matrix
GBE	Green People´s Energy (German: Grüne Bürgerenergie)
GTP	Growth and Transformation Plan
IRENA	International Renewable Energy Agency
IWMI	International Water Management Institute
MEFCC	Ministry of Environment, Forest and Climate Change
MFIs	Micro finance institutions
MoA	Ministry of Agriculture
MoFED	Ministry of Finance and Economic Development
MoWIE	Ministry of Water, Irrigation and Energy
MoWR	Ministry of Water Resources
NDVI	Normalized Difference Vegetation Index
NGO	Non-governmental Organization
NPV	Net present value
PCDP	Pastoral Community Development Program
PB	Payback period
PV	Photovoltaic
RATA	Regional Agricultural Transformation Agency
RTI	Radar Technologies International
RUSACOS	Rural Saving and Credit Cooperatives
SDG	Sustainable Development Goal
SNNPR	Southern Nations, Nationalities, and Peoples Region
TDA	Tigray Development Agency
TFC	Total fixed costs
ToR	Terms of Reference
TR	Total revenue
TVC	Total variable costs

EXECUTIVE SUMMARY

This study report discusses the findings of a market assessment on solar irrigation for smallholder farmers in Ethiopia. The study was commissioned by GIZ and implemented by NIRAS-IP Consult and Practica Foundation from May to August 2020. The research focuses on the private smallholder irrigation segment (< 5ha) in the national regional states of Amhara, Oromia, SNNP and Tigray. Structured interviews have been realized with over 30 officials from federal and regional government institutions, as well as 13 technology suppliers and 16 farmers, including solar pump, petrol pump and manual pump users. Strategic discussions with key experts from the public, private and research community have been realized to reflect on the findings and to develop recommendations. The study shows that the solar irrigation market in Ethiopia is underdeveloped due to limited supply, demand and supportive initiatives. The diversity and volume of solar irrigation technologies on the Ethiopian market is very small due to import and foreign currency challenges. As a result, the market is donor-driven, leading to an absence of stock, supply chains, services and information that targets or can be accessed by farmers. Demonstrated systems are expensive, not optimized for local conditions, not promoted and not available for purchasing. As a result, farmers indicate that solar pumps are interesting, but they are not willing and able to purchase a solar pump at the moment. To increase farmers' demand it is necessary that suppliers start offering integrated solutions including solar pumps, suitable application systems, local services, information and accessible finance. A broad alliance of government institutions and donors is needed to smoothen the supply hurdles, which could lead to increased competition, reduced prices and better services. Specific low-risk finance instruments need to be developed in order to stimulate the solar irrigation market. The identification of solar irrigation target zones by the government could contribute to supportive local policies, as well as targeted promotion and capacity building initiatives, in order to create the necessary enabling environment for solar-powered irrigation development to take off.

1. INTRODUCTION

1.1 THE RISE AND INTEREST OF SOLAR IRRIGATION

The first solar-powered pumps were installed in the late 1970s. Nevertheless, it was not until 2009 when the price of solar panels started to decrease dramatically, making solar technologies affordable for agricultural purposes. Prices continue to drop which may trigger a win-win-win-win situation for food, water, energy and climate when developed across Africa[1]. The International Renewable Energy Agency (IRENA) is projecting a 59 percent cost reduction for electricity generated by solar PV by 2025 compared to 2015 prices (FAO, 2018). The cost reductions and increasing awareness of the potential benefits of this technology, has compelled a growing number of countries to launch programs to accelerate its deployment. As an example, Bangladesh has set a target to deploy 50,000 solar pumps by 2025; India, 100,000 by 2020; and Morocco, 100,000 by 2022 (IRENA 2016).

Stimulating solar irrigation is an effective climate change mitigation strategy, it provides opportunities for small-scale private farmers to reduce out-of-pocket production costs and it allows for irrigation development in areas with slightly deeper groundwater that cannot be accessed by fuel-powered suction pumps. Government and donors emphasize the benefit on the environment as fuel-powered systems rely on non-renewable energy sources and produce carbon emissions that are detrimental to the

[1] https://gggi.org/is-solar-irrigation-set-to-take-over-africa/

environment. Solar irrigation can potentially reduce the CO2 emissions per energy unit of water pumping (CO2-eq/kWh) by 97 to 98 percent as compared with diesel pumps, following a life cycle assessment by GIZ documented in FAO (2018). The opportunity offered by solar irrigation for sustainable development, emissions reduction and climate resilience makes it a preferred contender for climate financing (FAO, 2018). As a result, solar-powered water technologies are increasingly facing interest amongst donors and NGOs, as they can provide a clean and potentially cost-effective solution to increase agricultural production. Access to water for irrigation is key to many small-scale farmers in order to sustain their livelihoods and food security (FAO, 2015b).

In countries with supportive government policies, the demand for solar pumps is increasing rapidly. In India, the demand for solar pumps is rigorously increasing owing to the dropping prices as well as government subsidies: up to 90% of the price of small solar pumps in Bihar state (IISD, 2019). A review by Chandel et al. (2015) shows that solar PV-based pumping can be more economically viable in urban and rural areas compared to both hydrocarbon energized and electrical pumps. According to FAO (2018), out of 25 countries in the study, 52 percent strongly agreed that there were significant positive changes in agricultural productivity after the installation of solar irrigation. Yet, the 52% may point at important differences amongst countries. In fact, the physical, socio-economic and institutional environment are a large determinant for the success and potential of solar irrigation development. Hence, a country-specific market study is needed to get concrete insights in the current state and potential of solar-powered irrigation development in Ethiopia.

SUMMARY BOX

- ***Price of solar panels have decreased dramatically***
- ***Increasing awareness of the potential of solar-powered irrigation systems***
- ***Solar irrigation seen as integrated solution to food, water, energy and climate challenges***
- ***Donors and government subsidies have boosted solar irrigation in specific countries***
- ***Sustainability and growth highly depend on country-specific context and policies***

1.2 GREEN PEOPLE'S ENERGY

Overall the GBE initiative is implemented on behalf of the Federal Ministry for Economic Cooperation and Development (BMZ), and jointly undertaken by Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH and KfW Development Bank.

This initiative is embedded in the reality that 570 million people in sub-Saharan Africa still do not have access to modern energy technologies and services. The existing supply of electricity across many countries in the region cannot cover its demand. With limited technologies available locally, energy production is costly, inefficient and causes harmful side-effects to human health. Energy demand in Africa will continue to rise disproportionate to the existing supply due to high population growth, dynamic economic growth and the development of higher standards of living in some areas.

Africa's demand for energy is expected to increase by 80% through 2030. Meeting this demand is a challenge for all of us because sustainable economic development and the achievement of Sustainable Development Goal (SDG) 7 *(access to affordable, reliable, sustainable and modern energy for all)* is only possible if sufficient energy is available.

The most challenging part of this agenda will be the significant improvement of access to modern and renewable energy in rural areas. The initiative **Green People's Energy for Africa** launched by Federal

Minister Dr. Gerd Müller in June 2017, is designed to support these goals. As part of the Marshall Plan with Africa, the initiative supports the development of decentralised renewable energy systems in rural regions of Africa with the involvement of citizens, municipal structures, cooperatives and companies.

Special attention is paid to the promotion of local value creation through the supply of energy for businesses and social institutions such as schools or health centers, and the promotion of framework conditions for investments. (https://gruene-buergerenergie.org/en/initiative/#background)
It further continues the work and accompanies the EnDev initiative as well as the African Renewable Energy Initiative (AREI), the Africa-EU Energy Partnership (AEEP) and the EU Energy Partnership for Poverty Eradication and Sustainable Development (EUEI).

For its operations ***in Ethiopia***, Green People's Energy for Africa collaborates closely with the Ethiopian Ministry of Water, Irrigation and Energy (MoWIE) as well as with the Energising Development Ethiopia Project. As such it is structured into three output areas.
The tender "Conducting a solar irrigation market analysis in Ethiopia" has been released as one of the preparations for output 2: "Promote use of solar PV energy for enhancing social services and production".

EnDev (Energising Development) *is the largest multi-donor and multi-country energy programme supported under German development cooperation. The BMZ is one of the lead donors to the programme, and together with the Netherlands, Norway, the UK, Switzerland and Sweden it aims to provide a total of 22 million people with access to modern, climate-friendly and affordable energy by 2021. Being implemented by the Dutch SNV and the German GIZ, EnDev is currently active in 25 countries, with a focus on the least developed African nations. In the period up to the end of 2018, EnDev helped 21.3 million people, 21,150 social institutions (such as health centres and schools) and 46,500 small enterprises across the world to get access to modern energy services.*

1.3 RESEARCH OBJECTIVES AND SCOPE

The research aims to assess the current supply and the current and potential demand of solar PV irrigation for the specified irrigation sectors. As for the supply side, an inventory has been made of the different national distributors, followed by in-depth research to assess their distribution network, geographical scope, clients, products, services (including after-sales), maintenance capacity, sales volumes, prospections, challenges, conditions for adequate current operations, as well as for upscaling. Lessons learnt and experiences on credit solutions are also included, as finance is a critical factor for scaling because of the high up-front investment for solar irrigation systems compared to fuel-powered irrigation technology.

With respect to analysing the potential demand, IWMI (2018) solar irrigation suitability maps have been accessed, re-interpreted and compared with the shallow-groundwater mapping results from the ATA. The analyses has allowed the research team to determine the market for both solar suction and intermediate depth pumps based on the groundwater depth. In concordance with the IWMI (2018) study, it was proposed to focus the assessment on areas with water at less than 25 meters' depth, since the scope for upscaling beyond this is limited due to the large amount of energy required for water lifting leading to very high investment costs per unit of water pumped.

The target market of the research is the off-grid household-size or small-scale enterprise (<5ha) irrigation segment. This segment has been interpreted as the private smallholder farmer segment and therefore the study excludes an analysis of community irrigation systems. The World Bank (2018) nowadays targets and refers to this segment as farmer-led irrigation development (FLID). Formally speaking, FLID implies farmer-driven processes without major donor or government support. The target segment of this study is in line with the Household Irrigation Strategy by MOA and ATA (2015) defining household irrigation as featured by “a command area less than 5 ha, for plots of fewer than ten households”. This contrasts to “small-scale irrigation projects” which “cover less than 200 ha” and “are operated at the level of farmer groups and households” (ibid). Since communal systems cannot be classified as household irrigation nor as a small-scale enterprise, this segment is beyond the scope of the study.

Three target groups were mentioned in the study requirements: farmers with no irrigation systems, farmers with fossil-fuel-generator-powered irrigation systems (hereafter referred to as fuel-powered irrigation systems), and solar irrigation systems. Previous studies (Practica, 2015; 2018) have shown that the manual irrigation segment constitutes a large potential market for solar irrigation. Therefore, it was decided to shift focus from farmers with no irrigation systems to farmers withdrawing water for irrigation manually (e.g. using buckets, rope pumps or treadle pumps). Farmers that currently do not use irrigation at all, i.e. the rain-fed farming systems, are unlikely to shift to solar irrigation on the short term without external support.

Target Groups

Farmers with no irrigation activities	***Farmers irrigating manually***	***Farmers with fuel-powered irrigation systems***	***Farmers with solar-powered irrigation systems***
Not in study scope	*Target groups of this study*		

1.4 RESEARCH METHODOLOGY

The approach to the solar irrigation market study was data based, oriented to the beneficiary while covering all the client requirements. The description of requested services in paragraph 2.3 till 2.5 in the ToR can be translated into three main outputs:

1) Quantitative & qualitative analysis of current supply-situation for solar irrigation systems and related services in Ethiopia
2) Qualitative & quantitative analysis of current and potential demand for solar irrigation systems and related services in Ethiopia.
3) Development of recommendations for GBE to engage in the promotion and stimulation of the solar irrigation market on the local, regional and/or national level

The proposed process to deliver the services consisted of three working packages that combined yield the necessary data and insights to realize the specified outputs. Each working package counts a set of research methods and activities that have been carried out by the research team. The GIZ-project’s process landscape is presented in the figure below.

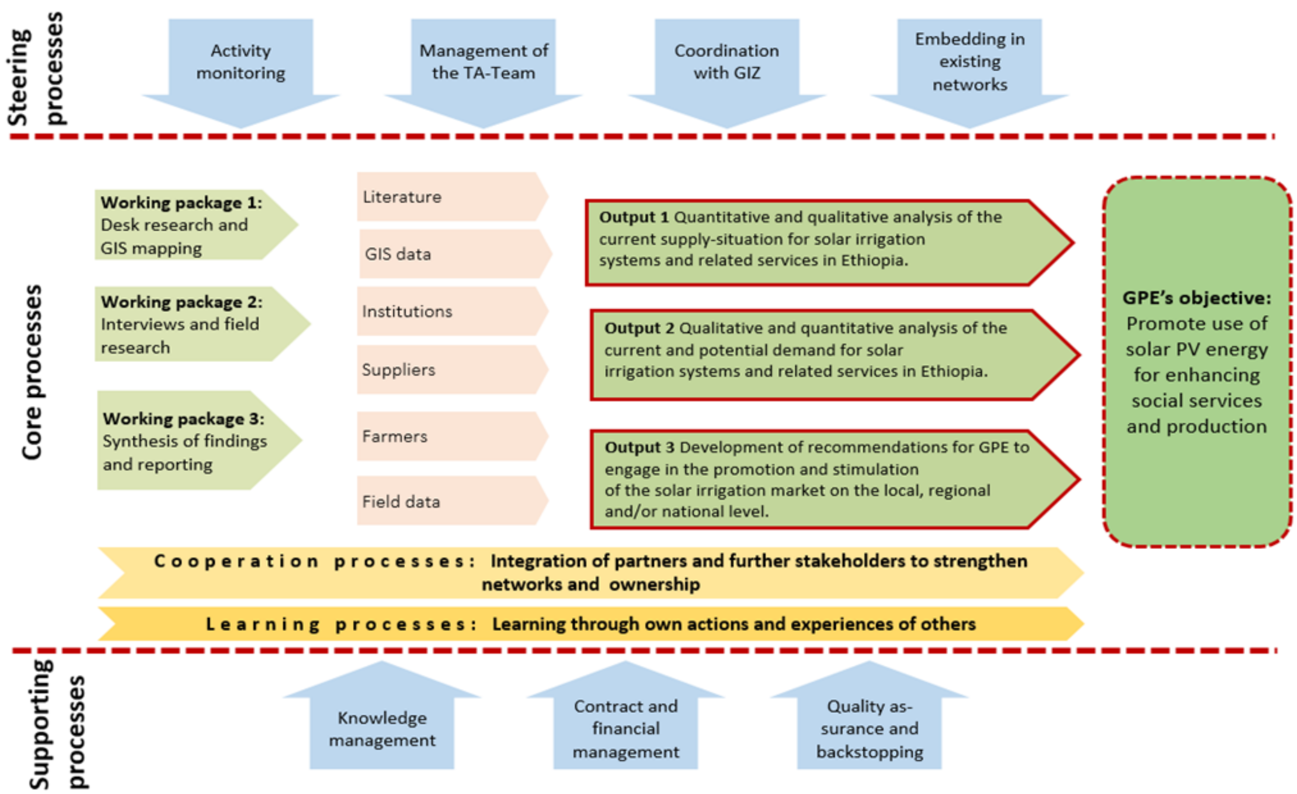


Figure 1 Process landscape for GIZ market study

Working package 1: Desk research

Prior to the implementation of interviews and field research, a desk research has been carried out including 1) a stakeholder analysis and 2) mapping of high potential areas.

Stakeholder analysis for data collection

The stakeholder overview in the ToR has been complemented using the network and experience of the experts and through an online literature and project research about solar irrigation initiatives in Ethiopia. Based on the stakeholder analysis a prioritization for contacting and interviews was established based on the relevance of the organization for the research outputs and type of information to be collected. For each organization the key persons to talk to has been identified by the experts and validated through contacting each organization by phone prior to the appointments.

Mapping high potential areas - The mapping of high potential areas consists of four steps:

1. Validation of IWMI suitability analysis via ATA shallow groundwater mapping
2. Remote sensing and machine learning to identify the current irrigated area
3. Re-creating solar irrigation suitability maps following IWMI (2018)
4. Identification of high potential target areas for solar irrigation projects

The methodology and results of this component are described into more detail in chapter 5.

Working package 2: Interviews and field research

The main research methodology in this study were structured interviews with farmers, technology suppliers and public, donor and research organizations. Since the successful collection of reliable data is crucial for the study a user-friendly and efficient structure of questionnaire has been put in the center from the start. The interviews can be found in Annex E-G.

Structured farmer interviews have been done with 16 farmers spread over the four regions to make cost benefit analysis of their irrigated production systems and to assess their perception on solar-powered irrigation pumps.

Farmer field observations were realized simultaneously, although since the assignment was planned during the rainy season, no measurements could be taken regarding the pump discharge, water level, field size, etc. This has been mitigated by involving local government staff to clarify the differences between the time of research and the irrigation season.

Supplier and institutional interviews were held at national level and in the regions. Different questionnaires were developed for government institutions, suppliers and NGOs. farmers. The table presents the number of interviews per group in Addis and the regions, which adds up to a total of 13 structured interviews with suppliers and 35 interviews with institutions.

Stakeholders	*Interviews (total)*	*Federal*	*Amhara*	*Oromia*	*SNNP*	*Tigray*
Farmers	16		4	2	9	1
Technology suppliers	13	13				
Institutions	35	6	8	6	9	6
Total	**64**	**19**	**12**	**8**	**18**	**7**

This number of interviews is much smaller than the planned number of interviews, mainly as a result of COVID-19 restrictions. Due to the restrictions, the farmer association meetings that were intended to serve as a platform to implement a lot of questionnaires in a short time, could not take place during the implementation period. Therefore, the planned questionnaires have been replaced by structured interviews and field observations with individual farmers. The second reason for the small number of farmer interviews, is the fact that the research plan was to target solar pump farmers first, and identify fuel-powered pump and manual pump users in the vicinity, so that production systems, input costs and market prices would be similar. However, identifying and finding farmers using solar irrigation systems has been particularly difficult. Since solar irrigation is mainly coordinated by ATA, which is a federal government agency, the district level experts from the agriculture or water resources departments were mostly unaware of the solar irrigation activities in their district. Moreover, the number of solar pump users in Ethiopia is very small in the first place, with only 238 solar irrigation pumps reported by the interviewed government institutions together, on a population of over 80 million people in the combined four target areas. Lastly, attempts to increase the number of interviews in Oromia during the last phase of the assignment have failed due to security challenges and organized road blocks obstructing travel in the region.

The number of interviews with suppliers and institutions is also smaller than planned. This results mostly from the fact that responsible staff members have been working from home due to COVID restrictions. The region of Tigray could not be visited at all due to imposed travel restrictions. As a response, emphasis has therefore been put on phone interviews and online questionnaires. Yet, soon after the online questionnaires were shared with potential interviewees, a three-week national internet shutdown due to political unrest forced the team to give up this research method.

Working package 3: synthesis of findings and reporting

The development of recommendations for GBE on the promotion of solar irrigation in Ethiopia mainly depends on the data collected in working package 1 & 2. Working package 3 mainly is the synthesis of interviews, literature and field research, as well as strategic discussions and critical reflections with ATA, (government), IWMI (research institute) and Solar Development PLC (largest solar pump supplier). The recommendations and findings are documented in the market analysis report.

SUMMARY BOX

- ***Output quantity has been affected by COVID restrictions, internet shutdown, social unrest***
- ***Local governments lack awareness of farmers using solar irrigation -> difficult to identify***
- ***Focus on in-depth interviews to understand the market development and challenges***

2. SMALLHOLDER PRIVATE IRRIGATION IN ETHIOPIA

2.1 FARMING SYSTEMS AND IRRIGATION TECHNOLOGIES

Ethiopia's economy is based mainly on agriculture, including crop and livestock production, which contributes 45% of the national Gross Domestic Product (GDP), more than 80% of employment opportunities and over 90% of the foreign exchange earnings of the country. However, the Ethiopian economy, particularly agricultural development, is extremely vulnerable to external shocks like climate change, global price fluctuations of exports and imports and other external factors. Irrigation is one of the key pathways to build resilience towards climate change eventually leading to poverty reduction and key development goals.

Irrigation is one of the mechanisms for improving food security and achieve agricultural growth in developing countries. About 10% of the arable land in Ethiopia is irrigable land (MoFED, 2013), however less than 6% of the irrigation potential is utilized and the country's reliance on rain-fed agriculture limits productivity and increases the vulnerability of farmers to droughts and the effects of climate change. According to USAID (2019) only 10% of the farmers in Ethiopia that depend on non-grid lighting sources practice irrigated agriculture. Sheahan & Barrett, 2017) estimate that, while the majority of agricultural land is purely rainfed, 1.3% is estimated to be under smallholder irrigation. Recently, the Ethiopian Agricultural Transformation Agency (ATA) has estimated that approximately 11 Mha would be suitable for irrigation of which 48% could be irrigated using groundwater.

Irrigation systems in Ethiopia are classified based on the total project area: I) Small-scale irrigation system (<200 ha). II) Medium- scale irrigation system (200-3000 hectare). III) Large- scale irrigation system (>3000 hectare). In total, 46% of the proposed irrigation developments in Ethiopia are in the small-scale irrigation category (Tesfaw, 2018). However, due to the lack of clear standardized criteria, definitions and consistent inventories, differences occur while categorizing the existing irrigation technologies as well as their spatial coverage (Awulachew et al, 2005). According to MoWR (2001), the small-scale irrigation schemes in Ethiopia are understood to include traditional small-scale schemes up to 100 ha and modern communal schemes up to 200 ha. This study focuses on the systems define by MOA and ATA (2015) as "household irrigation", also referred to in this study as farmer-led irrigation or private smallholder irrigation, see chapter 1.3.

Regarding technologies and irrigation methods used in the household irrigation segment; family drip, furrow, border, basin and flood irrigation are commonly used with the help of water lifting technologies such as fuel (diesel and petrol) pumps, rope and washer pumps, hand buckets, pedal or treadle pumps. Shallow hand dug wells, streams, rivers, ponds and roof water harvesting structures are sources of irrigation water (Yusuf and Zekarias, 2019). According to Likimyelesh et al (2017) fuel pumps are only used for irrigation while the other pumps are used to obtain water for multiple purposes i.e. irrigation, domestic use and livestock watering. Micro irrigation is a term often used, but it is not understood in the same sense in all regions of Ethiopia. Sometimes the term is used for small-sized schemes of less than 1 ha developed at household level, such as rainwater harvesting schemes, while others consider micro irrigation as drip irrigation schemes. In this study we refrain from using the term micro irrigation.

According to USAID (2019) half of the irrigating farmers use rivers and stream diversions, while 25% and 13% use pressure/hand pumps and motorized pumps respectively. In Ethiopia, the application of household and small-scale irrigation has been increasing, mainly based on petrol pump irrigation for lifting groundwater (IWMI; Agide, et. al., 2016). The number of petrol irrigation pumps has increased tremendously in areas where surface and shallow groundwater are available (Yusuf and Zekarias, 2019; Dessalegn and Merrey, 2015). However, maps and figures presented in chapter 5 will demonstrate that groundwater beyond suction depth (7m) constitutes the largest potential area for solar irrigation development in Ethiopia.

In 2019, a comprehensive field assessment on the existing situation of small fuel irrigation pumps in Ethiopia was carried out by Yusuf and Zekarias (2019). Based on the study data collected from Amhara, Oromia, Tigray and SNNP regional agricultural offices, around 156,609 fuel pumps have been officially reported from the four regions. Considering other regions such as Somali and Afar, the report estimated the national figure to reach a maximum of 200,000 pumps (ibid). The mean annual growth rates of the focus regions and the national is 18% and 10%, respectively. More than 200,000 ha of small farms of the assessed regions were irrigated by fuel driven pumps. (Table 1). Currently, extrapolating the reported growth rate, it is expected that around 220,000 fuel pumps exist in the country.

Table 1 Number and distribution of fuel driven irrigation pumps (Yusuf and Zekarias, 2019)

Pumps	***Tigray***	***Oromiya***	***Amhara***	***SNNPR***	***Total***	***National***
Functional, no	23,637	61,410	40,227	14,585	139,859	178,000
Non-functional, no	2,879	7,590	3,978	2,819	17,266	22,000
Ratio, %	11	11	9	16	11	11
Total	26,000	69,000	44,205	17,404	156,609	200,000
Growth, %	12	18	25	15	18	10
Average area irrigated, ha/pump	0.5	2.00	1.5	1.5		
Total area irrigated by pumps, ha	11,818.5	122,820	60,340.5	21,877.5	216,857	

2.2 POLICIES AND STAKEHOLDERS

Ethiopia places high priority on irrigation development within its transformation plan to sustainably intensify agriculture and improve food security. The 2nd phase of the Growth and Transformation Plan (GTP II) targets rapidly further extending land irrigated by small-scale schemes by an additional 1.75 million hectares, and ensuring that 80% of farmers have at least one source of water for irrigation and 50% will be supported to use the full package for modern irrigation (ATA, 2016).

The government of Ethiopia aspires to make the country a middle income country by 2025 and agricultural growth is the major pillar for achieving this goal. According to the growth and transformation plan (GTP) of the country, the government targeted the development of small scale irrigation farming in the country. The Climate Resilient Green Economy (CRGE) strategy aims at ensuring climate resilience agricultural growth and reduction of GHGs (FDRE, 2011). The full package modern irrigation system includes the efficient use of water through modern irrigation techniques such as drip, sprinkler and furrow, and provision of crop management extension packages. Following the global trend of increasing utilization of solar energy to power irrigation pumps, the Government of Ethiopia has initiated various projects on solar irrigation in four major regional states. The GTP plan aspires also for changing shallow well ground water to solar energy (FDRE, 2016). But the only pumping equipment currently accessible by the smallholders are the fuel pumps, which require regular maintenance. The major bottleneck to increased irrigated land in Ethiopia like elsewhere in sub Saharan Africa is the lack of low-cost productive technologies (Perry, 1997).

In Ethiopia, most regional states were working to achieve the small scale irrigation targets set by the government by developing river diversion schemes and fuel pump distributions. In Ethiopia over 4 million hectare of land will be developed by strengthening irrigation works that can be undertaken by smallholder farmers during the GTP II period from 2015 to 2020. The GTP supports the smallholder farmers, for instance, the Amhara regional state bureau of agriculture have purchased about 1,000 fuel pumps in 2020 at a unit cost of 14,000 ETB (327 EUR) for distribution to smallholder farmers. They have used the revolving fund for energy sector development to develop the small irrigation sector. The funds are drawn from the World Bank for energy sector development (World Bank, 2019). The fuel pumps will be distributed to safety net woredas at 50% cost sharing, while to commercial woredas at 100% cost of down payment. In the future, the regions have a plan to expand solar pumps, however, there are no suppliers or stores for solar pumps and the costs are very high. The market for solar irrigation pumps was underdeveloped because of the shortages of foreign currencies for solar suppliers and importers and financial constraints for farmers were the critical factors behind the slow development of the market for solar pumps.

Most of the demand for irrigation pumps in rural off-grid areas was served by fossil fuel-driven pumps. About 95% of the smallholder farmers supply over 90% of agricultural produces in Ethiopia. This smallholder farming will continue to dominate the Ethiopian agriculture and smallholders need to produce high value crops and products to ensure agricultural growth. This will increase the demand for small-scale irrigation in the country. In the four study regions of Ethiopia, there are more than 156,609 fuel pumps. In Amhara 44,205, in Oromia more than 69,000, in SNNPR 17,404, in Tigray 26,000 fuel based pumps (Yusuf and Zekarias, 2019). Some federal organizations, mainly in the MoA & MoWIE, are planning to supply and install solar-powered pumping systems for irrigation to replace the fuel-powered irrigation pumps. 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 (IWMI, 2018).

Regarding distributing of agricultural inputs including water lifting technologies for small scale farmers, different financial arrangements and modalities have been practiced in Ethiopia. The most common approach, especially for new technologies, is demonstrating the technologies on selected or model farmers' fields by covering either the whole or part of the investment costs as a subsidy. Long term loans are only available for small amounts. Another approach that is starting to be tested are asset management solutions. Once farmers become aware of the technologies and are confident on the benefits, they are obliged to cover the total costs either in cash or through alternative financial arrangements. Past experiences of fuel driven small irrigation pumps and the current trend of solar pumps are good examples.

Initially regional agricultural offices have imported limited numbers of pumps and distributed for farmers on long term loans. The demand for the pumps increased alarmingly and considerable numbers of farmers are buying in cash from shops. Currently, despite their expensiveness, about 98% of the surveyed households were willing to pay for irrigation pumps and related technology (Yusuf and Zekarias, 2019) especially if supported by institutions with credit arrangements. Getacherl et al. (2013) however found that a lack of access to water is a major constraint to purchase pumps, which implies that promoting irrigation technologies should be combined with efforts to increase access to low-cost water sources.

- ***This study focuses on the household and private smallholder irrigation segment (< 5ha)***
- ***Predominance of petrol pump irrigation in this segment (over 220,000 pumps to date)***
- ***Intensive government support for distribution and capacity building on petrol pumps***
- ***Scaling and willingness to invest in technology is limited to areas with low-cost water access***

3. CURRENT SUPPLY OF SOLAR IRRIGATION SYSTEMS

3.1 SUPPLIERS, PRODUCTS AND SERVICES

This chapter shows the results of interviews with the private sector. To get an overview of the available solar irrigation products and services in Ethiopia, 12 known international solar irrigation pump manufacturers have been contacted to provide details on their representatives in Ethiopia. Furthermore, through listing the leads in the terms of reference and the contacts within the research team, we identified more than 40 companies supplying solar and/or irrigation equipment in Ethiopia. After conducting an online company profile search we identified 13 companies that have effectively imported or dealt with solar irrigation technologies in the past 5 years. Finally, we conducted an in-depth interview with the selected 13 companies: ACME, Adams, Davies and Shirlif, Emu general PLC, Fosera, Key engineering, Lydetco plc, Mathy, Solar Development PLC, Solar Village, Solar Women, and Suntranfer private limited companies. All solar pumps are imported, from China, India, Kenya, USA, Germany, Denmark, Switzerland and Italy.

Available solar pumps

Table 3 shows an overview of the available solar pumps used for irrigation that are on the market in Ethiopia. The table is based on the 13 in-depth interviews with suppliers as well as technical sheets found on the website of the manufacturers. Besides the brands shown in the table, other solar irrigation brands that have been imported into Ethiopia in very small numbers by Watt International PLC (Mono pumps), Difful by Key Engineering PLC (5 Difful pumps) and one unknown retail company (Feili pumps). Solar irrigation pumps that are not on the market yet in Ethiopia include the Ningbo, Taifu, Xinya and mini Volanta.

The solar pump overview table includes the brand, origin, model, type, pump mechanism, suppliers, cost, warranty, power, discharge, status, clients, area and included application system per pump. All pumps are delivered with panels, panel frame, cables, installation service and transport cost, which are included in the price mentioned. If an application system is mentioned, it means this is also included in the provided cost, although the size is not always known. All pumps come with a 1 or 2-year warranty and are almost exclusively sold to government institutions and NGOs.

Looking at the technical details, a predominance of solar submersible pumps can be observed. Suppliers prefer submersible to surface pump because they are more versatile, i.e. they can be used no matter the groundwater depth. This is especially useful when supplying to large projects that are based on one pump type for the whole country. Also, the cost of small submersible pumps is not any higher than the cost of the few solar surface pumps that are currently on the market in Ethiopia (cheaper surface pump do exist in Kenya however). Submersible pumps are installed inside a well or borehole, which means it can be used to pump water from medium to large depths. Suction pumps on the contrary, such as the SF1 or Sunlight pump, are limited to a water depth of about 7-8 meters below the pump. Farmers, just like they do with fuel powered pumps, may lower solar suction pumps a few meters inside open wells, however only a few more meters can be added like this. Submersible pumps can be characterized by different pump mechanisms: centrifugal pumps, helical screw or rotor pumps, diaphragm pumps and piston pumps. Diaphragm pumps have a high efficiency, but a relatively short life span when used intensively, as is the case with irrigation. As a result, if used intensively or in poor water quality conditions, diaphragm pumps may need to be replaced every two to four years[2]. The other pump types have a much longer lifespan; however, it depends on the quality of the water. Centrifugal pumps are very sensitive to water quality and, in particular, to the presence of sand, which can significantly alter the lifespan of the pump. Helical screw pumps and piston pumps are much less affected by water quality (Practica, 2019).

The table differentiates between the status of pump brands on the Ethiopian market: distribution, retail and demonstration. Pump brands with the distribution status are characterized by a long-term supply and engagement of one or more distributors. Pump brands with the retail status have been imported once in small quantities only and may not be in stock, whereas demonstration pumps have been imported in large quantities in the past but without assuring a continuous supply. Most pump brands with the distribution status, i.e. Lorentz, Grundfos and Sunculture, are available in various models and with a large power (Wattage) array, which allows them to meet a wide range of technical and financial requirements. Depending on the exact pump model and number of panels, a different discharge will be generated for a given total head. The total head of a system, which is equal to the water depth, plus elevation head, plus the system pressure, is expressed in meters and directly determines the output for a given system. Therefore, the capacity of pumps is usually depicted through a pump chart, showing the discharge for a particular total head. When suppliers mention the discharge of a pump without specifying the corresponding head, no comparison can be made. This is why the table below shows the discharge for a total head of 10 meters as well as 18 meters. The discharge from the listed pumps range from 0.8 to 3 m^3/h at a total head of 10 meters. This comes down to an irrigated area of 0.13 to 0.5 ha per pump[3]. At a total head of 18 meters the discharge ranges from 0 (not attainable) to 2.4 m^3/h. It should be noted that Lorentz and Grundfos pumps are available beyond this discharge. The total cost of one pump system and installation ranges from 55,000 to 150,000 ETB (1,284 to 3,500 EUR) for the discharges just mentioned, and go up to 4,000,000 ETB (93,262 EUR) for large-scale systems.

Pump prices compared to Kenya market

When comparing the price of solar pumps compared to the prices on the Kenya market, it results that the same pump model in Ethiopia costs on average 2.4 times more than in Kenya (!)[4]. It is expected this is due to the fact that the Kenya market is more developed, which means more competition and larger sales volumes, as well as less problems to import and attract foreign currency. The Rainmaker pumps are

[2] https://thesolarstore.com/shurflo-9300-submersible-pump-c-53_62_154.html

[3] Based on a peak irrigation need of 3.8 mm/day in January, following http://www.fao.org/aquastat/en/climate-info-tool/ for a field of drip irrigated vegetables in Ziway from November to February on a loamy clay soil.

[4] Pumps price including panels and excluding installation cost. Exchange rates taken from OANDA at August 25th 2020. Kenyan prices are taken from the Sunculture website http://www.sunculture.com/wp-content/uploads/2020/08/SKL-JUL3020.pdf

partly assembled in Kenya, so for other pump brands the difference may be smaller but still applies. As a reference, small fuel pumps cost on average 15,000 ETB (350 EUR) (Yusuf and Zekarias, 2019).

Table 2 Comparative prices of pumps

Pump	Price Ethiopia (ETB)[5]	Price Ethiopia (EUR)	Price Kenya (Ksh)	Price Kenya (EUR)	Difference factor
Rainmaker 2C ClimateSmart Direct	50,000	1,169	55,000	426	2.7
Rainmaker 2C Kubwa/Large	65,000	1,520	83,000	644	2.4
Rainmaker2 with battery	85,000	1,988	103,000	799	2.5
Futurepump SF1/SF2	65,000	1,520	92,340	716	2.1

Water application systems and sources

As for the water application systems, 4 of the 9 solar pump suppliers do not provide any system. From the remaining 5 companies, all of them provide drip systems, while 4 also provide sprinklers, 3 also sell spray systems and 1 also provides misters. None of the interviewees was able to answer detailed questions about the application systems, such as the brand, cost or surface of the unit sold. Just like the solar pumps, application systems come with a warranty of 1-2 years and a complete installation is done by the company. Apart from the 160 drip systems installed with the ATA pumps, the combined number of irrigation systems sold amounted to 55 systems, excluding those sold by Davis & Shirtliff as no record was available. Since our focus was on solar pump suppliers, it is likely that other companies in the agricultural sector show much larger sales figures for irrigation equipment. Interviews with 35 institutions (including 33 government institutions, 1 university and 1 NGO) indicated that 67% of the solar pumps are installed with a drip system, 4 % with sprinklers and 29% of the systems use furrows.

According to the 13 private company interviews, 82% of the solar pumps is installed for groundwater usage, in deep boreholes (>25m), shallow boreholes (<25m) and hand dug wells. Only 18% of the solar pumps is used for surface water sources like rivers and lakes. This result is in line with the fact that most companies sell submersible pumps, rather than solar surface pumps. Interviews with 35 institutions showed no major differences. According to them 14% of the pumps were installed in deep boreholes, 55% in shallow boreholes, 14% in hand-dug wells, 17% in rivers and 0% in lakes. Hence a predominance of very shallow and shallow groundwater sources. The field observations indicate that most wells were unprotected. Some wells are prone to flooding and damaged due to excessive waters. Sediment may cause damage to the pump if not properly screened, or if materials are too fine.

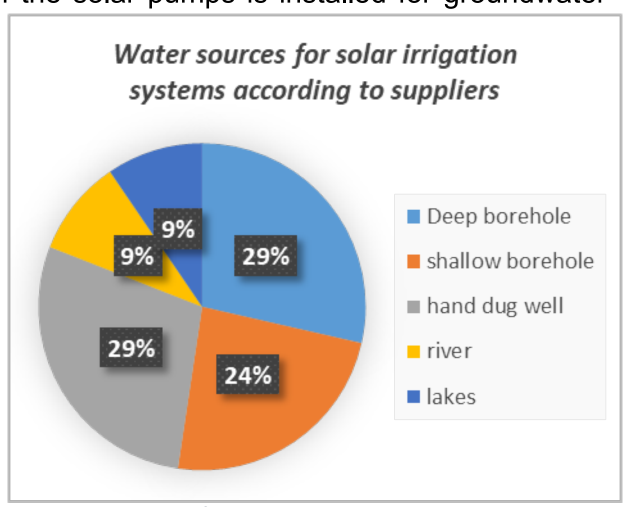


Figure 2 The sources for solar irrigation systems according to suppliers

[5] Pump prices excluding irrigation system and cost of installation.

Table 3 Overview of solar irrigation pumps for smallholder farms available in Ethiopia

Brand	***Origin***	***Model***	***Type***	***Pump mechanism***	***Suppliers in Ethiopia***	***Cost ETB***	***Warranty***	***Power***	***Discharge m^3/h at 10m***	***Discharge m^3/h at 18m***	***Status***	***Clients***	***Areas***	***Application system included***
Lorentz	Germany/ China	various	Submersible	various	Davis&Shirtliff, Emu, Admas, Lydetco, Solar Development PLC, Solar Village, Suntransfer	100,000-4,000,000	1y	100-50,000W	variable	variable	Distribution	Government, NGO	various	none
Grundfos	Denmark	various	Submersible	various	Davis&Shirtliff, Lydetco	600,000-1,200,000	1y	unknown	unknown	unknown	Distribution	Government, NGO	unknown	drip, spray, none
Nastec	Italy	small/med/large	Submersible	unknown	ACME	165,000-1,200,000	2y	unknown	unknown	unknown	now: Retail	Wateraid	Afar, Somali	drip
Sunculture	Kenya/ China	RainMaker 2C ClimateSmart Direct	Submersible	unknown	Solar Development PLC, Solar Village	50,000-85,000	1-2y	310W	0.9	0.8	Distribution	ATA, NGOs	Amhara, Oromia	None, sprinklers, hose
		RainMaker 2S						160W	not specified					
		RainMaker 2C-large (Kubwa)						620W	2.2	1.5				
Futurepump	India	SF1	Suction	Piston	Solar Development PLC	65,000	2y	80W	0.8	n.a.	Distribution	NGO	Amhara, Oromia	None, sprinklers,
Ennos	Switserland	Sunlight	Suction	Helical screw	Suntransfer	> 900 USD	2y	100-400W	0.9 - 2.6	0.5 - 2.4	Retail	NGO	n.a.	none
Shurflo	USA	unknown	both	Diaphragm	Lydetco	unknown	unknown	unknown	unknown	unknown	Retail	unknown	unknown	drip, spray
Solartech	China	unknown	Submersible	Helical screw	Emu General import PLC	unknown	1y	unknown	unknown	unknown	Retail	Oromia Bureau of Water and Energy	Oromia	none
Unknown pump ATA	China	unknown	submersible	unknown	Yasart	120000-150000	2y	300W	3	unknown	Demonstration	ATA	Oromia, Amhara, SSNP, Tigray	0.1 ha drip

Profile of the suppliers

Most, if not all, solar companies are running solar irrigation pumps as a side business and they import only after securing buyers. Out of 13 interviewed companies 8 are engaged in importing, installation and retail of solar technologies. IWMI (2018) estimated that fewer than 10 dealers import solar pumps for irrigation into Ethiopia, which is still accurate to date. One fourth of the interviewed companies provide engineering services and participate in distribution and manufacturing of solar lighting equipment. Only 53.8% of the companies are principally engaged in the supply of solar powered irrigation pumps. The majority (76.9%) are engaged in the supply of other solar technologies such as for electrification and potable water supply (Table 4). As for the services provided, 92% of the companies supplies and installs technologies, while 77% is also involved in design and engineering and 69% in maintenance of the systems. Training is offered by 46% of the companies.

Table 4 Profile of 13 private companies dealing with solar irrigation equipment

Categories of the private companies	*%*
Importer	84.6
Manufacturer	23.1
National distributor	23.1
Retailer	7.7
Engineering services	23.1
What kind of products do you supply?	
Agricultural equipment	7.7
Fuel-powered pumps	30.8
Solar powered pumps	53.8
Other solar appliances	76.9
Irrigation equipment	7.7
What kind of services do you supply?	
Design and engineering	76.9
Technology supply and installation	92.3
Maintenance	69.2
Training	46.2

Solar pump sales volumes

In the questionnaire developed we asked the private companies for the number of solar irrigation supplied within the last five years. In the last five years prior to the survey year a total of 1,725 solar irrigation pumps were supplied by private companies. The average number of solar pumps supplied per company in the last five years was 216 pumps with minimum and maximum of 5 and 1,000 pumps respectively (Table 5). The number of irrigation pumps reported by organizations and solar suppliers is not similar. This is because the reports from the private companies includes solar pumps distributed in different regions of Ethiopia, such as Afar and Somali, while the organization reports only consider the four regional states that are the focus of this study. Moreover, some companies could not differentiate between solar pumps installed for drinking water supply and irrigation, as they were reported as multi-purpose pumps. This corresponds to reality as some farmers use the pump for both irrigation as domestic usage.

Sales and after-sales services

Many of the interviewed companies fail to distribute the solar pumps on time due to the fact that they faced shortages of foreign currency and because solar irrigation projects are operational over long periods (more than a year) from importing to installations. As a result, most companies do not import solar pumps unless they have a guarantee that they have a buyer. That is why most solar importers import the solar pump equipment after they sign an agreement with organizations or private buyers.

Among the companies interviewed, Solar development PLC and Yasarat Engineering are the major suppliers of solar irrigation pumps in the last five years: respectively 1,000 and 160 solar pumps were supplied by them. A major difference is that Solar Development has sold solar pumps since 2015 to various clients and with sales number growing over the years, whereas the 160 pumps supplied by Yasarat was based on a single order by ATA. In terms of price, Solar Village and Solar Development PLC offer the cheapest pumps which costs about 55,000 ETB (1,284 EUR) to 65,000 ETB (1517 EUR) per solar pump including accessories and installations.

As indicated above, all solar pump suppliers provide a 1 or 2 years' warranty on both the solar pumps and irrigation system. This price is included in the equipment cost. The average number of technicians who assume the responsibility of maintaining the irrigation pumps was three while there are companies who do not have technicians and others with about eight technicians. It took a company on average ten days to repair a failed pump with minimum and maximum of seven and fourteen days. The implementing organizations however, disclosed that the availability of skilled technicians at the local level is a major obstacle. The required skills to repair the solar pump systems locally needs to be emphasized.

Demand and market size

The current demand for solar irrigation pumps in Ethiopia was assessed based on the private companies assessment. The results show a very large variation: nearly one quarter of the companies indicate that the demand for solar irrigation pumps in Ethiopia is either very high, high or low (Figure 3). The private companies currently supplying solar irrigation pumps acknowledged the high demand for solar pumps from NGOs, but were unable to provide a regular supply due to shortages of foreign capital. Regarding the future importance of investing in solar irrigation, respectively 53.5% and 46.2% of the interviewed companies indicate that solar irrigation is extremely important and somewhat important for their company. While asked how much are they willing to invest in solar irrigation sector, 76.9% and 23.1% are willing to invest a lot and medium on solar irrigation technologies.

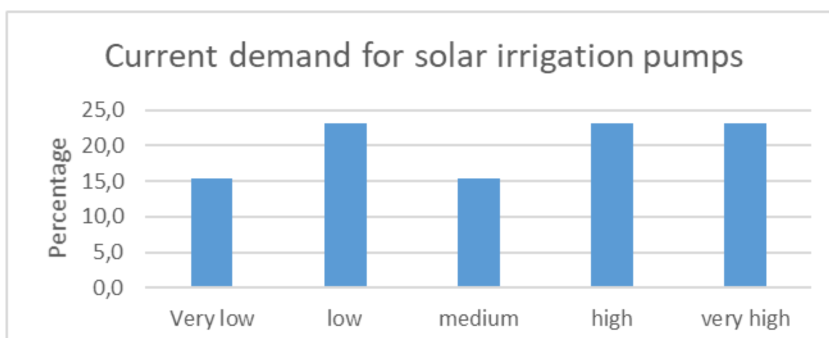


Figure 3 Demand for solar irrigation pumps in Ethiopia according to suppliers

IWMI (2018) noted that the demand for solar pump irrigation in Ethiopia has been rising. However, due to shortage of recorded data on the solar pump market and price information, it is difficult to conduct the demand and supply analysis for solar irrigation pumps in the country. The other major constraint was the fact that many private companies do not differentiate between pumps for household use and irrigation. Hence, we systematically collected data from both the private companies and the organizations engaged in developing the solar irrigation sector to assess the demand and supply status for solar irrigation technologies in Ethiopia. The collected data (see Table 5 5) show that demand for solar irrigation in Ethiopia has been increasing. While there exists strong interest in solar systems by governmental and non-governmental stakeholders, the supply and distribution of solar equipment is very limited. The interest of farmers towards solar irrigation is at an infant stage and the demand is relatively weak and requires awareness raising.

Table 5 The number of solar irrigation pumps sold in Ethiopia in the last five years.

Company / Year	**2015-2016**	**2017**	**2018**	**2019**	**Total**
ACME engineering PLC	5	255	6	13	279
Davis & Shirtliff			12	12	24
EMU general PLC	2	2	2	2	8
KEY Engineering PLC			3	3	6
Lydetco PLC		5	5	5	15
Solar Development PLC	50	150	400	400	1,000
Solar Village		3	3	4	10
Sun Transfer		1	2	2	5
Yasarat Engineering PLC				160	160
Total	**7**	**466**	**433**	**601**	**1,507**

	N	*Minimum*	*Maximum*	*Mean*	*Std. Deviation*
Number of solar pumps sold	8	5.0	1,000.0	215.6	328.9
Number of technicians	4	0.0	8.0	3.0	3.6

Sales forecast

Accurate forecasts are important for solar suppliers and other organizations in making plans to meet demand for solar pump supply. However, there is a lack of time series data on solar marketing in Ethiopia. Therefore, an evidence based solar pump demand forecasting was performed by using three scenarios i) Replacing the existing fuel based pumps ii) Installing solar pumps for irrigating potential plots of lands iii) trends of marketed solar pumps. For i & ii we use extrapolations by using the historical data. This method provides reliable result for no-change assumptions (Armstrong and Green, 2017). If we replace all of the existing fuel pumps in the four regional states, nominally 156,609 solar pumps will be demanded. Assuming the current price level and no installation costs, this would imply an investment of 238M EUR[6] or 1071M EUR if maintaining the average irrigated area of 1.5 ha per petrol pump (see Table 1). If we apply the 10% growth rate of fuel pumps on solar pumps, by 2025 about 481,512 solar pumps will be required. This is however difficult to implement since fuel pumps and solar pumps have different technical characteristics (discharge, pressure, required water depth, water quality, etc.) which makes them suitable for different areas and farming systems. In the last three years over 1,500 solar irrigation pumps were sold by the private suppliers. On average, the supply of solar pumps grows by 20.3% in the last three years. Accordingly, by 2025 the demand will reach 940 solar pumps per annum. Lastly, in the theoretic scenario that solar pumps will be installed for all of the land suitable for solar irrigation farming in the four major regions according to IWMI (2018), in total 8.3 million ha, the potential demand for solar irrigation pumps with irrigation capacity of 0.5 ha will be 16.8 million solar pumps. This would require an investment of 25,536M EUR in pumps and 1,965M EUR for the construction of manually drilled boreholes[7].

[6] Based on the cost of a Sunculture Kubwa pump (1520 €) which allows to irrigate 1/3 ha of vegetables in January in Ziway, based on a total head of 10m.
[7] Based on the current price of a Sunculture Kubwa pump (1520 €) without installation costs. (max area in that case is 5.6Mha due to pump capacity). Farmers reported a cost of 5,000 ETB (117€) for a manually drilled borehole of 15m depth, although cost may depend on the local hydrogeology and available drilling service suppliers.

SUMMARY BOX

- ***Very limited number of distributors consistently supplying solar pumps (< 5 country-wide)***
- ***Very small number of solar irrigation pumps in the country (1500 pumps sold in 5 years)***
- ***Mainly small submersible pumps, limited choice in water application systems***
- ***Price of a solar pump in Ethiopia is 2.4 times higher than the same pump in Kenya***

3.2 CLIENTS AND PROJECTS

According to IWMI, 2018, 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. There has been much efforts by the government and NGOs in rural water supply for irrigation purposes in Ethiopia. Still, the history of solar irrigation pump is very young in Ethiopia. It was in 2015 that IWMI and Africa RISING project introduced and tested the effectiveness of solar-powered SF1 pumps under farmers' circumstances (Kifle, 2015). The solar pump-based irrigation was tested in the Southern Nations Nationalities and Peoples Region (SNNPR) and in Oromia regional states (ibid).

This chapter reflects the outcome of in-depth interviews with 35 institutions, including 33 government institutions at federal and regional level. For the organizations and projects engaged in solar irrigation we consult the major stakeholders such as the ATA, MoA, and MoWIE then trace others using the snowball approach including respective regional offices.

Profile of interviewed organizations

Out of 35 representatives from the interviewed organizations, 90.2% and 70.4% of them have been involved in projects related to irrigation in general and solar irrigation in particular respectively. The major federal organizations include the Federal Ministry of Agriculture (MoA), the Federal Ministry of Water, Irrigation and Energy (MoWIE), the Federal Agricultural Transformation Agency (ATA), and the Ethiopian Institute of Agricultural Research (EIAR). The regional bureaus interviewed include the Bureau of Agriculture (BoA), Bureau of Water and Energy (BoWE), Regional Agricultural Transformation Agency (RATA), regional agricultural research institutes, universities and regional microcredit institutions. In addition, woreda level key informants were interviewed (Table 6).

Table 6 The profile of organizations interviewed

Regions	***Organizations interviewed***	***Number of interviews***
Federal	Ministry of Agriculture (MoA)	1
	Ministry of Water and Energy (MoWIE)	2
	Agricultural Transformation Agency (ATA)	1
	Ethiopian Institute of Agricultural Research (EIAR)	1
	Small & Micro Irrigation project (SMISS)	1
Amhara	Amhara Agricultural Research Institute (ARARI)	1
	Agricultural Transformation Agency (ATA), Amhara	2

	Amhara Regional Bureau of Agriculture (RBoA)	1
	Amhara Water, Irrigation and Energy Development Bureau	2
	Amhara Credit and Saving Institution (ACSI), Amhara	1
	Bahir Dar University	1
Oromia	Oromia Agricultural Transformation Agency (OATA),	1
	Oromia Bureau of Agriculture & Natural Resources (OBoANR)	2
	Oromia Water, Mineral and Energy Bureau	1
	Oromia SMISS	1
	Catholic relief Meki	1
SNNPR	Southern Agricultural Research Institute (SARI)	1
	Southern Agricultural Transformation Agency (SATA)	1
	SNNPR Bureau of Agriculture and Natural Resources (SBoANR)	1
	SNNPR Irrigation Development and Scheme Administration (SIDSA)	1
	SNNPR Water, Mine and Energy Development Bureau (SWMEDB)	2
	Omo Micro Finance Institution (OMFI)	1
	Sidama Zone (new region)	2
Tigray	Tigray Agricultural Research Institute (TARI)	1
	Tigray Agricultural Transformation Agency (TATA)	1
	Tigray Bureau of Agriculture (TBoA)	1
	Tigray Water Resource Bureau (TWRB)	1
	Tigray Regional Mines and Energy Agency (TRMEA)	1
	Dedebit Credit and Savings Institution (DECSI)	1
	Total	**35**

The roles of different organizations interviewed are presented in figure 4. The majority of the organizations are participating in solar projects as implementers (59.3%). The organizations involve the agricultural, water and energy, and agricultural transformation agencies. The government funding is from the Ministry of Agriculture and ATA, with funding from the World Bank for Agricultural Growth Program (AGP). SMIS projects were funded by IFAD and the AGP programs. The Mashaf solar project was funded by the USAID while MoA & Mashaf provide technical and capacity building roles. The Ministry of Agriculture, and Ministry of Water, Irrigation and Energy administers procurement and funding for irrigation projects, but regional water bureaus own the schemes.

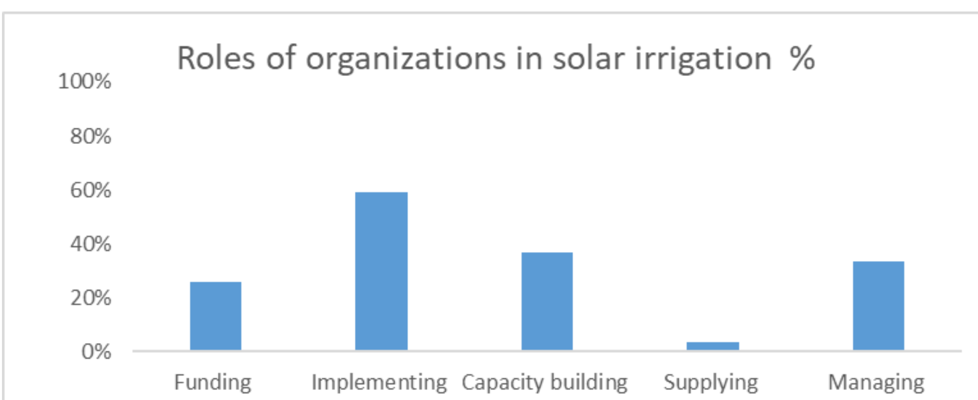


Figure 4 The roles of organizations in solar irrigation projects

Supply and installation of solar pumps in Ethiopia

According to the interviewed institutions, most of the solar PV systems are used for rural lighting and telecom services. The number of solar pumps and farmers operating solar pumps vary from region to region. As shown in table 7, the total number of solar pumps that exist currently (functional and nonfunctional) according to the government institutions, was reported to be 238 in total in the four regional states. The number of farmers operating or owning solar pumps was 244, while 48.2 ha land is currently registered as area under solar irrigation. The largest project has been implemented by ATA, which recently installed 160 solar pumps with 0.1ha drip systems at individual farmers' plots. They provided a three days training about the technology to the farmers so that they are aware of the advantages and are eager to use the solar pump in the coming dry season.

It should be noted that there is a lack of reliable data in the federal and regional offices about the number of solar pumps and number of farmers using solar pumps. For instance, the Tigray regional offices reported that the number of solar pumps installed by ATA was 20, while the company reported it installed 28 solar pumps. While 1 solar pump was attributed to IWMI, it was found that in reality 10 solar pumps were installed by them. Overall, the figures reported by suppliers are substantially higher, showing a total of over 1,500 solar irrigation pumps sold. It should also be noted that there may be other solar pumps on the market that are not identified by the government, nor by this study. However, because of the large number of institutions, distributors and international manufacturers that have been consulted, it is expected that the estimated numbers are not far from the truth.

Table 7 Projects and quantity of solar pumps reported by government institutions

Projects	***No of solar pumps***				***No of solar pumps***	***No of farmers***	***land (ha)***
	Amhara	*Oromia*	*SNNPR*	*Tigray*			
ATA	40	28	72	20	160	160	16
SMIS, ATVET centers (4), Small enterprises (12 each)	13	15	13	13	54	60	5.4
Solar Village	3	7			10	10	10
Mashaf project	1	2	1	2	6	7	11
Bahirdar University	2				2	2	1
CultiveAID (NGO center)				1	1		1.5
Catholic Relief (child center)		1	2		3		2
Channo Mille W/S/P			1		1	1	0.5
IWMI		6	4		10	10	2
Total	**59**	**59**	**93**	**36**	**247**	**250**	**49.4**

In addition to the small-scale solar pumps owned by individual or group farmers, the government plans a small number of large-scale, solar pump irrigation projects to be implemented in three regional states: in SNNPR south Omo pastoral zone, Tigray Tekeze area, and Amhara in Raya Kobo valley. The Raya Kobo and Shewa Ribit area irrigation project, targets 19 solar pumps in six woredas. The total area to be covered by the solar project is about 1,000 ha. In Tigray regional state the Tigray Development Agency planned to install 100 solar pumps for smallholder farmers, with plans to launch a medium scale solar irrigation around Tekeze river. The Koga irrigation project in Amhara regional state intends to purchase and install 20 large discharge solar pumps (IWMI 2018). Different NGOs such as the Catholic Relief

Service and Cultivd have been using solar pumps to supply electrification and water supply in rural schools for children.

Types of farms and farmers participating in solar irrigation

The solar irrigation projects in Ethiopia target all kinds of farming systems such as communal gardens, smallholder farms and commercial farms. But, more than half of the solar pumps were launched for smallholder farmers for irrigating less than one hectare of land (55.6%). Similarly, all kinds of farmers are targeted for solar irrigation projects such as rainfed farmers (44.4%), farmers who have been irrigating manually (44.4%), and farmers using fuel powered pumps (40.7%) (Table 8). Among the currently installed solar irrigation projects in Ethiopia 55.6% and 33.3% respectively were implemented on household smallholder private farms of less than one and exactly 0.1 ha lands. Of these solar pumps distributed to farmers 25.9% were on communal farms owned by a group of farmers.

Table 8 Types of farms and farmers participating in solar irrigation

Farm type supported	*%*	*Main target group for solar irrigation*	*%*
Communal gardens	25.9	Rain-fed farmers	44.4
Household gardens < 0.1 ha irrigated	33.3	Farmers irrigating manually	44.4
Smallholder private farms <1 ha irrigated	55.6	Farmers using fuel-powered pumps	40.7
Commercial farms >1 ha irrigated	14.8	Large scale irrigation schemes	11.1

Mode of solar pumps supply for smallholder farmers

About 55.6% of the organizations interviewed indicate that the supply of solar pumps for smallholder farmers was by donation (Table 9). However, 29.6% report there are in kind contributions from farmers such as the construction of water storage stands, well and labor during installations. In its business model assessment IWMI (2018) suggests that loans (66%), grants (33%) and the government budget (1.2%) should finance the solar-related expenses. The key informants of different organizations argued that cost sharing for solar technology adoption would help farmers to feel ownerships and ensure sustainability rather than donation.

Table 9 Arrangements for supplying solar equipment to farmers

Arrangement	*%*
Donation	55.6
Donation with in-kind contribution from farmers	29.6
Donation with some financial contribution from farmers	3.7
[no response]	11.1

Success and relevance of solar irrigation

About 89.9% of the organizations involved in solar projects in Ethiopia have never conducted cost benefit analysis of the solar irrigation projects. Two regional organizations report that they have conducted the payback period for medium scale solar projects and report a 5-6 years' period for return on investment. 70.4% of the organizations indicate that it is difficult to judge whether the installed solar pumps are successful or not. However, 29.6% perceive most of the solar projects as successful, even though it is too early to conduct the impact assessment. As a result, 81.5% the interviewed organizations are willing to scale up the promotion of solar pumps and have been planning solar irrigation in the near future (Table 10).

Table 10 The success and future interest of organizations for expanding solar irrigation

Questions	*%*
Was the introduction of solar irrigation successful?	29.6
Have you done cost benefit analysis?	11.1
Is your organization planning any solar irrigation in the near future?	81.5

The reasons for institutions to engage in solar irrigation

The majority of the organizations interviewed show that water use efficiency (70.4%) and environmental sustainability (85.2%) will be ensured when using solar energy for irrigation. According to government officials it is clear that solar energy systems offer a clean and simple alternative to fuel-powered pumps. The interviewed officials also indicate that solar pumping systems aid the reduction of operation and production costs (59.3%) and that the equipment is more durable (55.6%). The interviewed organizations did not mention the existence of supportive and enabling environment, nor the existence of high farmers' demand as a reason for engaging in solar irrigation. In addition to the specified reasons for the use of solar irrigation our key informants also reported that Ethiopia is a country at the middle of equator with 12 months of sunshine and that the use of solar pumps during dry and sunny seasons do not require fuel deliveries. Moreover, solar pumps can be used for agricultural operations in off grid remote areas. Farmer key informants also indicate that the solar pump will save time for women who otherwise travel long distances to fetch water for domestic use.

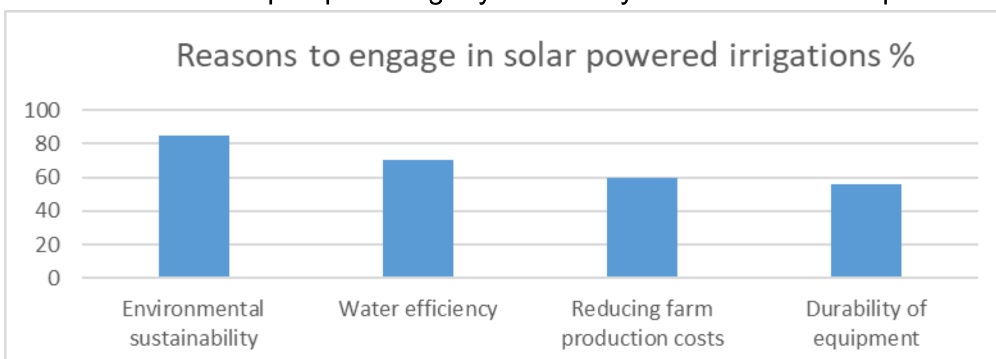


Figure 5 Reasons for institutions to promote solar irrigation pumps

Modality and beneficiaries targeting for future projects

While asked what will (most likely) be the main farm type to support with solar pump equipment, 48.1% and 40.7% of the organizations suggest that respectively smallholder private farms of less than 1ha and household gardens of less than 0.1 ha should be supported. Also, 33.3% suggest that communal farms owned by a group of farmers should be the main target group (Table 11). The most likely modality of promoting the solar irrigation pumps in the future was through donation (51.9%), donation with some financial contribution from farmers or cost sharing (33.3%), and 18.5% donation of the solar equipment's with in-kind contribution from beneficiary farmers.

Table 11 Farmers targeting and future mode of support options according to institutions

Targeting	*%*	*Likely modality*	*%*
Communal gardens	33.3	Donation	51.9
Household gardens < 0.1 irrigated	40.7	Donation with in-kind contribution from farmers	18.5
Smallholder private farmers < 1 ha irrigated	48.1	Donation with some financial contribution from farmers	33.3
Commercial farms > 1 ha irrigated	37	Loan: equipment cost paid back by farmers over time	14.8

The best model to expand solar irrigation

As shown in Figure 6, credit availability for farmers (66.7%), empowering cooperatives to supply solar irrigation to members (55.6%) and government subsidies (40.7%) are identified by the interviewed institutions as the top priority areas for expanding the adoption of solar irrigation pumps by smallholder farmers.

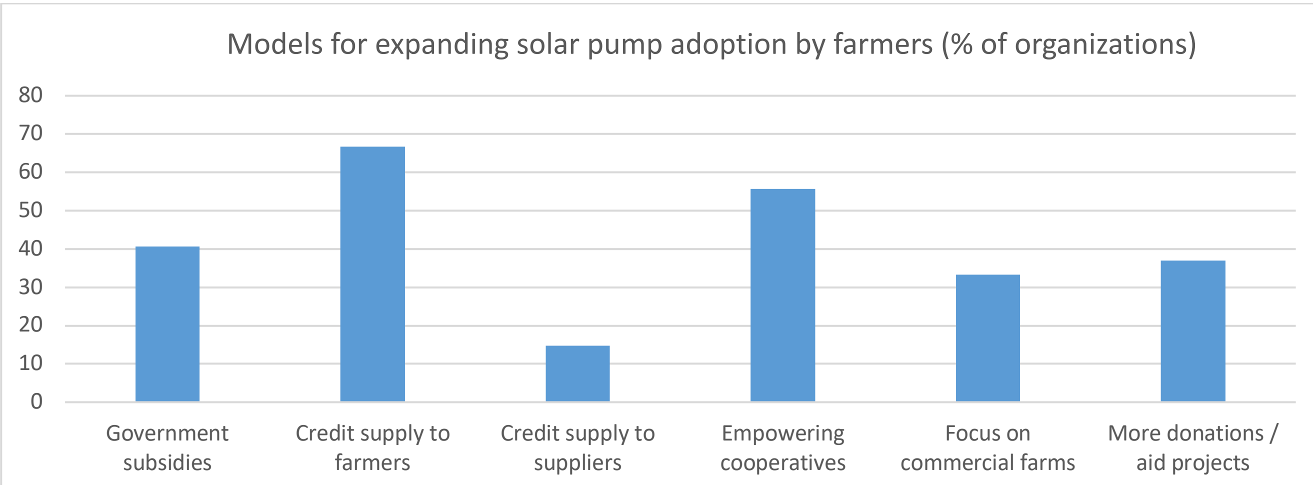


Figure 6 Possible models for expanding solar irrigation for farmers

Future projects for solar irrigation development

ATA has a solar pump expansion plan for four regional states, according to regional ATA key informants about 210 solar pumps will be installed. Accordingly, 60, 40, 90 and 20 solar pumps respectively will be installed in Amhara, Oromia, SNNPR and Tigray regional states. However, the federal ATA indicates that the organization will assess the performance of installed solar pumps before scaling up. As an example, the ATA is piloting and testing Sunculture solar pumps in Oromia regional state. Tigray Development Agency (TDA) in collaboration with the Regional Bureau of Water and Energy planned to install about 100 solar pumps as of the next year.

Most of the organizations indicate that solar irrigation has a huge demand and that it will be successful if adequate attention is given. For next year the demand for solar irrigation by the interviewed organizations was 378 solar pumps and 114 ha of land will be irrigated under smallholder farmers production. There are also large scale solar irrigation projects ongoing. These are the SNNPR pastoral project on South Omo on commercial banana plantation to irrigate 1,000ha, the Kobo- Raya project in Amhara to irrigate nearly 1,000 ha and the Tigray Tekeze area project to irrigate about 100ha. Amhara Regional Bureau of Agriculture has a plan for large scale solar irrigation development for which a design, and drilling wells are completed. In Koga project about 700 ha and in Kobo project about 1,300 ha land will be prepared for the sola irrigation projects. In the Awash river basin 19 deep boreholes were prepared for the large scale solar irrigation projects. The pumps will be installed and donated to target farmers with some in-kind contribution in well preparations. Some of the funds are supported through the Sekota declaration projects, from JICA, IDE and CARE Ethiopia. Some of the challenges are shortage of land to install the solar panels which in some areas cover 1-2 ha land. Five woredas includes, Semen Shewa, Harbu, Mersa, Ambasel Wuchale and Shewa Robit. The project will cost about 220 million ETB (ca. 5.1 Mill EUR) and 19 solar pumps are included. The design and installation of the 19 solar pumps will be conducted in collaboration with Bahirdar University Institute of Technology (BIT).

Bahir Dar University Faculty of Electrical and Computing (BIT) has been working to produce a solar panel within the next three or four months' time, as well as an invertor. They also have a model 5 kW solar powered irrigation that is being piloted with two farmers. They currently have been working with private companies such as Awramba Technologies PLC who will take over and commercialize the panels and solar-powered irrigation systems developed by BIT. Awramba Technologies focuses on manufacturing solar and LED products to provide efficient lighting and is based in Bahir Dar. The solar technologies installed by BIT are funded by USAID. BIT aspires that in the near future solar technologies will be produced by the institute and the price will fall. They report that they are at the final level of solar technology development, manufacturing SPIC - the most important part of solar irrigation.

In SNNPR one large scale solar project was under bid by SNNPR Water, Mines and Energy Bureau for the pastoral development office in south Omo. About 7 solar pumps will be installed to irrigate a banana farm of about 1,000 ha. The Omo river will be the source of water. The project is a shifting from cannel irrigation to solar irrigation. It is an upgrading project at a cost of 1.9 million USD and is funded by the World Bank under the pastoral community development program (PCDP).

SUMMARY BOX

- ***Over 30 government institutions interviewed in 4 regions***
- ***Main motivation for solar irrigation: environment and water efficiency***
- ***Solar irrigation pumps are fully donated in 95% of the cases (70% in future plans)***
- ***Credit supply to farmers seen as most promising upscaling strategy***

3.3 CHALLENGES IN SUPPLY CHAIN AND MARKET DEVELOPMENT

An open question to the interviewed suppliers about the main constraints in solar irrigation development, showed that the principal problem according to the private sector is the shortage of foreign currency, followed by a lack of awareness amongst farmers, a high investment cost and a lack of knowledge in the government (see figure 7).

In-depth interviews with key experts in the private sector helped to understand the challenges related to foreign currency and the import process.

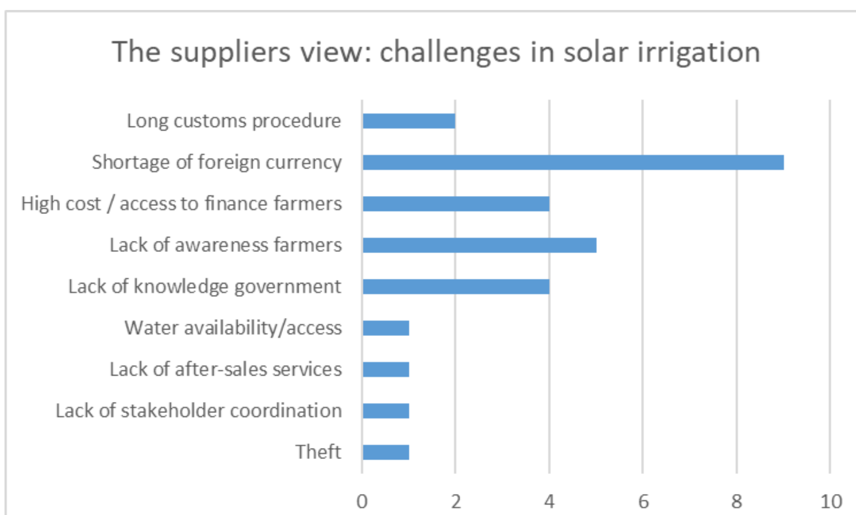


Figure 7 Overview of challenges in solar irrigation

Import process

Generally, it takes at least 6-8 months to order and receive something from abroad. The steps are:

1. The manufacturer sends a Proforma invoice
2. The distributor applies for a Letter of credit from the bank
3. The bank says NO, there is not enough foreign currency
4. The distributor waits in a queue in order to get an allocation of foreign currency by the National Bank. If you are very lucky this step takes 3 months, but it can take up to 12 months. It is also possible that the request is declined.
5. The Ethiopian bank sends a notification to the international bank: LC = approved
6. The distributor prepares the documentation; this takes 2-3 weeks.
7. Shipment of pumps, about 2 months to arrive in Ethiopia
8. Customs clearance, about 2-3 weeks.

The queueing time can be reduced by getting a priority. This is valid for manufacturing companies in Ethiopia, and nowadays also for agricultural inputs and technologies, including pumping. This works in theory, but in practice there are many companies in the priority list and the queuing still takes very long. Suppliers mention it is a pity that in the process to import pumps and apply for foreign currency, the government does not prioritize solar more than fossil fuel technologies in the agricultural sector. As a result, petrol and diesel pump import volumes are much larger than for solar pumps, since with the same amount of US dollars many more fuel pumps can be purchased compared to solar pumps.

Foreign currency

Attracting foreign currency on the international market instead of depending on the National Bank is very complicated. If an Ethiopian company has a foreign shareholder it is considered as a foreign company. Foreign companies are not allowed to operate in the retail, wholesale or installation sector, only in manufacturing. Attracting loans from foreign banks is also difficult, because the Ethiopian company cannot pay back in foreign currency, only in ETB.

The only possible foreign investment of hard currency is through grants and diaspora remittances, or through NGOs that pay in foreign currency. In that case pumps can be imported and delivered in only 3 months. Suppliers mention that without foreign relations, there are no legal options to obtain sufficient foreign currency to import solar pumps.

The impact on client targeting

Some companies even mention that the demand for solar pumps is huge, and that this is not a major limiting factor to sales. The limiting factor is the amount of pumps the company can import. Often, requests from clients cannot be met because there are not enough pumps in stock. As a result, suppliers need to prioritise whom of their potential clients they will sell to. Due to the foreign currency problem, preference is given to clients that can pay in foreign currency. Selling directly to farmers is limited, let alone offering products to them on credit.

Tax exemptions

As from 2019, the government of Ethiopia has exempted all agricultural machinery, including solar and fuel powered pumps, from import duties, which otherwise would range from 0-35% depending on the type of product. Next to this, all solar products are exempted from VAT, worth 15% of the gross product price. The VAT exemption is only applied to the solar panels. Unfortunately, the panels only constitute a fraction of the cost of solar irrigation systems, especially when installation services are also included. The pump, hoses, panel frames etc. are not tax exempted for the supplier, even though in theory there are ways for the client to benefit from more tax exemptions.

In general suppliers indicate that benefitting from tax exemptions is challenging and time consuming due to the involved bureaucracy. Some enterprises mention that tax exemptions are particularly applied when supplying pumps to government institutions. Allegedly, it is also easier to get access to foreign currency when supplying to government institutions. Acquiring sufficient foreign currency when importing for private customers is reported to be very difficult. According to FAO (2015) the Ethiopian Investment Agency is encouraging farmers and investors to produce crops for export, as a strategy to bring more foreign currency into Ethiopia.

The remaining challenges mentioned by suppliers, including the high cost of the technology, farmers lack of access to finance, and the lack of knowledge at the government level, have been integrated in chapter 4.3: criteria for increased farmer demand.

The main challenges related to solar irrigation according to the government institutions

Most of the interviewed government institutions report that there are no problems related to the state policies concerning solar irrigation in Ethiopia. The green energy policy of Ethiopia and the solar VAT (15%) tax exemption policies are very encouraging. According to the institutions, the major challenges related to the solar irrigation pumps were related to lack of appropriate knowledge and skills both at the organizations and farmers level (37%). They mention that in many organizations engaged in solar irrigation there are no skillful experts, while the problem at smallholder farmers is very severe. The key informants also indicated that high level government officials have low level of awareness about the usefulness of solar irrigation technologies. Many farmers have also low level of understanding of the technological nature. About 25.9% and 22.2% of the institutions respectively report the problem of technology and finance/supply related to solar technology.

Solar pumping systems have high initial capital costs, which can be discouraging. The key informants also report problems related to security issues. The solar panels are one of the most theft-prone components of the system and it should be protected from theft as there are cases in which theft problems are observed. There are very few cases where the solar pumps malfunction as per the report of farmers, however, site selection and design defects are identified as the causes for the non-functional solar pumps in Sidama zones SNNPR, and Silte zones SNNPR. In case solar pump equipment is damaged, there are no local maintenance services provided or supported by the government as is the case for fuel pumps. Compared to solar pumps, fuel pumps have the advantage of low capital cost and profitability, and they are easy to use. However, the fuel supply may be expensive and unreliable in remote places (Excell, 1991). Thus, relatively high cost of initial investment; and lack of awareness are the major barriers for farmers to adopt solar pumps.

SUMMARY BOX

- ***Suppliers face severe challenges in obtaining foreign currency to import solar pumps***
- ***The import process is time consuming: 6 months up to more than a year***
- ***The result: no stock, few companies, little competition, sales mainly to projects, no farmer demand***
- ***View of the government: the problem is farmer awareness and technical capacity, not policies***

4. CURRENT DEMAND FOR SOLAR IRRIGATION SYSTEMS BY FARMERS

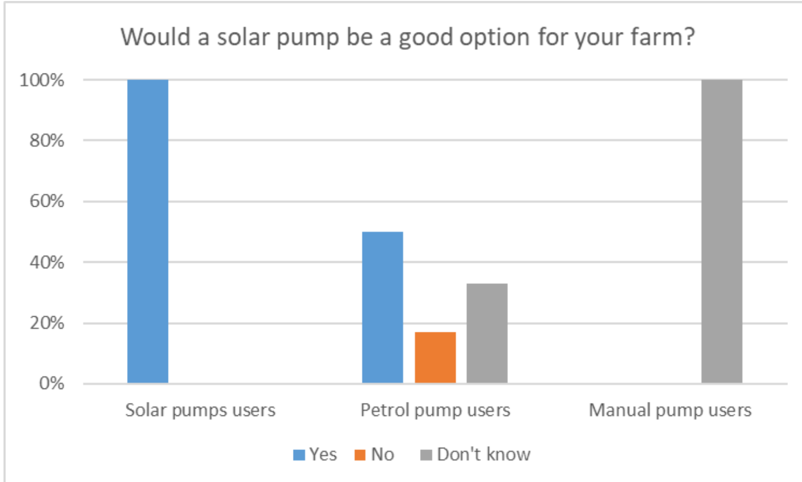
4.1 AWARENESS, INTEREST AND DEMAND PER FARMER TARGET GROUP

This chapter presents the outcome of combined in-depth interviews, field observations and cost benefit analyses with 15 farmers, visited in Oromia (2), SNNPR (9) and Amhara (4), and a phone interview with 1 farmer in Tigray. The interviewed farmers include 9 solar pump users (of which 4 also use a petrol pump), 6 petrol pump users and 1 rope pump user. All farmers interviewed are smallholders who operate less than 4 ha land. It has been particularly difficult to find farmers withdrawing water manually, whether through rope pumps, treadle pumps or buckets, as this is usually done in zones where no solar and/or petrol pumps are used. The popularity of manual pumps seems to be decreasing drastically due to the high labor effort. In Sankura woreda (Silti zone), 13 manual pumps were distributed to farmers in 2016, however within two years all pumps have been replaced by petrol pumps.

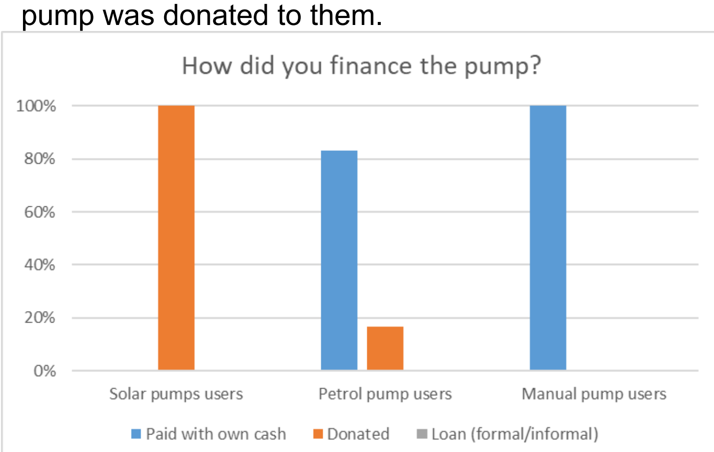
Identifying solar pump users has been a time consuming activity as well, due to the limited knowledge about these systems within the local government. In the end, the solar pump users interviewed concern mainly users of ATA systems, as well as other projects. As a result, 100% of the interviewed solar pump users indicated that they have started solar powered irrigation because they received support from a project. However, some suppliers mention, despite NGOs and government being their main clients, a limited number of direct sales to farmers is also happening.

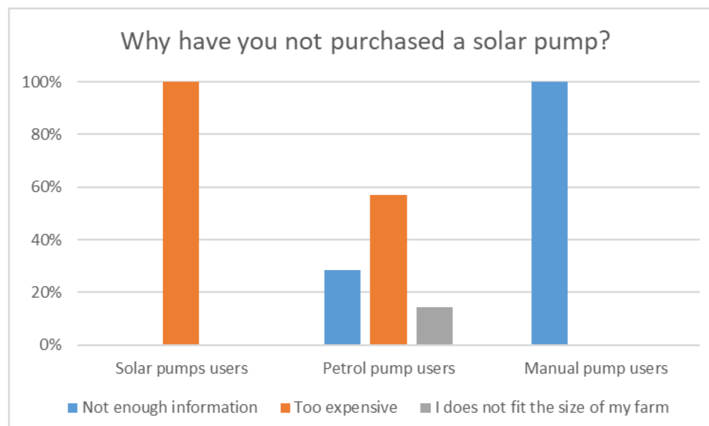
Overall, the awareness about solar pumps is high amongst the interviewed farmers. This is because only farmers living in kebeles with solar pumps have been interviewed. From the non-solar pump users, 2 out of 7 indicated they did not know about solar pumps, neither have they heard about it or seen it. The other farmers did know about it, which implies that demonstration farms could be a successful way to increase awareness.

The interest amongst farmers in solar pumps varies amongst the target groups. Nigussie et al. (2017) pointed out that the interest to invest in irrigation also varies within the household, however intra-household gender differences were beyond the scope of this study. From the solar pump users, all farmers mention that it is a good option for their farm. Petrol pump users are more divided: while 50% mentions it is a good option for their farm, 33% mentions they don’t have enough information, while 17% mentions that the capacity of solar pumps is not enough. The main reason for interest in solar pumps is because the fuel availability and high prices are challenging the farmers across all regions. Prices are on average 35 ETB (EUR 0.82) per liter, which is 65% higher than the official price. According to farmers, both national supply problems and local bureaucracies have contributed to scarcity of fuel and oil supply. The supply of fuel for pumps has been restricted legally and farmers require a written permission from the local authorities before receiving the allowed quota (less than 5 liters per farmer at a time). The scarcity and the increasing price of fuel has limited farmers’ production and technology use. Farmers indicating that a solar pump is not good for their farm explained that the pump discharge is too small for them.



Even though the government supports farmers by offering petrol pumps on credit or partly subsidized (based on the socio-economic status of a farmer), most petrol pumps have been purchased by farmers themselves (83% of the farmers in this study). All solar pump users on the contrary indicated that the pump was donated to them.





While asking farmers about their willingness to invest in solar pumps most farmers reported that the initial cost of buying a solar pump is not affordable. Farmers report that solar irrigation technologies, even though not available on market, are too expensive for farmers to purchase outright. Without subsidy or access to finance they would likely be unable to buy the pumps. In Ethiopia there are no subsidies for the energy sector including solar powered pumps. Yet, fuel is subsidized. Amongst petrol pumps users, 57% indicated they could not purchase a solar pump themselves due to the high cost, while others mentioned they did not have enough information, and that the pump does not fit the size of their farm.

To conclude, the interview results from smallholder farmers shows that the advantages of solar pumps for irrigation is acknowledged, but its high price is a major limiting factor in its adoption amongst the generally resource-poor farmers. It is recommended to consider the lessons learnt from previous research by Getacherl et al. (2013) and others about the willingness to invest in motorized and manual lifting devices in Ethiopia. According to this study, access to water and finance are amongst the main barriers. Generally, farmers have revealed that they are positive and willing to go for the solar pumps mainly because of the ever-increasing cost of diesel or petrol. Farmers rated solar pumps as successful as they save labor and stay longer without damage. Although there are technical challenges related to the capacity and relatively small flow of solar pumps, farmers generally found the solar pumps to be friendly and easy to use. Most of the interviewed farmers are aware of the benefits of solar irrigation systems, and would be willing to replace their fuel pumps, but could not afford the solar pumps price.

In terms of capacity, the solar pumps installed by ATA are designed to irrigate only a plot of 0.1ha, although it is assumed that its capacity could be stretched up to a larger size. Farmers suggest that the irrigation capacity shall be improved at least up to 0.5 ha; and 1 interviewed solar pump users has taken the initiative to expand his field. In fact, the research team estimates that 0.5 ha is the maximum irrigable surface for the ATA pumps in January (see Annex A), provided that a corresponding drip system is installed. In addition, the attitude of farmers towards water that is slowly delivered and applied by drip systems is fairly unfavorable. Many farmers think that the amount of water from drip systems in insufficient for the plants. This requires training and awareness raising about efficient use of water. A lower purchase cost and larger capacity of solar pumps are mentioned as the main conditions for increased farmer demand.

SUMMARY BOX

- ***100% of the identified solar pumps have been donated***
- ***Most farmers are interested, but nobody would buy a solar pump***
- ***The high price is the main barrier, followed by the small capacity compared to fuel pumps***

4.2 COST BENEFIT ANALYSIS OF FUEL AND SOLAR-POWERED SYSTEMS

A cost benefit analysis to compare solar irrigation systems with fuel-powered systems depend on a number of factors, including initial capital costs, operational costs and durability. In rural areas where fuel is expensive or where reliable access to the electricity grid is lacking, solar can provide a relatively flexible and climate friendly alternative energy source (FAO, 2018). Solar pumps bypass typical fuel cost issues, have low maintenance costs and have proved reliable in the field. However, a key limitation is capacity; typically a solar-driven electric pump can only irrigate a plot of 0.3 to one hectare in size (Farm Africa, 2020). According to the IWMI (2018) and its analysis of potential gains and benefits, a direct purchase of solar pumps by farmers is feasible, as well as out-grower schemes and pump supplier finance options. In other studies, while the initial costs of installing solar pumps are higher as opposed to diesel pumping systems, it has been established that the use of solar energy systems in the long term translates to higher savings. However, this outcome highly depends on the cropping system and local market.

In a study conducted in Lorentz (2013) on the planned return on investment for solar systems Dadaab camps of Kenya, it was estimated that a daily saving of $ 54 per borehole would be delivered over a 20-year period if solar energy was used to power the pumping systems as opposed to the previous existing diesel powered systems. IDE Ethiopia evaluated that farmers using solar pumps saw increases in crop yield and reported the Sunflower Pump saved them $400 in the first year, compared to traditional diesel pumps. In South Sudan, it was calculated that over a period of 10 years the total costs are 10 times higher to install and run a diesel powered system as opposed to a solar powered system. Zegeye et al. (2017) found that the breakeven point between PV water pumping system and diesel pumping system is found to be less than four years.

Given the highly variable cost of fossil fuels, solar panels today offer farmers a source of renewable power for pumping water, without continuous out-of-pocket fuel expenses. Yet, the initial investment costs for setting up a solar-powered irrigation system are often prohibitive, typically between 8,500 and 13,500 EUR per ha (Farm Africa 2020). The operational and maintenance costs are relatively low at 45-90 EUR per hectare. It should be noted that private smallholder solar irrigation systems are often smaller than 0.25 ha because of the high investment cost. With the right selection of high-value crops and the right management mechanisms, solar irrigation could represent a good long-term investment (ibid). According to a study conducted by ATA (2018), the average cost (ETB/ha) and service life for solar pumps is 6,600 ETB/ha (154 EUR/ha) and 10 years respectively, yet considering the current high price level of solar pumps that are available on the Ethiopian market, an investment of 195,000 ETB/ha would be more realistic. Cost benefit analyses are highly dependent on the local economy, available technologies and prices. Therefore, this study includes a specific cost benefit analysis to compare solar pumps with fuel-powered pumps in Ethiopia.

Assumptions

Yield (kg/ha) is assumed not to be impacted by the selected pump technology. As explained by Schmitter et al. (2016): "The variability of water productivity between technology groups as well as within a group is very high as various factors (i.e. crop management, time of irrigation application, rainfall variability, fertilizer application method, inherent soil fertility) influence the overall productivity.

Most studies comparing solar and fuel-powered pumps are based on diesel pumps, see e.g. Agrawal and Jain (2015), KPMG and Shakti Foundation (2014), World Bank in Bangladesh (2015). Also, "subsidies for electricity and fuel affect the competitiveness of solar solutions in almost all of these cases" (FAO, 2018). In Ethiopia, the majority of fuel-powered pumps in Ethiopia are petrol pumps, and fuel is subsidized in Ethiopia. This study will focus on petrol, not diesel pumps.

The reported life span of regular 4-cylinder petrol irrigation pumps is 2-5 years (World Bank, 2011) or 3-5 years (IWMI, 2009). Diesel pumps have a life expectancy that is over twice as long (FAO 1986; IWMI 2009; Alves, et al 2014; Chris, et al., 2013; Hossain, et al 2015 Girma, et al 2015). Since the majority of fuel powered pumps in Ethiopia are petrol pumps, this study will focus on a comparison of solar pumps and petrol pumps. In the cost benefit analysis, an average life span of 5 years will be used for the petrol pumps. The 2-5 years' life span mentioned in the World Bank study results from West Africa, where the irrigation need is higher and pumps are used more frequently, which reduces the life span. An assessment by Yusuf and Zekarias (2019) covering 63 pump users showed an average of 5.68 service years for petrol pumps in Ethiopia[8]. This could be the result of improved technology since the studies mentioned above, or point at a better functioning maintenance network for petrol pumps in Ethiopia.

For solar irrigation pumps, an average lifespan of 15 years will be used, as this is mentioned in most literature as well as by suppliers. It should be noted that the life span of 15 years is based on usage of a pump in good quality water in a drilled well. If a pump needs to be replaced after 5 years, due to the high purchase cost this will drastically affect the results of the cost benefit analysis presented below.

A cost benefit analysis is based on the assumption that revenue is fully reinvested in the productive activity. Yet in reality, the re-invested part is usually less than 50% amongst smallholder farmers, as the rest is used for household expenses, social events, domestic investments, capital investments, construction of the house, etc. Hence, in reality the payback period of investments is larger than suggested by economic analyses.

[8] It should be noted that the average lifespan of petrol pumps by the interviewed farmers did not exceed five years, the majority failed in two to three years' time.

Methodology
This study applies two approaches for cost benefit analysis of the irrigation systems for solar and fuel based pumps. The first approach is to analyze costs and benefits of using either solar or fuel pumps for an ***ideal farm model***. In this case average costs can be estimated by multiplying the average quantity of inputs for production of crops by the average unit price paid for the inputs (seed, land, labor, chemicals etc.). The second approach is based on the ***actual farm model***. In the latter case, direct and opportunity costs invested by the farmer and income earned from sale of the crops was estimated from interview results. In this case the costs and revenues given are based on figures reported by farmers. In order to compare different technologies, this chapter focuses on the outcomes of the ideal farm models, showing the results for petrol pumps, Yasart solar pumps and Sunculture solar pumps. The outcomes of the actual farm models can be found in Annex B.

The cost-benefit analysis could provide evidence for decision makers about the financial consequence of investing in solar or fuel irrigation systems. The aim of this chapter is to compare the viability of solar water pumping systems and fuel water pumping systems. To assess the financial cost benefit of adopting solar irrigation pumps or fuel pumps, different indicators could be used. The gross margin, the net present value (NPV) and the payback period (PB) could be applied (FAO, 2018). These indicators are the important decision-making tools for investors, governments, donors and financial institutions. The higher the gross margin, the more cash a farm business gains from the sale of crops, after returning the production costs.

For calculation of costs and benefits the following formulas are used:

$$Total\ Revenue = Produce\ Price * Quantity\ sold$$

$$Total\ Variable\ Cost = Input + Land + Labour + O\&M\ cost$$

$$Margin = Total\ Revenue - Total\ Variable\ Cost - Interest\ Cost$$

$$Depreciation\ cost = \frac{Equipment\ cost - salvage\ value}{Useful\ life}$$

$$Net\ revenue = Margin - Depreciation\ cost$$

$$Payback\ period = \frac{Total\ Investment\ Cost}{(Margin\ x\ 2\ )}$$

Revenue analysis
The revenue from the use of solar irrigation system versus fuel based pumps was calculated for different vegetables in different regions. For the ideal farm model, assuming modest agronomic management, the prices of yields were estimated by using the average prices reported by farmers for regional markets. In addition, price and yield information was collected from interviewed farmers and from Central Statistics Agency (CSA, 2019).

Total Variable costs
Variable inputs, such as seed, fertilizer and pesticides, can generally be unambiguously attributed to the crop production process. The costs of land, labor and material inputs were estimated at actual costs incurred as reported by the farmer for the actual farms, while average market values such as the prices of inputs from input suppliers for the ideal farms. For estimating the quantity of inputs and outputs national data have been used as reported by Derso & Zeleke, A. (2015). The chemical costs such as fertilizer and pesticides were calculated based on the local prices. Accordingly, the average cost per hectare of

fertilizer and pesticide for an ***ideal farm*** was nearly 4,000 ETB (93 EUR) and 3,000 ETB (70 EUR) respectively.

Most of the land cultivated by farmers who received the solar pumps are owned by the farmers or freely leased to the farmers from kebele administrations (e.g. SNNPR Silte zone). In order to value the land at the local price, we estimated the value of rent for land at the particular local area as an opportunity cost. Accordingly, the cost of land per hectare ranges between 15,000 to 30,000 ETB (350-700 EUR) per hectare per annum. The opportunity cost of land varies by location and the average land cost per annum was 20,000 ETB (466 EUR) per hectare. The value of land in Oromia and SNNPR was less expensive compared to Amhara and Tigray regional states. The access to shallow groundwater is also included in the cost of land.

Labor costs for agricultural and irrigation practices are estimated based on local values as most farmers operate by their own labor. The average wage per day and labor costs per season per ha are 150 ETB and 18,000 ETB (3.5–425 EUR) respectively for an ideal farm, with a minimum and maximum of 14,250 ETB and 36,000 ETB (333-840 EUR) respectively. It is assumed that the labor requirement per hectare is equal for all pumping systems compared. Due to the relatively small flow of solar pumps compared to petrol pumps, the pumping time for solar pumps to deliver the same volume of water is much larger. Therefore, the assumption of equal labor input for irrigation is only valid if automated irrigation systems, such as drip kits or spray tubes are installed.

On the actual farms, the maintenance cost of fuel based pumps on average is 707.5 ETB (16.5 EUR) per production season, the minimum and maximum being 300 ETB (7 EUR) and 1,200 ETB (28 EUR) respectively. At least every year about 1,415 ETB (33 EUR) is invested to maintain the fuel based pumps, while there are practically no maintenance costs required for solar based pumps. When we predict the maintenance cost based on a 5 years' life span keeping prices constant, 7,075 ETB (163 EUR) is required for maintaining petrol pumps. In literature, an accepted practice in estimating maintenance costs for fuel pumps is to use a percentage of the initial cost of the unit as the annual cost. Following (Baranchuluun, et al, 2014, Frazier, 2017) we consider 6% for fuel pump equipment maintenance in our calculations, resulting in an annual maintenance cost of 1,200 ETB (28 EUR) for fuel pumps.

The availability and access to petrol by farmers in Ethiopia is a major challenge. Farmers have limited opportunity to buy petrol due to supply scarcity and government restrictions. Farmers must present a permission letter to the petrol supplies in order to purchase the petrol. Moreover, the price of diesel and petrol has increased from time to time. For instance, in Oromia the price fluctuates between 30 to 70 ETB (0.70-1.63 EUR) per liter seasonally. An average of 10,500 ETB (245 EUR) per season per hectare is used for the cost benefit analysis. The operation and maintenance activities necessary for the solar pump are estimated nearly nil. As seen from the result (Table 13 & 14), the total investment cost of solar systems is high when compared to fuel pumps, but the total variable cost is low due to fuel-free operation of solar PV systems.

Total Investment Cost
The total investment cost consists of equipment purchase and installation and the cost for digging or drilling a well. The investment costs were estimated at a one-hectare basis and then converted to smaller irrigated surfaces.
The estimated cost of digging a well as reported by farmers minimum 3,000 ETB (70 EUR) and maximum 10,000 ETB (233 EUR). The digging of the new wells was performed by the beneficiary farmer for the solar pumps installed by ATA. However, the quality of wells constructed is low because most of the wells are open, non-concreated, and vulnerable to damages. For the ideal farm business, we estimate that an investment of 10,000 ETB (233 EUR) is required for well construction.

For each pump the maximum irrigated surface was calculated based on the crop water requirement of an average vegetable field in Ziway and a TDH of 10m (see Annex A). The resulting maximum surface is 0.5 ha for a Yasart (ATA) pump and 0.32 ha for a SunCulture Kubwa pump. For areas larger than this, the purchase of an additional pump has been taken into account. The Yasart pump comes with a drip system of 0.1ha, therefore for larger areas the investment cost also includes the expansion of the drip system. The main comparative advantage of the fuel based pumps is its ability to irrigate up to 4 ha of land in a season, while the capacity of the existing solar pumps is used to irrigate less than 0.5 ha.

According to the information obtained from Yasart Engineering PLC, the overall purchase and installation cost of the solar irrigation pump donated to farmers by ATA ranges between 120,000 ETB and 150,000 ETB (2,800-3,500 EUR). This overall cost varies depending on the location of the farmers. The current market price for fuel pumps ranges between 15,000 to 20,000 ETB (350-466 EUR). However, many farmers have purchased the Robin and Koshin pumps at costs ranging from 8,500 to 12,000 ETB (200-280 EUR) depending on their location and time of purchase (most of them purchased more than two years ago). There are also other more low-cost solar pumps for piloting in Amhara Regional States; these are the Sunculture brands. According to information from one of the suppliers, these solar pumps have a larger irrigation capacity compared to those installed by Yasart Engineering PLC[9]. The Sunculture pumps range from 50,000 ETB (1,170 EUR) to 85,000 ETB depending on the type and accessories. The total investment cost, including purchase and installation costs, used for the analysis were 20,000 ETB for petrol pumps, 150,000 ETB for Yasart pump and 65,000 ETB for Sunculture Kubwa pumps.

Depreciation Cost
The deprecation is calculated by the straight line method (VCC, 2013), assuming the salvage value, or remaining value, to be zero at the end of the useful life. As explained above, in this study we take a 15 life span for solar pump and wells, and a 5 years' lifespan for petrol pumps.

Interest Cost
We have considered that the purchase of solar or fuel pumps have been carried out through a loan from a bank or micro finance institutions (MFIs). The average fixed interest rate is 12% per annum (Tarozzi, et al, 2006). An average loan period of three years has been assumed to calculate the average interest cost per season.

The payback period (PB) is the expected number of years it will take for an entrepreneur to recoup the *cash* it invested in a project (FAO, 2018). The cash flow is represented by the margin per season, which is equal to the total revenue, minus the total variable cost and interest cost. The depreciation cost is excluded since it does not represent a cash expenditure. The payback period in years is based on the assumption of two seasons per year. It expresses the profitability of the investment in terms of time. Between two alternative irrigation systems, the investor is likely to choose the one with the shorter payback period.

The net present value (NPV) of an investment is the present value of expected future net cash flows, discounted at the cost of capital, less the initial outlay. The NPV is defined as the aggregated net incremental benefit over the project's lifetime. The formula for calculating the NPV (Hussain & Bhattarai, 2005) is

$$NPV = \sum_{t=0}^{T} \frac{R_t - C_t}{(1+r)^t}$$

[99] This is correct if it is compared with the currently installed drip system of 0.1 ha. However, the capacity of the pump itself is estimated to be larger for the Yasart (ATA) pump.

Where, NPV is Net Present Value, R_t $revenue\ in\ each\ year$ C_t costs in each year, t = number of year, r = discount or interest rate

The discount rate r shows the level of interest rate that if the irrigation pump is not purchased and the farmer would earn 8% return on its deposited capital. This is the average interest rate for depositing the money in the bank (NBE, 2018). Whenever the NPV is positive (NPV > 0), the investment is considered worthwhile or profitable (FAO, 2018).

Results ideal farm model

Table 12 presents the cost benefit analysis for using fuel pumps in an ideal farm. The result shows that all crops except maize have a high gross margin and positive NPVs. The average pay-back period for fuel pumps for 1ha, 0.4ha & 0.1ha, and respectively are 0.2, 0.5 and 2.2 years. The ideal farm model shows a very robust rate of return for fuel irrigation pumps except for maize which is very risky.

Table 12 Cost benefit analysis of an ideal farm when fuel pumps are used

	Per 1 hectare per season						Per 0.1 ha		Per 0.4 ha		Per 1 ha	
Crop	***Total Variable Cost***	***Total Invest Cost***	***Total revenue***	***Net revenue***	***Margin***	***Pay back (year)***	***Margin***	***PB (y)***	***Margin***	***PB (y)***	***NPV***	***IRR***
Onion	61,600	30,000	150,000	85,267	87,600	0.2	8,040	1.9	34,560	0.4	275,712	130%
Maize	45,800	30,000	42,000	-6933	-4600	n.a.	-1,180	n.a.	-2,320	n.a.	-76,616	n.a.
Tomato	50,360	30,000	135,000	81,507	83,840	0.2	7,664	2.0	33,056	0.5	271,939	151%
Cabbage	50,210	30,000	100,000	46,657	48,990	0.3	4,179	3.6	19,116	0.8	132,943	83%
Garlic	57,550	30,000	144,000	83,317	85,650	0.2	7,845	1.9	33,780	0.4	271,976	135%
Potato	50,200	30,000	121,500	68,167	70,500	0.2	6,330	2.4	27,720	0.5	254,826	126%
Avocado	75,820	30,000	200,000	121,047	123,380	0.1	11,618	1.3	48,872	0.3	404,351	152%
Average[10]	**55,934**	**30,000**	**127,500**	**68,432**	**70,766**	**0.2**	**6,357**	**2.2**	**27,826**	**0.5**	**877,217**	**130%**

Table 13 shows the cost benefit analysis of Yasart solar pump systems for the ideal farms. If Yasart pumps were used the payback period ranges from 1.9 to over 35 years depending on the crop and irrigated area. The current installed Yasart solar pump systems cover 0.1ha and therefore result in extremely long payback periods. However, if the irrigated area is expanded to a capacity of 0.4 ha, the average pay-back period will drop to 3.8 years.

[10] To calculate the average pay-back period, maize has been excluded in all ideal farm models due to the negative or very low margin.

Table 13 Cost benefit analysis of an ideal farm when Yasart solar irrigation pump used

	Per 1 hectare per season						For 0.1 ha		For 0.4 ha		
Crops	***Total Variable Cost***	***Total Invest Cost***	***Total revenue***	***Net revenue***	***Margin***	***Pay back (year)***	***Margin***	***PB (y)***	***Margin***	***PB (y)***	***NPV (1ha)***
Onion	49,900	442,000	150,000	59,287	82,820	2.7	4,010	20.0	32,060	3.3	416,750
Maize	34,100	442,000	42,000	-32913	-9380	n.a.	-5210	n.a.	-4820	n.a.	-356634
Tomato	38,660	442,000	135,000	55,527	79,060	2.8	3,634	22.0	30,556	3.4	395,806
Cabbage	38,510	442,000	100,000	20,677	44,210	5.0	149	536.9	16,616	6.3	104,739
Garlic	45,850	442,000	144,000	57,337	80,870	2.7	3,815	21.0	31,280	3.3	400,176
Potato	38,500	442,000	121,500	42,187	65,720	3.4	2,300	34.8	25,220	4.2	281,783
Avocado	64,120	442,000	200,000	95,067	118,600	1.9	7,588	10.5	46,372	2.3	813,721
Average	**44,234**	**442,000**	**127,500**	**42,452**	**65,986**	**3.1**	**2,327**	**108**	**25,326**	**3.8**	**293,763**

Annex B presents the ideal farm cost benefit analysis for the Sunculture Kubwa solar pump. The average payback period was 1.2 years, for 1 ha; 1.4 years for 0.32 ha and 4.9 for 0.1 ha. The lower pay back periods imply that an investment in Sunculture pumps provides a higher return than the Yasart (ATA) pumps, because of the lower investment cost. However, it should be noted that the Yasart system includes a drip irrigation system, whereas the Sunculture system does not. In a 1-hectare system, the cost of the drip system represents 30% of the total investment cost. In fact, a solar pump without irrigation system will incur a very high labor requirement, hence reducing the profitability of the solution. Therefore, to compare different options, the complete solution needs to be considered.

Due to the difference in capacity, each pump has an optimal irrigated surface under which the profit margin is the highest and the payback term the shortest. Therefore, the irrigated area needs to be taken into account when comparing different pump systems. In Figure 8 the payback period is shown for a petrol pump, Sunculture pump and Yasart pump with and without drip system. In this figure it is assumed that once the maximum capacity of the pump is exceeded, an additional pump needs to be purchased. The results show the need for optimized systems when investing in solar-powered irrigation pumps.

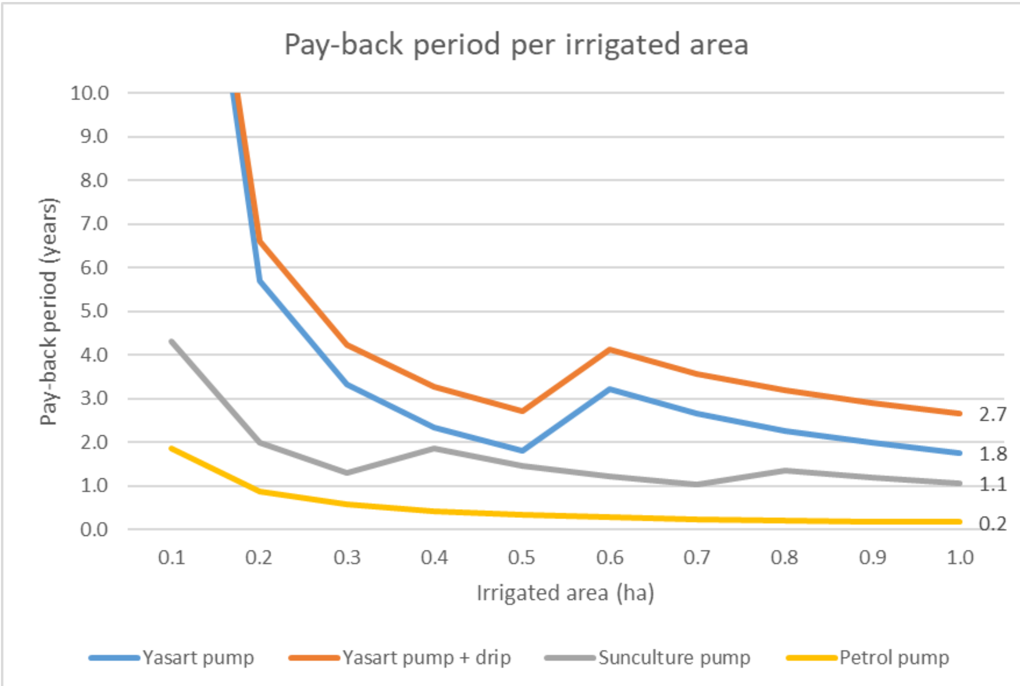


Figure 8 Payback period per pump per irrigated area of onions. Values shown for Yasart and Sunculture pumps without water application system are featured by a much higher labor requirement, the cost of which is not included in this cost benefit analysis.

Results actual farms

The tables in Annex B show the results of the cost benefit analysis for the 15 smallholder farmers interviewed. The results show the high risk and volatility of the horticultural market, with payback terms for the same solar pump (Yasart) ranging from 0.5 years for a farmer growing onions in Tigray, to 38 years for a farming producing cabbage in SNNPR. The variety and risk is even larger for fuel pump producers, as two out of seven farmers spent more on inputs and fuel than they received when selling their produce. On the other, the other five petrol pump users showed very high profit margins and a payback term of less than one season (0.1 year on average), because of the large irrigated area per pump (on average 1 ha).

Conclusions

First of all, the high risks in horticultural production imply that the selection of high-value crops and agronomic practices are critical for the investment of solar irrigation systems to be profitable. Comparing the solar and fuel-powered systems of the interviewed farmers, using fuel pumps is more profitable than solar pumps because of the large area that can be irrigated, but also riskier due to the higher variable costs. The results of the ideal farm models per pump type also show that an investment in petrol pumps can be paid back in a much shorter time (0.2 years) compared to a one hectare optimized solar-powered system with drip irrigation (3.1 years). Solar-powered irrigation systems that are not used to its full capacity are featured by much longer payback terms. The figures for solar pumps may change in the future, since prices of solar pumps are expected to decrease when the market in Ethiopia is further developed. The high investment cost at the moment (3 to 10 times higher than petrol pumps) and the smaller capacity make it more attractive to invest in petrol pumps from a financial perspective, considering equal contexts. In a context of deeper groundwater, low yielding wells or multiple use systems however, the use of petrol pumps is more complicated or even impossible. Therefore, instead of using general cost benefit analysis, the choice of a petrol or solar pump need to be made based on the local farm conditions.

SUMMARY BOX

- ***Average payback time for solar-powered irrigation is 3 years for optimized systems***
- ***Profitability highly depends on crop choice and irrigated area per pump***
- ***At the current price level, investment in petrol pump irrigation is more profitable***
- ***Actual farm economics can be very different from ideal farm models***

4.3 CRITERIA FOR INCREASED FARMER DEMAND

"Solar pumps are very good if not too expensive and small in capacity"

This quote from a solar pump user illustrates the righteous feedback from farmers who have used or seen solar pumps in action. Solar pumps have an investment cost that is at least 4 times larger than petrol pumps, for a discharge that is 4-5 times lower[11]. This makes it critical to design, demonstrate and supply systems that optimize output and reduce costs. Optimizing and adjusting solutions to a specific farming context requires a good understanding about the complete solar powered irrigation system at both the supplier, government and farmer level.

Technical capacity and knowledge

Both the interviewed institutions and companies agree that there is a low level of understanding about solar pumps amongst the government officials and experts involved in solar irrigation projects. As a result, the design and implementation of solar irrigation systems is featured by many challenges. It was reported that the site selection process of major demonstrations projects was poor, as the company did not receive the exact locations for the installations and there was no reliable baseline study done. According to one company, approximately 60% of the selected sites were not appropriate for solar irrigation, which resulted in a lengthy adjustment process. In another project, it was mentioned that water shortages in the dry season led to limited use of the installed solar pumps. In some woredas the drip systems were not installed yet, while in Hawassa Zuria one water tanker has fallen down and completely broken due to the flooded wooden frame supporting the tank. On two other farms the irrigated production was interrupted by inundations, and due to deepening water tables some solar pumps failed to pump water into the tank. It is unknown if this is caused by the pump capacity or wrong installation of the pump. Other farmers observed a reduction of pump discharges without any sign of water level changes. Solar pump suppliers indicated they would like to be involved more in the site selection and validation of the systems to be installed, in order to improve the functionality and durability of the systems.

An important issue observed by farmers and the research team, is the design of demonstrated solar irrigation systems. Most farmers reported that the solar pump is too small for their farm. However, following field observations and pump discharge estimations on a farm, the research team found that under the observed conditions a pump could be used to irrigate 0.5 ha of vegetables during the dry season. Nevertheless, the installed drip system covered a mere 0.1 ha. One farmer in Tigray using the ATA system reported he had added one valve himself, which allowed him to double the area to be irrigated by the existing drip system. Hence, the pump has sufficient capacity but due to the small drip system most farmers perceive the pump as a technology that is not powerful. While demonstration is the purpose of the ATA sites, the installation of relatively expensive systems with a very small irrigation area does not help promotion, as it provides a poor reputation of solar pumping technology amongst farmers.

[11] Based on comparing the Sunculture Kubwa pump (1520€, 1/3 ha) with an average petrol pump (350€, 1,5 ha).

Technical package

In order to increase demand amongst farmers, the promoted technology needs to meet the conditions of the targeted farming systems. This starts at the capacity of the water source, which should be sufficient to sustain the capacity of the installed pumping system. If due to a limited aquifer yield a solar pump only delivers a small quantity of water, this may affect the perception on solar irrigation technology. The ATA is making an important contribution by establishing manual drilling service providers in the woredas where shallow groundwater was mapped (see chapter 5.1). Manually drilled boreholes allow farmers to get access to slightly deeper groundwater that cannot be accessed by hand-dug wells or by fuel powered pumps. In areas with groundwater beyond suction depth, solar pumps could be welcomed by farmers as a way to start irrigating where this was previously not possible.

Suppliers mention that when solar pumps are demonstrated within irrigation systems that are equal to fuel powered systems, farmers are unhappy about the quantity of water coming from the pump. Hence, it is important to make a difference by combining solar pumps with access to groundwater, as well as efficient application technologies like drip, spray, or other automated systems. Especially the suppliers mention that farmers should be supported with appropriate crop choices and irrigation alternatives. The use of automated and efficient water application systems will increase the irrigated area per system and reduce the need for labor. In this way, solar pumping is not just about saving fuel, but also labor costs, which is an element that farmers appreciated the most about solar pumps. As farmers in Hawassa Zuria put it: “the best feature of drip irrigated solar systems is their simplicity (only closing and opening) for operation; being free of physical engagement while irrigating which in turn eliminated the tiresome jobs; and being free of any operational costs such as fuel, labor, and maintenances.” However, similar or even larger labor reductions can be achieved when combining efficient application systems with fuel pumps, although due to the large areas this incurs relatively high investment costs. If on the contrary, solar pumps are installed with conventional furrow systems or hosepipes, a farmer will need to spend the full day irrigating a small piece of land. Again, un-adapted systems in which a fuel pump is simply replaced by a solar pump, will lead to a decline rather than increase in farmers’ demand.

Showcasing and information

The appreciation of solar pumps and modern application systems takes time, especially when farmers are used to see large discharges of water from diesel pumps. In that case, demonstration, information and joint evaluation sessions with farmers are crucial in order to show that efficient application systems can effectively increase yields and reduce operational costs.

Providing clear and simple information about solar pump is also key to increase farmers demand, however difficult. Most farmers are familiar with petrol pumps and know about the capacity they need in order to cover a given field of crops. Since such experience and references are lacking for solar pumps, farmers rely on the suppliers and the government to inform them about the technologies that work for them. Designing an optimal solar powered irrigation system is challenging as a lot of variables come in: different pump brands, models, number of panels, water needs depending on the crops, season and soil type amongst others, as well the water source, depth, the elevation and the selected water application system. Various suppliers and organizations have developed tools that allow extension workers and suppliers to provide a customized advice to farmers. The challenge however is to adjust such tools to the particular Ethiopian farming system and make it accessible through an understandable format.

Functional supply and services chains

Increased demand resulting from demonstrations can be monitored through increased sales. For the moment however, neither farmers nor supporting organizations can buy a demonstrated solar pump yet, as the supplier only imported the exact number of pumps that was ordered by ATA. Hence, technologies are demonstrated while there is no supply chain in place. Demonstration projects without stimulating demand and building local supply chains happens in various projects. One enterprise that sold pumps to a demonstration project even indicated that the price of the pump was a secret. The absence of a supply chain also implies there is no service network to do reparations and maintenance. However, one enterprise mentioned that the government should also play a role in securing operation and maintenance: "in many parts of Ethiopia many of the solar water supply systems failed after installation due to lack of proper assessment and regulatory services to provide maintenance sustainably".

Finance

IWMI developed three business models for solar irrigation development in Ethiopia: i). Individual farmers buying solar pumps for their own use, with micro-financing. ii). An out-grower or insurance scheme model, using commercial loans or micro-finance (applicable to agro-companies, particularly out-grower schemes with contracted farmers, that may be interested in investing in solar irrigation pumps) iii). A supplier model with micro-financing or commercial.

As shown in chapter 4.1, the high price of solar irrigation equipment impedes most farmers to purchase solar pumps using their own resources, which highlights the need for finance solutions. In Ethiopia, the major sources of finance for rural populations come from microfinance institutions (MFIs) that lend money to the poor in the absence of fixed assists as a collateral, particularly as group lending. The solar pump is a capital-intensive technology. Thus, the role of financing is imperative to enable the large-scale adoption of solar pumps. The regional MFIs provide could provide loans for smallholder farmers, however the loan ranges available to smallholder and commercial farmers could not cover the high purchase costs of solar irrigation pumps.

The regional MFIs are involved in providing loans to energy companies and farmers from the Development Bank of Ethiopia (DBE). Most MFIs have no issue with mobilizing loanable funds for renewable energy, but the lack of off-grid solar product supply in the market makes the demand for loans lower than anticipated (USAID, 2019). Hence, there is a mechanism for targeting smallholder farmers to access credit for the purchase of solar irrigation equipment, but the availability and supply of relatively low-cost solar irrigation equipment is required. This problem could be solved by availing a similar mechanism as the World Bank renewable energy funds, which currently enable MFIs to provide loans for globally certified lighting products through the Development Bank of Ethiopia. Many of the regional MFIs currently underutilize this fund to provide credit services to farmers.

In addition to the regional MFIs, Rural Saving and Credit Cooperatives (RUSACOS) provide credit solutions to smallholder farmers in rural areas of Ethiopia. According to the key informants during data collection RUSACOs financial solution is preferable to smallholder farmers because of their low level of loan interest rates (less than 12%, usually 9%). The annual interest rates of MFIs for loan varies between 15% to 19% depending the type of business and collateral available by the borrower. Repayment periods are generally for one to three years. The borrowers can use the loans as they wish, with the only condition that the amount obtained be employed for income-generating activities.

Table 14 Loan characteristics of MFIs in Ethiopia

	Loan size					
Regional MCIs	**Smallholder farmers (<25 ha)[12]**	**Commercial farmers (> 25ha)**	**Private companies (solar suppliers)**	**Payback period**	**Loan interest rates**	**Collateral**
Dedebit Credit and Saving Institution (S.C.) (DECSI) Tigray	6,000	5,000-30,000	200,000 to 1.2 million ETB	1-3 years	17% for farmers and 14% for suppliers	Land certificate& Group liability for farmers. Building /house for suppliers
Amhara Credit and Saving Institution (S.C.) (ACSI), Amhara	5,000	20,000-70,000		1-3 years	17% - 19%	Business plan, its feasibility and success prospects, land certificate , Group collateral for organized farmers (3-7 members)
Omo Micro-Finance Institution (S.C.) (OMFI)	Depends on business plan & collateral	Depends on business plan & collateral	Depends on business plan & collateral	One year	15-17%	The profitability of the business, Land tenure/ certificate, building and machinery
Oromia Credit and Saving Share Company (OCSSCO)	Up to 5,000 for private and 15,000 for groups	15,000	Depends on business plan & collateral	1-3 years	17%	Land tenure/ certificate, building and machinery

The study by IWMI (2018) mentions that further analyses is needed on the market-based, supplier-managed financing mechanisms in the Ethiopian context. Supplier managed finance solutions could potentially reduce bureaucracy, interest rates and payment default, as well as increase service levels by the suppliers. Yet, most suppliers indicate they cannot afford selling solar pumps on credit as long as the foreign currency issue is not solved. The same suppliers do offer credit and payback solutions for solar lighting products, which are featured by a much lower cost, but using the same mechanism for selling solar pumps is considered too risk. The Smallholder Solar Pump Alliance is an exception, as they are currently developing financing models for Sunculture small irrigation pumps[13] in Amhara.

According to IWMI (2018), a number of public and donor institutions plan to provide support for solar pump irrigation projects in the coming years in Ethiopia. For the 2016/2017 budget year, the Rural Electrification Fund includes renewable energy interventions, including solar power. The anticipated cost of the plan for 2016/2017 is ETB 1.6 billion (or approximately USD 70,645,000). 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 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 (IWMI, 2018). The development bank of Ethiopia is in charge of providing agricultural loans

[12] While 25ha is the limit, the average landholding of smallholder farmers is only 2 ha per farmer. The smallholders account for more than 95% of the farmers in Ethiopia.
[13] https://p4gpartnerships.org/partnership/smallholder-solar-pump-alliance

SUMMARY BOX

- ***Demonstrated technical packages need optimization to gain farmers' interest***
- ***Demonstration needs to be combined with promotion and supply chain development***
- ***Current financial products available for smallholder farmers cannot cover solar pump costs***

5. POTENTIAL DEMAND AND OPPORTUNITIES

5.1 FARMER-LED IRRIGATION – A GROWTH MARKET

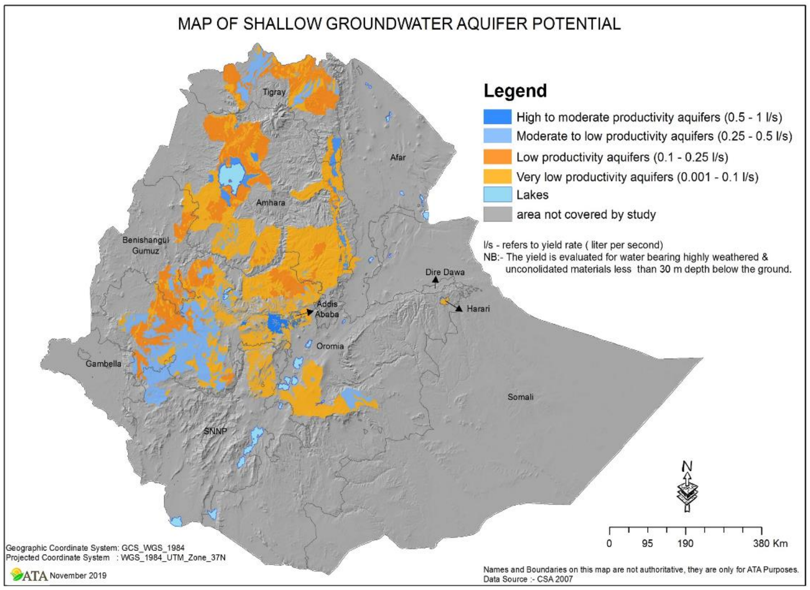
Traditionally, investments in irrigation have focussed on large-scale systems. This is reflected in statistics of countries, in which large-scale systems are usually present, but smallholder agriculture is underreported. Farmer-led irrigation development (FLID) is a concept that focusses on smallholder farmers, alone or as a collective, that drive irrigation development - meaning the establishment, improvement or expansion of irrigated agriculture by acquiring the necessary irrigation technologies and skills, and developing output markets. Many actors, including the World Bank and IWMI, recognise the importance of FLID in increasing productivity and enhancing food security. Supporting FLID starts with a thorough, local understanding of the extent and potential for farmer-led irrigation, and many actors are actively involved in supporting country-level diagnostics of farmer-led irrigation extent and potential for upscaling. In Ethiopia, farmer-led irrigation exists, but the extent is not well known. This chapter aims to assess the current extent of farmer-led irrigation in Ethiopia and the opportunities for growth through solar irrigation development. The approach starts with a detailed study of the IWMI (2018) methodology and the available ATA shallow groundwater mapping as requested in the Terms of Reference. Next to this, Practica Foundation has realised a complementary study, with the aim to generate quantitative insights on the potential market and high potential zones for solar irrigation development. This study consists of mapping the current irrigated area, re-mapping the suitability for solar irrigation, and combining these to identify high potential zones for supporting solar irrigation development. A separate report of the study including a detailed methodology and results section is available on request.

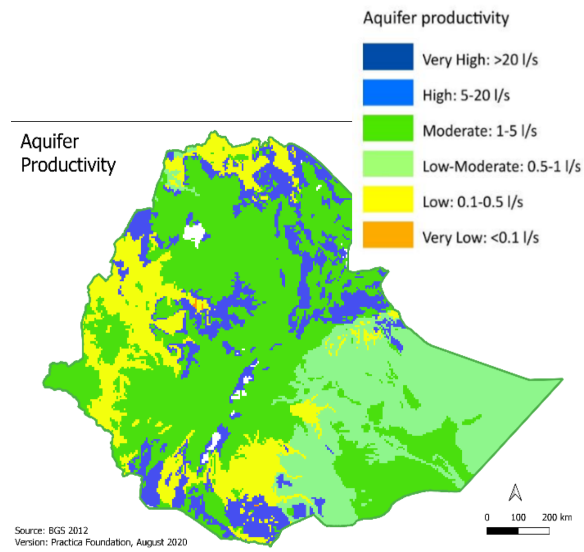
5.2 COMPARISON OF IWMI AND ATA GROUNDWATER DATA

The groundwater depth, productivity and storage data used for the suitability maps by IWMI (2018) are based on the groundwater maps produced by the British Geological Survey (BGS) and described in MacDonald et al. (2012). The study has produced three maps: groundwater productivity, storage and depth. The maps show information at a continental or regional scale in order to be used at a nominal scale of approximately 1:20 m. The data to determine transmissivity, a major indicator for groundwater productivity, was drawn from existing borehole data.

The ATA maps are based on the shallow groundwater mapping project described in ATA (2019). In 2013, ATA, with financial support from AGP and in collaboration with Radar Technologies International (RTI) and Addis Ababa University (AAU) started a mapping project to identify the potential of irrigation using shallow groundwater up to 30 meters' depth. In the first phase 32,400 km² were mapped in 89 woredas making use of WATEX radar technology. As from 2016 the results were calibrated by AAU, pointing out the availability of 3 million m³ of shallow groundwater, allowing for 100,000 ha of irrigated land. Water quality was also tested for bacteriological and physical contaminations. The study showed that in 90% of the pilot areas the shallow groundwater quality was suitable for irrigation purposes (ATA, 2019). After this, ATA has worked with iDE to train service providers on manual well drilling. In the selected areas over 90 wells have been drilled, and local businesses have been trained and licensed to provide ongoing services to farmers. The results show that 85-90% of the drilled wells provided proper shallow groundwater for irrigation. ATA mentions that sufficient yield for household irrigation of 0.4-0.5 ha is obtained when 0.1-1 l/s can be withdrawn.

The ATA and BGS maps show a remarkable difference (factor 10 to 20) in terms of groundwater productivity. Areas classified as high to moderate productive aquifers, such as the Fogera and Dembia floodplains, are reported by ATA to have a yield of 0.5 – 1 L/s, whereas the BGS indicates a yield of 5-20 L/s for the same area and classification (high productivity).





ATA explains that the difference originates from significant differences in scale, coverage and water depth. The BGS maps show that the water depth in the area that overlaps with the ATA mapped areas is between 0-50 meters. Unfortunately, the depth of the boreholes used by MacDonald et al. (2012) to determine the transmissivity is not described. A request for clarification sent to the authors of the article has not been answered. This makes it difficult to compare the BGS data to the ATA map, which has a clearly defined focus on shallow groundwater between 0 and 30 meters' depth. Nevertheless, the large difference and potential impact of the low aquifer productivity reported by ATA merit further research, e.g. by implementing pump tests on the developed wells and boreholes. Boreholes constructed for communal hand pumps used for drinking water are generally rejected if producing less than 0.28 l/s (1 m^3/h). IWMI (2018) considers an aquifer productivity below 0.1 l/s as unsuitable for solar irrigation development. This is in line with the ATA, which also mentions that 0.1 – 1 l/s is sufficient yield for a household irrigation system of 0.4- 0.5 ha[14]. If a farmer is to grow vegetables in the dry season from November to February, the peak demand in January is 3.8 mm/day, which implies that a maximum of 0.06 ha can be irrigated when pumping at 0.1 L/s[15]. If indeed a yield of 0.1 l/s is taken as a threshold for solar irrigation suitability, substituting the BGS data by the ATA map would imply that large areas in Amhara, Oromia and northern SNNPR are unsuitable for solar irrigation development (see light orange area in ATA map above).

Nevertheless, Gowing et al. (2020) argue that the potential of using shallow groundwater to expand the irrigated area in Ethiopia is considered to be very large. Based on field work in North West Ethiopia, they

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[14] Source: email correspondence with Dr. Kebede Teshome, Phd. Director Irrigation and Drainage, Production and Productivity at ATA.

[15] See table XX for water need estimation based on http://www.fao.org/aquastat/en/climate-info-tool/ resulting in a peak demand of 3.8 mm/day in January when growing vegetables in Ziway from November to February. Table XX shows that when a drip system is used, the pumping need is equal to 36 m^3/ha/day. This is equivalent to 1.66 l/s for one hectare based on 6 peak sun hours. Hence, a yield of 0.1 l/s allow to irrigate 0.1/1.66 = 0.06 ha per well.

write that: “We conclude that arguments previously put forward against the promotion of shallow groundwater use for agriculture in SSA appear exaggerated. Our analysis challenges the view that shallow aquifers are unproductive and that irrigation will have unacceptable impacts on wetlands and other groundwater-dependent ecosystems. We believe lessons from this case study are transferable, and there is a case for arguing that shallow groundwater represents a neglected opportunity for promoting sustainable small-scale irrigated agriculture in sub-Saharan Africa.”
Yet, this conclusion needs to be validated locally and during the irrigation season, as the results of well tests reported in the same study show that the seasonality of available groundwater is large. While well yields of 1 l/s are achievable at the end of the wet season, the mean yield in the dry season is a mere 0.07 l/s (ibid). This means that the potential size of a second irrigated crop cycle is reduced drastically, which has a large impact on the cost benefit analyses presented above.

To take into account the potential limits of aquifer yield on the maximum irrigated area per well, the ATA map has been used as a third layer to determine the selection of high potential zones for solar irrigation development (see chapter 5.5).

5.3 CURRENT IRRIGATED AREA MAPPING

A number of maps exist that show the extent of irrigated area in Ethiopia. Examples are AQUAMAPS (FAO, 10km resolution), WAPOR (FAO, 100m resolution), and IWMI (10km resolution). An important issue of the current maps is that they have a low resolution, which causes them to miss the farmer-led irrigation segment. The FAO also offers a number of 30m resolution layers but only in limited areas, and not yet with an irrigated area classification. In the past years, a number of tools have come available that allow the analysis to take place at a higher resolution. Notably, the recent availability of high-resolution (10m) Sentinel-2 data, combined with the computational processing power of Google Earth Engine, have opened up a new world of possibilities. A recent PhD study by Vogels (2019) that focused on the Great Rift Valley of Ethiopia, shows that it is possible to identify and map small-scale irrigation for areas smaller than 1 hectare. In this way, the extent of Farmer Led Irrigation Development (FLID) can be determined more accurately.

Methodology

The method used in this report focusses on the identification of current FLID areas during the off-season cropping period in Ethiopia. It is a combination of analysis of high-resolution remote sensing data and ground truthing data. Machine learning classification is used to distinguish between irrigated land and other land uses. To identify irrigated areas, we make use of the known patterns of rainfall and the growing season. One of the complications in the case of Ethiopia is the variation in rainfall patterns across the country, as displayed in the image below[16]. Irrigation takes place at multiple times: both to prolong the growing season at the end of the rainy season, but also in the dryer months. This difference in irrigation periods can be an issue during classification, especially in the case where irrigation in the dry season is compared to riverine vegetation that can also be abundant in the same period. As our period of analysis, we choose October 2018 until June 2019, thus capturing the end of the rainy season, the dry season, and the start of the next rainy season.

The summarised steps used for the analysis were:

1. Use Sentinel-2 Top-Of-Atmosphere reflectance imagery to create a dry season (December - March) mosaic, followed by the creation of monthly mosaic images for EVI and NDWI indexes.

[16] Kidanewold, Belete & Seleshi, Yilma & Melesse, Assefa. (2014). Surface Water and Groundwater Resources of Ethiopia: Potentials and Challenges of Water Resources Development. 10.1007/978-3-319-02720-3_6.

2. Include pair-wise differences between consecutive monthly values to show changes from month to month.
3. Use the GLCM method to capture spatial structure and texture in the vicinity of pixels, to differentiate between agricultural and natural vegetation. Altogether, 26 bands were used for classification.
4. Pre-processing: smoothen images to reduce noise.
5. Identify irrigated areas by using an application built in Google Earth Engine that displays EVI and NDWI at a certain location. In this way, manual inspection of both high-resolution imagery can be combined with inspecting the EVI and NDWI curves at a single location.
6. Training and validation of data. In total, 4947 points were identified in Ethiopia, of which 1984 were irrigated areas, and 2963 were non-irrigated areas. Care was taken to cover the different climate zones with training points. The training data was split in two parts: 70% was used to train the machine learning model, and 30% was used for validation.
7. Machine learning: use of Random Forest model to classify the image in Google Earth Engine.
8. Computation of results at a 30m resolution.
9. Postprocessing the classification result to remove noise.

Results actual irrigated area mapping

To assess the quality of a classification, the validation part (30%) of the training data is used. This data has never seen by the model, so it is a fair assessment of the accuracy. Overall, the classification result for Ethiopia is good, with an overall accuracy of 95.5%. The next figures show the result of the actual classification and including the post processing, for irrigated areas near lake Basaka and near Ziway. A total irrigated area of 1,373,000 ha was found for Ethiopia.

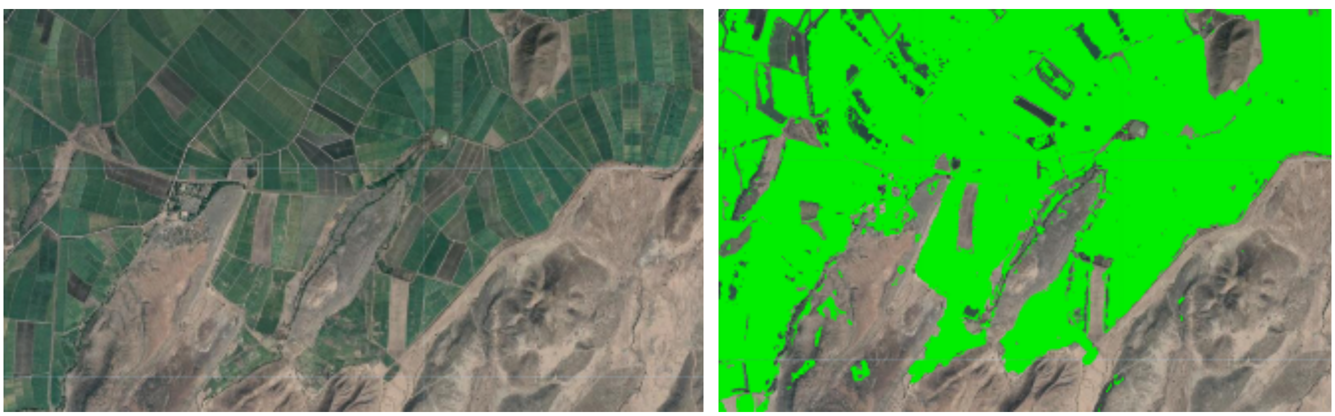

Figure 10 Satellite image near Lake Basaka

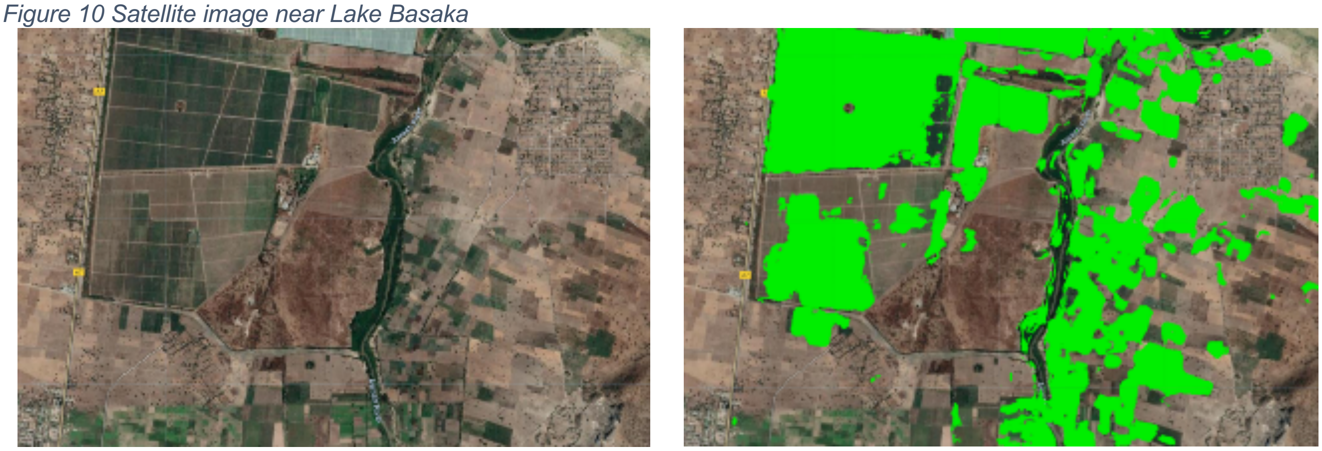

Figure 11 Satellite image near Lake Ziway

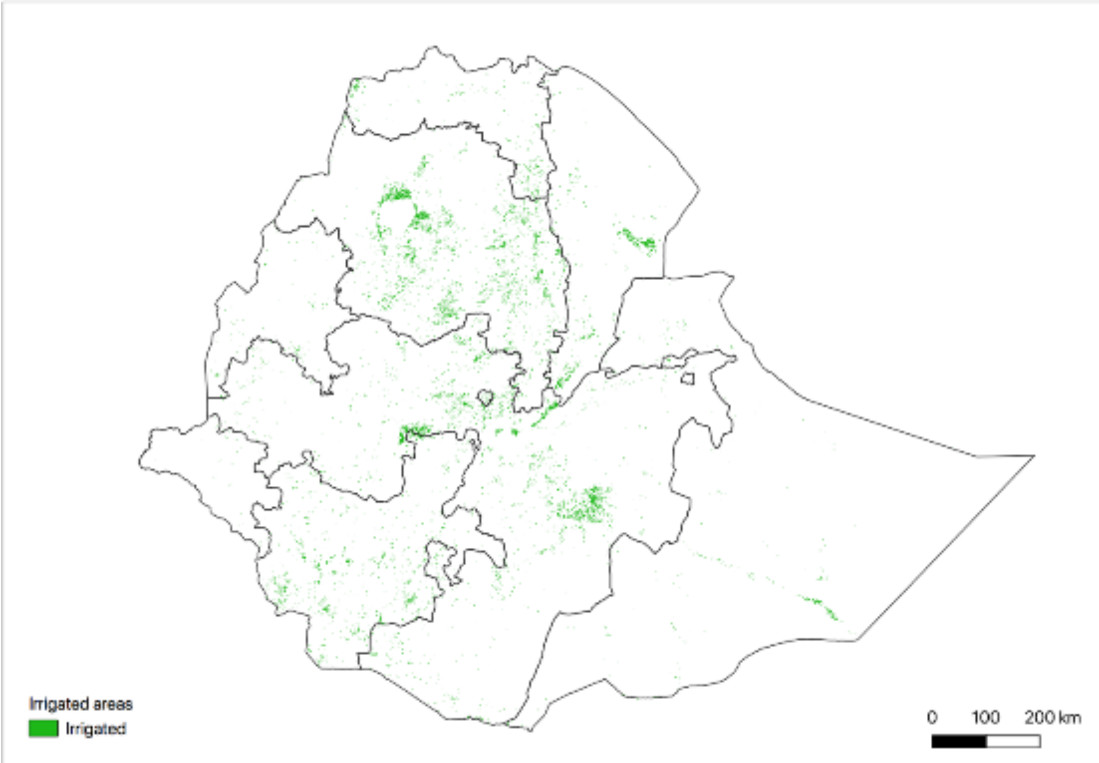

Figure 12 Map of irrigated areas in Ethiopia

5.4 SOLAR IRRIGATION SUITABILITY MAPS

Methodology

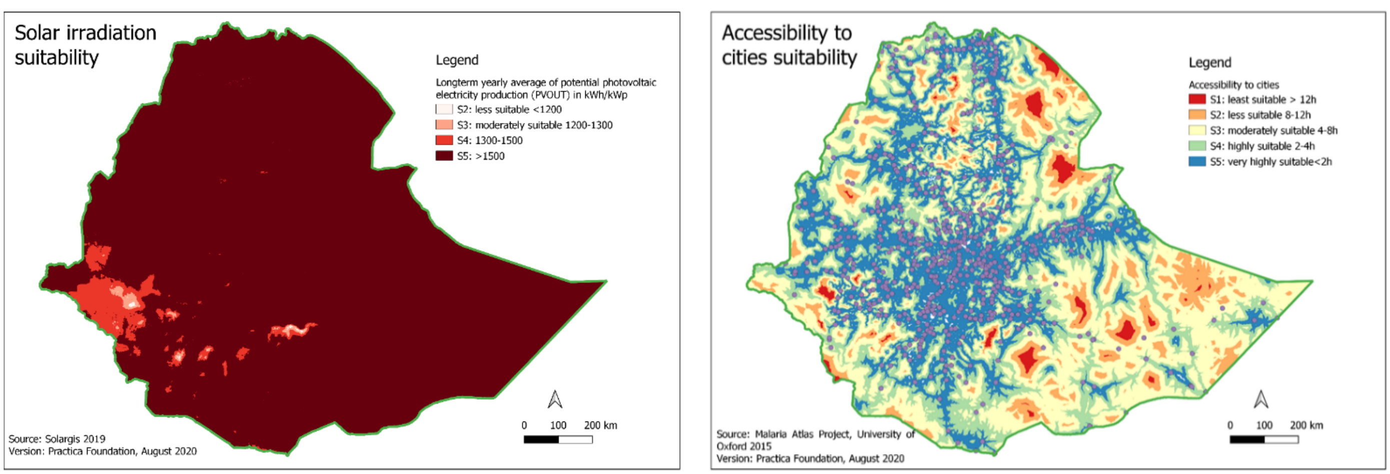

Figure 13 Left: suitability map based on solar irradiation. Increased cloud cover on the south side of the Bale mountains and in the plains of Gambella lead to decreased suitability for solar irrigation. Right: suitability map based on travel time to cities.

To map the areas with a high potential for the development or expansion of solar irrigation, we mainly followed the methodology described in a recent paper by IWMI (2018). A number of modifications were made based on different decisions and the availability more recent data since the IWMI study was realised. The approach is documented in Practica (2020) and differences compared to IWMI (2018) are discussed in Annex C.

The procedure starts with excluding areas that have one of the following features: protected areas, land cover other than agriculture, grass, shrub and bare land, elevation <500m and >3200m, precipitation < 900mm, bedrock < 30m, slope > 8%, groundwater storage < 1000mm, aquifer productivity < 0.1 l/s. Next, suitability layers have been created based on the classifications described by IWMI (2018), including: irradiation, slope, groundwater depth, aquifer productivity, groundwater storage, proximity to surface water and accessibility to cities. Depending on the scenario (surface water, very shallow (0-7m) or shallow groundwater (7-25m)), different weight factors were applied to these layers, resulting in a score for solar irrigation suitability.

Results

Just like in IWMI (2018), suitability maps have been created for the following water source scenarios: 1) groundwater 0-25m; 2) very shallow groundwater 0-7m ; 3)surface water; 4a) surface and very shallow groundwater 0-7m; and 4b) surface and groundwater 0-25m. See figure 13 below as an example. The identified suitable areas in the total scenario (4b) correspond well with the irrigation potential show some correspondence to a different map produced by IWMI and published in FAO (2015), see dots in figure 14.

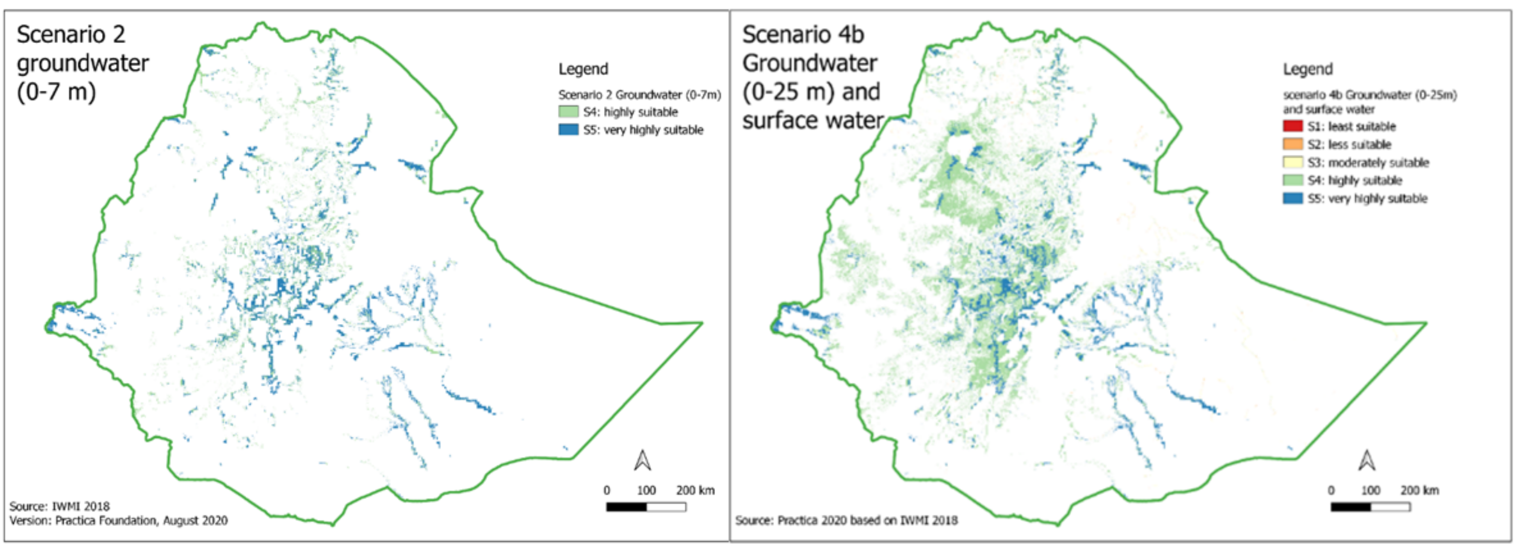

Figure 14 Left: Groundwater map (0-7 m) for Ethiopia; Right: Groundwater and surface water map (0-25 m) for Ethiopia.

Different approaches compared to IWMI (2018)

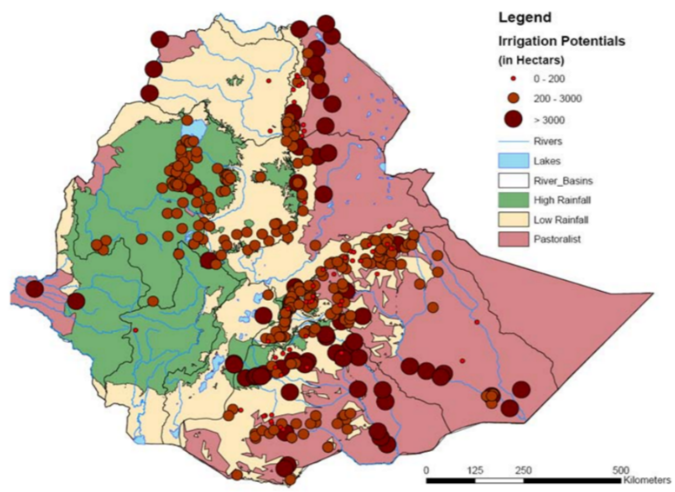

Figure 15 Irrigation potential acc to IWMI in FAO (2015)

Apart from the different input layers discussed above, four decisions are the major causes for differences in our results compared to the suitability scenarios developed by IWMI. Firstly, for scenario 3 (surface water), it was decided to create additional 'proximity to rivers' and 'proximity to reservoirs' constraints, in order to exclude all areas more than 300m away from surface water sources from this scenario. This leads to a much smaller potential for surface water irrigation[17] (108 kha compared to 1136 kha in the IWMI study). Secondly, for scenario 4a and b which are in fact combinations of scenario 1,2 and 3; instead of defining new weighing factors, we decided to use the outcome of the scenario with the highest value, leading to a more positive result. Thirdly, in our approach, areas with less than 100 ha have been included in the suitability mapping. The reasoning is that areas < 100 ha can also be considered suitable, in particular for farmer-led irrigation development. The newly added 'accessibility to cities' suitability layer is considered sufficient to cover the distance to markets criteria. Fourth major difference results from using the new Photovoltaic Electricity Potential map by SolarGis and redefined boundaries which leads to a more positive outcome, or larger suitable area, as compared to IWMI (2018). A quantitative comparison of our results compared to IWMI (2018) per region and per scenario can be found in the full mapping report (Practica, 2020). A detailed overview of the input layers and suitability criteria used by IWMI (2018) and Practica (2020) is presented in Annex C.

5.5 SOLAR IRRIGATION GROWTH POTENTIAL

Based on the solar irrigation suitability mapping scenarios, a distinction can be made on the growth potential per water source scenario. The largest potential for solar irrigation development is found in the shallow groundwater depth range from 7-25m. This scenario is specifically interesting for solar irrigation as water at this depth is largely inaccessible to fuel-powered pumps. The second largest potential is found in areas with very shallow groundwater (0-7m) and the smallest potential is found for irrigation using surface water. The total areas are presented in Table 15. It should be noted that the outcomes of the study have not been validated yet and that there are uncertainties especially regarding the aquifer productivity. Therefore, the numbers cannot be used as such, but only serve as an indication for the regions and water resources that have most potential for scaling solar-powered irrigation. The total suitable areas found by IWMI are shown in the one but last column as a comparison. The results differ due to the use of different output maps and reclassifications.

[17] Based on highly to very highly suitable areas.

Table 15 Areas suitable for solar irrigation per water source scenario, per region

Region	***Suitable area for surface water (kha)***	***Suitable area using very shallow groundwater (0-7m) (kha)***	***Suitable area using shallow ground water (7-25m) (Kha)***	***Suitable area in total (kha) by Practica***	***Suitable area in total (kha) by IWMI (2018)***	***Currently irrigated area (kha)***
Addis Abeba	0.2	11.6	9.9	21.7	2	3
Afar	4.8	345.5	4.4	354.6	8	112
Amhara	28.1	1,162.3	2,793.1	3,983.5	1,834	549
Benshangul-Gumaz	4.3	37.4	242.1	283.9	21	5
Dire Dawa	0.4	0.0	0.9	1.3		0,2
Gambela	1.8	228.6	133.4	363.8	16	3
Harari	0.0	7.3	0.8	8.2	0.7	0
Oromia	28.5	2,550.2	2,675.0	5,253.7	3,569	471
Somali	12.2	351.5	32.5	396.2	125	46
SNNP	8.1	690.4	1,355.4	2,053.8	1,087	129
Tigray	19.7	346.0	112.1	477.7	147	56
Total	**108**	**5,731**	**7,360**	**13,198**	**6,810**	**1,373**

Looking at the outcomes per region reveals significant differences in scope. In Amhara and SNNPR, the suitable area for irrigation using shallow groundwater (7-25m) is about double the area that is suitable for very shallow groundwater (0-7). In Oromia however, these scenarios are almost equal, whereas in Tigray the scope for very shallow groundwater development is actually larger. Except for Tigray, the same conclusions can be drawn from the mapping results by IWMI (2018). The fact that shallow groundwater provides the largest scope for sustainable irrigation development in Ethiopia is confirmed by Gowing et al. (2016), and in line with the observations of iDE mentioning that "Ethiopia's agricultural productivity is extremely low, due to an underutilization of water resources, with only 6 percent of its groundwater used for irrigation"[18]. Yet, the numbers of suitable hectares presented above are by no means an indication of the sustainable potential for irrigation development. Water balance studies need to complement suitability analyses to estimate how many hectares can be irrigated sustainably.

[18] https://www.ideglobal.org/country/ethiopia

5.6 HIGH POTENTIAL ZONES FOR INTRODUCTION

As a last step in the mapping process, high potential zones for solar irrigation projects have been identified, through combining the current irrigated area map and the suitability maps. This is based on the notion that farmer-led irrigation generally develops in areas with existing irrigation activity, because of the available markets, inputs, knowledge and experience. An example to this is Beekman et al. (2014) showing how irrigation development takes place through expansion zones with existing farmer-led irrigation activity.

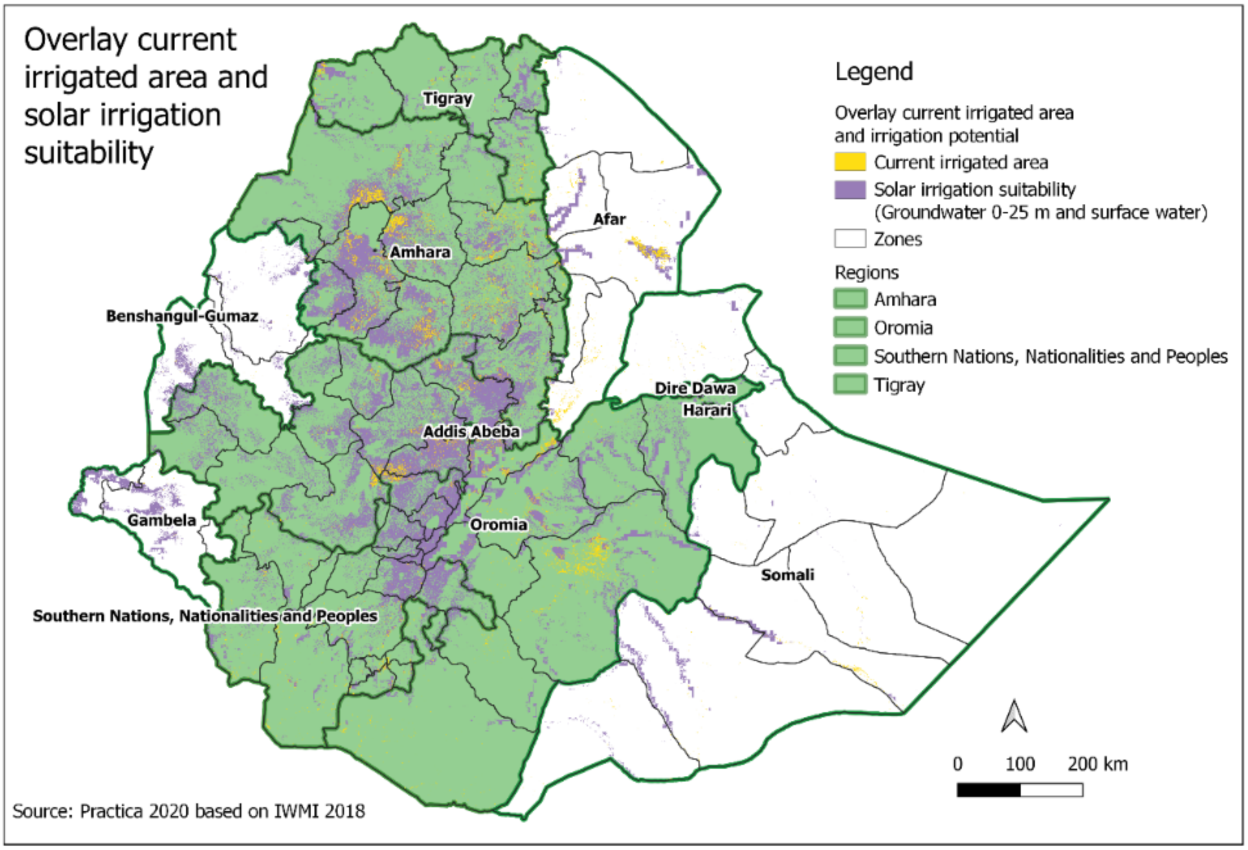

Figure 16 Overlay current irrigated area and solar irrigation suitability

The identification of high potential zones for solar irrigation expansion has been based on the selection of administrative zones in the four target regions (Amhara, Oromia, SSNP, Tigray) showing the largest clusters of high solar irrigation suitability AND current irrigated areas. Only the areas with a high or very high suitability under scenario 4b (all water sources) were taken into account. The resulting map is shown in figure 15 above.

The last step was to cross check the selected zones with the ATA map of shallow groundwater productivity and remove zones showing a very low aquifer productivity (0.001 – 0.1 l/s), see map in chapter 5.2. The last step has been included after consultation with the ATA. It was not included in the suitability mapping since a large part of the country has not been mapped yet. The following figure shows the map with the selected high potential zones. These selected high potential zones are:

- Amhara: North Gondar, South Gondar, West Goijam, North Wollo
- Oromia: East Shewa, South West Shewa, West Shewa, East Wellega
- SNNP: Gamo Gofa, Wolayita
- Tigray: Southern, Eastern

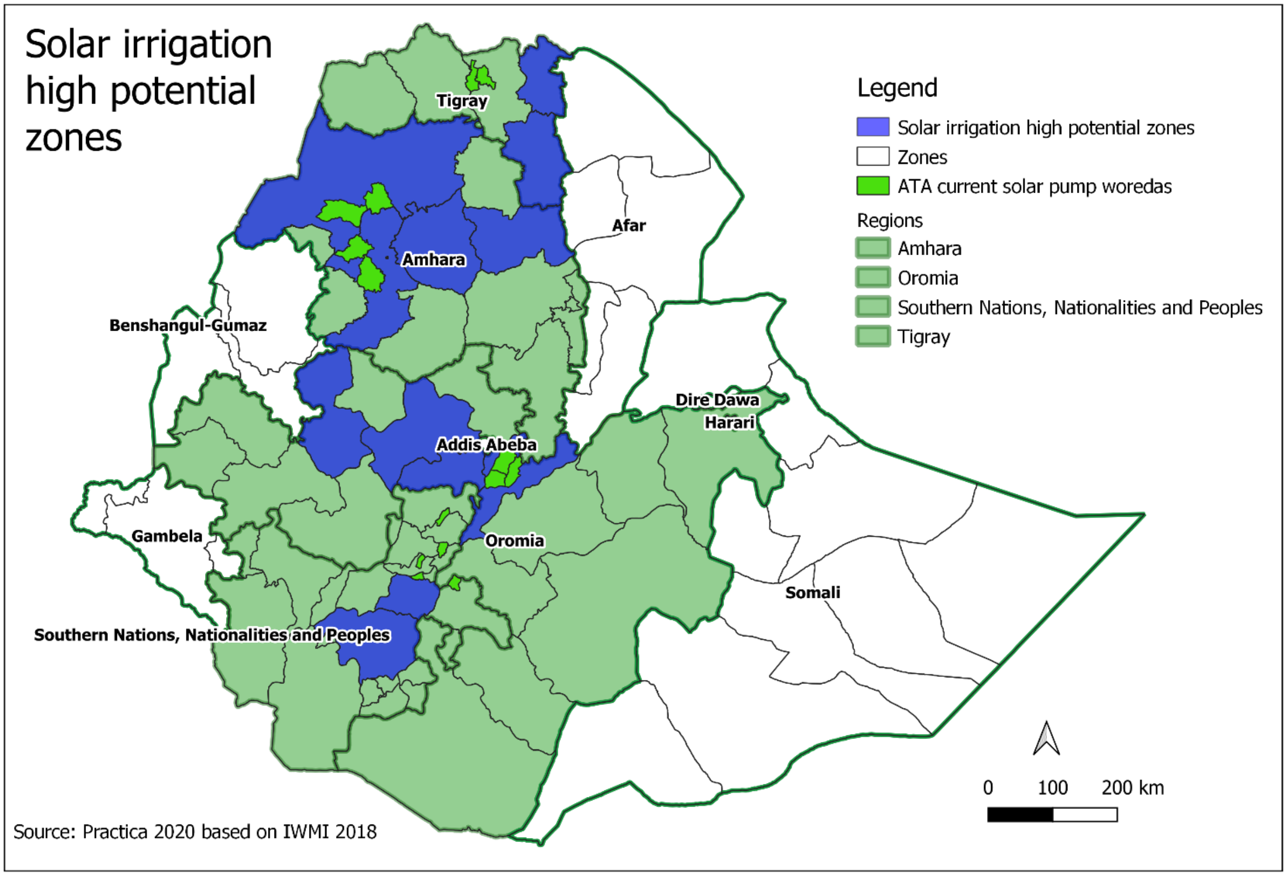

Figure 17 Solar irrigation high potential zones

SUMMARY BOX

- ***Current irrigated areas have been mapped to show distribution of farmer-led irrigation***
- ***IWMI and Practica have both updated the solar irrigation suitability maps***
- ***Large potential is shown for solar irrigation using shallow groundwater, but local validation is necessary***
- ***Aquifer productivity may be a limiting factor according to ATA map showing large areas with a maximum well yield < 0.1 L/s.***
- ***High potential zones for solar irrigation development have been suggested based on current irrigation, updated suitability analysis and the ATA aquifer productivity map***

6. RECOMMENDATIONS AND OPPORTUNITIES TO STIMULATE SOLAR IRRIGATION DEVELOPMENT

According to Adugna (2014) the key constraints of small scale irrigation development in Ethiopia are, poor management, market problems, financial shortage, insufficient technical skill, and institutional constraints. The lessons from the realized study show that the factors hampering solar-powered irrigation development are not any different. Yet, the technical and financial gap between the current supply situation and farmers demand and abilities are even larger as is the case for fuel powered pumps. At the current price level, performance, availability and level of support, solar pumps cannot compete with fuel powered pumps. The vast majority of the solar pump market depends on projects by government institutions and NGOs. However, increasing fuel prices and restricted fuel availability, have generated interest from farmers in solar-powered alternatives[19]. Increasing water scarcity and deepening water tables call for technologies like solar pumps, which can tap from the huge volume of shallow groundwater that is inaccessible for fuel-powered pumps. The ambitious government plans for upscaling irrigated land may depend on sustainable groundwater abstraction as upscaling possibilities for surface and very shallow groundwater are limited. Besides, the government has set environmental targets that justify increased support for solar irrigation development by government and donor institutions. Based on the interviews with farmers, suppliers, and institutions, this chapter will present a set of recommendations based on four principles.

6.1 INCREASE OPPORTUNITIES FOR IMPORT AND SUPPLY

In short, there are very few private actors involved in solar irrigation in Ethiopia. While solar energy has a history of 15-20 years in Ethiopia, the market for solar pumps has barely taken off. Most companies have no stock and no technical know-how and use solar pumps as a side business only. In the whole country there are only 5 to 6 companies that mainly focus on supplying solar pumps. The major reason is that without connections to parties that can provide foreign currency, it is almost impossible to order and import solar pumps. As a result, suppliers only import pumps to fulfill confirmed orders by institutions. For the few companies that do have some stock of pumps in the country, it is more attractive to sell to clients that pay in foreign currency (donors, NGOs) or that can increase access to foreign currency (government institutions). This situation undermines the ability of the private sector to promote and sell solar pumps to farmers, and even more so to provide pumps on credit. Moreover, the difficulties and effort faced by suppliers lead to higher prices: on average small solar pumps in Ethiopia are 2.4 times more expensive than the same pumps in Kenya. Reducing the cost of solar pumps is a major requirement for upscaling solar powered irrigation[20].

Government institutions and some companies indicated that more research and funding should be dedicated to local manufacturing of solar irrigation pumps. However, it can be questioned whether this is the most effective strategy to reduce the supply side of the problem. The experience, available machinery and specialized technical skills as well as high quality and low-cost raw materials in Asia are difficult to compete with. Though local manufacturing sounds interesting from a national capacity building, employment and economic perspective, it is an uncertain trajectory that would need to be researched first. Solar pump assembly, following the example of Sunculture in Kenya, may be a more realistic pathway.

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[19] Although it should be noted that so far, despite these constraints the growth of fuel-powered pumps has not slowed down.

[20] This conclusion is also shared by TechnoServe: https://www.technoserve.org/news/innovative-initiative-will-help-equip-ethiopian-farmers-with-solar-irrigati/

Government	▪ Identify effective processes for importation and foreign currency requests for solar irrigation technologies, to increase the speed of the import process ▪ Include solar pumps, accessories and installation costs in the VAT tax exemption for solar products, instead of only solar panels ▪ Streamline policies supporting fuel-powered and solar-powered irrigation development
Suppliers	▪ Develop a long-term strategy for involvement of the company in solar-powered irrigation instead of pursuing one-time tenders ▪ Select trustworthy manufacturers with stable brands that can supply spare parts, technical support and promotion materials ▪ Focus on high potential areas and build local supply and service networks as well as promotion strategies
Donors	▪ Make available a revolving fund for low-interest loans in foreign currency with restricted use for importing solar pumps and efficient water application technologies. ▪ Include mandatory targets for sustainable supply chain development for any suppliers wishing to make use of the fund (e.g. through assuring regional stocks, offering a finance solution for farmers, building technical capacity, etc.)
Researchers	▪ Assess the feasibility for manufacturing and/or assembly of high quality and affordable solar panels, pumps and efficient irrigation equipment in Ethiopia

6.2 LINK SOLAR IRRIGATION TO SHALLOW GROUNDWATER

Recently, water scarcity has become an emerging constraint for irrigation in low land areas. This has increased the cost of production (e.g. in the Harari region), and according to Yusuf and Zekarias (2019), it could potentially lead to abandoning farm production systems and technology expansion in the future, unless mitigated. Linking solar powered irrigation to water access could be an important strategy to promote solar irrigation development. By increasing access to shallow groundwater through establishing local manual well drilling capacity, the ATA is building an enabling environment for solar irrigation systems. If water levels in the manually drilled tube wells drop below 7-8 meters, by physical law no fuel-powered pump can be used to withdraw the water. Most solar powered pumps are submersible pumps that can be lowered into the tube wells (provided that the diameter is sufficient) and push the water out. Besides this, the ATA reports that aquifer productivity is generally below 1 l/s. Small solar pumps that function throughout the day are an effective technology to withdraw water from low-yielding aquifers. Petrol pumps are featured by discharges of over 5 l/s, which cannot be sustained by most aquifers. As a result, farmers use hand-dug wells with some storage capacity and spend a lot of time waiting for the open wells to recharge. Hence, in the context of shallow groundwater use, solar pumping provides a comparable advantage compared to fuel-powered pumps. Moreover, Gowing et al. (2016) indicate that the largest potential for smallholder irrigation is by using groundwater from 0-20 meters' depth. The figures presented in chapter 5 show that from a suitability perspective, the scope for solar irrigation is the largest for shallow groundwater (7-25meters). Therefore, linking solar irrigation to shallow groundwater development can be a major growth strategy that may also serve future GTP targets to sustainably increase the irrigated areal. Targeting water at larger depths is not recommended, due to the high investment cost in deep boreholes and the lower discharge when pumping from larger depths.

Government	▪ Use manual well drilling programs to de-risk farmers and lower the barrier of access to water. Target areas with good potential for accessing shallow groundwater. ▪ Implement yield tests on shallow boreholes to determine the capacity and models of solar pumps that can be promoted in target areas ▪ Make geohydrology data available to suppliers and other actors supporting solar-powered irrigation development. ▪ Establish a governance framework for sustainable shallow groundwater development, bringing together the ATA, MoWIE, MinAg and the regional water and agriculture bureaus.

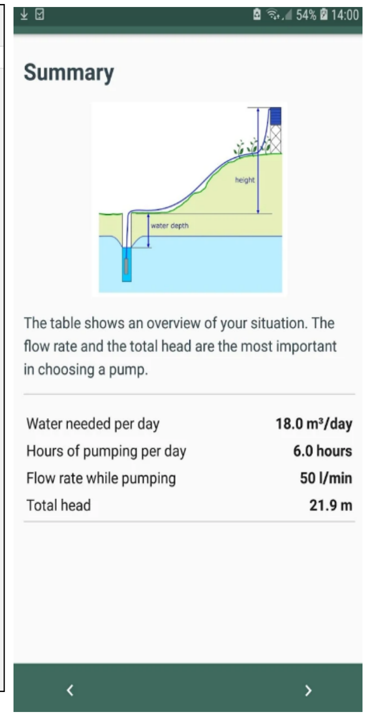
6.3 PROMOTE ADAPTED AND INTEGRATED SOLUTIONS

As described in chapter 4, simply replacing a fuel-powered pump by a solar pump while maintaining similar conditions will fail to meet the water needs of a farming system. Yet there is increasing scope and interest in solar pumps in different areas and farming segments. Access to groundwater, especially in low yielding aquifers, in one example of a favorable condition for solar irrigation development. According to this study, farmers are interested in solar pumps because the technology is free of fuel, labor, physical engagement and it is easy to operate. However, most of these characteristics actually depend on the water application system that comes with the pump. The perceived ease of operation and reduced labor need are a result of the drip system more than the pumping system. In fact, without the drip system farmers would actually spend more time in the field compared to fuel pump users, due to the smaller discharge of solar pumps. Hence, it is recommended to promote packages of solar pumps with efficient application systems that reduce the labor need.

On the other hand, the application system should not increase the already substantial barriers for farmers to move into solar irrigation. Drip systems are relatively expensive and can be challenging in terms of durability, maintenance and necessary changes in agricultural practices. While in theory efficient application systems will allow farmers to irrigate a larger area because of water savings, a fixed system can also restrict farmers' flexibility to expand or choose for particular crops, like onions, that are better served by overhead systems such as spray tubes or low-pressure sprinklers. In order to adapt solar irrigation solutions to various contexts and production systems, it is important to diversify the available and demonstrated water application technologies. Even though easier to manage from a project perspective, one-size-fits-all solutions on national level fail to address the heterogeneous landscapes and farming systems that characterize Ethiopia. Local solutions, jointly developed to include the expertise of farmers and suppliers, could lead to better adjusted technical packages.

Ultimately, provided that sufficient technical know-how is available, adapted technologies could lead to optimized systems, in which the water source, pump capacity, irrigation system and crop system are integrated. The cost benefit analyses have shown that using a solar pump to its maximum capacity, can reduce the average payback time of an investment by a factor 3 to 10. When promoting integrated solutions, a solar pump with a capacity of 0.5ha will not be used to only irrigate 0.1ha, as is the case in the current largest solar irrigation program in Ethiopia. Basic tools to simplify solar irrigation system configuration exist (see box[21]) but have not been adapted to the Ethiopian context. Integrated solutions should also consider the cost and finance mode of the technical package, as well as the technical support mechanism available to farmers. Demonstration and promotion will only be fruitful if the systems are also scalable from a farmer's financial point of view.

The Solar Irrigation Pump Selector was developed by Practica Foundation to help farmers, extension workers and suppliers to select a solar irrigation pump that fits with the water source, topography and irrigation system requirements. A prototype for the Kenyan market is available in the store.



Finally, introducing new technologies and practices will be more beneficial if accompanied by technical support for farmers. As Schmitter et al. (2016) concluded while introducing solar pumps and other technologies to farmers in Lemo district: "Guiding 58 farmers in how much to irrigate at specific crop stages did not only increase yield but also positively affected the profit obtained from the plots. Results suggest that providing appropriate water management advice as one of the core components of best management practices need to be combined with the information on appropriate water lifting devices to provide relevant information for farmers' best option and choice whilst ensuring sustainable intensification".

Government	▪ In demonstration projects, invite farmers and suppliers to co-design irrigation packages that are adjusted to local farming systems and geohydrology. ▪ Focus on demonstration of affordable solar irrigation technologies ▪ Monitor and evaluate the performance, durability, cost and farmers' satisfaction of different solar irrigation systems
Suppliers	▪ Diversify the offer of water application systems
Donors	▪ Support and encourage the government to diversify their approach
Researchers	▪ Support government and suppliers through high quality monitoring and evaluation studies based on field experiences ▪ Develop communication, decision-making and technical optimization tools for solar-powered irrigation systems

6.4 ALIGN INTERESTS AND SUPPORT INITIATIVES

The government of Ethiopia plays a key role in creating a more enabling environment for solar irrigation development. As detailed above, a lot is expected from the government in terms of smoothening the

[21] Solar Irrigation Pump Selector is available in the play store through: https://play.google.com/store/apps/details?id=nl.hiemsteed.solarpumping&hl=en_US

supply side, decreasing the costs, integrating technology and the local context, capacity building, etc. Hence, to upscale solar irrigation in Ethiopia buy in is needed not just from ATA, but also from the Ministry of Agriculture, Ministry of Water, Irrigation and Energy, Ministry of Finance and even from the National Bank of Ethiopia. To mobilize such a large supportive alliance, it is necessary to demonstrate how solar-powered irrigation can address a range of multidisciplinary targets and needs. Some examples are:

- MoWIE: Water scarcity reduction by increased use of shallow groundwater instead of surface water
- MinAg: Increasing the irrigated area and food security in woredas where water is not accessible through conventional technologies
- EFCCC: Increased sustainability through reduction of CO_2 emission and longer lifespan of technologies
- MOFED/Climate Resilient Green Economy facility: Attracting increased foreign investment in green technologies.
- National Bank: Reducing dependency on petrol, which is imported from abroad and subsidized.

A wide supportive alliance may also contribute to streamlining policies on national as well as local level. A multidisciplinary assessment of water scarcity, food security, technical suitability and market potential, could set a point of departure for defining conclusive policies and streamlining support for fuel and solar-powered irrigation development. That is, according to Yusuf and Zekarias (2016), the government is involved in 34% of fuel pump supplies. On the short term, most likely priority will be given to the target to increase the irrigated areal, which will be realized quicker and cheaper through promoting fuel-powered pumps. The GTP III is currently being developed and the uptake of solar-powered irrigation in it would be an effective way to consolidate the broad government support that is needed[22].

*In 2020, the **Amhara regional state bureau of agriculture** has purchased about 1000 fuel pumps at a unit cost of 14,000 ETB (EUR 327) for distribution to smallholder farmers. They have used the revolving fund for energy sector development to develop the small irrigation sector. The funds are drawn from the World Bank for energy sector development (World Bank, 2019). The fuel pumps will be distributed to farmers in safety net woredas at 50% cost sharing, while in commercial woredas at 100% cost of down payment.*
A similar fund that is restricted to solar irrigation could boost the market, if coordinated well.

Coordination is necessary not just on a government level, but also amongst donors and NGOs wishing to stimulate solar irrigation development. Suppliers mention that currently activities by NGOs and donors are sometimes duplicated or even contradictory. When companies are trying to sell pumps, or offer products on a credit arrangement, it is not helpful if free demonstration pumps are installed in the same area. Any instruments or financial incentives used by governments and NGOs should preferably be coordinated or jointly implemented with solar pump suppliers that are active in the particular area. An example of coordination initiatives in the solar energy sector is the Ethiopian Solar Energy Development Association (ESEDA)[23].

Finally, it should be considered that different types of farmers, and particularly female farmers, face different challenges in securing access to land, water, technologies and finance. Future support initiatives should be inclusive and gender-response in order to respond to the diversity in features, challenges and opportunities of different farmers.

22 The GTP II which finishes in 2020 includes targets on wind energy for light services and water pumping; as well as the promotion of decentralized off-grid solar energy supply. Solar energy for water pumping is not mentioned specifically (FDRE, 2016).
23 https://www.gogla.org/about-us/members/solar-energy-development-association-seda-e

Government	▪ Build a supportive alliance of government institutes and explore how solar-powered irrigation can address multiple needs.
NGOs	▪ Coordinate projects with suppliers and government agencies active in the project area
Donors	▪ Lobby for the integration of solar irrigation targets in the GTP III ▪ Focus on strategies to develop solar-powered irrigation in an inclusive and gender-responsive way.

6.5 FOCUS ON CAPACITY BUILDING FOR SUSTAINABLE SUPPLY CHAINS

The enormous expansion of fuel-powered irrigation by private smallholder farmers in the last decade could serve as an example for strategies aiming to develop the solar irrigation market. Yet, due to the high cost and limitations in discharge and water pressure associated with solar irrigation technology, the process will be more challenging and strategic cooperation among the public, private and donor community will be critical. The main success factor for the booming petrol pump market is the existence of a functioning supply chain, with stocks, spare parts and technical capacity available throughout the country. Apart from demonstrating and distributing petrol pumps, the Ethiopian government has also invested in a country-wide operation and maintenance network. Despite the fact that 70% of the farmers indicated that available fuel pump maintenance services were poor, and that spare part provision was expensive and of poor quality (Yusuf and Zekarias, 2019), the fact that widespread services exist in many woredas is a great achievement.

The solar pump supply chain on the contrary is almost non-existent. The 160 solar pumps demonstrated by ATA cannot be purchased by potentially interested clients, since the supplier imported just the amount of pumps to fulfill the order. Demonstration without building supply chains does not stimulate the market, it is only useful for testing, monitoring and evaluation purposes. Solar irrigation pumps cannot be found in shops or hardware stores, but only in the warehouses of a small number of suppliers. In fact, even the stock in warehouses in Addis Abeba is limited, due to the limitations in supply discussed before. A lack of available and accessible products also implies a lack of technical capacity and spare parts, which puts the durability and projected long lifespan of solar pumps at risk. As detailed in chapter 4.3, suppliers mention that a lack of technical capacity causes problems during the site selection and design phase already. As a result, the suppliers demand more involvement, however for quality control it is essential that government experts managing solar irrigation projects also develop sufficient knowledge on the topic. Hence, a supporting network of skilled technicians is necessary on both the supply and government side. The fact that national distributors count on average only 3 skilled solar pump technicians is a worrisome illustration of the current state of affairs regarding technical capacity for solar-powered irrigation systems.

Gov + NGOs	▪ Ensure the integration of supply chain development in demonstration projects. When launching tenders for demonstration sites, evaluate bidders on after-sales services, capacity building plan, promotion effort and, possibly, finance solutions for interested farmers. ▪ Involve suppliers in site selection, system design, and building local operation and maintenance capacity ▪ Link irrigation to agricultural value chain development. Build on farmer unions and/or farmer service centers at district level to provide agricultural inputs, technologies and services.

Suppliers	▪ Establish simple feasibility criteria for solar irrigation sites and share these with clients ▪ Establish a network of trained field technicians in target areas
Donors	▪ Support capacity building on solar irrigation design, services and practices through TVET and training for local government officials.

6.6 INCREASE ACCESS TO FINANCE TO GENERATE FARMER DEMAND

The widespread and fast market development of fuel-powered pumps is the result of a demand by private farmers, enabled by the relatively low cost of the technology. For solar irrigation pumps, there is basically no private demand yet. This can partly be attributed to a lack of awareness; however, the most important factor is the prohibitive cost of solar irrigation systems. If solar pumps are not affordable for private farmers, there will be no private demand in the regions, which implies there is no incentive for rural marketing and supply chain development or for providing other services to farmers. To make solar pumps affordable for farmers, the cost needs to be reduced while at the same time increasing farmers' access to finance. The recommendations in chapter 6.1 to smoothen the supply chains and increase tax exemptions could contribute to lower prices, but may not be sufficient to generate large farmer demand. Smart subsidies from the government could reduce the product price and stimulate farmers demand, especially when suppliers are involved by offering integrated product/service/finance solutions. Yet, some suppliers warn that subsidies should be handled with care. If subsidies are applied to solar pumps, it should be clearly visible to the client, since otherwise farmers will not trust the suppliers when higher prices apply again after the subsidy duration. Suppliers recommended a short-term (6-months) subsidy, followed by prices going back to normal so as to avoid market distortion. This was mainly mentioned as a marketing strategy, since temporary discount may attract some customers. However, if a long-term subsidy commitment can be assured and clearly communicated, this may actually lead to a more sustainable growth in farmer demand.

Access to low-risk and low-interest finance should also be increased, as most farmers cannot afford a solar pump even at a reduced price. Most banks do not deal with smallholder farmers due the high risk and lack of collateral. Asset finance solutions offered by suppliers are based on the principle that the product (e.g. solar pump) is the collateral. Thus, when farmers do not pay back, the asset is taken away by the supplier. These kind of finance solutions may have a larger potential, since farmers' risk is reduced (they may lose the pump, but not their land), and the suppliers have an interest to provide good advice and maintenance services, as pump failure would affect farmers' ability to pay back to them. Various modalities exist with overlapping definitions: Pay-As-You-Go or leasing involves paying a fee per period of usage, generally but not always leading to ownership of the technology once a certain amount of accumulated payments has been reached. The latter is also referred to as a rent-to-own solution. The advantage compared to renting or fee-for-service models is that farmers eventually own the technology and reduce their operation costs. The donor community could be engaged to provide soft loans to technology suppliers that agree to offer asset finance solutions to farmers in high potential zones.

Looking at the large number of challenges, it is the combined effect of the recommendations above that could effectively boost the market development and sustainability of solar-powered irrigation systems. Cost reduction, access to finance, supply chain development, information, promotion, coordination and capacity building are all critical elements to undertake simultaneously in order to generate farmer demand and create sustainable markets.

Government	▪ Consider long-term and visible subsidies reducing the high cost of solar-powered pumps in order to increase farmer demand ▪ Combine subsidies with low-interest loans for sustainable and efficient irrigation technologies
Suppliers	▪ If farmers demand is possible after reducing the costs of solar pumps and increasing access to finance, set up large marketing campaigns in the high potential zones to increase awareness.
Donors	▪ Provide smart subsidies and/or soft loans to de-risk suppliers and enable them to develop, test and offer integrated product, service and finance solutions to farmers

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A. SOLAR PUMP CAPACITY CALCULATION

Step 1: Irrigation need assessment

Tool: http://www.fao.org/aquastat/en/climate-info-tool/

Result: Maximum irrigation need = 117.88 mm/month = 3.8 mm/day

Input parameters:

Location	Ziway
Crop	Vegetables (average)
Planting date	1 November
Soil	Loamy clay

Soil Water Balance

Month	Prc.	ETc	ETa	Crop Days	ETc-Crop	Crop Deficit	GW Recharge	Drain	Soil Water
	mm/m	mm/m	mm/m	days	mm/m	mm/m	mm/m	mm/m	mm
Jan	12	117	13	31	117.8858	104.4461	7.928468		5146.053
Feb	26	74	20	8	32.05714	22.0334	5.403245		4679.987
Mar	55	71	47	0			4.807894		5570.178
Apr	63	65	55	0			3.992921		5553.799
May	81	63	61	0			4.086732		6291.083
Jun	90	58	58	0			6.221592		6734.765
Jul	163	54	54	0			15.98551	30.77223	8981.583
Aug	179	56	56	0			17.80258	101.7006	9344.325
Sep	116	57	57	0			17.11341	45.67774	8931.985
Oct	35	59	53	0			15.54462		8121.287
Nov	12	80	43	30	80.45333	36.52467	10.73125		6452.597
Dec	5	107	19	31	107.0129	87.0496	9.364985		5540.806

Step 2a: Calculating maximum irrigated surface per pump (Scenario groundwater at 8m depth)

Parameters		
Brand	**Unknown submersible pump**	**RainMaker2C Kubwa (large)**
Technical sheet	unknown	http://www.sunculture.com/wp-content/uploads/2020/08/SKL-JUL3020.pdf
Expected life span (years)	15	15
Client	ATA	project with PAYG
Supplier	Yasart	Sunculture
Total cost (ETB)	135000	45000
Application system	0.1 ha drip	hose pipe
Motor efficiency (%)	80	80
Pump efficiency (%)	55	55
Pump group efficiency (%)	44	44
Losses powering system (%)	85	85
Irradiation (kWh/m2/day)	5	5
System dimensions		
Total wattage	300	620
Water depth (m)	8	8
Tank height (m)	2	2
Total head (m)	10	10
Flow (L/min)	50	38
Flow (m3/h)	3.0	2.3
Yield m3/day	18	14
Planting density (%)	85	85
Irr need m3/ha/day	32	32
Water efficiency %	90	75
Pumping need m3/ha/day	36	43
Max surface (ha)	**0.50**	**0.32**

Step 2b: Calculating maximum irrigated surface per pump (Scenario groundwater at 18m depth)

Parameters	
Brand	RainMaker2C Kubwa (large)
Technical sheet	http://www.sunculture.com/wp-content/uploads/2020/08/SKL-JUL3020.pdf
Expected life span (years)	10
Client	Project with PAYG
Supplier	Sunculture
Total cost (ETB)	45000
Application system	hose pipe
Motor efficiency (%)	80
Pump efficiency (%)	55
Pump group efficiency (%)	44
Losses powering system (%)	85
Irradiation (kWh/m2/day)	5
System dimensions	
Total wattage	620
Water depth (m)	16
Tank height (m)	2
Total head (m)	18
Flow (L/min)	25
Flow (m3/h)	1.5
Yield m3/day	9
Planting density (%)	85
Irr need m3/ha/day	32
Water efficiency %	75
Pumping need m3/ha/day	43
Max surface (ha)	**0.21**

B. COST BENEFIT ANALYSIS

Cost benefit analysis of an ideal farm when SunCulture solar irrigation pump is used

	Per 1 hectare per season						Per 0.1 ha		Per 0.32 ha			
Crops	**Total Variable Cost**	**Total Invest cost**	**Total revenue**	**Net revenue**	**Margin**	**Pay back (y)**	**Margin**	**PB (y)**	**Margin**	**PB (y)**	**NPV (1ha)**	**IRR (1ha)**
Onion	49,900	205,000	150,000	89,700	96,200	1.07	8,710	4.3	30,732	1.2	707,484	149%
Maize	34,100	205,000	42,000	-2500.08	4,000	n.a.	-510	n.a.	1,228	n.a.	-65,899	n.a.
Tomato	38,660	205,000	135,000	85,940	92,440	1.1	8,334	4.5	29,529	1.3	686,541	175%
Cabbage	38,510	205,000	100,000	51,090	57,590	1.8	4,849	7.7	18,377	2.0	388,393	104%
Garlic	45,850	205,000	144,000	87,750	94,250	1.1	8,515	4.4	30,108	1.2	694,843	156%
Potato	38,500	205,000	121,500	72,600	79,100	1.3	7,000	5.4	25,260	1.5	572,517	148%
Avocado	64,120	205,000	200,000	125,480	131,980	0.8	12,288	3.1	42,182	0.9	999,523	168%
Average	**44,234**	**205,000**	**127,500**	**72,866**	**79,366**	**1.2**	**7,027**	**4.9**	**25,345**	**1.4**	**569,057**	**149%**

Actual farm Costs and benefits from smallholder farmers interviewed : solar pumps

Region	**District**	**Pump**	**Area (ha)**	**Crops**	**Total Variable Cost**	**Total Invest cost**	**Total revenue**	**Net revenue**	**Margin**	**Pay back (y)**
Oromia	Alemtena	unknown	2	avocado	56,200	370,000	75,000	-5,867	18,800	19.7
SNNP	Silte	Yasart	0.1	cabbage	5,864	123,000	7,500	-2,464	1,636	37.6
	Hawassa Zuria	Yasart	0.1	maize	7,110	125,000	9,600	-1,677	2,490	25.1
Tigray	Taitay Maychew	Yasart	0.2	onion	42,850	125,000	162,500	115,483	119,650	0.5
Amhara	Semien Mecha	Yasart	0.1	garlic	9,470	123,000	10,000	-3,570	530	116
	Fogera	Sunculture	0.125	tomato	6,850	54,000	11,000	2,350	4,150	6.5
	Semien Mecha	Mashaf	2.5	avocado	88,200	197,500	295,000	193,633	206,800	1.0

<u>Actual farm</u> Costs and benefits from smallholder farmers interviewed: petrol pumps

Region	District	Area (ha)	Crops	Total Variable Cost	Total Invest cost	Total revenue	Net revenue	Margin	Pay back (y)
Oromia	Alemtena	1	cabbage	83,609	12,500	120,000	35,141	36,391	0.17
	Alemtena	1.25	tomato	104,422	12,500	750,000	644,328	645,578	0.01
SNNP	Hawassa Zuria	2	cabbage	91,850	17,000	192,000	98,450	100,150	0.08
	Silte	0.35	cabbage	17,672	11,500	16,740	-2,082	-932	n.a.
	Alicho Wuriro	1	potato	51,900	11,500	39,600	-13,450	-12,300	n.a.
Amhara	Fogera	0.5	onion	36,234	7,000	48,000	11,066	11,766	0.30
Tigray	Taitay Maychew	1	onion	104,500	11,000	500,000	394,400	395,500	0.01

Ideal Farm model - Example of cost breakdown: Petrol pump systems

	Seed rate and cost per hectares			Fuel cost per ha for irrigation			Oil & lubricant cost per ha (6%)			Oxen rent for ploughing			Labour costs			Land rent	Fertiliser: DAP		
Crops grown	kg/ha	unit price (ETB)	**seed cost/ha**	**lit/ha**	**unit price**	**fuel cost/ha**	**lit/ha**	**unit price**	**oil cost/ha**	No of ploughing	Uni tprice	**Oxen cost**	Mandays	wage rate	**labour cost /ha**	**Land cost per season**	rate kg/ha	unit cost	cost
Onion	4	3000	**12000**	300	35	**10500**	8	150	**1200**	4	300	**1200**	120	150	**18000**	**10000**	150	18	2700
Maize	25	64	**1600**	300	35	**10500**	8	150	**1200**	4	300	**1200**	120	150	**18000**	**10000**	100	18	1800
Tomato	0.4	3400	**1360**	300	35	**10500**	8	150	**1200**	4	300	**1200**	110	150	**16500**	**10000**	200	18	3600
Cabbage	0.7	1300	**910**	300	35	**10500**	8	150	**1200**	4	300	**1200**	100	150	**15000**	**10000**	300	18	5400
Garlic (500 clove)	1.5	4200	**6300**	300	35	**10500**	8	150	**1200**	4	300	**1200**	120	150	**18000**	**10000**	200	18	3600
Potato	200	15	**3000**	300	35	**10500**	8	150	**1200**	4	300	**1200**	110	150	**16500**	**10000**	100	18	1800
Avocado (seedlings)	420	30	**12600**	300	35	**10500**	8	150	**1200**	4	300	**1200**	240	150	**36000**	**10000**	240	18	4320

	Fertiliser: UREA				Pesticide				Revenu			Investment		
Crops grown	rate kg/ha	unit cost	cost	**fertilizer cost/ha**	rate lit/ha	price per litre	**pesticide cost/ha**	**Total Variable Cost**	Production (Qt/ha)	price per Qt (ETB)	**Total revenue (ETB)**	Well cost	Purchase cost /ha	**Total Investment Cost**
Onion	100	15	1500	**4200**	30	150	**4500**	**61600**	150	1000	**150000**	10000	20000	**30000**
Maize	100	15	1500	**3300**	0	150	**0**	**45800**	70	600	**42000**	10000	20000	**30000**
Tomato	100	15	1500	**5100**	30	150	**4500**	**50360**	150	900	**135000**	10000	20000	**30000**
Cabbage	200	15	3000	**8400**	20	150	**3000**	**50210**	100	1000	**100000**	10000	20000	**30000**
Garlic (500 clove)	150	15	2250	**5850**	30	150	**4500**	**57550**	120	1200	**144000**	10000	20000	**30000**
Potato	100	15	1500	**3300**	30	150	**4500**	**50200**	135	900	**121500**	10000	20000	**30000**
Avocado (seedlings)	0	15	0	**4320**	0	0	**0**	**75820**	200	1000	**200000**	10000	20000	**30000**

	Per 1 hectare per season								Per 0.1 ha		Per 0.4 ha		Per 1 ha		Per 0.4 ha
Crop	**Total Variable Cost**	**Total Investment Cost**	**Interest**	**Depreciation**	**Total revenue**	**Net revenue**	**Margin**	**Payback (year)**	**Margin**	**PB (y)**	**Margin**	**PB (y)**	**NPV**	**IRR**	**NPV**
Onion	61600	30000	800	2333	150000	85267	87600	0.2	8040	1.9	34560	0.4	275712	130%	110285
Maize	45800	30000	800	2333	42000	-6933	-4600	-3.3	-1180	-12.7	-2320	-6.5	-75700	n.a.	-30280
Tomato	50360	30000	800	2333	135000	81507	83840	0.2	7664	2.0	33056	0.5	184651	151%	73861
Cabbage	50210	30000	800	2333	100000	46657	48990	0.3	4179	3.6	19116	0.8	110897	83%	44359
Garlic	57550	30000	800	2333	144000	83317	85650	0.2	7845	1.9	33780	0.4	271976	135%	108790
Potato	50200	30000	800	2333	121500	68167	70500	0.2	6330	2.4	27720	0.5	254826	126%	101930
Avocado	75820	30000	800	2333	200000	121047	123380	0.1	11618	1.3	48872	0.3	404351	152%	161740

C. SUITABILITY MAPPING COMPARISON

To map the areas where there is potential for the development or expansion of solar irrigation, we mainly followed the methodology described in the paper by IWMI (2018). In the tables below, the base layers and suitability classifications are given for the approach used in this study (Practica, 2020) as well as the original study (IWMI, 2018).

Input layers

	Input layers Practica (2020)				**Input layers IWMI (2018)**			
Layer name	**Source**	**Spatial resolution**	**URL**	**Year**	**Source**	**Spatial resolution**	**URL**	**Year**
Elevation	SRTM 30m 1 Arc second	30	https://earthexplorer.usgs.gov/	2016	same			
Slope	same		Derived from elevation layer	2016	same			
Irradiation	Solargis	30.0 arc sec.	https://globalsolaratlas.info/download/ethiopia	2019	Derived from elevation, slope and aspect			2017
Rainfall	CHIRPS	0.05 arc sec.	https://data.chc.ucsb.edu/products/CHIRPS-2.0/	2019	WorldClim	900	http://www.worldclim.org/	2005
Groundwater depth	BGS	5000m	https://www.bgs.ac.uk/research/groundwater/international/africanGroundwater/mapsDownload.html	2012	same			
Aquifer productivity	BGS	5000m	https://www.bgs.ac.uk/research/groundwater/international/africanGroundwater/mapsDownload.html	2012	same			
Aquifer storage	BGS	5000m	https://www.bgs.ac.uk/research/groundwater/international/africanGroundwater/mapsDownload.html	2012	same			
Landcover	Copernicus	100m	https://developers.google.com/earth-engine/datasets/catalog/COPERNICUS_Landcover_100m_Proba-V_Global	2015	Woody Biomass Inventory and Strategic Planning Project (origin: LANDSAT)	30	n.a.	2004
Depth to bedrock	ISRIC	250m	https://data.isric.org/geonetwork/srv/eng/catalog.search#/metadata/bfb01655-db81-4571-b6eb-3caae86c037a	2017	same			
Accessibility to cities	Univ. of Oxford	1000m	https://developers.google.com/earth-engine/datasets/catalog/Oxford_MAP_accessibility_to_cities_2015_v1_0	2015	Derived from town population: Town population. Ethiopia - Woody biomass project (based on 1987 census). It was not used directly as input in the model, instead to derive proximity to town.	Point layer	n.a.	2004
					AND Road map Vector Ethiopian Roads Authority (ERA)	vector	n.a.	2010/2011
Rivers	Open Street Map	Vector	https://wiki.openstreetmap.org/wiki/Mapfeatures	2020	Origin: Ministry of Water Resources	vector	n.a.	2007/2008

Protected areas	IUCN	Vector	https://www.protectedplanet.net/country/ETH	2020	International Union for Conservation of Nature (IUCN) database	vector	n.a.	2010
Reservoirs	Open Street Map	Vector	https://wiki.openstreetmap.org/wiki/Mapfeatures	2020	FAO - Agwater solutions project	vector	n.a.	2012
Irrigated land	n.a.	n.a.	n.a.	n.a.	International Water Management Institute (IWMI) (origin: Moderate Resolution Imaging Spectroradiometer [MODIS]) (available upon request)	250	n.a.	2014
Suitability for small pumps	n.a.	n.a.	n.a.	n.a.	FAO – Agwater solutions project	Vector	n.a.	2012

Constraint layers

Layer name	Constraint Practica (2020)	Constraint IWMI (2018)
Protected areas	Protected areas are excluded	same
Land cover	Land cover other than agriculture, grass, shrub and bare land	same
Agro-Ecology (Elevation and Rainfall)	Constraint are areas in which Annual precipitation is lower than 900mm AND Elevation is below 500m or higher than 3,200 m -> results in a smaller constraint area	Constraint are areas in which Annual precipitation is lower than 900mm OR Elevation is below 500m or higher than 3,200 m -> results in a larger constraint area
Depth to bedrock	Depth to bedrock < 30 m	same

Suitability layers with equal constraints IWMI (2018) and Practica (2020)

	Score					
	Very highly suitable	Highly suitable	Moderately suitable	Less suitable	Least suitable	Constraint
	5	4	3	2	1	0
Slope	0-2%	2-4%	4-6%	NA	NA	>8
Groundwater depth (0-7m)	0-7m	NA	NA	NA	NA	>7
Groundwater depth (0-25 m)	0-7m	7-25m	NA	NA	NA	>25
Aquifer productivity (l/s)	> 0.5	0.5-0.1	-	-	-	<0.1
Groundwater storage (mm)	25,000-50,000	10,000-25,000	1000-10,000	-	-	<1000

Suitability layers with different constraints IWMI (2018) and Practica (2020)

		Score					
		Very highly suitable	Highly suitable	Moderately suitable	Less suitable	Least suitable	Constraint
		5	4	3	2	1	0
Practica (2020)	Irradiation (kWh/kWp)	>1500	1300-1500	1200-1300	<1200	NA	NA
	Proximity to rivers (m)	<50m	50-100m	100-200m	200-300m	-	>300m
	Proximity to reservoirs (m)	<50m	50-100m	100-200m	200-300m	-	>300m
	Accessibility to cities (min)	<120 minutes	120-240 min	240-480 min	480-720 min	>720 min	-
IWMI (2018)	Irradiation (kWh/m2/y)	3,000-2,500	2,499-2,000	1,999-1,750	1,749-1,500	1,499-1,300	<1,300
	Proximity to rivers (m)	<50	51-100	101-200	201-300	>300	NA
	Proximity to reservoirs (m)	<50	51-100	101-200	201-300	>300	NA
	Proximity to town (km) And population	200 km >100,00	100 km 45,000 100,000	50 km 15,000 – 45,000	25km 2,500-1,500		

Weighing factors for scenario development
The specific weighting factors used by Practica (2020) were equal to those used by IWMI (2018) with the following exceptions:

- The weight factor of the “Accessibility to cities” layer used by Practica (2020) was calculated by adding up the weight factors for “Distance to roads” and “Proximity to town” used by IWMI (2018). [e.g. for scenario 1: Distance to roads = 0.04, Proximity to town = 0.04, hence Accessibility to cities = 0.08]
- For Scenario 4a (groundwater 0-7m) + surface water, Practica used the maximum value of scenario 2 (groundwater 0-7m) and 3 (surface water) combined, whereas IWMI (2018) developed specific weight factors for this scenario.
- For Scenario 4b (groundwater 0-25m) + surface water, Practica used the maximum value of scenario 1 (groundwater 0-25m) and 3 (surface water) combined, whereas IWMI (2018) developed specific weight factors for this scenario.

Main differences in outcome explained:
A major reason that explains the higher outcomes in scenario 1, 2 and 4 in Practica (2020) compared to IWMI (2018) is the use of different base layers and suitability classifications for **solar irradiation**. Practica (2020) made use of a base layer that includes the impact of temperature and cloud cover to depict local Photovoltaic Electricity Potential (kWh/kWp). IWMI (2018) used the elevation, aspect and slope to derive the direct normal irradiation (kWh/m2). Hence, the approach by IWMI (2018) is based on a different unit and higher boundaries, resulting in a smaller area classified as suitable based on the available irradiation. Practica decided to use an approach with lower boundaries because of the drop in panel prices which makes it possible to add panels to compensate for lower irradiation values.

Another difference is caused by the **agro ecology** constraint layer that has been created by combining the elevation and rainfall layer. Practica (2020) has defined a constraint area as an area in which rainfall is less than 900mm and elevation either less than 500m or more than 3200m. As a result, the outcome of the Practica (2020) study implies that some zones in generally low (Gambela) and dry (Somali) regions could be considered suitable for solar irrigation, e.g. if close to a surface water or shallow groundwater resource.

In contrast with IWMI (2018), Practica (2020) created additional constraint layers for '**proximity to rivers'** and 'proximity to reservoirs' because solar irrigation development more than 300 meters away from surface water is not considered as suitable for the surface water scenario. As a result, the outcomes of the surface water scenario by Practica (2020) show considerably lower values than the same scenario by IWMI (2018).

The **accessibility to cities** layer used by Practica (2020) was used to cover the distance to markets criteria. This scenario leads to a more positive outcome compared to the proximity to town and population layers used in IWMI (2018).

Since **scenario 4** is in fact a combination of surface water and groundwater, Practica (2020) combined the suitability of both scenario's (scenario 1 or 2 and 3) and chose the outcome of the scenario with the highest value, in order to show the best outcome of either the groundwater or surface water scenario. IWMI used a different classification.

Another important difference explaining the higher values by Practica (2020) is that contrary to IWMI (2018), **areas with less than 100 ha** have not been left out of the suitability mapping. The reasoning is that areas smaller than 100 ha can still be considered suitable for small scale irrigation.

It should be stressed that neither the results of IWMI (2018), nor the even higher estimation of **suitable areas** for solar irrigation development by Practica (2020), are an indication of the **sustainable potential** for irrigation development. The sustainable potential, which is based on the available volume of groundwater resources that can be abstracted without negative consequences for the environment and other water users, has not been assessed in this study.

D. STAKEHOLDER ANALYSIS

Stakeholder analysis for solar irrigation development in Ethiopia: A Desk review

The stakeholder analysis is a desk review of the key stakeholders who can influence, or has an interest in, solar irrigation development in Ethiopia, mainly in four regional states such as Amhara, Oromia, Southern regions and Tigray. It assess the roles, interests and level of influence of the relevant stakeholders through a desk review based on prior experience and review of existing profiles. The objective of this stakeholder analysis is to identify key stakeholders for conducting a solar irrigation market analysis for Green Peoples Energy project of the GIZ.

The table below illustrates stakeholder roles, interests and level of influence in solar irrigation development. The first cluster are government organizations and institutions who play a leading role in policy making, financial supply, research and development, technical support and sustainability of the development of solar irrigation schemes in Ethiopia and four regional states. The second cluster of stakeholders are international institutions and NGOs who have a stake on small scale irrigation development via projects, funding and finance solutions. The third cluster stakeholders are the private companies involved in import and distribution of solar irrigation pumps in Ethiopia and regional states. The private business clusters are mainly for profit maximization and plays a primary role in the supply chain of solar irrigation equipment's. The fourth group of stakeholders are private farmers and community who have been practicing and will be willing to adopt solar irrigation technologies at their income disposal and in the availability of financial access. These are the primary stakeholders who will be affected either positively or negatively.

Stakeholder	Roles	Interest	Influence
Federal and regional government institutions			
Ministry of agriculture/ Regional bureaus of Agriculture	Responsible for Policy making, capacity building and financing	Strong interest in irrigation development of the country/ regions	High
Ministry of water irrigation MoIWE and energy / regional bureaus of IWE	Responsible for the management of Water resources, develop and implement water laws and regulations, conduct study and research activities, provide technical support	Strong interest in irrigation development	High
Federal Jobs creation commission / Regional offices for job creation	Develop entrepreneurship & innovative jobs Financing	Jobs creation	Low
Ethiopian Institute of Agricultural Research / EIAR Oromia, Amhara, SNNPR, and Tigray Agricultural Research Institutes	Research & development generate, develop and adapt agricultural technologies	Research stake, technology testing irrigation mechanization, including solar energies)	High

Agricultural Transformation Agency	Implementing irrigated shallow Ground water irrigation development	Irrigation development	High
Development Bank of Ethiopia	Providing finance	Provides loans for Commercial Agriculture	Medium
International institutions and NGOS			
International Fund for Agricultural Development	Funding opportunity loans support programmes	small-scale irrigation development rural financial inclusion	High
World Bank	Funding opportunity Policy directions	Strong interest in assisting Ethiopia's growth & poverty reduction	Low
German Agro action / Welthungerhilfe	enhance sustainable food and nutrition security/humanitarian	Clean drinking water, sanitation facilities	Low
World Vision	Water, Sanitation and Hygiene projects	Provision of improved sanitation services	Low
Ethiopian solar energy foundation	Credit solutions Capacity building		
AgriTerra	expert advice and training to cooperatives and farmer organisations	On demand service provision	Low
SOS sahel	improve the living standards of smallholder farmers and marginalized pastoralists	community-based natural resources management. Food security, agriculture, policy analysis, value chain analysis and development, pro-poor value chain development.	Low
GIZ Green Innovation Center GIC			
GIZ strengthening drought resilience SDR			
GIZ support t sustainable Agricultural Productivity in Ethiopia SSAP			
GIZ support to responsible Agricultural Investment S2RAI			

FAO sub regional office for eastern Africa: Ethiopia office	Agricultural productivity and competitiveness sustainable natural resource, food and nutrition security		Low
Embassy of the kingdom of the Netherlands	Development and trade partnership	Funding opportunities	Medium
Global Green Growth Institute			
IWMI	Research and development in areas of agriculture, water and energy	Research projects on irrigation and livestock value chains Prior research on solar irrigation	High
SNV	Development projects	Providing technical support to government in biogas, sustainable markets, clean fuel, cooking and heating, off-grid and mini-grid electricity.	Low
JICA	Agriculture and Rural Development projects	improving market access and improving small-scale farmer income	Low
Farm Africa	SMALL-SCALE IRRIGATION project in Tigray	introduced motorised and treadle pumps	Medium
Private sector companies / businesses	Import, Assemble and Supply of solar PV Credit solutions Capacity building	High interest in business/ profit maximization	High
Private farmers			
Community/ cooperatives Farmers Community representatives Women’s group	Improving agricultural productivity Adapting to climate change	Access to agricultural technology Solar irrigation facilities	High

E. FARMER INTERVIEW GUIDE

Sampling Farmers per region:

Start with solar irrigation farmers, then look for nearby farmers with similar production systems using fuel or manual irrigation.

General

Region _____________ Woreda ____________ Kebele _____________ GPS _______________ Name _______________ Sex ____ Phone (if applicable) _______________ Farmer __ worker ____ investor ____

Solar pump (surface/submersible) _______ fuel pump (petrol/diesel) ____ manual (bucket/treadle) _______ other ________

Is irrigated agriculture the principal income generating activity? Yes ____ No _____

Water access

Shallow borehole (< 25m) _____ Deep _____ hand-dug _____ river ____ lake____ other ____

For in-depth interviews only
Water depth in May (before the rains) ______ Total depth of well ________ Total cost of well _______
Water availability throughout the year? Yes ___ No __ If No which months have no water _______________ which months insufficient water _______________

Pump flow measure with bucket tests; current water depth (measured); Additional head while measuring (if applicable); Add for solar pumps the weather conditions during visits (rainy/heavy cloud/slightly cloudy /sunny)

Pumps

Brand _______________ Model _______________ Purchasing cost _____________ Purchasing year _____________ Panels (type/size) purchasing cost _______________ Total wattage of panels (if solar) ___________ Maximum head (m) _______________ Maximum flow _______________ Nominal flow _______________ Pump life _______________ supplier _______________ distance form farm _______________ Ownership mechanisms (donated/ in cash / informal loan / other) _______________

Services from supplier (no / installation / maintenance /spare part supply /training/ warranty) _______________ if in cash at what costs for installation _______________ for maintenance ____________ if warranted for how long? _______________

Accessories

Lists of accessories (suction hose, cables, etc.)_______________ Purchasing costs _______________

Operations

Ease of pump operation: Easy _______ Medium ______ difficult _______ Movability ____________ what types of supports from responsible actors' _______________ Challenges related to the pump

Water distribution

Earthen canals _______ cans/bucket ______ hosepipe _______ sprinkler ______ drip ________other ___

If hosepipe/sprinkler/drip/other: Purchasing cost (ETB per units) ________

If sprinkler/drip/other: Brand or model ______________ Lifespan (years) ______________ Installation cost ______________ Supplier or from which shop ______________ distance ______________
Services from supplier (none / installation / reparation (paid) /spare part supply / warranty) ______________

Production system

Total farm size ______________Cropping patterns and types ______________ cropping intensity ______________ Peak irrigation season (duration of months) ______________ Size of total irrigated area during that period ______________ proportion of irrigation products for market (in % or other) ______________

Take GPS location somewhere in a field that was irrigated this year (using app)

During which months was this field irrigated? July 2019 / Aug 2019 / Sep 2019 / Oct 2019 / Nov 2019 / Dec 2019 / Jan 2020 / Feb 2020 / Mar 2020 / Apr 2020 / May 2020 / June 2020

Cost benefits analysis for a defined plot (In-depth interviews only i.e. 6 per region). Preferably when the field and pump are accessible and production system is similar with solar pumps

Production cost (for the selected plot size only)
Crop(s) ______________ Cultivation Period ______________ farm size (measured if applicable) _______ input types used and rates (seeds, fertilizer, pesticides, other) ______________ input costs ______________

Labor for field preparation/ irrigation/weeding/planting/chemical and fertilizer application/others (number, duration, costs) ______________

Irrigation interval ______________ Irrigation time/duration (hours) ______________ Number of irrigation per season ______________

Equipment depreciation cost
Maintenance costs per season: for pumps ______________ for distribution system ______________
Fuel (petrol or diesel) consumption (irrigation/season per crop) ______________ fuel cost _________
Lubricant consumption season for each crop ______________ costs ______________
Fuel collection time per season (hours) ______________

Revenues

Yield per ha per crop ______________ farm gate price of each crop ______________

Strategy

What are the main constraints to expand your irrigated area? ____________________________ ______________ what asset would you buy in case you had a very good harvest? ______________

Perception about solar pumps

Solar pump users

All farmers

Do you know about solar pumps? Yes / No ___________

How do you know about it?

- Mouth-to-mouth
- I've seen it at a farm
- I have seen it in a shop
- Other ______________

Would a solar pump be a good option for your farm? Yes / No ________ Why (not)? ______________

Which ones are true about a solar pump?

- Has a longer life-span than a fuel pump
- Can go deeper than a fuel pump
- Is easier to repair than a fuel pump
- Is more powerful than a fuel pump

With a solar pump I would need to (it is the same question with the above)

- use a high storage tank
- invest in expensive and modern irrigation systems
- make small and cheap adaptations only
- change nothing compared to my current plot

How much would you be willing to invest in a solar pump? ______________

Solar pump none users;

Why have you not purchased a solar pump?

- Too expensive
- Not enough information
- It does not fit the size of my farm
- There is no nearby supplier
- Other: …..

What must happen before you can switch to solar irrigation?

Solar pump users

What did you use before starting solar pump? No irrigation / manual / fuel pump / other ____________

Why did you switch (use) to solar irrigation?

- I received support from a project (specify)
- It was recommended by others (specify)
- I wanted to reduce operation costs
- I wanted to save time

- Other

What has changed when you started to use a solar pump?

- I have increased my irrigated area
- I have reduced my irrigated area

- I am spending more time irrigating
- I am spending less time irrigating

- I am making more profit than before
- I am making less profit than before

Do you have anything else to say?

F. SUPPLIER INTERVIEW GUIDE

Solar irrigation study - private sector survey

This study is organised in the frame of the GIZ Green People's Energy for Africa project, which aims to improve the conditions for decentralised energy supply in Ethiopia. The data collected through this survey will be used to develop recommendations for GBE to sustainably and effectively promote and stimulate the solar irrigation market in Ethiopia.

The study, assisted by the German Government, is being carried out by Niras-IP and Practica Foundation on behalf of the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH.

The survey should take about 15-20 minutes to fill in. We thank you in advance for your collaboration. For questions, please contact Berry van den Pol through berry@practica.org

1.Name of your organisation

2.Your name (optional)

3.Your position in the company

4.Your email (optional)

5.Your phone number (optional)

6.What is the category of your company?

- ☐ manufacturer
- ☐ national distributor
- ☐ retailer
- ☐ agent
- ☐ engineering services
- ☐ other

7.What kind of products do you supply?

- ☐ Agricultural equipment
- ☐ Fuel-powered pumps
- ☐ Solar powered pumps
- ☐ Other solar appliances
- ☐ Irrigation equipment
- ☐ Agricultural inputs (seeds, fertiliser, pesticides, etc.)
- ☐ other

8.What kind of services do you supply?

- ☐ Design and engineering
- ☐ Technology supply and installation
- ☐ Maintenance
- ☐ Training
- ☐ other

9.Do you sell solar irrigation pumps?

- Yes
- No -> go to section 3

Section 2 - Solar irrigation pumps

11.Which solar irrigation pump brands do you sell?

- Lorentz
- Grundfos
- Dayliff
- Sunflo
- Futurepump
- Sunculture
- Feili
- other

12.Which solar pump models do you sell?

13.Which is your bestseller solar pump model?

14.The following questions will focus on your bestseller solar pump model.

What kind of pump is your bestseller model?

- suction pump
- submersible pump

15.What is the price of your bestseller pump in ETB?

16.Does this include the solar panels?

- Yes -> go to question 18
- No

17.What is the price of the total number of panels to be installed with the pump? (please specify the currency)

18.What is the total wattage of the panels to be installed with the pump?

19.What additional accessories are needed?

- Hose
- Panel frame
- Electrical cables
- other

20.What is the price of these accessories? (please specify the currency)

21.Does the pump price include the cost of installation?

- Yes -> go to question 23
- No

22.What is the cost of installation for one pump? (excluding transport)

23.What would be the transport cost when installing one pump in Ziway?

24.Does the price include a warranty?

- Yes
- No -> go to question 26

25.What is the warranty period?

26.What is the nominal or rated flow of the bestseller pump? (please specify the unit)

27.What is the head for the nominal flow?

28.What is the maximum head of the pump?

29.What is the maximum flow of the pump? (Qmax)

30.What are the main water sources used with this pump?

- unknown
- deep borehole
- shallow borehole (<25m)
- hand-dug well
- river
- lake
- other

Section 3 - Water distribution technologies

31.Do you sell any irrigation equipment? (for instance drip, sprinklers, etc.)

- Yes
- No -> go to section 4

33.Which types of irrigation equipment do you sell?

- drip
- sprinklers
- misters
- spray
- other

34.Which brands do you sell?

32.How many irrigation equipment units did you sell in 2019?

35.Which exact type is sold the most for solar irrigation purposes?

36.The following questions will focus on the type of irrigation equipment sold the most for solar irrigation purposes.

What surface (m2) can be irrigated with one unit?

37.What is the cost of one unit? (please specify the currency)

38.What materials are included in this cost?

- ☐ Tubes
- ☐ Connections
- ☐ Spare parts
- ☐ other

39.What is the extra cost for installation? (excluding transport)

If it is included, please put zero.

40.Does the product come with a warranty?

- ☐ Yes
- ☐ No

41.What is the period of the warranty?

42.What is the average lifespan of the technology in years?

Section 4 Distribution

43.Who are the actors in the solar irrigation supply chain in Ethiopia?

44.Where are they based?

45.How many solar pumps did you sell/distribute in 2019?

46.How many in 2018? (estimation is OK)

47.How many in 2017?

48.How many in 2016?

49.How many solar irrigation pumps did you sell in total from January 2010 till December 2015?

50.Who are your main clients?

- ☐ Government agencies
- ☐ NGOs
- ☐ Smallholder farmers (< 1 ha irrigated)
- ☐ Commercial farmers (> 1 ha irrigated)
- ☐ Farmer groups
- ☐ Local retailers
- ☐ Selling agents
- ☐ other

51.What are the main woredas where your solar pumps are used?

52.In which towns do you have a representation?

53.What after-sales services do you provide?

- ☐ scheduled maintenance
- ☐ repairs on demand
- ☐ technical advice
- ☐ other

54.How many technicians are available for after-sales services in the country?

55.Where are spare parts stored?

- ☐ locally
- ☐ regionally
- ☐ nationally
- ☐ I have to import them

56.How many days does it take on average between a reported pump failure and reparation by your technicians, for rural areas?

57.Which percentage of your sales comes from solar irrigation products?

Section 5- Institutional environment

59.Who is doing the feasibility studies and design of solar irrigation systems?

- ☐ your company
- ☐ NGOs
- ☐ government
- ☐ engineering companies
- ☐ other

60.Do you know the engineering/design cost for a 1 ha solar irrigation system?

61.Which government institutions are involved in solar irrigation? What is their role?

62.What are the tax exemptions or subsidies available for solar irrigation?

63.To what extent are you able to make use of these measures?

64.How do you manage the need for foreign currency? (if applicable)

65.What do you think the government could do to stimulate the solar irrigation market?

66.Do you offer any solar irrigation pumps on credit or lease?

- ☐ Yes
- ☐ No -> go to question 73

67.What kind of credit or lease solutions do you offer?

68.What are the requirements for a customer to be awarded a pump on credit?

69.What are the pay back terms?

70.What is the cost of finance? (including interest, administration, etc.)

71.How do you collect the installments?

- home visits
- central collection point
- bank transfers
- mobile money
- other

72.Why does your company deliver products on credit or lease?

73.Why doesn't your company provide products on credit or lease?

74.What kind of support would you need to offer (more) products on credit?

Section 6 Looking ahead

75.How do you evaluate the current demand for solar irrigation products?

- Very low
- Low
- Medium
- High
- Very high

76.How do you think the market will develop in the near future?

77.What is the success formula of your company in the solar irrigation sector?

78.How important are solar irrigation products for your company?

- Extremely important
- Somewhat important
- Neutral
- Not important

79.How much are you planning to invest in solar irrigation in the near future ?

- None
- Little
- Medium
- A lot

80.What would your company need to invest (more) in solar irrigation?

81.In your opinion what are the challenges of solar irrigation?

82.What do you think is needed to allow solar irrigation in Ethiopia to scale up?

83.Could you share contact details of other relevant actors in solar irrigation?

84.Do you have any solar irrigation product sheets available? If yes, please paste the link or send an email with attachment to berry@practica.org

G. INSTITUTION INTERVIEW GUIDE

Solar irrigation study - Institution survey

This study is organised in the frame of the GIZ Green People's Energy for Africa project, which aims to improve the conditions for decentralised energy supply in Ethiopia. The data collected through this survey will be used to develop recommendations for GBE to sustainably and effectively promote and stimulate the solar irrigation market in Ethiopia.

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The survey should take about 15-20 minutes to fill in. We thank you in advance for your collaboration. For questions, please contact Berry van den Pol through berry@practica.org

1.Name of your organisation

2.Your name (optional)

3.Your position

4.Your email (optional)

5.Your phone number (optional)

6.What are the focus themes of your organisation in Ethiopia?

7.Has your organisation been involved in any projects related to irrigation in Ethiopia in the last five years?

- ☐ Yes
- ☐ No -> go to question 9

8.Could you please list the main irrigation projects in Ethiopia in which you have been involved?

9.Has your organisation been involved in any project related to solar irrigation in Ethiopia?

- ☐ Yes
- ☐ No -> go to question 38

Section 2 Details of solar irrigation projects

Please answer the following questions for the project in Ethiopia with the largest solar irrigation component.

If you have worked on multiple solar irrigation projects, you can enter key details of other projects at the end of this section.

10.Name of the project

11.Start year

12.End year

13.Donor

14. Involved government institutes

15. Other partner organisations

16. Role of your organisation

17. Regions in which solar irrigation activities were implemented

G. Amhara
H. Oromia
I. SNNP
J. Tigray
K. Gambela
L. Somali
M. Afar
N. Benishangul-Gumuz
O. Harari

18. Woredas in which solar irrigation activities were implemented

19. Could you name the companies from which you purchased the pumps?

20. What were the principal water sources?

- ☐ unknown
- ☐ deep borehole
- ☐ shallow borehole
- ☐ hand dug well
- ☐ river
- ☐ lake
- ☐ other

21. What was the principal solar pump brand used?

- ☐ unknown
- ☐ Lorentz
- ☐ Grundfos
- ☐ Dayliff
- ☐ Sunflo
- ☐ Futurepump
- ☐ Sunculture
- ☐ other

22. What was the main type of water distribution system in the gardens?

- ☐ unknown
- ☐ earthen canals
- ☐ spray cans or buckets
- ☐ hosepipes
- ☐ sprinklers
- ☐ drip

- ☐ other

23. What was the main farm type supported with solar irrigation?

- ☐ communal gardens
- ☐ household gardens < 0.1 ha
- ☐ smallholder private farms < 1 ha irrigated
- ☐ commercial farms > 1 ha irrigated
- ☐ other

24. What was the main target group for solar irrigation?

- ☐ rain-fed farmers
- ☐ farmers irrigating manually
- ☐ farmers using fuel-powered pumps
- ☐ other

25. How many farmers have benefited from the solar irrigation pumps?

26. What was the arrangement with the farmers when supplying equipment?

- ☐ donation
- ☐ donation with in-kind contribution from farmers
- ☐ donation with some financial contribution from farmers
- ☐ loan: equipment cost paid back by farmers over time
- ☐ other

27. What is the total number of solar pumps distributed in the project?

28. What was the estimated total cost of the solar irrigation equipment in the project? (excluding water source and fencing)

29. What was the estimated total area (ha) covered by solar irrigation in the project?

30. What was the total estimated cost for planning and design of the solar irrigation systems in the project?

31. What was the approach towards maintenance and sustainability?

32. Was the introduction of solar irrigation successful? Why (not)?

33. What were the main lessons learnt?

34. How does the success of solar irrigation differ between farmers with different characteristics? (think about gender, experience, age, etc.)

35. Has your organisation done a cost/benefit analysis for solar irrigation?

- ☐ Yes
- ☐ No -> go to question 37

36. What was the average return on investment time (in years)?

37. What other solar irrigation projects has your organisation been involved in? Please mention:

- project name
- period
- woredas
- number of solar pumps distributed
- type of pumps

Section 3 Looking ahead

38. Is your organisation planning any solar irrigation activities in the near future?

- ☐ Yes –> go to question 40
- ☐ No -> go to question 39

39. What are the reasons for not engaging in solar irrigation? -> then go to question 44

40. What are the reasons to engage in solar irrigation?

- ☐ environmental sustainability
- ☐ water efficiency
- ☐ reducing farm production costs
- ☐ durability of equipment
- ☐ supportive enabling environment
- ☐ large demand by farmers
- ☐ other

42. What will be the main farm type to support?

- ☐ communal gardens
- ☐ household gardens < 0.1 ha
- ☐ smallholder private farms < 1 ha irrigated
- ☐ commercial farms > 1 ha irrigated
- ☐ other

43. What will be the arrangement with the farmers when supplying solar irrigation equipment?

- ☐ donation
- ☐ donation with in-kind contribution from farmers
- ☐ donation with some financial contribution from farmers
- ☐ loan: equipment cost paid back by farmers over time
- ☐ other

44. What are the main challenges related to solar irrigation?

- ☐ Technology
- ☐ Finance
- ☐ Supply chain
- ☐ Enabling policies
- ☐ Knowledge and skills
- ☐ other

45. What developments are needed to allow solar irrigation in Ethiopia to scale up?

46.What will be the best model to expand solar irrigation?

- Government subsidies
- Credit supply to farmers
- Credit supply to suppliers
- Empowering cooperatives
- Focus on commercial farms
- More donations / aid projects
- other

47.Could you share contact details of other relevant actors in solar irrigation?

48.If you have any relevant documentation to share, please fill in the link below, or send an email with attachment to berry@practica.org

PICTURES

Amhara – Fogera woreda

Amhara – North Mecha woreda

Oromiya – Bora woreda

SNNP – Alicho Wuriro woreda

SNNP – Hawassa Zuria woreda

SNNP – Sankura woreda