INTERMEDIATE-DEPTH SOLAR PUMPING IRRIGATION SOLUTIONS FOR SMALLHOLDERS IN THE NIAYES REGION

Final report

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The multidisciplinary team in charge of this study carried out by the PRACTICA Foundation:

- Stephan Abric, senior expert in small scale irrigation, main author,
- Gert Jan Bom, senior expert in innovative technologies, and Berry van den Pol, young expert in solar irrigation, in charge of the technical backstopping and quality insurance
- Youssouf Diallo, senior expert in irrigation technologies, and Papa Magatte Ly, young expert in solar pumping, in charge of the complete monitoring at field level

Intermediate-depth solar pumping irrigation solutions for smallholders in the Niayes region

Final report

Solutions de pompage solaire pour l'irrigation à des profondeurs intermédiaires pour les petits producteurs de la région des Niayes

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Table of contents

List of figures

List of tables

ACRONYMS

TA	Technical Assistance
AUMN	Association des Unions Maraichers des Niayes
CILSS	Permanent Interstate Committee for Drought Control in the Sahel
DC	Direct current
ECOWAS	Economic Community of West African States
DC	Direct Current
DGPRE	Directorate of Management and Planning of Water Resources
GSM	Global System for Mobile communications
HCD	Human-Centered Design
TDH	Total Dynamic Head
IFPRI	International Food Policy Research Institute
IMWI	International Water Management Institute
MPPT	Maximum Power Point Tracking
PV	Photovoltaic
REGIS-ER	Resilience and Economic Growth in Sahel – Enhanced Resilience
SMEs	Small and Medium sized Enterprises
USAID	United States Agency for International Development
VAT	Value-Added Tax
VSEs	Very Small Enterprises
2iS	Sahel Irrigation Initiative

SUMMARY

The aim of the activity was to test the feasibility of intermediate-depth solar pumping solutions for irrigation[1] in the Niayes region in Senegal that can meet the needs and expectations and address the constraints faced by smallholders in cultivating agricultural land in areas where the water table is too deep for motor pumps.

When water is located at a maximum depth for surface pumping with a motor pump (8 to 10 m), farmers must go through a technological step leading to the choice of solar electric pumping to increase the potential of irrigable land that has hitherto not been exploited. However, smallholders (those with an irrigable area of less than 0.5 ha) do not have the financial capacity required to access the conventional solar pumping solutions available in the Senegalese market. A study conducted by PRACTICA Foundation[2] in collaboration with Global Good[3] determined that there is a market for low-cost solar pumps that can pump water to the surface from between 7 and 20 m below the surface (potential of 13,000 ha) that require a small initial investment and have low operating costs, and have sufficient daily pumping capacity to ensure the profitability of an irrigated area of between 2,500 and 4,000m^2 planted with market garden crops, an area found to be the size of plots farmed by many smallholders. For this segment[4] of producers almost all the solar pump supply is of Chinese origin.

Research into the international market for pumps that meet the criteria specified in the study has resulted in the selection of nine solar pumps available on Asian e-commerce websites, and which have been lab-tested to compare the performance of each. The results of these lab tests reveal homogeneity in the performance of these pumps, with this performance consistent with manufacturer features. Subsequently, four of these pumps, representing a sample of existing pumping techniques (centrifugal, helical, piston and diaphragm), one of which was made in Burkina Faso (the mini volanta pump), were chosen for field tests with four pilot smallholders in the Niayes region. The tests focused on the components of the irrigation solution: a manual drilling, a solar pump that operates in the sun (without a battery) and a system for water application (drip system, spray tube, spray hose, mini center pivot system).

The Association de Unions Maraichers des Niayes (AUMN), an umbrella group of 18 unions and federations with 17,500 members, was the point of contact and the main operational partner in the implementation of tests with smallholders, who are at the center of the process to construct the solar irrigation solution. The solution is not only technological; it must also incorporate the conditions of an environment that is favorable to the development of a sustainable commercial chain in which the AUMN could play a leading role.

Technical parameters (flow, pressure, daily volume, irrigation and pumping time slot, irrigated surface area, duration of irrigation, voltage and PV power), economic parameters (production costs, amount harvested, sale of products) and behavioral parameters (change in perception, impact of the change) of four farms were monitored during a gardening season. The results

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[1] This concept refers to the relationship between the surface pumping limit and the need to use submersible pumping

[2] PRACTICA Foundation is a Dutch international NGO that specialises in the commercial development and application of appropriate innovative solutions in the water, energy and sanitation sectors - www.practica.org

[3] Global Good is the product of a partnership between an intellectual property firm and the Gates Foundation for the development of solutions to the main problems faced by underdeveloped countries - www.intellectualventures.com

[4] A market segment represents a distinct, homogeneous group of smallholders (clients)

obtained provided answers on the performance of solar pumps and more generally on irrigation solutions, information on the costs and profitability of different systems, to determine the driving forces behind and barriers to the adoption of solar irrigation solutions and to set out the opportunities for and challenges to the creation of a sustainable and inclusive commercial chain.

The choice of characteristics of solar pumps (daily volume, TDH, power of the generator) and performance resulting from the same depend on the yield of the shallow aquifer, which is limited in tests to 4m^3/h for a depth of 17m. Boreholes are made using manual drilling techniques to minimize the initial cost of the solution. Under these conditions, the average volume produced is 15m^3/day (2.5m^3/h at peak flow) with a dynamic water depth of 11m for the irrigation of a measured surface area of 3,000 to 3,500m^2, and just 2,000 to 2,500m^2 if pumping volume is limited to 10m^3/day (pumping with mini volanta piston pump). In addition, the results of the pilot not allowed to highlight a link between reliability and the origin of the pump. However, regardless of the quality of production and its origin, the pump chosen should be of a pumping system that is not sensitive to water quality (presence of sand in suspension), such as a helical or piston pump. Diaphragm pumps are not recommended for intensive use such as irrigation.
In addition, tests showed that 70% of water produced is directly distributed with efficient techniques for applying water to the plot without using an elevated storage basin (water tower). For around 6 hours a day, flow and pressure are sufficiently stable for the drip systems and spray tube, which operate at low pressure (2 to 4 m), to function correctly. When pressure is too low (in the early morning and late at night, or during cloudy periods), water is stored in small basins on the ground for irrigation with a watering can.

The solar irrigation solutions tested (manual drilling, solar pumping, water application) are profitable for market garden crop production and there is a very fast return on investment (after two to three crop seasons) due to low water production costs. However, the initial cost of acquisition remains high (FCFA 1.5 – 2.5 million / USD 2,585 – 4,374). The cost of replacing the pump is equal to around 20% of the cost of the solar solution, which will have a lifespan of less than four years, and even less under certain conditions (duration of pumping, water quality). Therefore, it is important to keep the cost of the pump as low as possible and to encourage smallholders to make provision for its replacement. It is for this reason that pumps made in China for a third of the cost of their European rivals are of particular interest to smallholders.

Surveys and discussions reveal an erroneous perception of the performances and capacities of solar pumping which can hinder its adoption among local farmers. In the absence of advice, certain accepted ideas have seen early-adopting smallholders, who are often community leaders, choose the incorrect solar pumping solution. The resulting experience, which is spread by word-of-mouth to a whole area of production, can create doubt within the community of smallholders. In general, users of solar pumping are precocious innovators who want technology and expect good performance. Most remaining potential buyers seem convinced that solar pumping is an interesting option, but are waiting for practical solutions adapted to their requirements.

In Niayes, intermediate-depth pumping is an interesting niche market (potential of 6,500 hectares[5]). However, the dynamic is uncertain and not encouraging for domestic suppliers and investors in the private sector who are used to institutional markets created by projects, and not private ones. In contrast, the umbrella organization of farmer groups has expressed an interest in this market and seems able to direct an equitable commercial chain between Chinese manufacturers and end consumer smallholders. These organizations are prepared to work with all partners in the sector to the extent that products and services offered meet the requirements and are consistent with constraints faced by their members.

The development and dissemination of inclusive intermediate-depth solar pumping solutions for irrigation at affordable cost opens opportunities in CILSS countries to accelerate the increase in irrigated area supported by the Sahel Irrigation Initiative (2iS).[6] Groundwater reserve located no more than 20 m below the surface are of clear benefit in stimulating the development of small-scale agriculture in sub-Saharan Africa (Gowing et al., 2016).

[5] The depth of water considered for calculating the irrigable earth potential is 10 to 14 m. It takes into account the maximum depth (20m) that can be reached with the manual drilling techniques used in Senegal

[6] http://pariis.cilss.int/

1. Introduction

In arid parts of Africa, access to irrigation is considered a way to improve land productivity, increase the resilience of farming operations to the growing consequences of climate change, stabilize and increase incomes for farmers, reinforce food security and nutritional diversity and create employment. Moreover, irrigated land accounts for a small share of total land under irrigation in sub-Saharan Africa, where just 5% of agricultural land is irrigated (IMWI 2010) and where water shortages constitute an obstacle to growth and improvements in well-being.

In sub-Saharan Africa, at least 10 million farmers are located on land where groundwater is inaccessible at a reasonable cost due to the excessive water depth for surface motor pumps.
According to a study by PRACTICA and Global Good (2015), an estimated 60,000 smallholders in the six countries of the Sahel (Burkina Faso, Mali, Mauritania, Niger, Senegal and Chad) have irrigable land with groundwater between 10 and 20m below the surface. The inability to access this water at a reasonable cost hinders the potential for the production of market garden crops with high value-added.

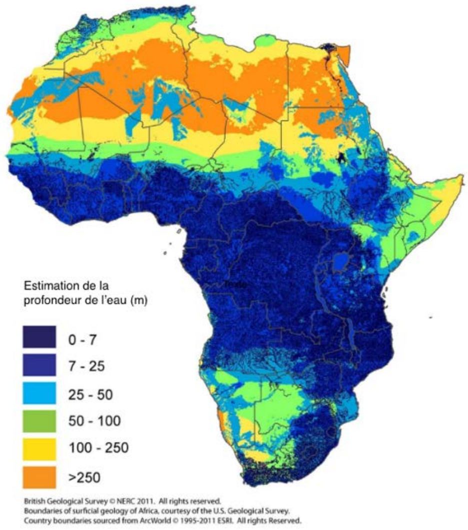


Figure 1 Estimate of depth of water in Africa

A number of recent publications highlight the potential for the exploitation of groundwater to expand areas under irrigation in sub-Saharan Africa:

- Groundwater up to 20m below the surface has the greatest potential to stimulate small farming operations in sub-Saharan Africa (Gowing et al., 2016).
- Renewable aquifers are under-exploited in the Sahel and east Africa (Altchenko & Villholth, 2015)
- Groundwater resources close to the surface represent a missed opportunity to intensify small-scale agriculture in a sustainable manner and concerns in relation to the low transmissivity of aquifers, the small yields of wells, the vulnerability of aquifers and conflicts over resources are exaggerated (Gowing et al., 2016).
- 83% of the potential for the development of irrigation lies in small-scale irrigation, which is more profitable given that it relies to a large extent on the capture of groundwater resources (African Dryland report, World Bank / IFPRI, 2014)

Solar pumping is considered as a very promising way for farmers to reduce their production costs and thus improve their living conditions. At present, apart from land irrigated with manual pumps, almost all land irrigated from groundwater is pumped using the fuel-powered surface pumps to a depth not exceeding 10 meters.
However, hydrological maps reveal vast productive aquifers that are slightly deeper (intermediate depth of 7 to 20 m), but which can only be reached with submerged pumps, the cost of which is prohibitive in the local market.

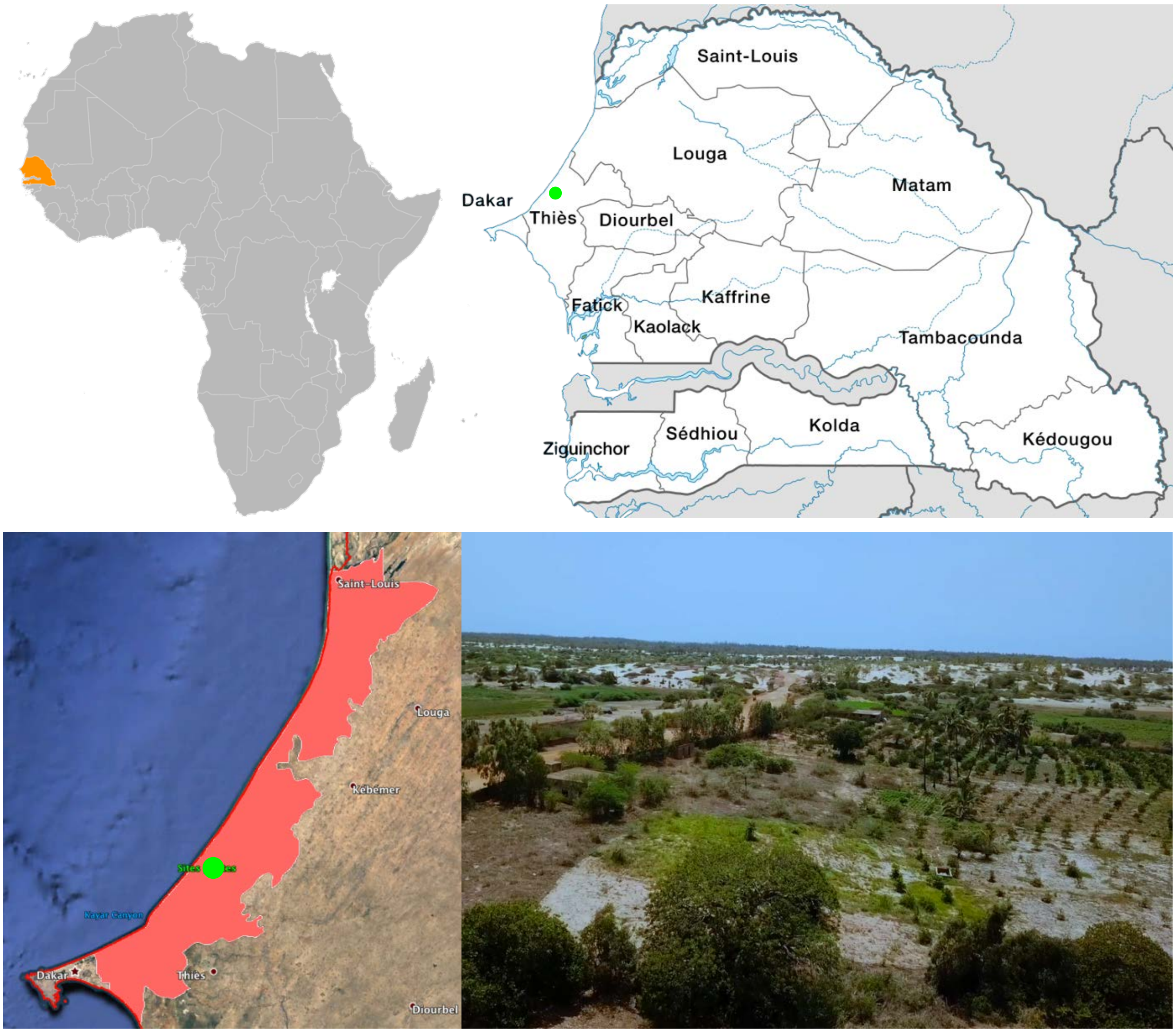


Figure 2 The location of Senegal in Africa, Senegal, areas of Niayes and a view of Niayes

Senegal is a very arid country with a rapidly-growing population, a large proportion of which already lives in cities, in particular the capital, Dakar, which has a population of more than 2.4 million. The Niayes region is a strip of land 10km wide and 150km long consisting of dunes and depressions that cover productive aquifers. Some 17,500 smallholder farmers grow vegetables on individual plots of land no larger than one hectare in area (and generally less than half a hectare) but produce on a total area of 5,000 ha. These dynamic, market-oriented farmers supply 80% of vegetables consumed in the capital, Dakar.

Almost all of these farmers extract water using fuel- or diesel-powered surface pumps. In practice, motor pumps can pump water up to a depth of 7m. To extract water below this level, some smallholders dig a counter well[7] to create favorable pumping conditions. The use of the motor pump with a counter well (see figure 3) up to a depth of 10 m is restrictive, with high operating costs. The sole alternative is to use a submerged electrical pump powered by a thermic or solar-powered generator. The cost of solar pumps in the local market and level of

[7] A contre puit is an excavation dug next to a well that reduces the pumping height of a surface pump (motor pump) to less than 7m.

technical expertise required to choose and install the equipment are barriers to the adoption of appropriate irrigation solutions.

Figure 3 Unproductive deep well with a motor pump, motor pump and counter well, counter well

In December 2015, PRACTICA, in collaboration with Global Good, conducted a study in Senegal to explore the market and determine the design criteria for a solar pump for irrigation when water is located at an intermediate depth of 7-20m. This study was motivated by the observation of the lack of an appropriate and affordable solar pumping solution for smallholders with less than 0.5 ha of irrigated land under cultivation. During its evaluation, PRACTICA, using local hydrological maps, revealed that an additional 13,000 hectares of land could be irrigated if water located at an intermediate depth could be pumped out. Moreover, surveys of farmers and representatives of smallholders' organizations confirmed that there is great interest in intermediate-depth solar irrigation solutions. Finally, the design criteria defined by the study indicate that the solar pump must be able to produce 10 – 12 m^3/day at a depth of 15 m, with an investment cost of 600 euros (pump and solar generator) to irrigate an area of 2,000 to 4,000m^2, depending on the season and frequency of irrigation.

Following this study, Niayes seemed to be the most promising area in which to experiment with intermediate-depth solar pumping solutions for irrigation for small-scale farmers, with prospects for development in other regions of Africa.
The piloting of the feasibility of different irrigation solutions has provided useful insights and prospects developed in this report, with the main parties presented below providing answers to the questions posed by solar pumping at these depths:

- The performance of solar pumps and irrigation solutions: Several solar pumping techniques exist, but which solutions are best suited to the pumping conditions faced by smallholders? In addition, information on the variability of the day-to-day performance of each pump (flow, pressure, daily volume) allows smallholders to choose and adapt water application techniques to the plot that are part of the solar irrigation solution. Are these efficient, low-pressure techniques compatible with solar pumping, and should water storage be used?

- Investment, costs and benefits of solar pumping: The solar solution must be affordable for smallholders, but at what price and for what profitability? Where in the commercial chain can steps be taken to reduce the cost of solar pumping? Are solar pumps made in China an alternative to their European rivals for smallholders?

- Driving forces behind and barriers to the adoption of pumping for irrigation: Everyone talks about solar pumping for small-scale irrigation, but very few in fact do it. The market is finding it difficult to develop and is in decline. How do smallholders understand and perceive solar pumping, and what are their expectations of it?

- Opportunities and difficulties in the creation of a commercial chain: The solution must no longer be solely technological: it must incorporate the conditions of an environment that is favorable for the development of sustainable commercial chains, on demand and at an affordable cost. Who are the players in this chain prepared to offer this service? Can smallholder organizations play a leadership role in the development of an equitable commercial chain, and are they prepared to do so?

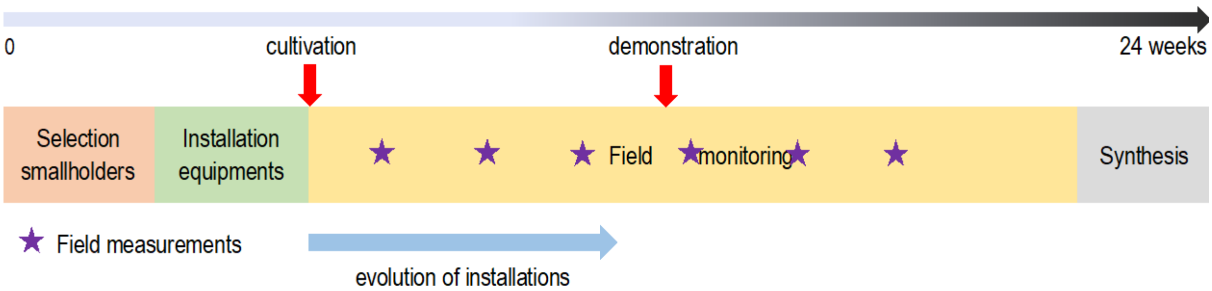
Finally, the report draws conclusions on the lessons learnt from the pilot and describes the approaches to scale up intermediate-depth solar pumping solutions for irrigation for smallholder farmers in Senegal and west Africa.

2. METHODOLOGY FOR TESTING SOLAR PUMPING SOLUTIONS

The pilot was conducted over 6 months (from mid-April to mid-October 2018).
The team consisted of:

- A senior head of mission expert in irrigation and innovative technologies: 30 days of TA over 6 months
- A junior specialist in solar pumping and irrigation: 10 days
- A senior specialist in irrigation technologies, involved for 5 months on a part-time basis
- A junior specialist in solar pumping (5 months on a full-time basis)
- A senior technician specializing in irrigated market garden crops, provided by the local partner for 5 months

Figure 4 Plan for implementation of the pilot scheme



21. Pump selection process and laboratory test results

The results of laboratory tests conducted in 2017 and early 2018 have been used to select the pumps tested in the field in Senegal.
During this period, a review of the international market (e-commerce) resulted in the selection of 10 solar pumps that met the criteria identified in the market study conducted at the end of 2015 with the financial support of Global Good:

- Volume of 10 to 12m^3/day
- Total depth of 15m (depth of water + depth available for irrigation)
- Price of 600 euros (pump and solar generator)

All of the pumps selected are manufactured in Asia except for the volanta pump, which was made in Burkina Faso.
The performance of some pumps (annex 2) was compared in laboratories in the United States and Netherlands:

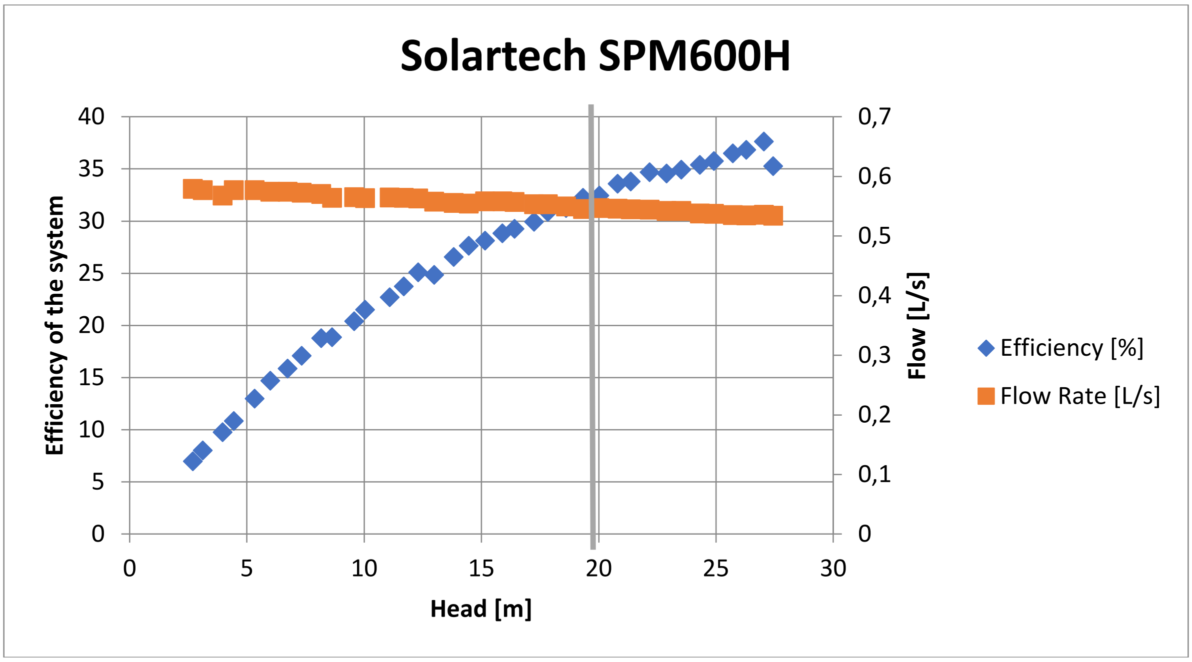
- The efficiency curve[8] of the pumping system
- The head curve as a function of flow[9]

[8] Efficiency (also referred to as performance) of the pumping system = Efficiency of motor X efficiency of pump. Efficiency of motor = mechanical power / thermic power. Pump efficiency = power output / power input
[9] This curve indicates the flow and head obtained at each point of operation

Table 1 Pumps selected for laboratory tests

Brand	Model	Type of pump
Ding Feng	3SSW4-33-48-550	Centrifugal
Jintai	JS4-3.0-60	Helical
SolarTech	SPM600H	Helical
Taifu	4TSC2.5-70-48/500	Centrifugal
Xinya	4SPS3/60-D36/500	Helical
Zhejiang Feili	4FLS1.5/25D36/500	Centrifugal
Difful	3DPC3-25-24-200	Centrifugal
Sunculture - Rainmaker	SP300	Diaphragm
Kerry	M123T-20	Centrifugal
Mini volanta		Piston

Figure 5 Example of efficiency and flow curve of the Solartech pump



The final choice of pumps selected for the pilot in Senegal was made with particular attention paid to a representation of different existing pumping technologies in the sample (diaphragm, piston, centrifugal, helical), not on the performance of the pumps. Except in the case of the diaphragm pump, the performance of each pump tested in the laboratory was relatively close to and consistent with that indicated by its respective manufacturers.

The mini volanta pump
In 2017, with the support of the REGIS-ER (USAID) program, PRACTICA developed a solar pump made by the Centre Sainte Famille in Burkina Faso. This pump was designed based on the criteria set in the study of the market in Senegal. The mini volanta is a piston pump without electronic power control device (MPPT), which makes it less sensitive to breakdown and easier to repair. In the event of a breakdown or malfunction, the other submerged solar pumps are difficult to repair in the context of rural west Africa.

Four pumps from these tests were selected for field tests in Senegal:
- The Rainmaker SP300 submerged diaphragm pump distributed by Sunculture in Kenya, but made in China
- The piston mini volanta pump made and distributed by the Centre Sainte Famille in Burkina Faso
- A centrifugal submerged pump, the Difful 3DPC3-25-24-200, made in China and available in Senegal
- A submerged pump with helical rotor made in China (the Solartech SPM600H)

22. Operational implementation

The partnership – To facilitate the execution of activities in the field, PRACTICA and the **Association des Unions Maraichers des Niayes (AUMN)**, whose registered office is located in Thiès, have signed a partnership agreement. The AUMN represents smallholders and other associated partners in activities.
PRACTICA is responsible for achieving the results of the pilot scheme and provides quality assurance for activities entrusted to the AUMN.

An essential partner
The AUMN is an umbrella group for 18 evolving farmers' unions and federations (17,500 members) in the areas of market garden crops, arboriculture and forestry. It is an essential player in the Senegalese horticultural community: it provides a framework for consultation, cooperation and negotiation between professionals in horticulture and agroforestry. Apart from its role as an umbrella, trade union and lobbying structure, the AUMN supports entrepreneurship among farmers to increase the profitability and efficiency of horticulture and agroforestry.

The choice of sites and smallholders – Four pilot gardens were selected according to several specific criteria:
- Depth of water 7 and 20 m below the surface
- The farmer must be the owner of his land
- The location of (and access to) the garden must facilitate monitoring and demonstrations
- The smallholder must be a private individual operator
- Minimum area of 3,000m^2 that can be developed

A partnership agreement (annex 18) signed between the pilot smallholders and the AUMN sets out the obligations of the smallholder during the whole pilot phase:

- To supply the labor required for the preparation and irrigation of a maximum area of 3,000 m^2
- To respect conditions of use of the equipment tested
- To follow the advice given for the preparation of the pilot garden and the management of the market garden crops under irrigation
- To give feedback on the equipment installed and propose modifications to the development under the supervision of the AUMN or its representatives
- To ensure the guarding and security of the equipment put at its disposal

Initially the four pilot gardens had to be located on two sites with different typologies. However, the unsuccess of a manual drilling on the first site redirected the choice of all gardens to the second site in order to avoid falling behind the implementation timetable and to limit the costs of the pilot.

Test protocol – For each garden, the preparations made and equipment installed were as follows:

- **A manual drilling,** 15 to 20 m deep and with a minimum flow of 4 m^3/h. Manual drilling are made by local businesses that master the technique.
- The installation of **a solar pump**, including the **generator**. All pumps are imported via air freight, while solar panels are purchased locally. The pump is installed by PRACTICA.

Table 2 Characteristics of solar pumps

Brand	Difful	SolarTech	Mini volanta	Sunculture
Model	3DPC3-25-24-200	SPM 600H		Rainmaker - SP300
Type of pump	Centrifugal	Helical	Piston	Diaphragm
Power (kW)	0.20	0.60	0.15	0.07
Sizing parameters of the pump				
Theoretical peak flow (m^3/h)	2.5	2	1.1	0.71
Theoretical max. volume (m^3/day)	17	16	9	6
Theoretical TDH (m)	15	15	15	15
Theoretical irrigable surface (m^2/day)	2,800	2,600	1,500	1,000

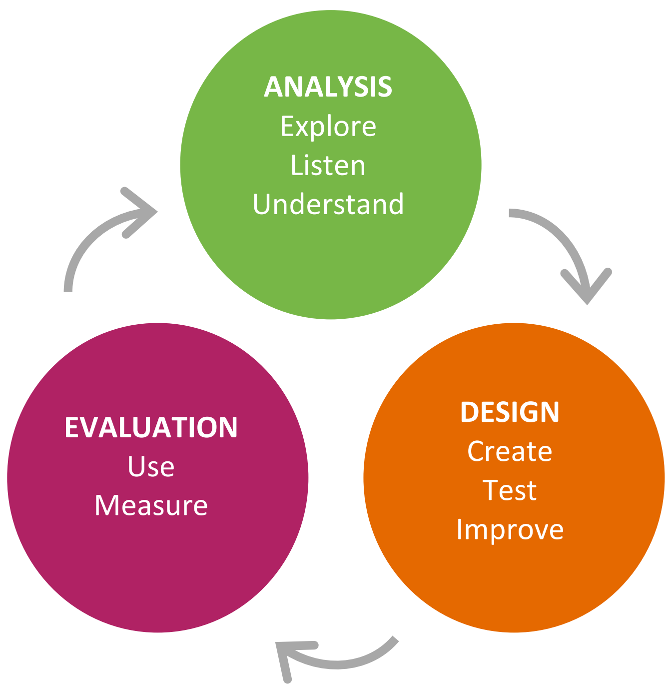
- The installation of **water application equipment**. Several low-pressure water application techniques have been tested to determine their compatibility with solar pumping and smallholder practices.

Table 3 Characteristics of water distribution systems

Type	Brand	Specification	Origin
Spray tube	San Fu	50m roll	Imported from Burkina Faso
Drip system	Nétafim	500m² kit	Purchased locally
Spray hose	None	25m roll	Purchased locally
Mini center-pivot system	None	Range 12m	Imported from Burkina Faso

Due to material reasons, not all techniques are systematically tested on all gardens and the solution may consist of a combination of irrigation techniques. The test is conducted over time, assuming a duration of 4 hours/day during which the pump produces sufficient flow and pressure to allow the various irrigation techniques to function under optimal conditions. The remaining water produced is stored in existing or new basins with a volume of 1.8 m^3 for manual irrigation of areas not irrigated during the day with a watering can, or is used the following day.

Formulation of the irrigation solution – In each garden, the development of the solar irrigation solution follows a **self-learning process** that consists of refining the technical solution to the requirements and practices of the smallholder (the HCD approach[10]), while considering the limitations on the performance of the solar pump tested and conditions for the use of irrigation techniques. This process is the driving force behind the development of the solution. It is carried out in three iterative phases, which are illustrated below.



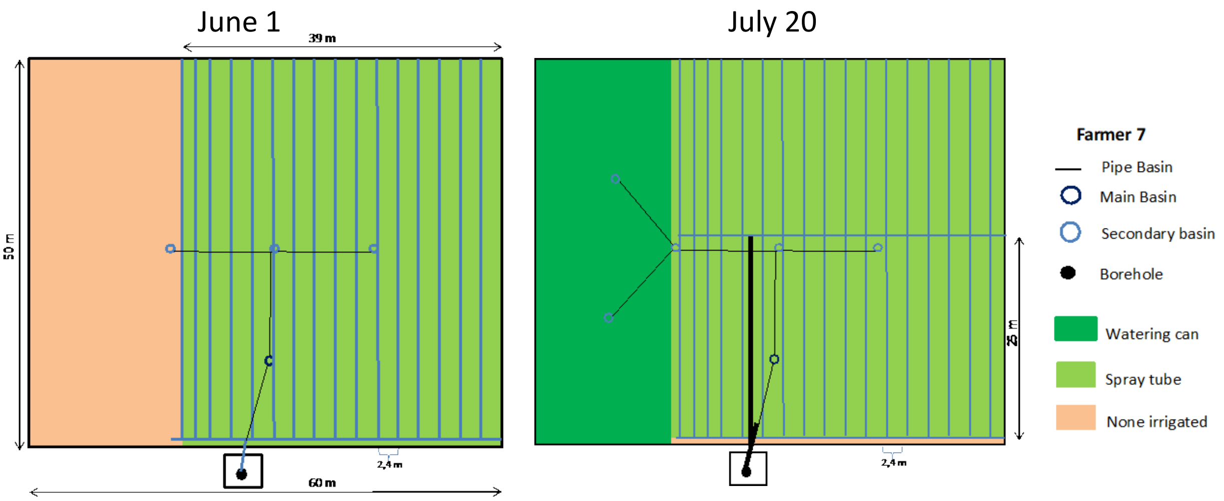
[10] The human-centred design approach (HCD) is an approach to the design of products and services that emphasises the "natural" needs and behaviours of people, rather than the characteristics of a product or the expectations of management figures who are at times far removed from reality.

Changes can be made to techniques for the application of water on a plot of land during the first 6 weeks. After each week, the smallholder assesses the technical performances recorded and the level of satisfaction with PRACTICA. A number of different options are possible:

- A reduction or increase in the area irrigated using the technique tested
- A change to the development plan or to the irrigation technique used
- The association of another technique with that already tested
- The abandonment of the technique and its replacement with another

The protocol in place allows changes to the development to ensure that the development meets the needs of the smallholder. It is also a way to adapt the development to the performance of equipment and to conditions in the environment that can be changed.

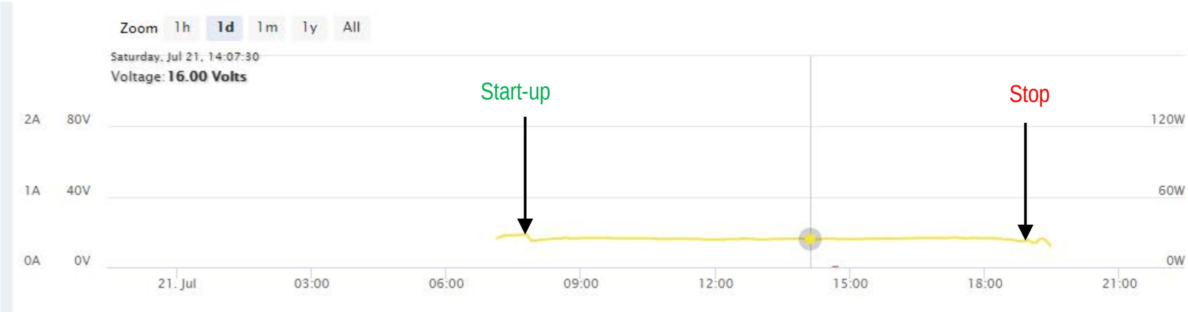
Below is an illustration of the evolution of the development of a garden between June 1 and July 20 (see annex 8). The initial length of the spray tube was reduced from 50 m to 25 m, in order to improve the uniformity of irrigation due to the reduction of insolation during the winter season.



23. Technical-financial follow-up and monitoring of the adoption process

Technical follow-up – Several parameters are measured in the field at regular 15-day intervals: flow, pressure, daily pumping volume, irrigation time slot, area irrigated and duration of irrigation. In total, six series of measurements were carried out over the course of the pilot.
Inconsistencies in the measurement of pressure were recorded in the last two series of measurements. These were caused by the onset of clogging in certain gauges.
A logger provides the voltage and power delivered by the panels to each pump on an ongoing basis. It also indicates the start-up and stop time of each pump.

Figure 6 Data collected by a logger



In practice, the data on two pumps (mini volanta and Sunculture) could not be used: there was a problem with the GSM network and/or a problem with the compatibility of the logger and/or an electrical problem.


Figure 7 Pressure, volume and flow measurements

Financial monitoring – This refers to the monitoring of expenses incurred in the purchase of agricultural inputs, payment for labor used on agricultural and irrigation operations, the purchase of packaging and production transport costs. The amount harvested and the sales are also recorded.

Monitoring of the adoption process – The introduction of new solar irrigation solutions necessarily requires an adaptation of existing practices and a change in the perception of techniques introduced.
This process of change, as well as the driving forces behind and the barriers to the adoption of solar irrigation solutions, is studied with the pilot smallholders and smallholders who do not use the solutions tested.

A questionnaire was formulated to monitor the **perception of solar irrigation solutions by smallholders**. It is addressed before installation (To), during use (To + 6 weeks) and at the end of the pilot (To + 15 weeks) to measure the change in the perception of these solutions among user-smallholders. Alongside this questionnaire, the study of the change in behavior is also interested in the **day-to-day agenda of each smallholder** from sunrise to sunset. A diagram sets out the time allocated to each event/activity (sleep, meals, rest, social or religious activities, irrigation, other economic activities, breeding, transport) that makes up a working day prior to the installation (To) of the irrigation solution and during its use /adoption (To + 6 weeks) (see annex 8).

3. THE PERFORMANCE OF PUMPS AND SOLAR IRRIGATION SOLUTIONS

"Solar-powered irrigation solution" is a term in the pilot that refers to a set of techniques (water capture, water extraction and water application) using solar energy, to provide a response to the issue of the practice of irrigation by smallholders (those who farm an area of less than 0.5 ha) when groundwater is at a depth of between 10 m and 15 m.

31. Water capture

Water capture techniques - To capture groundwater, the smallholder uses a concrete well or a borehole drilled manually. Manual drilling[11] are gradually replacing the concrete wells due to the fact that they are less expensive, easier to make and produce a greater flow with the use of motor pumps. Another alternative consists of installing a well point (see annex 12) inside a concrete well to increase its yield. However, manual drilling is not seen by the smallholder as a technique that provides access to water deeper below the surface, but as a means with which to obtain a larger volume of water with a motor pump when the water is shallow[12], no doubt due to the absence of suitable pumping solutions to reach these depths.

In Niayes and across Senegal as a whole, a number of very small enterprises (VSEs) engage in hand auger drilling (see annex 11) to capture water from groundwater aquifer with which to irrigate market gardening plots. A conic auger can penetrate soft layers of soil and remove materials from the drill hole. Upon reaching the aquifer, a cylindrical auger (bailer) fitted with a valve at the end brings material up to the surface with an up and down movement. The walls of the drill hole are held in place with temporary casing. Due to the wide drilling diameter (240mm drilling and equipment with a 200mm pipe), heavy equipment is used to put the metal temporary casing and bailer in place. In other countries in west Africa, the diameter of equipment used for manual drilling for irrigation rarely exceeds 120 mm. In Senegal, other manual drilling techniques (manual rotary, jetting, percussion) are little-known or not used.

Characteristics of manual drilling – Boreholes are drilled to a depth of 17 m at a cost of FCFA 300,000 / USD 520 (FCFA 17,647 /meter compared with around FCFA 60,000 /meter for a concrete well of 1.5 m to 2 m), a price that is consistent with the tariffs used by smallholders. The static level is between 9.5 m and 11 m below the surface, and the dynamic level during pumping does not exceed 1 m. The yield of drilling locations is 4.5 m^3/h. The minimum yield required was set at 4 m^3/h. One borehole was declared negative with a yield of 1.9 m^3/h, while another was stopped at 12 m due to the presence of rock.

The flow obtained are consistent with the hydrogeological context of the Niayes region. The capacity of the manual drilling or well is the main factor that limits the potential irrigable area. For reference purposes, the theoretical daily volume obtained through solar pumping for 6 hours/day at full power is equivalent to 27 m^3 / day, i.e. a maximum irrigable[13] surface of around 4,500 m^2/day.

The limited impact of the increase in irrigated areas on the aquifer

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[11] At the time of a market study conducted by PRACTICA in 2016, manual drilling was few or non-existent. The manual drilling market has experienced strong growth over the last two years.

[12] In Niayes, it is commonplace to see a motor pump connected to two parallel boreholes drilled manually.

[13] Average water requirement for market garden crops in Niayes: 60m^3/day/hectare or 6mm/day

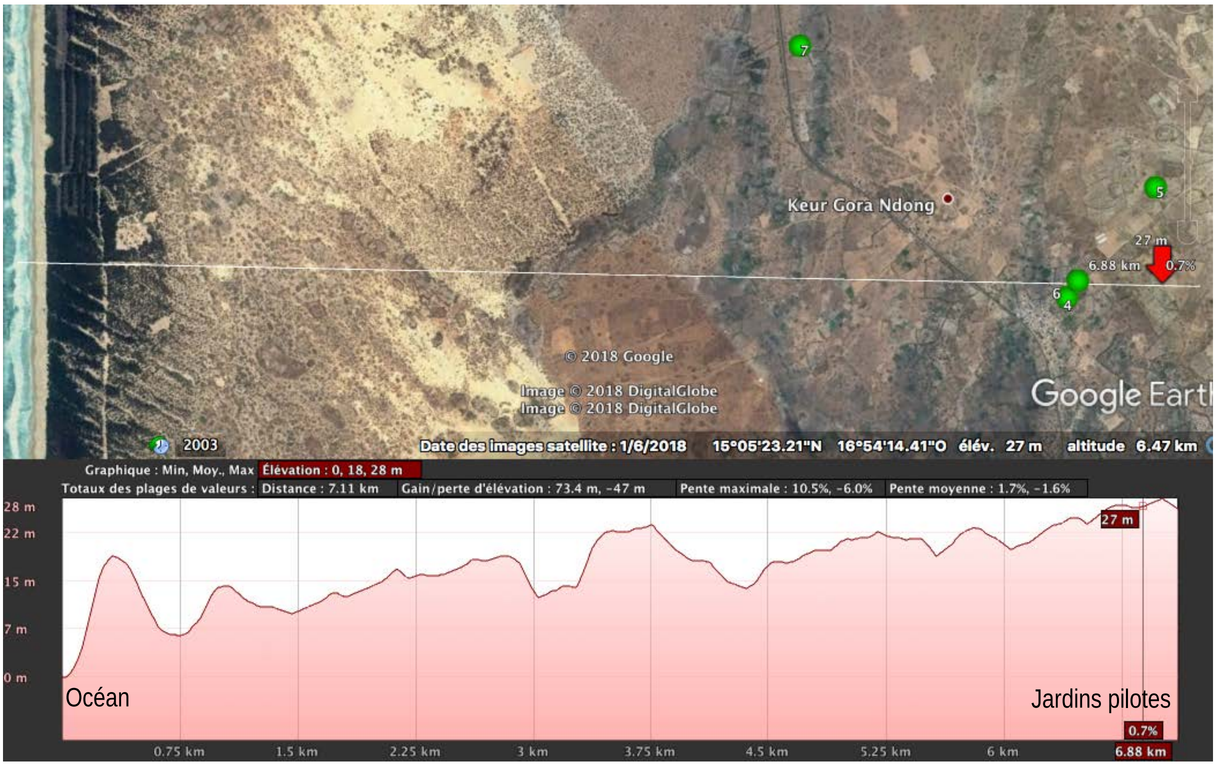
The quaternary aquifers exploited through the manual drilling have large water reserves: while their potential has been calculated 115,000m^3/day,[14] others have estimated daily production at 320,000 m^3/day. For an irrigated area of 9,067ha, irrigation water requirements have been calculated at 365,000m^3/day.[15] According to data collected, the balance of water extracted would be negative. In reality, it would seem difficult to arrive at an accurate estimate of the volumes withdrawn for irrigation due to the absence of reliable statistical data on areas of land irrigated using groundwater.

The DPPRE monitors changes in the piezometric level using a system of 114 piezometers, 54 of which are located in the sands of the quaternaries tapped by the manual drilling. The spacing of these piezometers is uneven, with a heavy concentration close to the catchment areas of the SONES and to leading industrial companies. Since the 1960s, data from only a number of projects have been available to monitor the evolution of the piezometric level over time. An analysis of changes in the piezometric level between 1962 and 2013 indicates that there has been a steady fall in the due to an extended period of rainfall shortages (DGPRE, 2014). The most significant falls could have been accentuated by the entry into service of large borehole and the commencement of chemical industrial activities. While there is no study or scientific publication that establishes a direct link between the increase in irrigated areas and the drop in the level of the aquifer, the use of water-efficient techniques is systematically recommended. Some irrigation water percolates into the ground to return to the aquifer, helping replenish the aquifer and maintaining moisture in the soil.

Land that could be irrigated using groundwater between 7 m and 20 m below the surface does not appear to represent a threat of over-exploitation of the aquifer due to the limited yield (4 m^3/h) and depth that could be reached (20 m) using manual drilling techniques, the high cost of solar pumping solutions and the necessary use of water-efficient irrigation techniques in order to maximize the area under irrigation. In addition, the main threat of over-exploitation is found in areas where water is shallow (less than 7 m) and easy to lift with motor pumps that can extract up to 15 m^3/ h with from two or three shallow tube well at the same time. In these cases, a fall in the level of the aquifer could, in specific geographical and hydrogeological areas, have a harmful economic or environmental impact: a reduction of moisture in the soil and the disappearance of certain plant species or cultivation practices and the premature drying-up of ponds and streams. There is no system to regulate and monitor volumes groundwater extracted for irrigation purposes in Niayes.

[14] Analysis of opportunities for the development of irrigation in the Sahel using groundwater, May 2015, PARIIS
[15] Study of the resource management plan of the sub-PMU of Niayes, Directorate of Management and Planning of Water Resources (DGPRE), August 2014

Figure 8 Pilot garden location map



The cross-section above illustrates the elevation from the ocean to the pilot gardens. The depth of water gradually increases with elevation and distance from the ocean. The pilot sites are located around 6 kilometers from the shoreline (as the crow flies).

Table 4 Performance of manual drill holes

No. of borehole	GPS	Static level (m)	Depth (m)	Dynamic level(m)	Flow (m^3/h)	Price (FCFA)
1	15.112019 -16.911534	9	12		Negative	50,000
3	15.11194 -16.91139	11.4	16.5		1.89	300,000
4	15.092780 -16.907500	9.5	16	10.3	4.5	300,000
5	15.094137 -16.900845	11	17	11.6	3.9	295,000
6	15.092439 -16.908562	10.1	17	10.8	4.5	295,000
7	15.11194 -16.91139	10	17	11.5	4.5	350,000

Prior knowledge of the capacity (yield) of the shallow aquifer exploited by manual drilling (depth of 20m) is an essential decision-making tool to choose how to use groundwater with solar pumping for the irrigation of market garden crops. The endogenous expertise of small manual drilling enterprises must always be explored and considered. At intermediate depths accessed by manual drilling (maximum depth of 20 m),[16] the maximum recommended area to be irrigated using solar pumping is 2,000 and 5,000 m^2/day.

Quality of construction & water quality – After two months of operation, maintenance on the pumps tested revealed the presence of sludge accumulated in the suction filter and in the wheels of the centrifugal pump.
One possible cause for this rapid scaling is fine particles of colloidal clay of a few microns. Several water analyses have revealed a high iron content in the water, which does not seem to cause clogging because iron cannot oxidize in water at the level of in the suction filter.

Figure 9 Sludge deposits on elements of the pump

Secondly, the installation of the gravel pack with the use of temporary casing is not appropriate and can lead to direct contact of the screen filter pipe with the aquifer and the migration of fine particles in the casing. Moreover, signs of premature wear have been found on the wheels of the centrifugal pumps, a sign of the presence of erosive materials suspended in the water.
These two hypotheses can be combined.

Outside the scope of the pilot test, the diagnosis of a broken-down Grundfos SP2 (solar) submerged pump by PRACTICA on the garden of a smallholder for two years revealed that the

[16] Yield between 2 and 4m^3/h for a borehole drilled manually 10 m to 20 m deep. According to the water resources management plan of the sub-PMU of Niayes (DGPRE, August 2014), the yield of the groundwater in most boreholes of the quaternary of the north coast is between 5 m and 10 m^3/h, with great variation in permeability due to clayey elements in the sandy aquifer.

wheels of the pump are completely clogged as a result of the accumulation of sludge, resulting in a problem with the electrics of the motor: the pump is beyond repair.

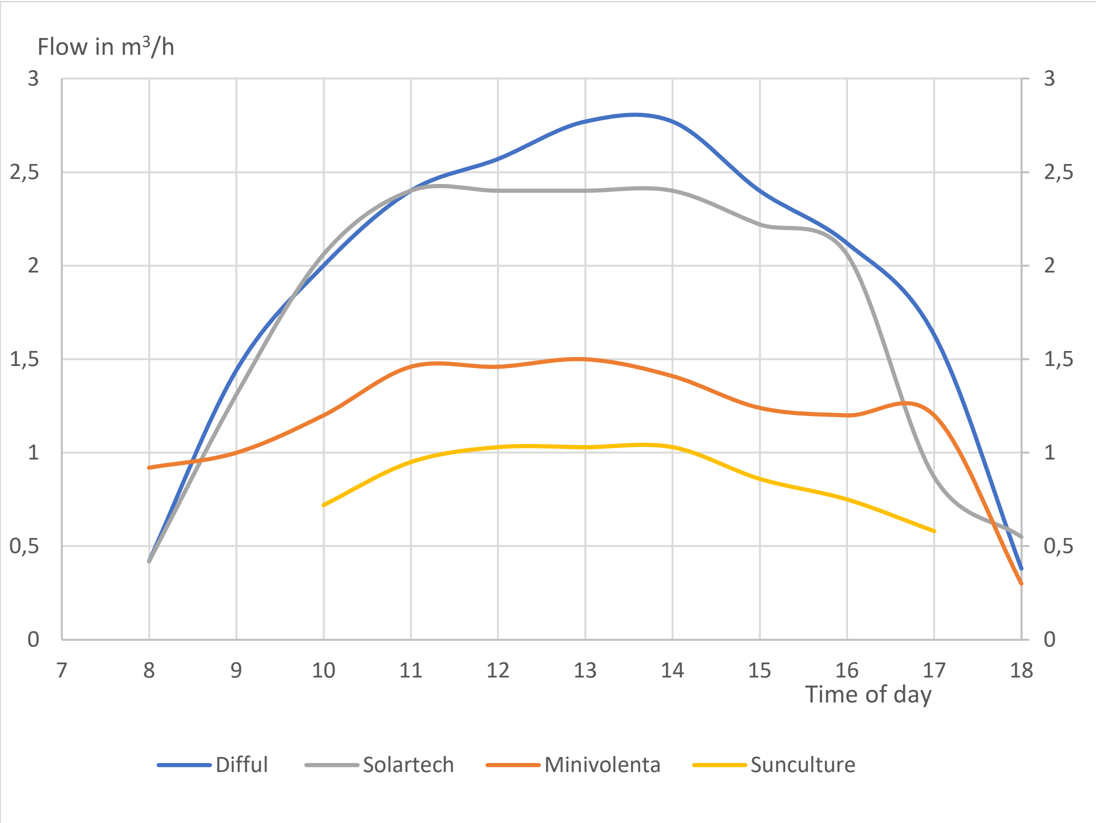
Centrifugal pumps are very sensitive to water quality and, in particular, to the presence of sand, which can significantly alter the lifespan of the pump. The lifespan usually permitted for solar-powered submerged pumps is 7 years. Under these conditions one should expect a shorter life (probably close to three years). Helical rotor pumps are less affected by water quality. Water quality has little or no effect on the lifespan of piston pumps.

32. The performance of solar pumps

Preliminaries – Photovoltaic panels transform solar energy into direct current (DC). Daily insolation is expressed in kilowatt hours/m²/day: 5.91 kWh/d/m² on average per year for the area of the pilot.[17] This value indicates the time the pump is operating at optimal power (in our case, around 6 hours per day). In fact, the power at which the pump operates varies over the course of the day in order to reach its maximum when the sun is at the zenith (between 12h and 13h).

The curve below illustrates the variation in hourly flow when measured in clear sky. In theory, the curve has a perfectly smooth bell shape; however, in practice one can see variations in insolation resulting from cloud cover.

Figure 10 Curves of variation of daily hourly flows



Description – The solar pumping systems tested during the pilot consist of several components:

o **A generator is** made up of photovoltaic panels PV with power peak of 100 to 150 watts, interconnected in series or in parallel[18] to reach the desired voltage and current according to the characteristics of electric motors. The current produced is a direct current.[19] The panels are attached to a fixed metal support at an incline of 15°. The support of the mini volanta and Sunculture pump can be adjusted manually to track the movement of the sun.

[17] Source: https://power.larc.nasa.gov/data-access-viewer/

[18] When wiring solar panels in parallel, the current is additive, but the tension remains the same. When wiring solar panels in a series the tension is additive, but the current remains the same.

[19] Abbreviated as "CC" in French and "DC" in English.

- An electronic device (**MPPT[20] or regulator**) that optimizes the operation of solar panels in order to provide maximum energy under variable insolation conditions. The mini volanta does not have an MPPT, but has a manual switch that allows two panels to operate in serial formation or in parallel, depending on the insolation, in order to optimize the power produced (and, in doing so, produce more water).
- An **automatic protection switch** off the pump in the event of a lack of water, and which is available only on Difull and Solartech pumps. In the end, they were not installed due to the fact that they were defective.
- **A battery**, in the case of the Sunculture pump, to store the excess energy from the solar panel that is not used to extend pumping hours. The system that regulates the charging and discharging of the battery was defective, and was removed from the system.
- **The pump with the motor** is submerged in water. In the case of the mini volanta, the motor is installed on the surface. It rotates a wheel moving up and down of rods, moving a piston that opens and closes valves. All pumps operate on direct current.

Table 5 Characteristics of solar generators

Brand	Diful	SolarTech	Mini volanta	Sunculture
Model	3DPC3-25-24-200	SPM 600H		Rainmaker - SP300
Type of pump	Centrifugal	Helical	Piston	Diaphragm
PV output (Wp)	100	100	150	100
Number of PV required	6	6	2	2
PV output installed (Wp)	600	600	300	200
PV connection	Series	Series	Parallel	Series
PV tracking system	No	No	Yes (manual)	No
MPPT regulation system	Yes	Yes	No (manual switch)	Yes
Dry running protection	No	Yes	No	No

Figure 11 Diffull, Solartech, Mini Volanta and Sunculture pumps

[20] This is a maximum power tracking device that allows a solar generator to operate as close to its optimal operating point as possible on an ongoing basis.

Flow and pressure – These parameters vary in a reciprocal manner throughout the day, as can be seen in figure 11. The optimum is reached when the sun is at the zenith, at around 13h. The power produced is considered stable for around 6 hours per day in clear weather. The pressure measured indicates the head (pressure) available at the outlet of the pump. This head is the pressure available for water application on the plot, but does not indicate the TDH[21] or pressure supplied by the pump. The pressure available is 3 to 4 m except for the Sunculture pump, which does not provide pressure of more than 1.5m.

At the depths considered, the flow and pressure of the diaphragm pump are insufficient for low-pressure irrigation equipment to function under variable insolation conditions. Land must be irrigated with a watering can, and water must be stored in basins.

The measures carried out highlight the influence of insolation (clear and cloudy skies) on the daily pumping volume. The pilot was conducted at the start of the winter season under frequent cloudy period: the most unfavorable time of the year for solar pumping. However, at no point was there significant disruption to irrigation due to cloud cover. There is no need for recourse to a buffer supply of water storage to deal with this constraint, which will not jeopardize the growing season.

Table 6 Peak flow and pressure measured

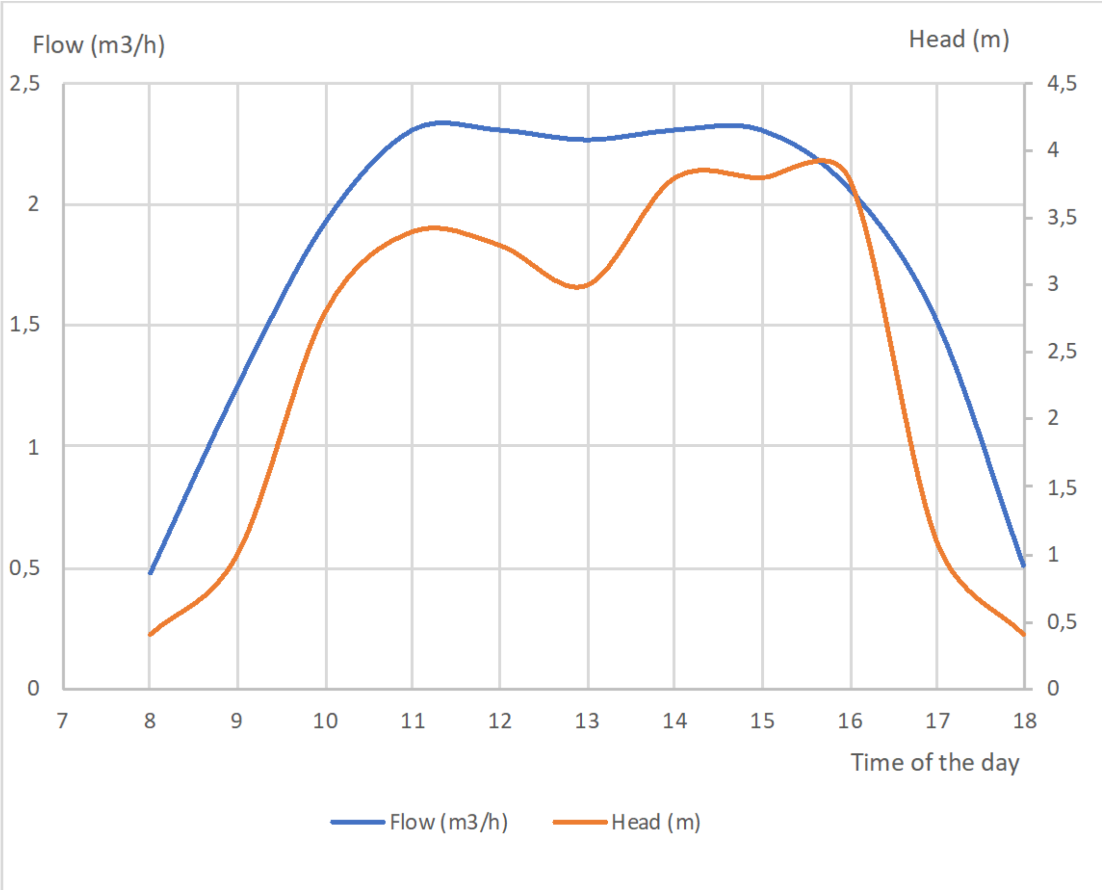
		Centrifugal	Helical	Piston	Diaphragm
Dynamic level (m)		10.3	11.5	11.7	10.8
TDH clear sky (m)		14.4	15.5	15.2	12.3
Peak flow at 13h (m^3/h)	Clear sky	2.8	2.6	1.5	1
	Cloudy sky	1.2	1.9	0.84	0.4
Variation in flow (f) insolation (%)[22]		57%	27%	44%	60%
Peak pressure at 13h (m)	Clear sky	4.1	4	3.5	1.5
	Cloudy sky	2.8	3	1	0.3
Variation in pressure (f) insolation (%)		32%	25%	71%	80%

It is difficult to compare with accuracy the influence of the variation in insolation among pumps based on observations of cloud cover, rather than direct measures of insolation. However, these results confirm the low sensitivity of helical pumps to the decrease of the insolation. The measures revealed a stoppage of the centrifugal pump (just a few minutes in the day) or late start-up in the presence of extensive cloudy sky.

[21] Total dynamic head = dynamic level (11m) + available pressure (3 to 4m)

[22] Percentage reduction in flow as a function of cloud cover

Figure 12 Flow and pressure curves for the Solartech pump (helical pump)



Helical pumps operate efficiently for a wide range of pumping conditions: the performance curve is constant as a function of rotation speed ranges. The maximum flow of this type of pump is around 3 m^3/h (around 18 m^3/day). Centrifugal pumps are used in wider flow ranges. The variation in flow can be smaller with the mini volanta pump (piston pump) if the photovoltaic panels are switched in parallel when there is cloud cover.

Daily volume and pumping time – It is interesting to note that the anticipated indicative volume calculated during sizing, based on the performance levels provided specified by manufacturers, lies within a range very close to the maximum volume and the average volume measured. On the other hand, when one compares the theoretical volume and the minimum volume measured, the difference is greater. However, at no point during the period of the pilot (May to August) was the volume of water produced insufficient for irrigation. The reduction in volume is offset by the reduction in evapotranspiration and in water requirements, and by the arrival of rain.

Table 7 Pumping volume

	Centrifugal	Helical	Piston	Diaphragm
Min. volume (m³/day)	11	13	8	3.5
Max. volume (m³/day)	18	17	10	7
Average volume (m³/day)	15.6	15.8	7.8	5.1
Theoretical sizing volume (m³/day)	17	16	9	6
Difference between theoretical volume and min. volume (%)	35%	19%	11%	42%

The type of pump has an influence on pumping time and an indirect influence on the daily pumping volume. Helical and piston pumps produce water from the moment they are switched on. The centrifugal pump produces water one hour after it is switched on, due to the fact that initially the motor does not have sufficient speed to start pumping.

Table 8 Pumping time and time slots

	Centrifugal	Helical	Piston	Diaphragm
Pumping start time	8h18 to 8h30	7h55 to 8h20	7h36 to 8h10	8h55 to 9h20
Pumping stop time	17h55 to 18h14	18h10 to 18h25	18h15 to 19h10	17h31 to 18h25
Average pumping time (h)	9.3	10.2	10.8	8.8
Switch on pump	7h10 to 7h31	7h50 to 8h12	7h36 to 8h10	
Switch off pump	18h30 to 19h07	18h05 to 18h14	18h15 to 19h10	
Average operating time (h)	11.4	10.2	10.8	

Pumping over the sun at continuous flow may seem slow (about 10 hours per day), it is compatible with groundwater resource of limited yield. Pumping with a motor pump and counter well (maximum depth of 10 m) meets the same constraints in terms of the duration of irrigation. Pumping with a motor pump rarely exceeds 15 minutes and recharge time is between 30 minutes and one hour, as the pump flow is greater than the yield of the well. The smallholder with a motor pump must store the water extracted, which will be applied manually.

Reporting of incidents – Incidents listed the pump or solar generator have been recorded and ranked according their severity level:

- Low: A minor breakdown that does not hinder irrigation; can be repaired by the smallholder.
- Moderate: A problem that affects irrigation; a repairman is required, with the problem resolved the same day.
- High: Irrigation is seriously affected; the intervention of a repairman is required and the breakdown will take more than one day to resolve.

Table 9 Follow-up of incidents

		Centrifugal	Helical	Piston	Diaphragm
Number of incidents recorded: Pump or solar generator	Low	1	2		
	Moderate				3
	High			3	2

Mini volanta – piston pump

The increase in the rotation speed of the motor following the change in the power of the generator (from 200 to 300 Wc) is the cause of breakdowns in the mini volanta (the rupture of rods in the threading). The diameter of these rods (8mm) was incompatible with the increase in speed. The solution: replacement by 10 mm diameter rods

Sunculture – Diaphragm pump

Upon the installation, the pump regulator was defective and eventually changed. The battery charge function was also defective. After 30 days of operation, a major breakdown caused by water entering the motor led to the replacement of the pump: it could not be repaired. Moreover, the brushes (carbon) of the motor showed signs of advanced wear.

Difful and Solartech – Centrifugal and helical pumps

The incidents reported relate to the accumulation of sludge in the suction filter of the pump during a maintenance operation. It is a problem associated with water quality, not the reliability of the pumps.

The mini volanta pump is still in its pre-production phase, when user feedback allows technical improvements to be made in order to improve the quality of production and the performance of the pump.
Doubts as to the reliability of the **diaphragm pump** were confirmed during the pilot. Originally, this type of pump, which is essentially a surface pump, is used to pump water (low flow) from the hold of a vessel[23] in a sporadic manner for short period of operation. A number of Chinese manufacturers copied the principle of this type of pump to sell pumps for irrigation that operate continuously for 7 to 8 hours per day. Moreover, this type of pump was not designed to be submersible, even though manufacturers have made efforts to ensure that the space between the motor and the pump is watertight. Commercially, it is an attractive pump due to the fact that it is compact, low cost and can pump water up to 60m. Its weaknesses: short life and low flow.

3.3 Application of water to the plot

Operating conditions – Each technique for applying water to the plot operates within a flow and pressure range. Depending on the position of the sun and insolation conditions (cloud cover), the flow supplied and pressure vary constantly throughout the course of the day. The choice of low-pressure techniques (2 to 5m) is compatible with the search for low TDH for solar pumping. A reduction in TDH can reduce the power required (and thus the cost of investment).

[23] http://shurflo.com/

Table 10 Conditions of use for water application techniques

Pump and method of irrigation	Flow (m^3/h)		Pressure (m)	
	Recommended	In practice	Recommended	In practice
Centrifugal- Drip system	1 (500m²)	1.2 to 2.8	2	1.5 to 5
Helical – Spray tube	1 (50m)	1.5 to 2.5 (2 x 25m)	2 to 4	2.1 to 5
Piston-powered – Mini center pivot	0.4 to 1.8	0.8 to 1.5	2	1.4 to 3.2
Diaphragm – spray hose[24]	1 to 2	1	2 to 5	1

Mini center pivot

The mini center pivot irrigation technique is not sufficiently mature in technical terms, and still presents constraints on its adoption by the smallholder. Substantial improvements are still required, but their integration was not part of the results expected by the pilot.

Spray hose

Achieving the performance limit of the diaphragm pump under the pumping conditions targeted by the pilot led to the rapid abandonment by the smallholder of spray hose. Similarly, other irrigation techniques are not compatible with the performance of this pump (Figure 8). In this specific case, land is irrigated using a watering can from storage basins filled by the solar pump. In addition, watering using a spray hose and the sole "non-automated[25]" technique tested, which is more sensitive to changes in pressure and flow during the course of the day. Watering with a spray hose does not provide significant value-added when compared with irrigation with a watering can and a basin, which is considered faster and more effective.

Spray tube

The mini volanta pump has insufficient flow to operate at least two line of spray tubes with a range of 25 m[26] : table 10 indicates a required pressure of between 1.5 and 2.5 m^3/h, when the maximum peak flow is 1.5 m^3/h. The centrifugal pump and helical pump provide sufficient pressure and flow.

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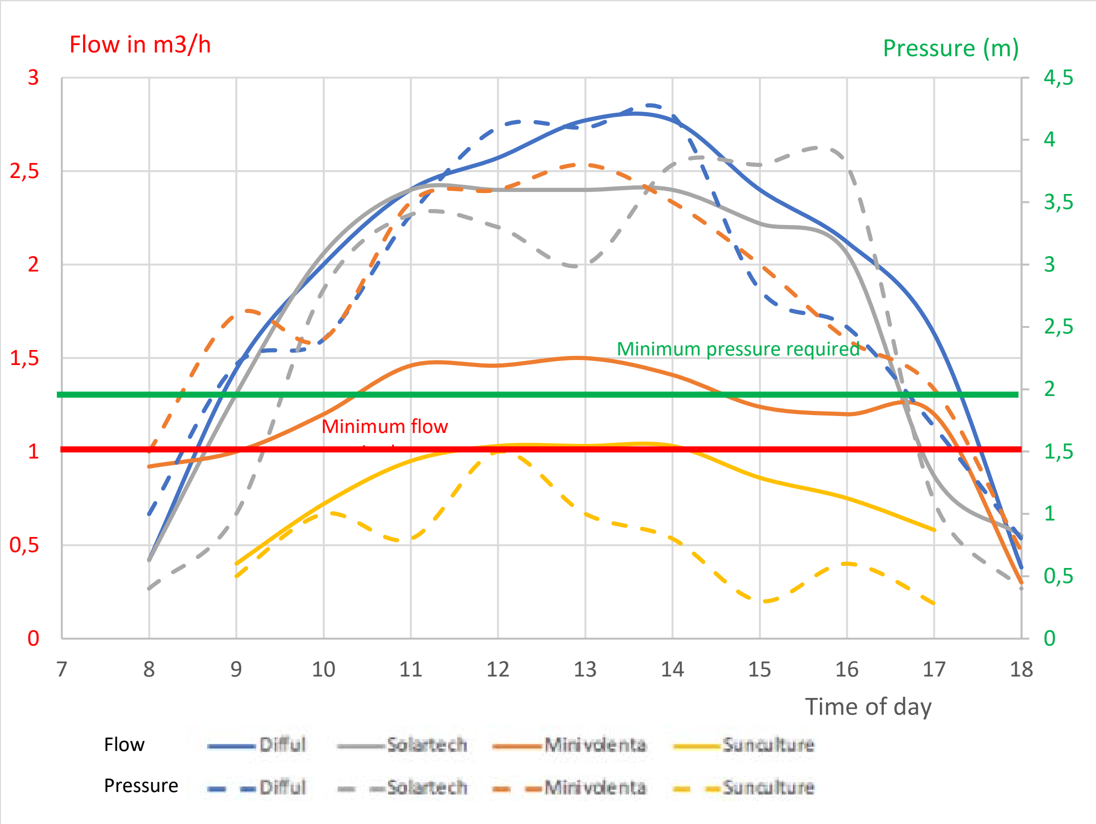
[24] The diameter used in the pilot is 20 mm. In Benin, 2 pipes are connected to a single pump for spray irrigation with a flow rate of 4 m^3/h and a pressure of 5 to 7 m. In the Niayes a 40 mm pipe is connected to the motor pump for irrigation with a spray hose

[25] A reference to the constant presence of labour to fit the pipe, when other techniques cover the whole surface. They are regulated by opening valves or moving irrigation equipment at regular intervals.

[26] The number and minimum length required to ensure the optimal effectiveness of irrigation

Figure 13 Flow / pressure curves and operating conditions of the drip system



Drip system

The drip system works with all pumps tested except the diaphragm pump. In Niayes, there are very few spontaneous adoptions of drip systems despite numerous attempts to introduce and develop them through various projects over the last five years. Apart from the initial purchase cost, water quality (water heavy in iron and/or fine colloidal particles) seems to be the main factor preventing its wider use: after a year or a few seasons of use, the transmitters soon clog up. During the five months of the pilot, a reddish deposit appeared in the primary and secondary pipes but without disturbing the irrigation significantly due to clogging transmitters drip or perforations in the spray tube. Each week, the sieve filter, and primary and secondary lines are opened up to flush accumulated fine particles. In addition, the variation in the pressure and flow of the pump during the course of the day allows the drip system and the spray tube operate at operating peaks higher than normal conditions of use, which could facilitate the removal of fine particles.

Water storage – In the early morning and late evening, when the flow and pressure are insufficient to operate for the various irrigation equipment, water is stored in low cost, interconnected circular above ground basins with a volume of 1.5 to 1.8 m^3 (around FCFA 20,000, or USD 35) distributed across the plot of land (see annex 15). The water stored is used for irrigation with a watering can. The optimization of investment in solar pumping depends on the optimal use of the volume of water produced in a day to irrigate the largest area. The use of efficient, water-saving techniques offers a good compromise between the low productivity of the aquifer and low level of water production during the day.

Table 11 Irrigation time and storage volume

Pump and irrigation method	Irrigation time (hours)	Irrigation time frame	Storage volume (m^3/day)
Centrifugal			
Drip system	3	12h to 15h (17h)	7.5
Watering can	3 - 4	8h to 12h or 13h to 16h	
Helical			
Spray tube	6 - 8	9h to 17h	5.6
Watering can	2	8h to 9h and 16h to 18h	
Piston			
Mini center pivot	4 - 5	9h to 14h	5.6
Watering can	3	15h to 18h	
Diaphragm			
Spray hose	0.8	14h to 15h	6
Watering can	2 to 3	16h to 18h	

The lessons learned from the pilot indicate a storage volume of about 30%[27] of the average volume produced by a solar pump over the course of a day: in the morning and the evening, when flow and pressure are too low. In other words, 70% of the volume produced by a solar pump in a day can be applied directly with efficient irrigation techniques without the use of water storage. The volume stored at the start and the end of the day is applied using a watering can. The peculiarity of this solution is the coexistence of two methods of irrigation (modern and traditional) allowing a maximum valorization of the daily volume produced and the flexible adaptation of the schedule of irrigation of the farmer according to the hazards. Indirectly, it is also a way to limit risk-taking in the event of poor performance and/or the absence of an appropriation of the new irrigation technique, facilitating the reestablishment of the previous irrigation technique (watering can).

Irrigation time – Caution should be exercised in the interpretation of recorded irrigation times as they depend on many parameters: area, insolation, techniques used, stage of crop growth, rainfall, volume of water stored the day before

[27] This is the optimum ratio obtained from pilot tests on an irrigated area of 3,000 m^2: 2,000 m^2 drip or spray tube, with the remaining 1,000 m^2 irrigated with a watering can with water storage.

With the use of water-saving techniques, irrigation time is 6 to 8 hours per day, in a time range between 9h and 17h. Before and after this time, water is stored in basins for irrigation with a watering can. The duration of irrigation can appear long but compatible with a limited yield of the water resource.

Irrigated area – In order not to skew[28] the results, and to be able to draw general lessons, the analysis focuses on drip system and spray tube. It is important to draw a distinction between the area irrigated each day and the total irrigated area due to the frequency of irrigation: it is two days (one day in every two) for irrigation with a watering can and one for other techniques.

Table 12 Irrigated area measured

Pump and irrigation method	Max. irrigated area (m^2/day)	Frequency of irrigation (day)	Total irrigated area (m^2)
Centrifugal	2,150		
Drip	1,400	1	2,900
Watering can	750	2	
Helical	2,520		
Spray tube	2,040	1	3,000
Watering can	480	2	

Tests for compatibility between the performance of pumps and the operating conditions of techniques for the distribution of water on the plot reveal several variations of irrigation solutions. Table 13 sets out the areas irrigated each day and the total areas irrigated using different solutions in order to maximize the daily volume produced by each pump.

Table 13 Total irrigated area per solar pump

	Centrifugal	Helical	Piston	Diaphragm
Total irrigated area (m^2)	3,500		2,250	Not applicable
Drip (m^2/day)	2,500		1,500	
Storage irrigation with a watering can (m^2/day)[29]	500[30]		350	
Total area (m^2)	3,000		Not applicable	Not applicable
Spray tube (m^2/day)	2,000			
Storage irrigation with a watering can (m^2/day)	500			

[28] Irrigation using a spray hose has been abandoned within a very short space of time and mini center pivot irrigation technology has not been sufficiently developed
[29] Frequency of irrigation: 2 days (one day in every two)
[30] The total volume stored is 5.6 m^3 in three basins of 1.8 m^3

79% of smallholders who participated in demonstration sessions expressed an interest in the solar irrigation solutions presented and, more particularly, in the one integrating the use of spray tube (see annex 17) with the submerged centrifuge or helical pump.

The optimal area irrigated each day is between 2,500 and 3,000 m^2, i.e. a total irrigable area of 3,000 to 3,500 m^2 with solar pumps that produce 15 to 16 m^3/ day at a dynamic depth of around 11 m and an aquifer whose yield is limited to 4 m^3/h.

Figure 14 Mini center pivot, spray tube, spray hose, drip

4. INVESTMENT, COSTS AND BENEFITS OF SOLAR PUMPING

4.1 Investment in the solar-powered irrigation solution

Total cost of investment – The costs indicated in table 14 reflect the investment required for each irrigation solution consisting of a manual drilling, a solar pump and a water application system. The diaphragm pump (Sunculture), spray tube and mini center pivot irrigation have been ruled out, either due to their unsuitability for the context of the pilot or due to the fact that at this stage, they are not considered sufficiently technically developed.

Table 14 Cost of solar irrigation solutions, inclusive of taxes

<table>
<tr><th></th><th>Centrifugal (15 m^3/j)</th><th>Helical (15 m^3/j)</th><th>Piston (8 m^3/j)</th></tr>
<tr><td>Manual drilling (FCFA)</td><td>300,000</td><td>300,000</td><td>300,000</td></tr>
<tr><td>Pump (FCFA)</td><td>348,000</td><td>732,000</td><td>1,012,000</td></tr>
<tr><td>Solar generator</td><td>538,000</td><td>538,000</td><td>270,000</td></tr>
<tr><td>Area irrigated (m^2)</td><td colspan="2">3,500</td><td>2,250</td></tr>
<tr><td>Drip (FCFA)</td><td colspan="2">768,200</td><td>497,400</td></tr>
<tr><td>Irrigation using a watering can (FCFA)</td><td colspan="2">87,500</td><td>58,333</td></tr>
<tr><td>Total (FCFA)</td><td>2,041,700</td><td>2,425,700</td><td>2,137,733</td></tr>
<tr><td>Cost FCFA/ha</td><td>5,833,429</td><td>6,930,571</td><td>9,501,036</td></tr>
<tr><td>Cost FCFA/m3</td><td>136,113</td><td>161,713</td><td>267,217</td></tr>
<tr><td>Area irrigated (m^2)</td><td colspan="2">3,000</td><td rowspan="6">Not applicable</td></tr>
<tr><td>Spray tube (FCFA)</td><td colspan="2">324,300</td></tr>
<tr><td>Irrigation using a watering can (FCFA)</td><td colspan="2">87,500</td></tr>
<tr><td>Total (FCFA)</td><td>1,597,800</td><td>1,981,800</td></tr>
<tr><td>Cost FCFA/ha</td><td>5,326,000</td><td>6,606,000</td></tr>
<tr><td>Cost FCFA/m3</td><td>106,520</td><td>132,120</td></tr>
</table>

Depending on the solar irrigation solution used, the minimum initial investment required is in a range of **FCFA 1.5 million and 2.5 million (USD 2,585 to 4,374) for an irrigated area of 3,000 to 3,500 m^2,** a cost per hectare of FCFA 5.1 million to 5.6 million (USD 8,850 to 9,720). With reference to the north of Benin,[31] investment in solar irrigation from groundwater under the same conditions (depth, volume and surface) is more than FCFA 10 million/ha (USD 17,350/ha). In the Sahel, the investment cost for irrigation of all types of farm is between FCFA 2 million and 11 million /hectare[32] (USD 3,450 to 18,960/hectare).

In the solution that requires the smallest investment (the Difful pump), the share allocated to the mobilization of groundwater (manual drilling + solar pumping) reaches 67% to 74% of the overall investment. Geological conditions that are favorable to the use of manual drilling

[31] Capitalisation on solar pumping for small scale irrigation in Benin – PRACTICA, financed by Belgian technical Cooperation, November 2017

[32] Strategic framework for agricultural water in the Sahel / Sahel Irrigation Initiative – World Bank (September 2017)

techniques maintain this item at an acceptable level, reducing the overall cost of the solution. With motorized techniques, the cost would be much higher (FCFA 3 to 4 million, or USD 5,250 to 7,000).

Table 15 Percentage of the cost of different components of solar irrigation solutions

	Drip	Spray tube
Manual drilling	15%	19%
Pump	43%	55%
Water application	42%	26%

The initial cost of groundwater mobilization with solar irrigation is closely associated with the cost of water abstraction, in particular techniques used according to geology. Manual drilling techniques should be used systematically were the geology is favorable.

Cost of solar pumping – All tested pumps were imported by air freight, as they were not available locally. In addition, a wide range of solar panels is also available on the Dakar market. To assess the feasibility of a solar pump supply chain, the components of the cost of importation were studied to estimate the sale price.

Taxes and customs duties on imports

Taxes and customs duties payable on the importation of solar pumps stand at 31%[33] of the declared purchase value. This is the rate applied for the import of three pumps from the Netherlands shipped via DHL, including customs clearance. A pump shipped from Burkina Faso via Air Burkina Express was exempted from VAT. The conditions for the application of this exemption are vague.

Table 16 Percentage of cost of taxes and customs duties

Customs duties	10%
Statistical charge	1%
Solidarity community levy	1%
ECOWAS community levy	0.50%
VAT	18%
Total taxes and customs duties	31%

Transport

The cost of air freight bound for Senegal varies according to the country of import:

- China about FCFA 10,000/kg (USD 17/kg)
- France (Europe) about FCFA 15,000/kg (USD 26/kg)
- Burkina Faso FCFA 2600/kg (USD 4.50/kg)

[33] Table of duties and taxes https://www.douanes.sn/fr/node/722

The delivery time between pick-up and receipt, including customs clearance, is 7-10 days.

The cost of ship freight[34] from China is about FCFA 3.7 million (USD 6,380) / container of 20 feet (33m^3). It can contain around 200 solar submerged pumps (excluding solar panels), which represents a high initial investment of around FCFA 27 million[35] (USD 46,540). The time required for transport, customs clearance and delivery from China is around 5 to 6 weeks.

Margin of the retailer

The margin of the retailer is estimated using the sale price of solar-powered submerged pumps (from a different range of the pumps tested) imported from China by Senegalese retailers via the Chinese e-commerce website Ali Baba. The initial purchase price in China can also be easily traced online. Transport costs (freight by air) and import taxes are also known. Therefore, it is easy to calculate the margin of the main importer, which is **around 30%.** This rate may be higher for a secondary distributor (non-importer) and increase the cost of sale quickly.

Selling price

The starting point for calculating the selling price of the pumps tested, if they were to be marketed in Senegal, is the purchase price from the exporter. In the case of VAT exemption, the sale price could be reduced by 18%.

The mini volanta pump is not intended to be imported but manufactured locally, as it is the case in Burkina Faso. However, the technical development of the pump and of the manufacturing and marketing chain currently in place in Burkina Faso have not yet reached a sufficient degree of maturity to determine the most effective strategy for its dissemination on a regional scale.

Table 17 Estimated sale price of solar pumps

	Centrifugal	Helicoidal	Piston-powered	Diaphragm
Purchase price of pump for export	113,481	244,027	457,858	194,819
Air freight (China - Senegal)	78,715	157,430	60,000	157,430
Customs duties (31%)	35,179	75,648	141,936	60,394
Retailer margin (30%)	68,212	143,132	197,938	123,793
VAT (18%)	53,206	111,643	154,392	96,558
Sale price to client (FCFA)	348,793 (USD 605)	731,879 (USD 1,270)	1,012,124 (USD 1,736)	632,994 (USD 1,098)

As a reminder, the conclusion of the market study carried out by PRACTICA at the end of 2015 indicated a potential for the development of a solar pump capable of producing 10 to 12 m^3

[34] Price obtained from a Chinese supplier (September 2018) from the port of Shenzhen to the port of Dakar
[35] Pumps, transport and insurance, taxes and customs duties, delivery

day at a depth of 15 m with an investment cost of 600 euros, i.e. around **FCFA 400,000 (USD 689) for the pump and solar generator**. This maximum price was a response to the unaffordable cost of locally available pumps.

The prices of the most promising pumps tested (diaphragm pump excluded) were compared with other solar pumps of equivalent performance available on the local market and European manufacture, which are considered more reliable.

Table 18 Comparison of solar pumps tested with pumps available in the local market

Brand Pump model	Africa Sun ASP240	Lorentz PS2-150 CSJ5-8	Difful 3DPC3-25-24-200	SolarTech SPM600H	Mini volanta
Type of pump	Helical	Centrifugal	Centrifugal	Helical	Piston
Country of manufacture	France	Germany	China	China	Burkina Faso
Pump power (kW)	0.37	0.3	0.2	0.6	0.15
Installed capacity (kW)	0.6	0.25	0.6	0.6	0.3
TDH (m)	15	15	15	15	15
Volume (m^3/j)	19	10	18	17	10
Price of pump (FCFA)[36]	882,000	758,208	348,793	731,879	1,012,124
Price of power FCFA/watt	2,384	2,527	1,744	1,220	6,747
Solar generator (FCFA)	570,000	290,000	538,000	538,000	270,000
Price of energy FCFA/watt	950	1,160	897	897	900
Total price (FCFA)	1,452,000 (USD 2,519)	1,048,208 (USD 1,819)	888,537 (USD 1,542)	1,271,099 (USD 2,206)	1 288,871 (USD 2,236)

The main points to remember are the following:

o The cost of energy production is globally equivalent irrespective of the pump used: FCFA 900/kW (USD 1.55/kW) to 1160 FCFA/kW (USD2/kW) installed. The slight variation is due to the cost of installation and the cost of solar panel supports. In Dakar, the purchase price of the solar panel is between FCFA 410 (USD 0.70) and FCFA 530/W[37] (USD 0.91/W).

o For daily production of 15m^3 (3,000 to 3,500 m^2 irrigated), the Chinese-made Difful pump is one-third the cost of its European rival. In the case of an equivalent type of pump (helicoidal), the Difful pump is half the cost. If we compare the purchase cost per unit of power (watt), pumps made in Asia are around half the cost of those made in Europe.

o A daily volume of production (10 m^3/day) and at equivalent power, the mini volanta pump made in Burkina Faso is twice as expensive as a pump made in Europe. For this same volume of production, a submerged centrifugal pump made in Asia bought locally[38] is a third of the cost.

In all cases, the maximum amount of FCFA 400,000 (USD 689) for the solar pumping (pump and generator) is exceeded and seems difficult to achieve.

[36] Solar panels + outlet pipe + panel support + drill head + installation
[37] Prices collected from five suppliers in Dakar in April 2018: ISTC, Yingli Solar, AOTM and Énergie Solaire
[38] The Sunculture pump that broke down in the middle of a pilot was replaced with a pump bought in Dakar at FCFA 260,000 (USD 448): Feili model 3FLD2.7-22-24-180.

Table 19 Cost of solar pumping according to pumping volume

Irrigated area (m²)	2,000 to 2,500	3,000 to 3,500
Volume (m³)	10	15
TDH (m)	15	15
Power of panels (Watt)	300 à 400	600
Cost generator	300,000 to 400,000	600,000
Cost pump	250,000 to 300,000	300,000 to 730,000
Total cost (FCFA)	550,000 to 700,000	900,000 to 1.3 million

At the same levels of performance, pumps made in China are one-third the cost of their European rivals. For an area of 2,000 to 3,500m², the floor price of solar pumping is FCFA 550,000 (USD 948) and rises to a maximum of FCFA 1.3 million (USD 2,256). 72% of smallholders surveyed[39] at a demonstration session said that they were able to invest more than FCFA 500,000 (USD 862) in solar pumping.

The production of pumps in Africa for export to the sub-region does not appear to be commercially competitive against pumps imported from China. On the other hand, production of the mini volanta pump in China or India and its assembly in Africa should not be ruled out. The feasibility of this model is under analysis.

4.2 Costs and benefits of solar irrigation

Financial analysis is based on the study of a consolidated operating account based on economic data collected from the four pilot sites in order to identify trends or orders of magnitude with uncertain margins of profitability of solar pumping in the context of the study. This approach smooths out financial results that depend on a multitude of factors: phytosanitary problems, a mastery of cultural techniques, soil quality, the motivation of the smallholder and social events.

The solar irrigation solution chosen is the one composed of a manual drilling, the Difful submerged centrifugal pump and spray tube + basins for the irrigation of a total area of 3,000m². It is the most appreciated by smallholders and has very strong potential for development.

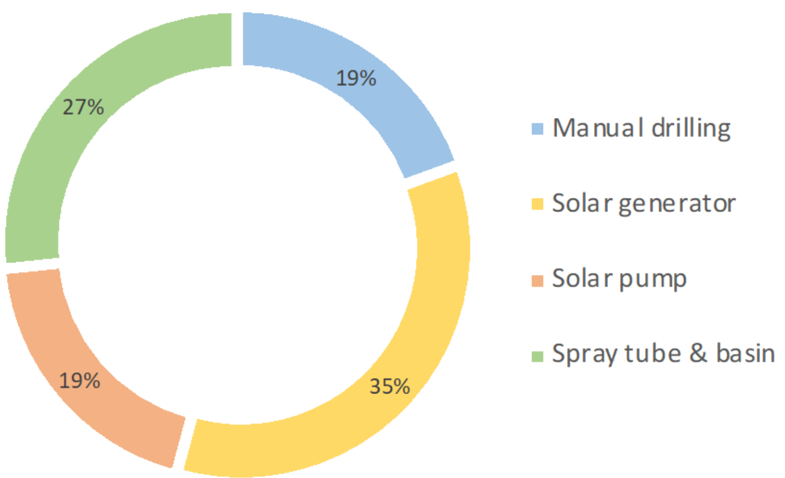
[39] A survey of 25 smallholders, with 63% declaring that they farm an area less than 1ha

Table 20 Characteristics of the solar irrigation solution

Water source	Manual drilling 17m, dynamic level 11m	
Pump	Centrifugal (Difful)	
Irrigation system	Spray tube	
Crops	Tomato, cabbage, eggplant	
Irrigated area	m^2	3,000
Duration of season	Months	4
Daily pumping volume	m^3/day	15
Total dynamic head	M	15
Investment		
Investment in manual drilling	FCFA	300,000
Investment in solar generator	FCFA	538,000
Investment in solar pump	FCFA	296,000
Investment in irrigation system	FCFA	411,800
Total investment	FCFA	1,545,800 (USD 2,664)

The pump and power regulator have a short lifespan (4 years) and their replacement is a priority: depending on the stage of development, a market garden crop cannot withstand the absence of irrigation for more than three consecutive days. The share of their replacement cost only represents 19% of total investment.

Figure 15 Distribution of cost of investment of the solar irrigation solution



Irrigation costs – 91% of irrigation costs consist of depreciation calculated from the expected lifespan of the various equipment (manual drilling, pump, solar generator, irrigation equipment). The determination of the lifespan depends on conditions and the specific context in which material are used: if water is not turbid, the lifespan is seven years. However, the presence of suspended material in wells or manual drilling used for irrigation could significantly alter this lifespan. Similarly, the duration of pumping and pumping volume can impact the renewal term. For irrigation, four years seems to be a realistic average depreciation period. Solar panels are generally depreciated over 20 years.

Note that the concept of depreciation is first and foremost an accounting concept, and has no impact on cash flow of the farmer. There is no obligation to make a voluntary provision or voluntarily saving for the renewal of equipment. However, mechanisms must be put in place to ensure the sustainability of the solution due to the small percentage of loans granted by financial institutions for investment (15% in Niayes[40]) in order to avoid falling into the virtuous cycle of expecting a grant or financial support from a project or development institution

Table 21 Irrigation costs

Maintenance and repairs		
Maintenance pump	FCFA/season	3,333
Maintenance of irrigation system	FCFA/season	1,000
Sub-total maintenance	FCFA/season	4,333
Depreciation of manual drilling		
Lifespan	Months	120
Cost of depreciation	FCFA/season	10,000
Depreciation pump		
Lifespan	Months	48
Cost of depreciation	FCFA/season	24,667
Depreciation solar-powered generator		
Lifespan	Months	240
Cost of depreciation	FCFA/season	8,967
Depreciation of irrigation system		
Lifespan	Months	48
Cost of depreciation	FCFA/season	34,317
Sub-total depreciation	FCFA/season	77,950
Irrigation costs	FCFA	82,283 (USD 142)

Production costs – For the most part, production costs consist of expenses incurred in the purchase of inputs. In this case, most of the labor provided is family labor. In Niayes, the use of seasonal labor is widespread. In reality, it resembles sharecropping[41], with an amount of about FCFA 600,000/season (USD 1,034/season) for the expected product on a garden crop area of 3,000m^2.

Table 22 Production costs

Seeds	FCFA	38,500
Fertilizer	FCFA	66,125
Chemicals products	FCFA	24,500
Temporary labor	FCFA	75,000
Total production costs	FCFA	204,125 (352 USD)

[40] Source: Horticulture census in Niayes, Directorate of Horticulture, 2012
[41] A sharecropper is a person who cultivates the land of a landowner in exchange for a share of the profit made on a harvest.

A voluntary decision has been made not to include family labor, so as to reflect the actual financial position of the smallholder.

Financial analysis – The calculation of the operating profit reveals a net margin[42] of around FCFA 1.5 million[43] (USD 2,585) on an area of 3,000m^2. Market garden activity is profitable with the solar irrigation solutions tested, but is a risky activity the income from which can vary greatly from one smallholder to another and from one season to another.

Table 23 Financial analysis

Financial analysis	FCFA	USD
Total operating costs	286,408	494
Operating revenue (turnover)	1,833,000	3,159
Gross margin	1,628,875	2,807
Net margin	1,546,592	2,666

The main problem is not the profitability of solar irrigation, but the capacity of the smallholder to mobilize the initial investment in the case of a new installation or the issue of financing the replacement of the "vital" installations of the solar irrigation solution: the pump. The low cost of pumps from China and the satisfactory results of operation recorded boost the investment effort of the smallholder and render the smallholder a more attractive business proposition for lending institutions, for the replacement of the pump, while at the same time reducing the amount to be financed "on credit".

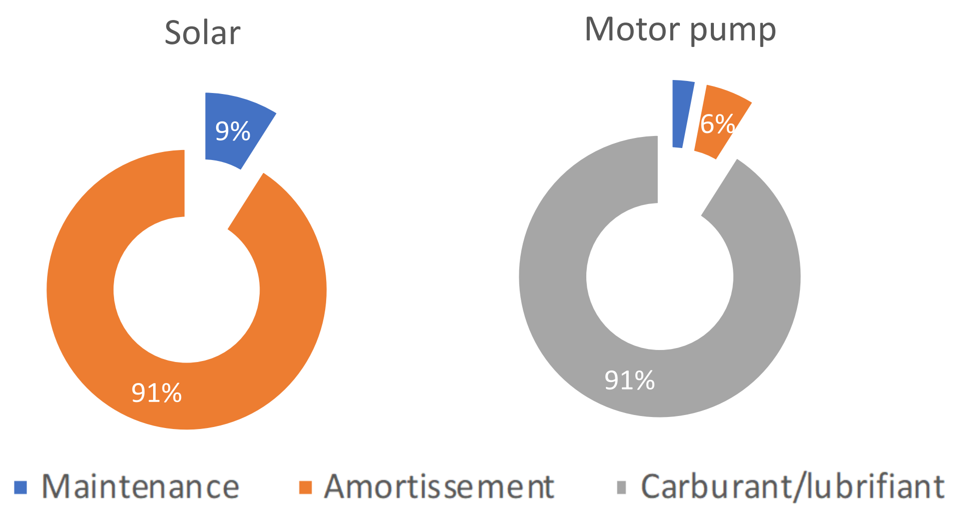
Comparison of thermic pumping and solar pumping – The use of a fuel motor pump for pumping water from a depth of 11 m for the exploitation of a new garden is not common due to the high operating cost (around FCFA 200,000 / USD 345/season). It also requires the smallholder to build a counter well, a well point and/or deepen the well: this represents investment estimated at FCFA 1.4 million (USD 2,413). The share of expenditure in water production between solar pumping and a motor pump is compared under identical pumping conditions: volume of 15 m^3/day and a TDH of 15 m (dynamic level of 11m + pressure of 4m), water application with spray tube and an area under irrigation of 3,000m^2.

Operation

The operating costs of a motor pump (fuel and lubricant) represent 91% of water production costs and 26% of total costs. In west Africa, in the absence of the use of efficient methods of applying water to the plot fuel and lubricant costs account for between 40% and 60% of total costs, hence the need for the smallholder to set up a rolling fund or access a short-term loan to meet these expenses. The attractiveness of solar pumping comes from the absence of operating costs, a very attractive argument **given that water produced is incorrectly thought of as free**.

[42] Gross margin - amortisations
[43] Around FCFA 900,000 in the case of crop-sharing

Figure 16 Comparison of distribution of water production costs



The costs of operating a motor pump for 2.5 crop seasons would cover the cost of purchasing a solar generator with lifespan of 20 years.

Depreciation

The cost of depreciation for solar pumping is equivalent to **91%** of the cost of water production, with no direct impact on the cash flow or financial flows of the operation, with no savings bond. The low cost of a motor pump (around FCFA 85,000, or USD 146) means that these pumps are easy to replace and has contributed to the growing development of the market for motor pumps, irrespective of the quality of the product sold. The limited capacity of the aquifer (between 2 and 4 m^3/h) at the pumping depths studied restrict the surface area that can be irrigated using a motor pump to that of a solar pump, whereas its performance potential could allow a doubling of its irrigated surface area.

The switch from motorized pumping to solar pumping at depths from 10 m and greater is due to:
- The maximum pumping conditions reached using a motor pump
- The high operating costs of thermic pumping
- An irrigable surface area limited by the yield of the aquifer
- A high investment for the abstraction of water (open well + counter well)

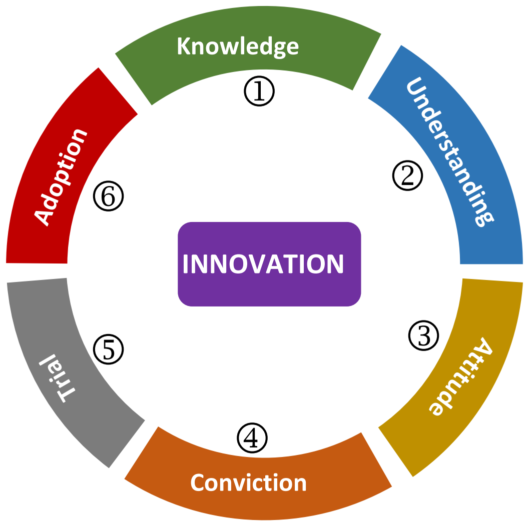
5. DRIVING FORCES BEHIND AND BARRIERS TO THE ADOPTION OF SOLAR PUMPING FOR IRRIGATION

51. General aspects of the adoption process

The adoption process can be described as a sequence of 6 stages followed by the client, from the stage of discovery to its adoption or rejection:

- Stage 1 - Knowledge: The client discovers the existence of the innovation through word-of-mouth or as a result of a visit
- Stage 2 - Understanding: The client identifies the main characteristics provided by the innovation
- Stage 3 - Attitude: The client assesses the pros and cons and forms a favorable or unfavorable opinion
- Stage 4 - Conviction: The client is convinced of the benefits and advantages of the product
- Stage 5 - Trial: The client decides to acquire the product
- Stage 6 - Adoption: Based on their experience, the client decides to adopt or reject the innovation. At this stage, it is the quality of the product that takes center stage.

Figure 17 Process for adopting an innovation



The driving forces behind and the barriers to the adoption have been studied with four pilot smallholders and in a sample of smallholders that do not use solar pumping. Due to the duration of the pilot and the methodology of the test, it was not possible to analyze the adoption process as a whole. The results of the various stages completed are summarized in the chapters below.

52. Smallholders that do not use solar irrigation solutions

During the pilot, 50 smallholders were invited to a demonstration session for the four solar irrigation solutions tested.

A questionnaire on the perception of solar pumping was addressed to a sample of 23 participants before (To) and after the demonstration (To + 1 week). While the participants selected have a varied profile, they share irrigated gardening practices in common.

Table 24 Profile of smallholders surveyed

Profession:	96% have gardening as their main activity
Irrigated area:	58% have an irrigated area of between 0.5 and 1ha, 38% an area of more than 1ha
Smallholder category:	67% consider themselves smallholders
Motivation:	60% wish to invest in the improvement of irrigation
Funding:	59% have a capacity of more than FCFA 500,000 and 23% of less than FCFA 300,000.

The analysis of the results of the survey relates to the first four stages of the adoption process, describing in detail the change in perceptions of solar pumping before and after the demonstration.

Knowledge - 73% of respondents declared that they had seen solar pumping on another farm. The survey does not contextualize the solar solutions tested and the extent of innovation in relation to their initial knowledge. **Solar pumping is not new to smallholder farmers.**

Understanding – The variability in the daily volume of water produced by a solar pump is effectively understood. Just 30% consider it necessary to have recourse to an elevated water tank, and 95% express the need to store water in basins on the ground. The questionnaire does not state whether or not the storage of water is intended for the operation of a water application system to maintain constant flow and pressure.

Most respondents (60%) consider a solar pump more powerful than a motor pump. The concept of power is subjective, and the questionnaire intentionally fails to provide further details to allow an expression of the perception of power. Surprisingly, the volume produced by a solar pump is seen as greater than that of a motor pump: 60% of those surveyed before and after the demonstration. One explanation given is the continuous operation of the solar pump throughout the day unlike the motor pump, which operates on an intermittent basis to allow water to rise in the wells.

Just 26% of the smallholders surveyed believe that a solar pump pumps water at a greater depth than a motor pump, with this figure rising to 66% after the demonstration. Pressure does not appear to be an element in the assessment of power of a criterion of choice of a pumping system.

The understanding of the main characteristics of solar pumping is rather confusing, or remote from its main advantage namely the ability to pump to a depth greater than motor pumps to irrigate plots where irrigation is impossible. The perception of solar pumping as a substitute for thermic pumping is well established. Smallholders tend to appropriate solar pumping by contextualizing it to their own experience acquired with motor pumps, while pumping conditions are totally different.

Attitude – Smallholders are aware that solar pumping results in a change in watering. However, opinions are divided as to the financial implications of this change, between inexpensive adaptations and in investment in modern, expensive equipment.

Fuel savings are the main impact expected of solar pumping, with all respondents citing this as a factor. Beliefs as regards the longer span life and more infrequent breakdowns of solar pumps compared with motor pumps are deeply felt, but just 10% of those surveyed believe that they are easier to repair. Labor savings are cited by 80% of respondents as an advantage of solar pumping; in this instance, it is water-saving techniques that are valued. It is difficult to assess the distortion and false ideas on the assessment of solar pumping depending on the irrigation technique used.

29% of respondents expressed an interest in reducing their carbon footprint via the use of solar energy for pumping.

Smallholders, agricultural technicians and decision-makers confuse solar pumping and water application techniques. One must be prudent when interpreting opinions. However, this confusion highlights the importance in a marketing or communications campaign targeting solar pumping to create a unique identity to what is called solar irrigation solution. As a matter of priority, the smallholder seeks out a relative advantage in financial terms with the reduction of fuel costs by considering solar pumping in a replacement of the motor pump.

Conviction – All smallholders surveyed have a good opinion of solar pumping (before and after the demonstration) and consider it beneficial to their operations. They recommend it to their entourage, in particular via word-of-mouth. 79% of respondents expressed an interest in one of the solar irrigation solutions presented.

In the last five years, solar pumping has penetrated the irrigation market but without unlocking it. Smallholders who use solar pumping are innovators or early "adopters" who want technology and expect performance. Most of the market of remaining smallholders, convinced of the merits of solar pumping, await practical solutions suited to their needs. This is the case with solar irrigation solutions tested or under development when water is found at an intermediate depth.

53. Pilot smallholders

A questionnaire similar to that distributed to smallholders who do not us solar pumping was addressed to four pilot smallholders. Unfortunately, the sample is too small to draw trends on the adoption process or changes in perception. The analysis does not provide new information, in particular given that the four smallholders were placed directly in test conditions. In parallel to this questionnaire the change caused to the day-to-day operations of the smallholder by the testing of solar irrigation solutions has been studied. An outline represents the time allocated to each event/activity (sleep, meals, rest, social or religious activity, irrigation, other economic activities, breeding, transport) that comprises a work day, before the installation (To) of the irrigation solution and during its use/adoption (To + 6 weeks).

Table 25 Daily schedule of activities before and after installation

Time of the day	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	0	1	2	3	4
Before																								
After																								

Sleep	Social activity	Other activities
Meals	Irrigation	Breeding
Rest	Other irrigation	Transport

The trends seen among the four pilot smallholders were as follows:

o The time devoted to irrigation is greater 1.5 to 3 additional hours.

o On the other hand, it is a less arduous task => a direct consequence of the use of automated irrigation techniques that require little labor. It is difficult to determine with any accuracy whether this increase in useful life is due to pumping when the sun is out or a result of the increase in area.

o There is no major change in the irrigation time slot, which is from 8h to 18h.

o On the other hand, the time spent on meals and rest, which is usually between 13h and 15h, is reduced by one hour. In reality, during the period considered "rest" time irrigation continues as it is automated, which is not the case with irrigation with a watering can.

Pumping over the sun at continuous flow (without batteries is not seen as a constraint that could have an impact on the increase in the duration of irrigation, if it is combined with efficient water distribution techniques. The benefit is the reduction in labor and in the arduousness of irrigation. The automation of irrigation allows irrigation to continue at the warmest times of the day, which are usually given over to rest.

Figure 18 Demonstration of solar irrigation solutions

6. OPPORTUNITIES AND DIFFICULTIES ASSOCIATED WITH THE CREATION OF A LINE OF BUSINESS

Solar irrigation is a profitable activity that offers a real market opportunity for the sale of appropriate products and services for smallholders. To do this, the private VSE or SME sector involved in the commercial chain must make profit to survive and ensure the sustainability of the chain. In a context where it is difficult to secure a balance between supply and demand are struggling to keep pace with the search for mechanisms and solutions for the establishment of a commercial chain, they must be supported.

61. Market analysis

Size of the market – The growth of the market for intermediate-depth solar pumps is heavily dependent on the existence of local skills for the opening of the manual drilling. In addition, given that the average depth that can be reached is rarely greater than 20m, thus reducing the favorable range of depth to between 10 and 14m[44] with solar pumps tested during the pilot. The potential area that can be irrigated using groundwater is without doubt less than 13,000 ha. Let us assume – conservatively - that this potential does not exceed 6,500 ha. A market estimate of **11,000 pumps** seems realistic, if the area irrigated by a pump is 3,000m^2 and the market penetration coefficient is 50%.

Market segment – With its 17,500 members, the AUMN offers a unique market less than 150 km from the capital Dakar. According to the most recent agricultural census,[45] the average area of land under cultivation is 0.7 ha and access to land is not seen as a major constraint. There is no competition in the acquisition of non-irrigated agricultural land that has no access to water, as it requires significant investment.

With access to credit granted to investment that does not exceed 15%, and in the absence of measures to encourage acquisition, the segment of the market at which solar pumping is aimed is limited to smallholders who are able to invest FCFA 0.5 million to 1.2 million (USD 862 to 2,068) in the solar pumping system alone. Of the sample of smallholders surveyed at the time of the demonstration, more than 59% said that they were able to invest more than FCFA 500,000 (USD 862).

[44] Minimum height in the borehole of 6m
[45] Horticulture census in Niayes, Directorate of Horticulture, March 2013

Changes in access to use of the land[46]
In the last 10 years, land pressure in Niayes has become a reality. Several factors have contributed to the depletion of land resources:

- Population growth
- The development of an intensive production system
- The urbanization of Niayes Centre to Niayes Sud
- Private investment in mining and agro-industry

Today, irrigation is practiced on the slopes of basins, once exploited during dry spells, thanks to the development of new pumping systems that require significant investment. Access to land use is highly dependent on the ability of farms to raise finance to access water or to acquire high-performance irrigation systems. The difficulties faced by small farmers in accessing credit for investment encourage the concentration of land ownership in the hands of economic actors capable of mobilizing the required finance.

The size of the market is interesting, but the uncertain and uninviting dynamic provide little incentive for private national investors accustomed to institutional market driven by projects and not private ones.

62. Actors of the commercial chain

There are three main categories of commercial actors with diverging interests and commercial strategy for the sale of promising intermediate-depth pumps.

Dealers who represent European brands of solar pump (Lorentz and Grundfos). These brands have built their reputation on the quality of the services and products sold, and on the renown of the brands they represent. They are based in Dakar, and are at times represented by secondary distributors in each province. Their ability to build up stock is a major asset. In general, these traders are generally hermetic to products of Chinese origin. Most sales to the market for irrigated agriculture target rich smallholders and projects supported by institutional funds.

The "Chinese" subsidiary, which is supported mainly by Senegalese dealers based in Dakar. There are no or few flagship Asian brands, and are often sold as unbranded products. Pumps are purchased online or through intermediaries that deal with China, and with whom they have established a relationship of trust. Product quality is very heterogeneous, and the quality of advice given on the choice or sizing of the pump uncertain. These dealers have a limited stock of pumps due to their limited cash flow, and to reduce the financial risk associated with an excessively large long-term immobilization of unsold products. They are highly capable of adapting to demand in the market.

[46] Text adapted from the final report contains changes in access to the use of land by poor rural populations in Senegal, IPAR, financed by IFAD & IIED, September 2015

Smallholder associations such as the AUMN can play a leadership role in the creation of a commercial chain for solar pumps. The AUMN is in the process of putting in place a central purchasing center for agricultural equipment in order to organize and centralize orders from its members. They have sufficient capacity to finance an aggregate purchase. One example of this is the importation from Europe of 260 tons of potato seeds for FCFA 180 million (USD 310,248). It is also a means by which to negotiate purchase prices with the main supplier and to reduce intermediaries.

The exporter is also an integral part of the chain. For pumps manufactured in China, e-commerce platforms have revolutionized commercial exchanges. However, it is difficult to find and identify useful information on them in order to choose the best pump from the multiple counterfeit products available. All pumps tested in the Netherlands and the United States were ordered on online platforms. Direct contact has been made via e-mail, WhatsApp and Skype with Chinese manufacturers. This is the prelude to any commercial relationship based on trust.

63. Conditions for the creation of a solar pumps business

Pumps manufactured in China - Pumps manufactured in China which have been tested (centrifugal and helical) appear to meet the expectations of smallholders, who have provided very positive feedback. To initiate the introduction phase and accelerate growth in sales of intermediate-depth solar pumps for irrigation, manufacturers must:

- Stimulate sales volumes without recourse to subsidies, so as to avoid creating an artificial bubble in demand that is detrimental to the sustainability of the distribution chain. The first adopters are among the innovators, a category of smallholder with the ability to invest in their operation to support the market introduction phase
- Reduce the cost of solar pumping so that it is accessible to the largest number of farmers during the growth phase
- Reduce the number of actors in commercial chain and approach the users' manufacturer
- Establish relationships of trust between the distributor and consumer and between the distributor and the importer

Among the potential commercial actors, the AUMN has the capabilities and beneficial experience to create an environment that fosters the emergence of a sustainable commercial chain:

- Orders can be grouped together until a sufficient volume to place an order via ship freight is achieved.
- The commercial risk of a slump in sales is low, since the pumps are paid for when the order is placed
- THE AUMN is the largest source of clients for solar pumps, with its 17,500 members generating 80% of the market for garden products
- The purchase price is half that charged by Senegalese dealers of pumps manufactured in Asia
- Farmers' organizations that are members of the AUMN cover the whole Niayes region that are in direct contact with members

To achieve the objective of a sustainable business of pumps made in China managed by the AUMN, several steps must be completed:

- The promotion of solar irrigation solutions via a marketing campaign targeting members of the AUMN
- Organize demand and srengthen the skills of the purchasing platform
- Establish a relationship based on trust with the Chinese pump-exporting manufacturer
- Provide training to AUMN partners who provide installation and repair services for solar irrigation solutions
- Import test of 200 pumps

The comparison of the calculation of the sale price of the centrifugal pump (Difful) in table 26 is based on the following assumptions: 1) the creation of a sustainable supply chain, 2) the disinterest of traders of European products loyal to a particular brand, 3) the significant financial risk of an order delivered by ship freight with the Chinese subsidiary.

Table 26 Comparison of assumptions for the import sale price of the Difful pump between AUMN and the Chinese subsidiary

Comments	AUMN	Components of price	Channel for import from China	Comments
Order for 120 pumps (- 20%)	92,000	Export purchase price	115,000	Order one pump
Ship container 20 feet	18,500	Freight	78,715	Air freight
31% purchase price	28,520	Customs duties & taxes	35,650	31% purchase price
No profit margin	-	Sale margin	71,103	30% purchase price + freight + taxes
10% export purchase price	9,200	Management fees	-	None
FCFA	148,720 (USD 256)	Client purchase price	300,468 (USD 518)	FCFA

The aim is to create and develop an equitable commercial chain:

- Create opportunities for small operations marginalized by a globalized conventional commercial system
- Improve commercial relationships – work for the social and economic well-being of small farmers and do not profit from them without their knowledge
- Transparency and responsibility in commercial dealings to do business with and for smallholders
- Payment of a fair price, adjusted to the context of smallholders

Pumps made in Burkina Faso – The export sale price of the piston mini volanta pump by the Centre Sainte Famille in Burkina Faso is not competitive for a number of reasons:

- High production costs: Labor and raw materials
- The absence of a national and regional commercial strategy
- Little entrepreneurial spirit
- A lack of visibility of the size and segment of the market

Since the launch of sales in Burkina Faso at the start of 2018, the line of business has proven difficult to put in place. The consideration of feedback from users has started and has led to improvements in the quality of the production and performance of the pump.

One alternative to the export of pumps from Burkina Faso would be to produce them in Senegal. This option poses significant challenges in terms of quality, the availability of raw materials, local skills, workshop equipment, the mobilization of funds for training and quality control in pre-production.
A production workshop located in Casamance has been created and several years ago, received training on the manufacture of the volante pump. However, the production site is far from the heart of the market. The continuation of this option cannot be guaranteed.

The outsourcing of production to India or China is currently being assessed, with assembly in countries in west Africa that have a promising market. An agreement in principle was entered into with FuturePump[47] for the production of the mini volanta pump at their factory in India. According to projections, this strategy could reduce the current purchase price from the smallholder by 30 to 50%. The next stages are:

- Investment in molds for the production of certain components
- Adaptation of the design to factory production
- The selection and evaluation of a business partner for assembly and marketing in a target country (such as Senegal)
- A small-scale test of the model (50 to 100 pumps)

[47] A company that sells the SF2 solar pump: https://futurepump.com/

7. WHAT LESSONS CAN BE LEARNT FROM THE PILOT FOR SCALING UP IN SENEGAL AND WEST AFRICA?

Pumps adapted to the context of small-scale irrigation

The international market is flooded with a multitude of solar pump manufacturers that can meet the needs of smallholders when water is located between 10 and 15 meters below the surface to produce a volume of 10 to 15m^3/day. Each pump is characterized by a pumping mode (diaphragm, piston, centrifugal, helical) that is more or less compatible with the targeted pumping conditions.

o Very often, shallow aquifer captured by wells or manual drilling contains sand or fines in suspension that reduce the lifespan of centrifugal pumps: pump wheels that have been clogged up or damaged due to wear. Lifespan is not doubt less than seven years, and probably close to three years. In this case, there should be a focus on helical pumps or piston pumps that are much less sensitive. The development of the mini volanta pump is aimed at piston pumping in order to incorporate the issue of the quality of groundwater captured for irrigation.

o Submerged diaphragm pumps, which are very popular due to their low cost, are not designed to operate for 7 to 8 hours per day, as is the case in irrigation. Originally, this method of pumping was designed for less demanding use. The technological transfer that occurred for irrigation has altered the reliability and lifespan of this type of pump.

o The maximum flow of helical pumps and piston pumps is more or less 2 to 3 m^3/h (10 to 18 m^3/day). However, it is perfectly suited to the limited yield. Centrifugal pumps can be used for larger flow ranges.

Pumping over the sun at continuous flow: An opportunity

o For 6 to 8 hours a day, 70% of daily production can be applied directly with the use of low-pressure, water-saving irrigation techniques. The remaining volume is stored in basins when flow and pressure are insufficient for the drip system or spray tube to function. Water stored in basins distributed across the plot of land is used for irrigation with a watering can. What makes this solution unique is the co-existence of two modes of irrigation (modern and traditional) that maximize daily production and allows the flexible adaptation of the irrigation schedule of the smallholder as a function of random events. Indirectly, it is a way to limit the risks incurred by the smallholder when adopting a new technique, allowing them to rapidly return to the traditional method previously used.

o Pumping over the sun at continuous flow is not considered as constraint that has an impact on the increase in the duration of irrigation if it is combined with efficient water distribution techniques. The benefit is the reduction in the quantity of labor and in the arduousness of irrigation. The automation of irrigation allows irrigation to continue at the warmest times of the day, which are usually dedicated to rest.

Risk of marginalization of access to solar irrigation solutions

o The main problem with solar intermediate-depth irrigation is not profitability but the cost of the initial investment, which is between FCFA 1.5 million and 2.5 million (USD 2,585 to 4,374) for the manual drilling, solar pump and spray tube, for an irrigated area of 3,500m^2.

70% of the cost of mobilizing groundwater resources (manual drilling and solar pump) at a depth of 10 to 15 meters is the minimum cost of investment to be met.

o While all indicators of financial analyses carried out on the profitability of market garden crops irrigated using solar pumping are positive, financial institutions provide smallholders with very little credit for investment (15% in Niayes). The fear is that access to solar irrigation solutions will be limited to smallholders or economic actors that are capable of mobilizing sufficient funds.

Manual drilling: Gateway to the development of solar pumping for small-scale irrigation

o The increase in irrigated area from groundwater through solar pumping is directly dependent on the existence of local capacities for drilling using manual techniques in order to keep the cost of investment as low as possible.

o The depth at which the development of the market for solar pumping for irrigation is aimed is the same as the average maximum depth that can be reached by manual drilling (20m). The feasibility map for manual drilling and yield of the aquifer would allow an evaluation of the size of the market for solar pumping and the potential irrigable area. It is a tool for strategic orientation on a national level, not an operational tool for implementation due to the variability in the quality of data available for the preparation of these maps.

o The poor quality of water obtained from manual drilling, which are used for irrigation, should have an impact on the orientation of the market towards more less sensitive pumping systems (helical and piston). Otherwise, the low cost of solar pumps available in the market will offset the impact of water quality on the lifespan of the pumps. The application of a strict construction or equipment standard for manual drilling will affect the cost of the borehole (increasing its cost by a factor of around five[48]), which is already considered too expensive by the mostly private clientele: in practice, probably not applied because it is not a constraint for a private market.

An advantage for pumps made in China

o At the same levels of performance, pumps made in China that have been tested are one-third the cost of their European rivals. This difference in price could be much greater in the event of the involvement of a direct importation subsidiary between an umbrella organization of smallholder farmers and the Chinese manufacturer.

o The solar pump is the vital element of the solar solution with a lifespan estimated at 4 years (or less, depending on water quality). Its replacement cost is about FCFA 300,000 (USD 517) for 15m^3/day at 15m. By way of example, it is three times the cost of a 3 CV fuel motor pump for an irrigated area of just 3,500m^2. Keeping prices as low as possible and a return in investment after one crop season should facilitate the renewal of the pump and compensate for its short lifespan. Given that the uncertain quality of water weighs heavily on the lifespan, it would be better to choose the cheapest pump on the market.

o Over the last 20 years, the price of motor pumps has been divided by six dues to the large-scale arrival of Chinese products on the African market, which itself is a consequence of the saturation of the Chinese market following the support given to the mechanization of Chinese

[48] The price of a manual drilling (depth of 15 m) adopting construction standard equivalent to mechanized borehole for drinking water is FCFA 1.1 millions. Price collected from a manual driulling companiy in Thiès.

agriculture in the 1980s. One can expect a similar downward trend in the cost of solar pumps over the next 10 years, driven by considerable investment by the Chinese government in green technologies. This investment will have an impact on the increase in demand and supply initially on the domestic market, then on the international market.

An incorrect perception of solar pumping among potential users

The concept of intermediate-depth pumping may be associated with a market segment corresponding to the transition from thermic pumping (motor pump) to solar pumping, motivated by the following factors:

- The maximum pumping conditions reached using a motor pump
- The high operating costs of thermic pumping
- An irrigable surface area limited by the yield of the aquifer
- A high investment for the abstraction of water (open well + counter well)

In this case, the aim is not to envisage the replacement of thermic pumping by solar pumping but to introduce a new technical option that will allow smallholders to **irrigate areas that are not currently developed using groundwater located at a depth that until now has been difficult to exploit.**

For this transition to be a success, an understanding of solar pumping by the smallholder is essential. The perception of solar pumping as a substitute for thermic pumping is well-established among smallholders. Understanding the main characteristics of solar pumping is somewhat confusing, and far from its main strength, i.e. the option to pump at a greater depth than motor pumps. Confusion between the advantages of solar pumping and those of techniques for the application of water on the plot is very common. This confusion highlights the importance in a marketing campaign targeting solar pumping to create a unique identity for what it known as a solar irrigation solution.

Over the last five years, with an acceleration since the COP21 in 2015, solar pumping has penetrated the irrigation market but without unlocking it. Smallholders who use solar pumping are innovators who want technology and expect performance. Most of the remaining smallholders, convinced of the merits of solar pumping, await practical solutions suited to their needs. This is the case with solar irrigation solutions tested or under development.

An importation business supported by umbrella farmer organizations

o Some well-established commercial players are reluctant to sell products of Chinese origin to preserve their image built on the sale of high-end products; others, who trade with china, seek a fast return on investment due to their very limited financial capacity to take a commercial risk to set up a pump subsidiary. Umbrella farmer organizations seem best-placed to establish an equitable commercial chain between Chinese manufacturers and end smallholder-consumers. The AUMN, for example, has experience of commercial exchanges with potato seed suppliers in France: 260 tons of potato seeds were imported for its members for more than FCFA 180 million (USD 310,248).

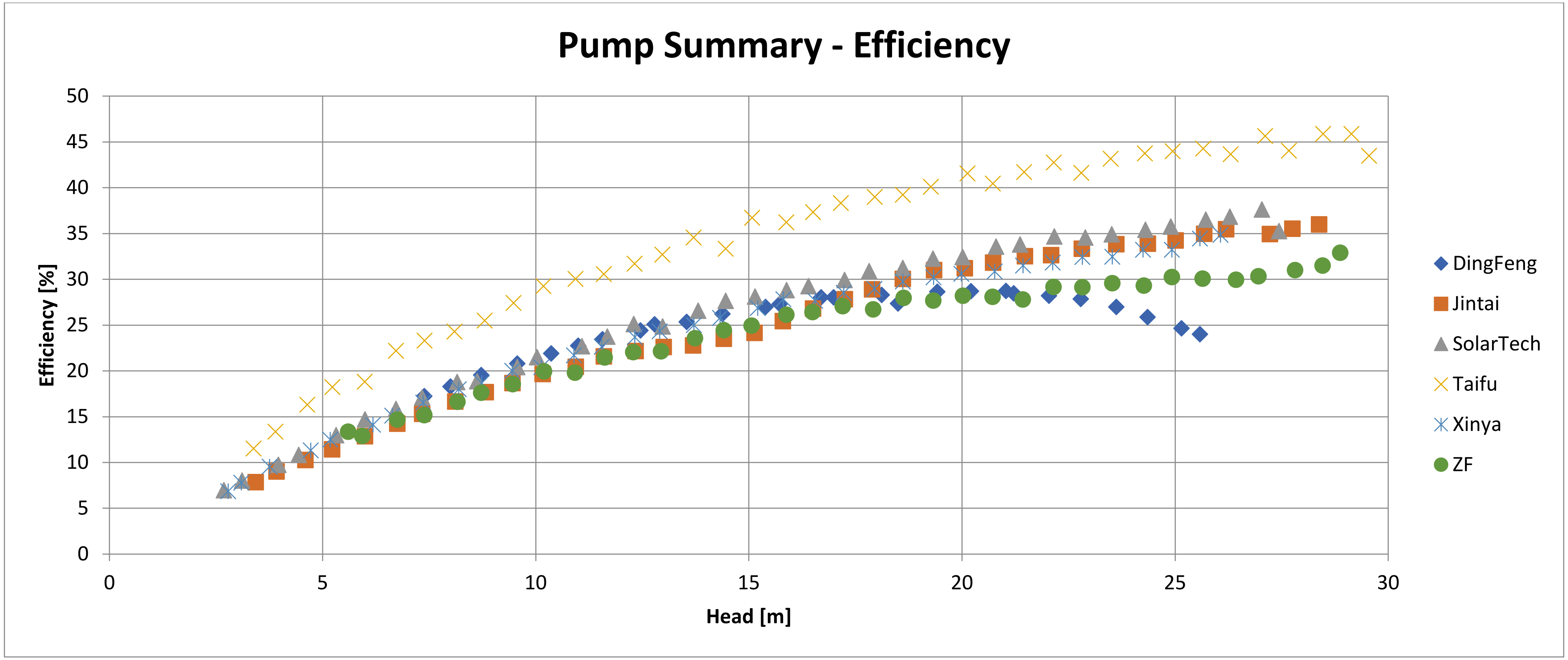
o The production of solar pumps in Africa for export to the sub-region does not appear to be commercially competitive against pumps imported from China. On the other hand, production of the mini volanta pump in China or India and its assembly in Africa is promising, as it would reduce the cost at which they are sold to smallholders.

ANNEXES

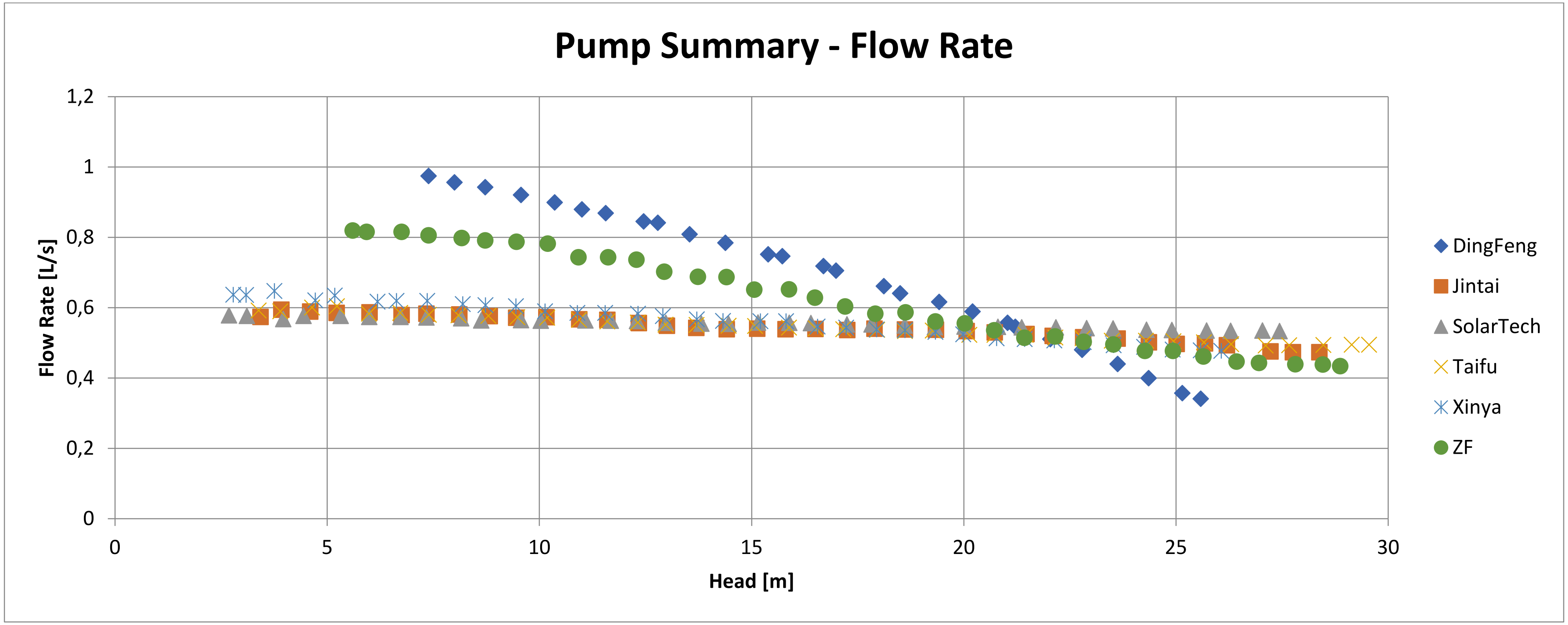
Appendix 1 List of solar pumps tested in a laboratory

Brand	Model	Pump type	Commercial contact
DingFeng	3SSW4-33-48-550	Centrifugal	Stop marketing
Jintai	JS4-3.0-60	Helical	https://jintaipump.en.made-in-china.com/product/ebEJXjYlXvWR/China-Solar-System-Brushless-DC-Pump-JS4-.html
SolarTech	SPM600H	Helical	http://www.solartech.cn/detail.aspx?cid=12108
Taifu	4TSC2.5-70-48/500	Centrifugal	https://www.alibaba.com/product-detail/PUMPMAN-48V-4TSC2-5-70-48_60458965374.html
Xinya	4SPS3/60-D36/500	Helical	https://french.alibaba.com/product-detail/water-pump-12v-24v-60101077471.html
Zhejiang Feili	4FLS1.5/25D36/500	Centrifugal	Stop marketing
Difful	3DPC3-25-24-200	Centrifugal	http://www.diffulpump.com/pid18107512/3inch-1hp-DC-burshless-solar-pump-plastic-impeller-solar-power-pump.htm
Sunculture - Rainmaker	SP300	Diaphragm	http://sunculture.com/products
Kerry	M123T-20	Centrifugal	https://m.alibaba.com/guide/shop/kerry-solar-powered-water-fountain-pump-for-garden-farm-irrigation_7642734.html
Mini volanta		Piston	Centre Sainte Famille - email: frerecharless@yahoo.fr

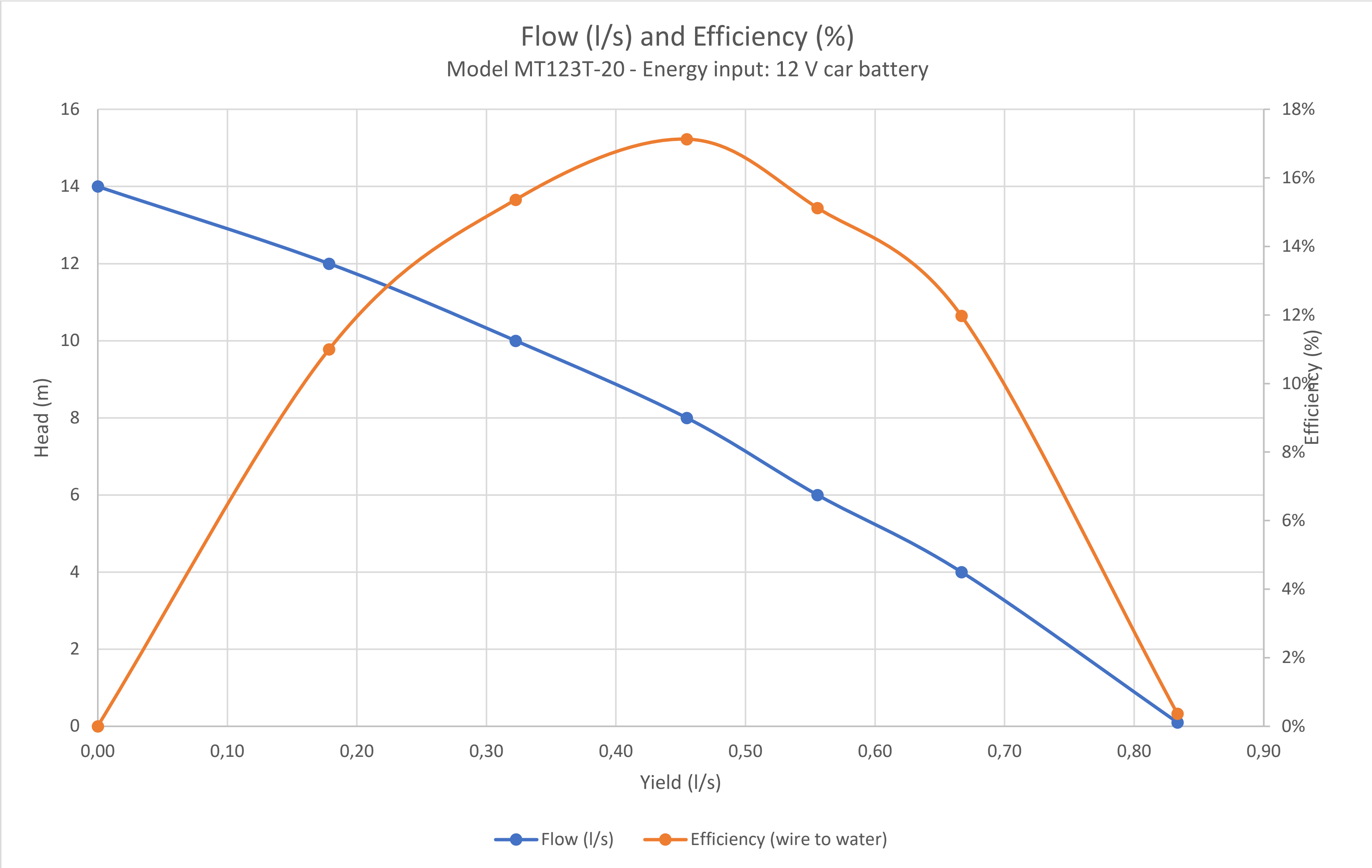
Appendix 2 Result of laboratory tests: Efficiency, flow and head curves



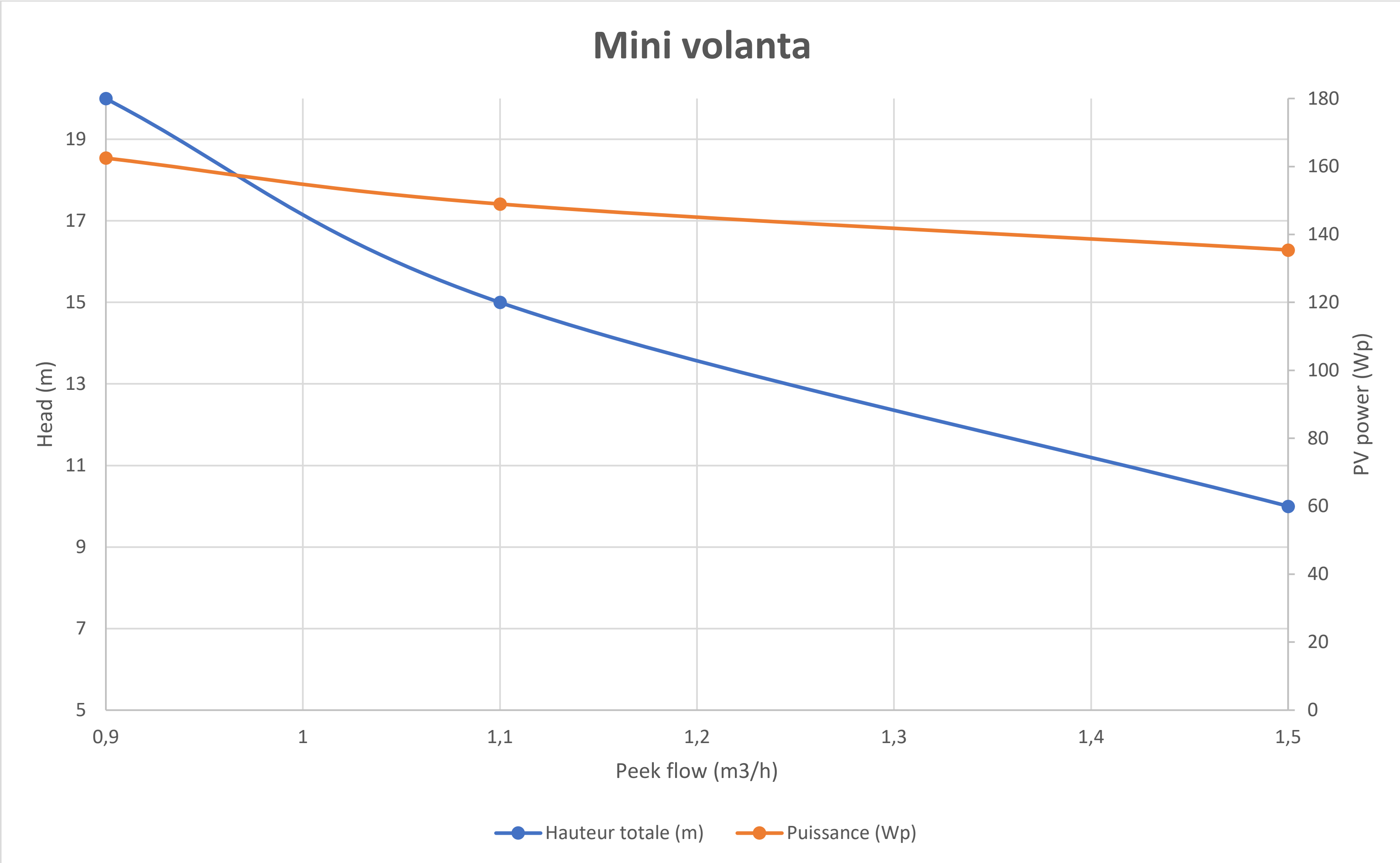
Source Global Good - http://www.intellectualventures.com/globalgood



Source Global Good - http://www.intellectualventures.com/globalgood



Source Practica Foundation - https://www.practica.org/



Source Practica Foundation - https://www.practica.org/

Appendix 3 Characteristics of the solar pumping systems tested

Brand	Diful	Solartech	Mini volenta	Sunculture
Model	3DPC3-25-24-200	SPM 600H		RainMaker - SP300
Pump type	Centrifugal	Helical	Piston	Diaphragm
Power (kW)	0,20	0,60	0,15	0,07
Pump sizing specifications				
Peak flow (m^3/h)	2,5	2	1,1	0,71
Volume max (m^3/day)	17	16	9	6
THD (m)	15	15	15	15
Irrigable area (m^2/day)	2800	2600	1500	1000
Measured pump specifications				
Peak flow (m^3/h)	2,8	2,6	1,5	1,0
Average volume (m^3/day)	15,6	15,8	7,8	5,1
Peak pressure	4,1	5,5	3,8	1,5
Dynamic level	10,3	11,5	11,7	10,8
Peak TDH calculated (m)	14,4	17	15,5	12,3
Irrigated area (m^2/day)	2150	2515	1350	630
Irrigated area (m^2)	3050	3000	1710	900
Solar generator sizing				
Maxi hydraulic output (W)	104	83	46	30
Efficiency	0,23	0,28	0,40	0,30
Rated pump input (W)	453	298	115	99
Required PV output (Wp)	589	387	149	128
PV output (Wp)	100	100	150	100
Number of PV required	6	6	2	2
PV output installed (Wp)	600	600	300	200
PV connection	serial	serial	parallel	serial
PV orientation	no	no	yes (manual)	no
MPPT	yes	yes	no (manual switch)	yes
Pump dry protection	yes	yes	no	no

Appendix 4 Summary of measures taken in the field

		Difful	Solartech	Mini volanta	Sunculture
THD (m)		10.3	11.5	11.7	10.8
THD clear sky (m)		14.4	15.5	15.2	12.3
Peak flow at 13h (m^3/h)	Clear sky	2.8	2.6	1.5	1
	Cloudy sky	1.2	1.9	0.84	0.4
Variation in flow (f) insolation (%)		57%	27%	44%	60%
Peak pressure at 13h (m)	Clear sky	4.1	5.5	3.8	1.5
	Cloudy sky	2,8	3	1	0,3
Variation in pressure (f) insolation (%)		32%	45%	74%	80%
Mini volume (m^3/day)		11	13	8	3.5
Maxi volume (m^3/day)		18	17	10	7
Average volume (m3/day)		15.6	15.8	7.8	5.1
Theoretical sizing volume (m^3/day)		17	16	9	6
Difference between theoretical volume and min. volume (%)		35%	19%	11%	42%
Pumping start time		8h18 to 8h30	7h55 to 8h20	7h36 à 8h10	8h55 to 9h20
Pumping stop time		17h55 to 18h14	18h10 to 18h25	18h15 à 19h10	17h31 to 18h25
Average pumping time (h)		9,3	10.2	10.8	8.8
Switch on pump		7h10 to 7h31	7h50 to 8h12	7h36 to 8h10	
Switch off pump		18h30 to 19h07	18h05 to 18h14	18h15 to 19h10	
Average operating time (h)		11.4	10.2	10.8	
Number of incidents recorded: pump or solar generator	Low	1	2		
	Moderate				3
	High			3	2

Appendix 5 Example of technical data table

Measures date	25/062018				
Time (h)	Flow (m^3/h)	Pressure (m)	Irrigation	Surface (m^2)	Insolation
6	0	0			
7	0	0			
8,5	0.34	1	storage	50	Moderate cloudy
9	1.64	2.2	storage	70	clear
10	1.71	2.4	storage	180	clear
11	2.25	3.4	storage	170	clear
12	2.57	4.1	storage	200	clear
13	2.57	4.1	drip	1000	clear
14	2.57	4.2	drip		clear
15	2.25	2.8	drip	250	clear
16	1.89	2.5	storage		clear
17	1.33	1.7	storage		clear
17,9	0.34	0.8	storage		clear
18	0	0			

Pumping volume (m^3/day)	18
Index water meter	439

Irrigation method	Irrigated area (m^2)	Irrigation time (h)	Labor	Irrigation frequency	Irrigation schedule
Basin + can	670	3	1	2	8h - 12h
Drip	1250	2	1	1	12h-13h/14h-15h

Appendix 6 Detailed costs of developments (final situation)

Farmer N° 4

Pump	Difful 3DPC3-25-24-200
Irrigation system	Drip & basin + watering can
Area drip system	1400m²
Area basin + watering can	1500m²

	Unit	Quantity	Unit price	Amount
Water capture				300,000
Manual drilling of 17m	Per unit	1	300,000	300,000
Water lifting device				730,727
Solar pump	Per unit	1	261,727	261,727
Outlet pipe PE32	Per meter	15	400	6,000
Head of borehole	Per unit	1	20,000	20,000
Electric wiring	Per meter	20	400	8,000
Solar panels (100w)	Per unit	6	60,000	360,000
Frame of panels	Per unit	3	25,000	75,000
Interconnected basins				113,900
Basins (1,88m³)	Per unit	4	22,000	88,000
PVC pipe 50 (6m)	Per unit	8	2,500	20,000
PE pipe 32	Per meter	6	400	2,400
Valve 32	Per unit	1	3,500	3,500
Drip system				407,400
Netafim kit 500m²	Per unit	3	135,000	405,000
PE pipe 32	Per meter	6	400	2,400
Transport & labor				180,000
Transport	Lump sum	1	15,000	15,000
Installation pump system	Lump Sum	1	75,000	75,000
Installation irrigation system	Lump sum	3	30,000	90,000
TOTAL Investment				1,732,027

Farmer N° 5

Pump	Mini volanta
Irrigation system	Mini center pivot & basins + watering can
Area center mini pivot	1350 m²
Area basin + watering can	360 m²

	Unit	Quantity	Unit price	Amount
Water capture				260,000
Manual drilling of 17m	Per unit	1	260,000	260,000
Water lifting device				910,649
Solar pump	Per unit	1	715,649	715,649
Outlet pipe PE32	Per meter	1	0	0
Head of borehole	Per unit	1	15,000	15,000
Electric wiring	Per meter	1	0	0
Solar panels (150w)	Per unit	2	75,000	150,000
Frame of panels	Per unit	1	30,000	30,000
Interconnected basins				87,500
Basins (1,88m³)	Per unit	3	22,000	66,000
PVC pipe 50 (6m)	Per unit	5	2,500	12,500
PE pipe 40 (6m)	Per unit	6	1,500	9,000
Center mini pivot				280,000
Center mini pivot	Per unit	1	200,000	200,000
Hose 32	Per meter	100	800	80,000
Transport & labor				120,000
Transport	Lump sum	1	15,000	15,000
Installation pump system	Lump Sum	1	75,000	75,000
Installation irrigation system	Lump sum	1	30,000	30,000
TOTAL Investment				1,658,149

Farmer N° 6

Pump	Sunculture SP-300	replaced by : Difull, 3FLD2-22-24-180
Irrigation system	Spray hose & basin + watering can	
Area spray hose	Abandoned for exclusive watering can	
Area basin + watering can	960m²	

	Unit	Quantity	Unit price	Amount
Water capture				300,000
Manual drilling of 17m	Per unit	1	200,000	300,000
Water lifting device				856,997
Solar pump	Per unit	1	532,997	532,997
Outlet pipe PE32	Per meter	15	400	6,000
Head of borehole	Per unit	1	20,000	20,000
Electric wiring	Per meter	20	400	8,000
Solar panels (100w)	Per unit	4	60,000	240,000
Frame of panels	Per unit	2	25,000	50,000
Interconnected basins				99,300
Basin (1,65m3)	Per unit	4	22,000	88,000
PVC pipe 40 (6m)	Per unit	4	2,000	8,000
PE pipe 25	Per meter	5	300	1,500
Valve 25 mm	Per unit	1	1,800	1,800
Spray hose				
Spray hose 25 mm	Per meter	50	500	
Valve	Per unit	1	2,000	
Spray head	Per unit	1	1,500	
Transport & labor				75,000
Transport	Lump sum	1	15,000	15,000
Installation pump system	Lump Sum	1	60,000	60,000
Installation irrigation system	Lump sum	1	15,000	
TOTAL Investment				1,331,297

Farmer 7

Pump	SolarTech: SPM600
Irrigation system	Spray tube + watering can
Area spray tube	2040m²
Area basin + watering can	960m²

	Unit	Quantity	Unit price	Amount
Water capture				300,000
Manual drilling of 17m	Per unit	1	200,000	300,000
Water lifting device				1,042,378
Solar pump	Per unit	1	573,378	573,378
Outlet pipe PE32	Per meter	15	400	6,000
Head of borehole	Per unit	1	20,000	20,000
Electric wiring	Per meter	20	400	8,000
Solar panels (100w)	Per unit	6	60,000	360,000
Frame of panels	Per unit	3	25,000	75,000
Interconnected basins				94,300
Basins (1,88m³)	Per unit	3	22,000	66,000
PVC pipe 50 (6m)	Per unit	8	2,500	20,000
PE pipe 32	Per meter	12	400	4,800
Valve 32	Per unit	1	3,500	3,500
Spray tube				324,300
Spray tube 32mm (Roll 100m)	Per unit	8	25,000	200,000
PVC pipe 32 (6m)	Per unit	14	1,500	21,000
PVC pipe 40 (6m)	Per meter	4	2,000	8,000
Valve 32	Per unit	34	2,300	78,200
PVC T 32	Per unit	32	300	9,600
PVC turn 32	Per unit	4	250	1,000
PVC glue	Per unit	1	6,500	6,500
Transport & labor				120,000
Transport	Lump sum	1	15,000	15,000
Installation pump system	Lump Sum	1	75,000	75,000
Installation irrigation system	Lump sum	1	30,000	30,000
TOTAL Investment				1,880,978

Appendix 7 Detailed follow-up of the evolution of solar solutions tested

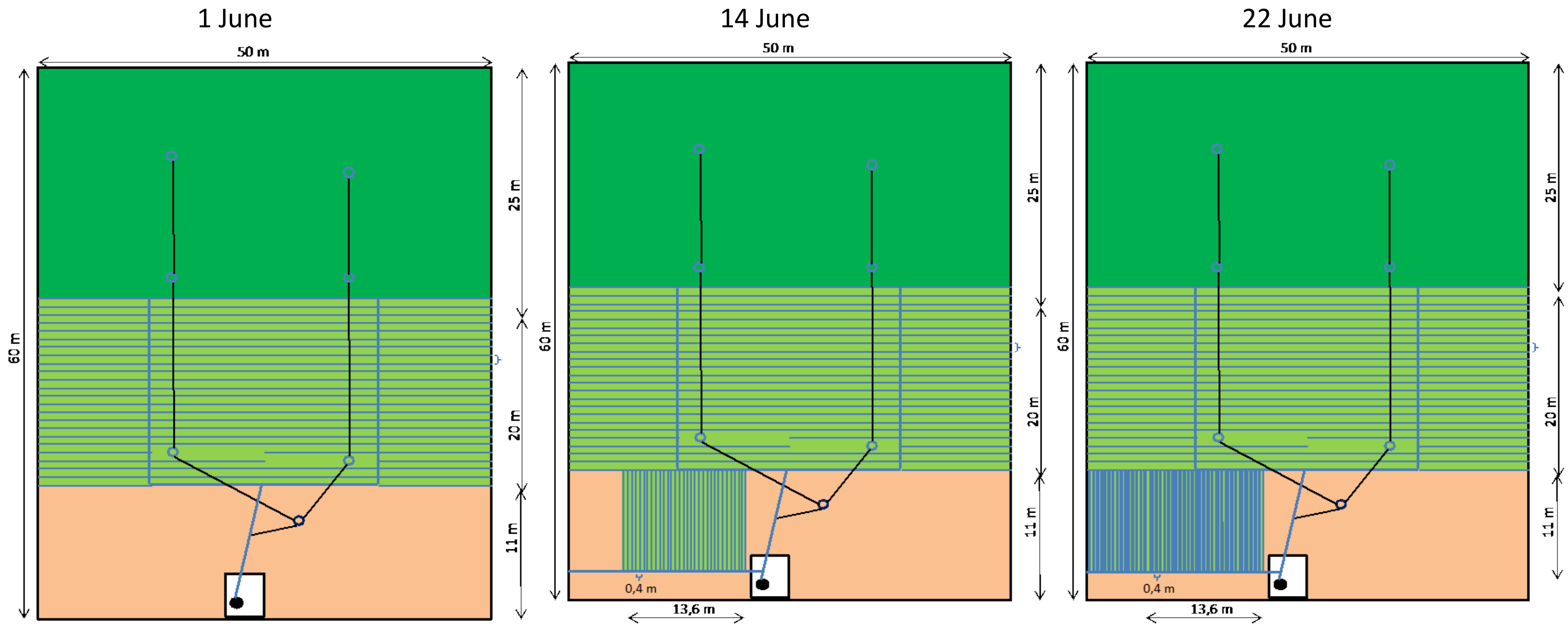
Farmer N° 4					
Modification date	01/06/2018	13/06/2018	22/06/2018	25/06/2018	final
Manual drilling (manual auger)					
Static level (m)	9.53				9,5
Total depth (m)	16				16
Dynamic level (m)	10.3				10.3
Difful pump					
PV output (Wp)	600				600
Depth pump installation (m)	14				14
Water storage					
Number of basins	6				4
Total volume (m^3)	11.3				7.52
Unit volume (m^3)	1.88				1.88
Sizing basin					
Diameter (m)	2				2
Height (m)	0.6				0.6
Water distribution					
PVC pipe length above ground (m)	36				36
Diameter (mm)	50				50
Drip system					
Length primary line (m)	20	20	15	10	65
Diameter (mm)	25	25	25	25	25
Lateral length (m)	12.5	12.5	12.5	12.5	12.5
Diameter lateral (mm)	8	8	8	8	8
Lateral spacing (m)	0.8	0.8	0.4	1	0.8
Number of laterals	86	121	142	152	140

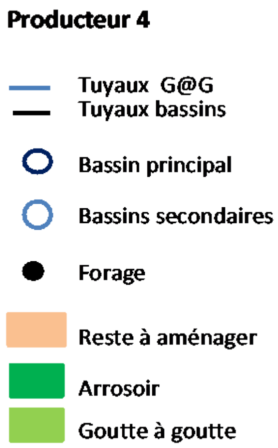
Farmer N° 5			
Modification date	01/06/2018	22/06/2018	final
Manual drilling (manual auger)			
Static level (m)	11		11
Total depth (m)	17		17
Dynamic level (m)	11.65		11.65
Mini volanta pump			
PV output (Wp)	200	300	300
Depth pump installation (m)	15		15
Water storage			
Number of basins	4		3
Total volume (m^3)	5.6		5.64
Unit volume (m^3)	1.88		1.88
Sizing basin			
Diameter (m)	2		2
Height (m)	0.6		0.6
Water distribution			
PVC pipe length above ground (m)	30	36	66
Diameter (mm)	50 / 40		50 / 40
PVC pipe length buried (m)			
Diameter (mm)			
Length hose pipe (m)	50		50
Diameter hose pipe (mm)	32		32
Mini center pivot			
Wet lengt (m)	10	10	10
Wet area (m^2)	120	78.5	100
Discharge (m^3/h)	1	1.5	1.2

Farmer N° 6			
Modification date	01/06/2018	02/08/2018	final
Manual drilling (manual auger)			
Static level (m)	10		10
Total depth (m)	17		17
Dynamic level (m)	10.83		10,83
Sunculture pump	Sunculture	Difful pump	
PV output (Wp)	200	200	400
Depth pump installation (m)	14.5	14.5	14.5
Water storage			
Number of basins	3		4
Total volume (m3)	4.5		6
Unit volume (m3)	1.5		1.5
Sizing basin			
Diameter (m)	1.8		1.8
Height (m)	0.6		0.6
Water distribution			
PVC pipe length above ground (m)	24		24
Diameter (mm)	40		40
Length spray hose (m)	50		50
Diameter spar hose (mm)	25		25

Farmer N°7			
Modification date	01/06/2018	21/06/2018	final
Manual drilling (manual auger)	10.5		10.5
Static level (m)	16		16
Total depth (m)	11.5		11.5
SolarTech pump			
PV output (Wp)	600		600
Depth pump installation (m)	14		14
Water storage			
Number of basins	3	4	3
Total volume (m3)	5.64		5.64
Unit volume (m3)	1.88		1.88
Sizing basin			
Diameter (m)	2		2
Height (m)	0.6		0.6
Water distribution			
PVC pipe length above ground (m)	48		72
Diameter (mm)	50		50/40
Spray tube			
Length primary line (m)	40	40	80
Diameter (mm)	32	32	32
Lateral length (m)	50	50	25
Diameter lateral (mm)	32	32	32
Lateral spacing (m)	2.4	2.4	2.4
Number of laterals	15	17	34

Appendix 8 Diagrams of the evolution of solar solutions tested

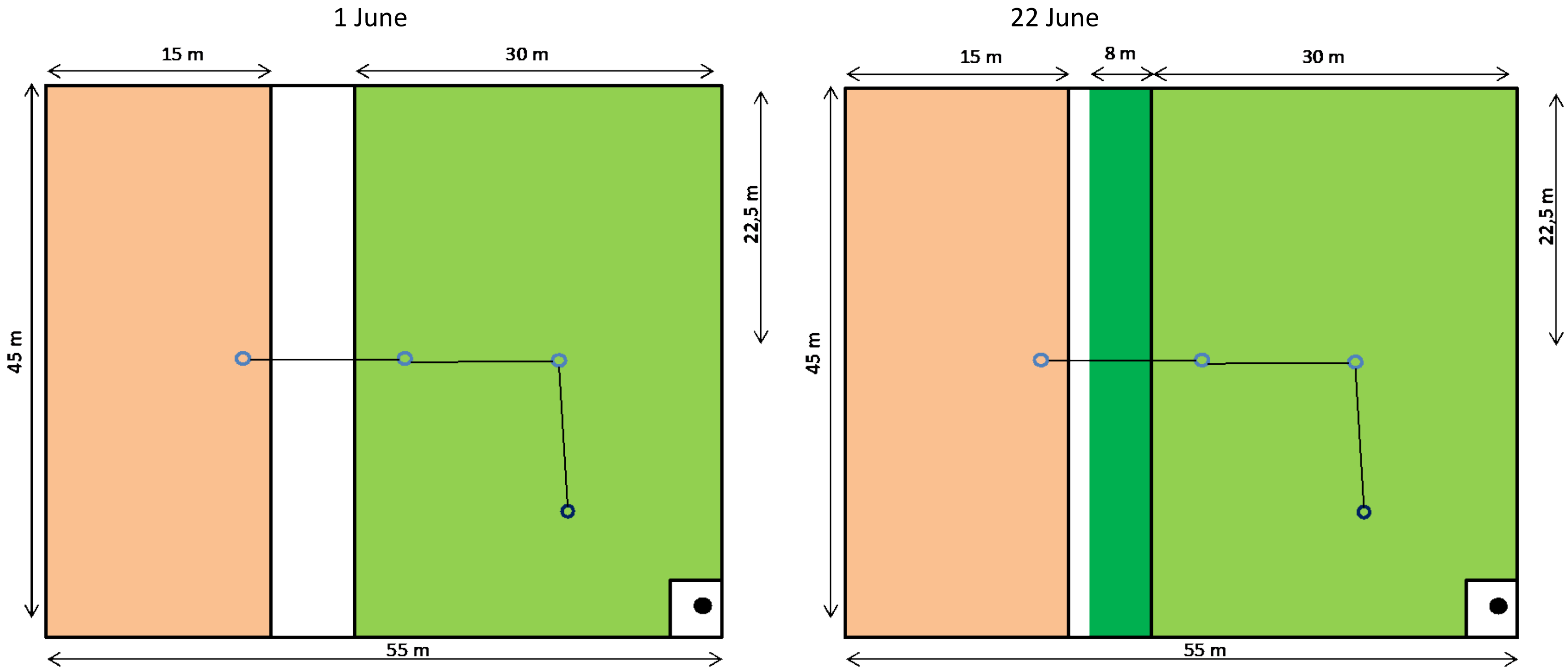


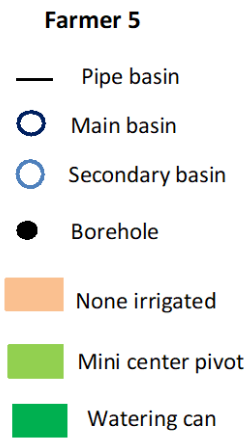


Difful pump & drip system

Modifications

- Increase in area irrigated using the drip system
- Adaptation of the spacing of drip due to cultivation practices

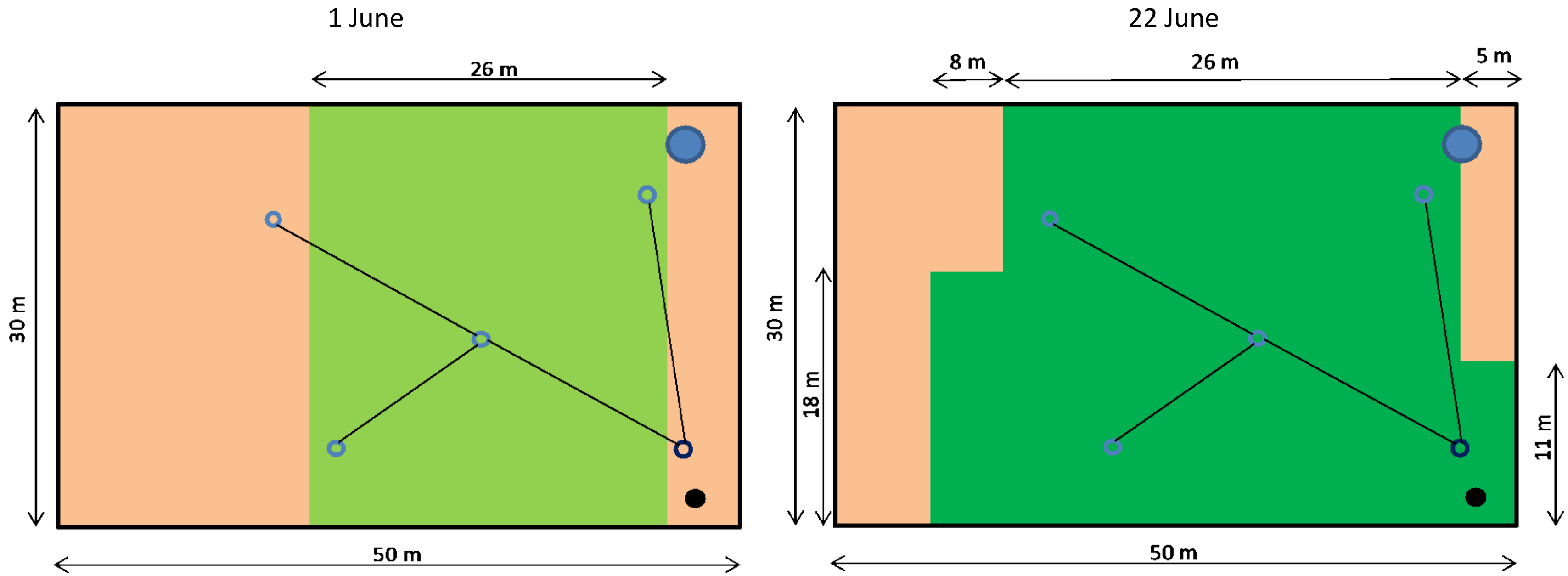




Mini volanta & mini center pivot

<u>Modifications</u>

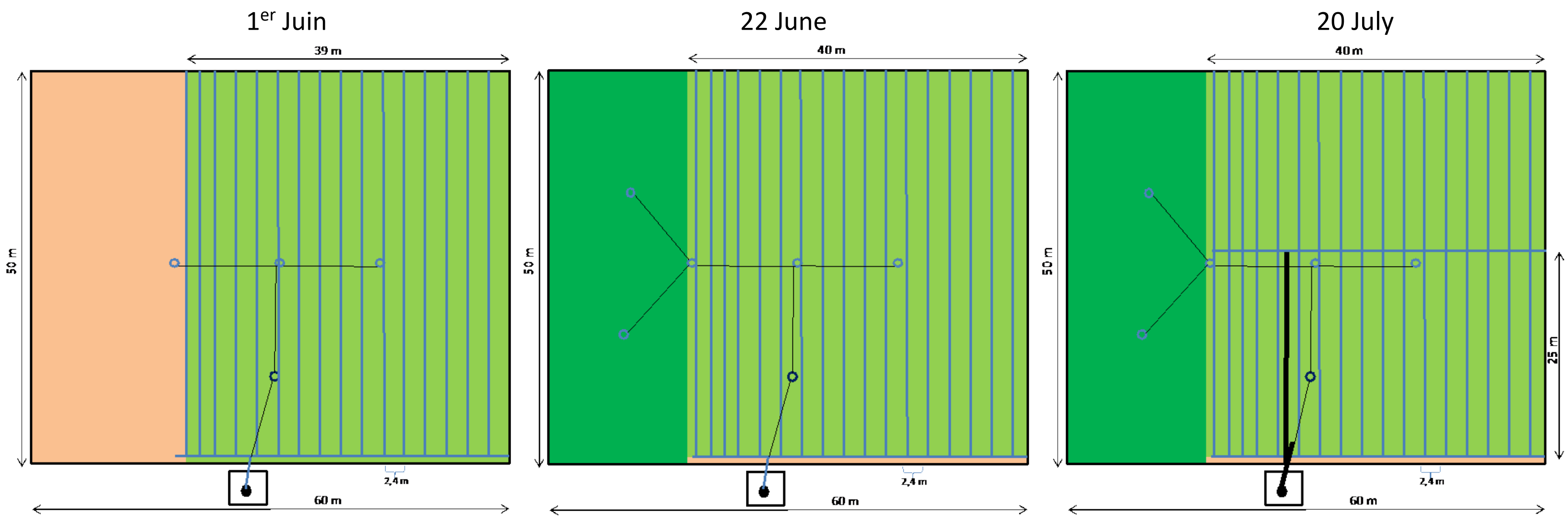
- Increase in the area irrigated using a watering can



Sunculture & spray hose

<u>Modifications</u>

- Abandonment of the spray hose for exclusive irrigation with a watering can supplied from basins



Farmer 7

Pipe Basin

Main Basin

Secondary basin

Borehole

Watering can

Spray tube

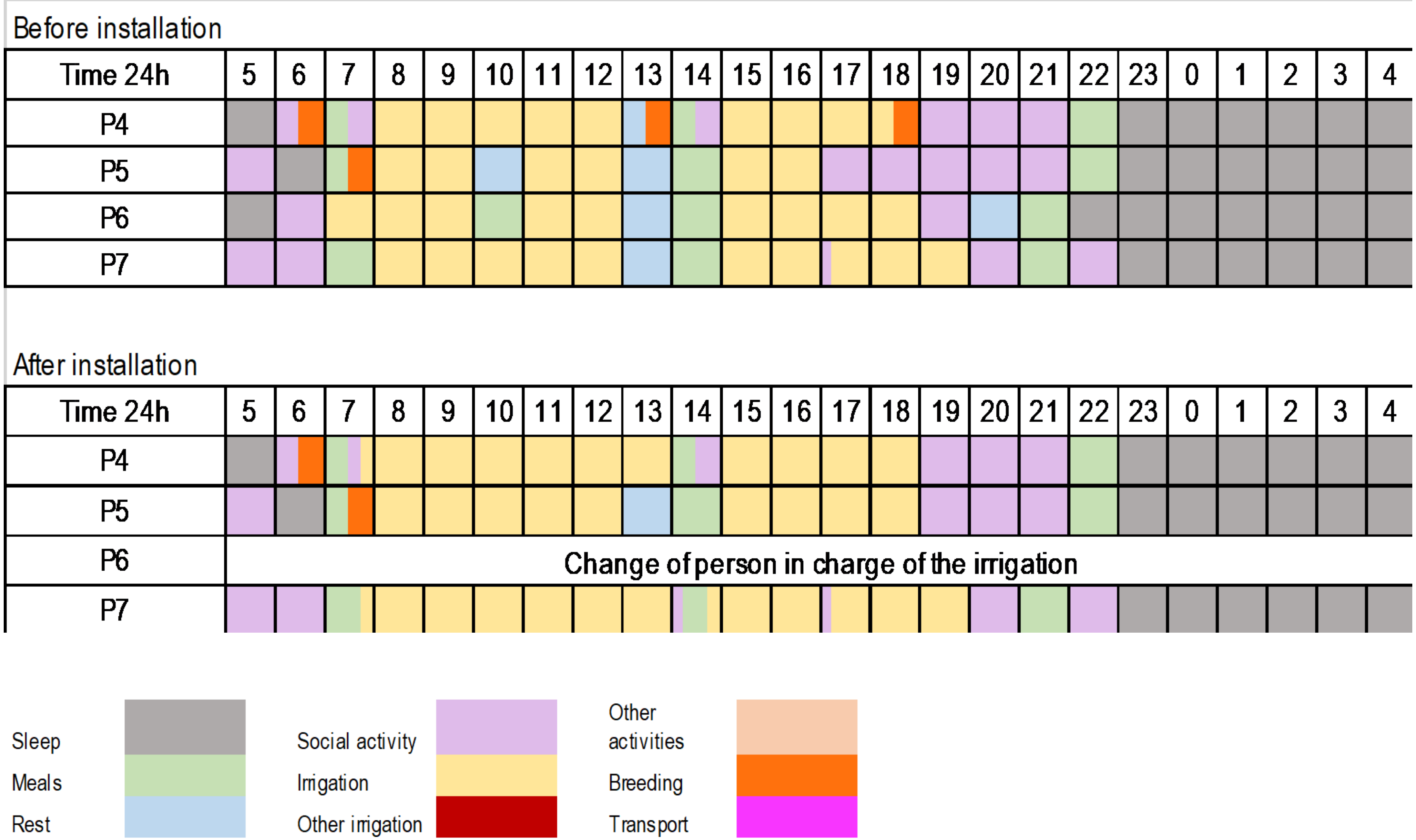
None irrigated

SolarTech & spray tube

Modifications

- Increase in the number of basins for irrigation with a watering can
- Reduction in the length of spray tube, from 50m to 25m

Appendix 9 Daily schedule of activities before and after installation



Appendix 10 Questionnaire on the perception of solar pumping before and after the demonstration

Name
Telephone number
Is irrigated market garden crop production your main activity?
Yes
No
What is your area of market crop production under irrigation?
< to 0.5ha
Between 0.5 and 1ha
> 1ha
How much are you able to invest in a solar pump?
FCFA 100,000 to FCFA 300,000
FCFA 300,000 to FCFA 500,000
FCFA 500,000 to FCFA 750,000
FCFA 750,000 to 1 million
> FCFA 1 million
Why have you come to this demonstration?
I was invited
I am curious
I am not interested, but I came anyway
I wish to invest in improvements to irrigation
You are…
A smallholder
A large smallholder
A businessman

Before demonstration	
Date of survey:	
1	Are you familiar with solar pumps (SP)?
	Yes
	No
2	If yes, how?
	Word of mouth
	I have seen them on a farm
	I have seen them at a private residence or AEP
	I have seen them at a business
	I use one
3	What is your opinion of SP?
	Good
	Fair
	Poor
	Don’t know
4	Can a SP replace a motor pump (GMP) in your garden?
	Yes
	No
	Don’t know
5	Is a SP more powerful than a GMP?
	Yes
	No
	Don’t know
6	If yes, provide details:
	It can pump water from a greater depth
	It pumps more water
	Greater pressure
7	If we compare a SP with a GMP, we could say that …
	It breaks down less often
	It is easy to repair
	It has a longer useful life
	Don’t know

8	A SP produces water…
	The same quantity throughout the day
	Constantly, but at varying levels
	With a strong flow, with the sun at its highest point
	from 7h
	to 18h
	Don't know
9	With a SP, water must be stored…
	In an elevated reservoir
	In basins on the ground
	It is not necessary or compulsory to store water
	Don't know
10	With a SP, one must…
	Change the way one irrigates
	Invest in costly modern equipment
	Make inexpensive adaptations
	Make no changes
11	A SP…
	Is not for me, as my garden is too small
	Is not for smallholders
	Is too complicated to use
	Is good for me
	No opinion
12	Can you tell me about a SP that allows one to?
	Save fuel
	Spend less time on irrigation
	Save water
	Use less labor
	No opinion

13	Solar pumping is good…
	As it is less polluting
	However, I cannot irrigate when I want
	Because I earn more at the end of the season
	It limits the fall in the water level of the aquifer
	As I can irrigate areas of my land where the water is too deep
	Don't know
14	Within my own circle, when it comes to solar pumping…
	I recommend it to everyone
	I advise against it
	I talk about it
	I share my experience
	I do not talk about it
15	Solar pumping is costly….
	In terms of its initial investment
	To operate
	To maintain

After demonstration	
Date of survey :	
3	What is your opinion of SP?
	Good
	Fair
	Poor
	Don't know
4	Can a SP replace a motor pump (GMP) in your garden?
	Yes
	No
	Don't know
5	Is a SP more powerful than a GMP?
	Yes
	No
	Don't know

6	If yes, provide details:
	It can pump water from a greater depth
	It pumps more water
	Greater pressure
7	If we compare a SP with a GMP, we could say that …
	It breaks down less often
	It is easy to repair
	It has a longer useful life
	Don't know
8	A SP produces water…
	The same quantity throughout the day
	Constantly, but at varying levels
	With a strong flow, with the sun at its highest point
	from 7h
	to 18h
	Don't know
9	With a SP, water must be stored…
	In an elevated reservoir
	In basins on the ground
	It is not necessary or compulsory to store water
	Don't know
10	With a SP, one must…
	Change the way one irrigates
	Invest in costly modern equipment
	Make inexpensive adaptations
	Make no changes
11	A SP…
	Is not for me, as my garden is too small
	Is not for smallholders
	Is too complicated to use
	Is good for me
	No opinion

12	Can you tell me about a SP that allows one to?
	Save fuel
	Spend less time on irrigation
	Save water
	Use less labor
	No opinion
13	Solar pumping is good…
	As it is less polluting
	However, I cannot irrigate when I want
	Because I earn more at the end of the season
	It limits the fall in the water level of the aquifer
	As I can irrigate areas of my land where the water is too deep
	Don't know
14	Within my own circle, when it comes to solar pumping…
	I recommend it to everyone
	I advise against it
	I talk about it
	I share my experience
	I do not talk about it
15	Solar pumping is costly….
	In terms of its initial investment
	To operate
	To maintain
16	Are you interested in the solar solutions presented?
	yes
	no
	the solar interests me but not the presented solutions
17	How much are you willing to invest for the solar solutions presented?
	FCFA 100,000 to 300,000
	FCFA 300,000 to 500,000
	FCFA 500,000 to 750,000
	FCFA 750,000 to 1 million
	FCFA > 1 million

Appendix 11 Technical data sheet for manual drilling (auger)

Hand auger drilling	
Local name	Manual auger
Name and contact	Ndiaré Diouf. Ph. 781241086 / Moussa Ba. Ph. 774136859
Origin of technology	Local
Purpose	To pump groundwater for irrigation
Principe	Drilling with manual techniques using conical auger, bailer and temporary casing
Equipment	Suspension equipment (h=1.8m base 1m x 1m), tripod hoist pole (H4m, D 90mm); add. center (D0.5m, L1m); steel temporary casing (D270-300mm, L=18m) conical auger (L0.5m, D300); auger valve (L0.8-1.2m, D150-180mm), chain pulley, cord (L25m, D12mm); drilling rods (L20m, S25x25), pump and generator
Materials	PVC pipe (D160/200, L6m), screw, grease, gravel pack, small tools, glue, cement, etc.
Consumables	2 liters of fuel for the motor pump, 2,000 to 3,000 liters of water
Number of personnel	4 – 6
Implementation time	1.5 to 2 days on average, development included
Screen filter pipe	Slots made with a hacksaw saw, thickness of 1 to 1.5 mm
Depth	12 to 18 m
Expected yield	2 to 4 m^3/h
Feasibility	Formation (alluvium and soft clay), maximum depth of the aquifer 12m
Cost	FCFA 200,000 to 300,000 (USD 345 to 517)
Lifespan	10 years, or more


Appendix 12 Well point technical data sheet

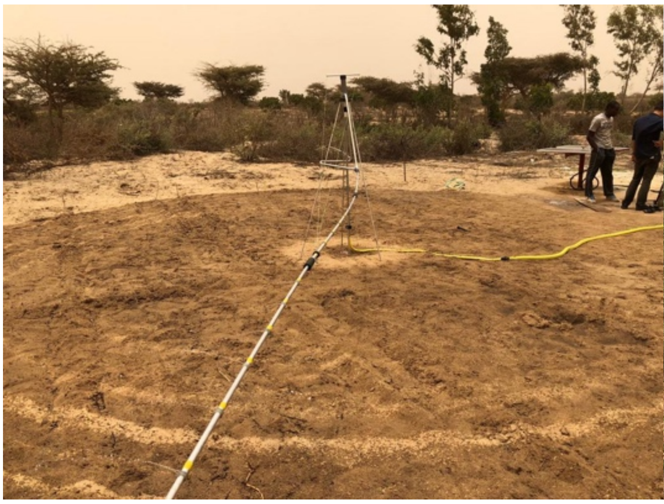
Well point	
Local name	SAMPE
Name and contact	Djibril Gadiaga 768718479
Origin of the product	Local
Purpose	Insert a screen pipe at the bottom of a well to improve the yield
Principle	It consists of driving a PVC pipe down with a large volume of water from a motor pump
Equipment	2" motor pump, 50mm PVC pipe; auger valve, cord, portico, pulley
Materials	PVC pipe (D160/200, L3-6m), mosquito screen 5-8 m^2, rubber strap
Consumables	2 liters of fuel, 2,000 to 3,000 liters of water
Labor	2 - 3 people
Implementation time	2h to 4h, depending on the length of the well pint and constraints on installation
Screen filter pipe	Heated holes with a 20 mm nail, 10cm spacing. Mosquito net around the filter screen pipe
Starter hole	Made with the bailer, 1m to 2m
Operation	Jetting with 50mm PVC inside the well point
Expected results	20% to 30% yield improvement of the well
Constraints of implementation	Hardness of the layers to be penetrated, supply of water on the site
Cost	FCFA 10,000 to 15,000/meter (USD 17 to 26), materials and labor included, filter screen with diameter of 200mm
Useful life	3 to 5 years


Appendix 13 Drip system technical data sheet

Drip-feed system	
Local name	Drip system
Origin of the product	NETAFIM / Israel
Principle	Drip irrigation consists of distributing water through a network of pipes under low pressure, providing water to the areas immediately surrounding plants cultivated
Composition	Emitter 2.0L/H 0.30m 600m; PE irrigation pipe 25/4 25M FDS; Talvit strainer 1"*1" 130 microns; plastic valve 1" FF; connectors (8mm M & F); connection dismantling kit
Suppliers	Des Systems d'Eau
Pressure	2m
Flow	0.9 m^3/h
Diameter	8 mm
Length	600 m
Coverage	500 m^2
Irrigated area	500m^2
Duration of irrigation	1h to 1h30
Price	FCFA 130,000 for 500m^2 (USD 224)
Space between the lines	80cm
Lifespan	3 to 5 years


Appendix 14 Mini center pivot technical data sheet

Mini-swivel	
Local name	Min center pivot
Introduction	2018 through the pilot
Origin of the product	Burkina Faso
Principle	Pressurized water turns a perforated ramp connected to a central plot
Suppliers	Centre Sainte Famille, Burkina Faso.
Pressure	2m
Flow	Between 0.5m and 2m³/hr
Diameter	Diameter of the ramp 18 and 12mm
Length	Length of the ramp 12m (radius of 6m)
Reach	12m diameter
Irrigated area	120m² for one watering. 1000m² by moving the pivot 10 times
Duration of irrigation	15 to 60 minutes per cycle, depending on climatic conditions, the soil and the preference of the smallholder.
Price	Mini center pivot FCFA 40,000 to 55,000 (USD 68 to 95). For 2,000 m², about FCFA 135,000 (USD 233), including submerged pipe
Diameter of perforations	1mm
Number of aligned holes	120 on the ramp
Lifespan	Estimated at least 10 years



Appendix 15 Circular basin technical data sheet

Interconnected basin + watering cans	
Local name	Basins
Principle	Storage of water in interconnected concrete basins from which land is irrigated using a watering can. The number of basins depends on the area to be irrigated.
Equipment	Shovels, trowels, buckets, tape
Material and materials	3 bags of cement, 2 round iron bars (diameter of 6mm), 6 wheelbarrows of sand
Duration of construction	4 basins per day + 1 day one week after for fitting and finishing touches
Dimensions	Diameter 2000 x 60
Volume	1.9m^3
Irrigated area per basin	200 to 300m^2
Duration of irrigation	45 to 60 min
Manufacturers	Local
Price	FCFA 22,400 (USD 39) material + installation + fitting + connection
Useful life	Between 5 and 10 years


Appendix 16 Spray hose technical data sheet

Flexible tube	
Local name	Lance
Principle	A hose is connected directly to the pump for direct spay irrigation
Supplier	Local
Pressure	3m to 5m at the exit of the watering pipe
Flow	1m to 2m³/h
Diameter	25 to 32mm
Length	50m
Irrigated area	800 to 1,000m² per day
Duration of irrigation	150 to 200m² for 1 hour
Price	FCFA 30,000 (USD 52) for 50m of 32mm pipe
Lifespan	2 to 3 years

Appendix 17 Spray tube technical data sheet

Spraying sheath	
Local name	Spray tube
Introduction	2018 by the pilot
Origin of the product	TAIWAN - Shuen Yue Industrial under the brand name San Fu
Principle	Perforated PE strips unfolded on the ground between the rows of crops Spraying of water that creates a fine rain with variable reach
Composition	1 valve for 1 25m or 50m strip, network of 1 32mm PVC area
Suppliers	Agrimodern (Burkina Faso)
Pressure	3 to 4m
Flow	Estimated at 1m³/h for 25m
Diameter	32mm
Length	100m roll
Reach	2m to 3m
Spacing	2m to 2.5m
Cover	40 rolls per hectare
Irrigated area	100m² to 150m² for 50m line
Duration of irrigation	15 to 20 min with 1 50m line
Price	FCFA 20,000 (USD 34) for 100m roll
Diameter of perforations	0.4mm to 1mm
Number of aligned holes	3
Spanlife	2 to 5 years – Not advised in the presence of rodents


Appendix 18 Agreement between the AUMN and pilot smallholders

Between:

The Association des Unions Maraichères des Niayes,
Recorded in the Trade and Personal Property Credit Register under RCN SNTHS2005C2689 on 11 August 2005
with its registered office at Villa 79 Cité Malick Sy derrière le Lycée Malick in Thiès, SENEGAL
and its mailing address at BP 1283 Thiès Principale, telephone number 339523052
Represented by its president, Mohamed Dia
Hereinafter referred to as the "**AUMN**"

The AUMN is assisted in the implementation of activities by its technical partner, **PRACTICA Foundation**.

And

Mr Ngagne Gadiaga,
A market garden crop smallholder in Ngadiaga, Notto Gouye Diama
with telephone number 768718479
Hereinafter referred to as the "**Smallholder**"

The following has been agreed and decided upon:

Article 1. : Purpose of the agreement protocol

The purpose of this agreement protocol is to put procedures in place for a solar irrigation test on the farm of the smallholder.

Article 2. : Description of the equipment installed

The irrigation fittings and equipment installed on the farm of the smallholder are as follows:

- A manual drilling
- A solar pump
- Irrigation materials and/or the construction of water storage infrastructure

Article 3. : Obligations of the AUMN

- Provide the smallholder with training in the use of the equipment being demonstrated on their site.
- Install the equipment and infrastructure necessary for a maximum area of 3,000m^2
- Alter the irrigation layout on the proposal of, and in consultation with, the smallholder
- Assume responsibility for the maintenance of equipment and repairing breakdowns, other than those due to misuse of the equipment or infrastructure
- Provide the smallholder with advice on parcel planning and the management of crop schedules
- Return the equipment to the smallholder at the end of the test period in accordance with the conditions set in this agreement
- Provide the inputs for the development of a maximum area of market garden crops of 3,000m^2

Article 4. : Obligations of the smallholder

- Physically participate in works for the development of equipment.
- Supply the labor required to develop and irrigate a maximum area of 3,000m^2

- Respect the conditions of use of equipment tested
- Follow advice given for the development of the pilot garden and on the management of irrigated market garden crops
- Provide their opinion on the equipment installed and propose modifications to planning under the supervision of the AUMN or its representatives
- Provide guards and security to protect the equipment provided to them
- Authorize access to its garden for all persons with an interest in the test in progress, and provide information in its possession
- Authorize AUMN personnel and its representatives to access its garden at any time, whether they are present or not
- Authorize the organization of demonstration visits in its garden in its presence

Article 5. : Duration of the protocol

This protocol enters into force on the date it is signed by the AUMN and the smallholder, and ends on 30 September 2018.

Article 6. : On-lending terms

The drill hole and storage basins are on-lent at no cost to the smallholder and without conditions. On-lending terms for equipment, the solar pump and irrigation equipment are as follows:

- The smallholder can acquire some or all equipment at no cost. Equipment not acquired by the smallholder is returned to the AUMN.
- If the obligations of the smallholder are not respected, the AUMN can recover all equipment installed.

Article 7. : Special clauses

The AUMN remains the owner of the equipment for the whole duration of this agreement.

For the duration of this agreement, the AUMN reserves the right to recover equipment in the event that the smallholder fails to meet its obligations.

Article 8. : Settlement of disputes

If a dispute arises from the interpretation or implementation of this agreement, priority will be given to resolving said dispute in an amicable manner, with recourse to one or more conciliators an option.

This partnership agreement has been prepared in French in two (02) original copies, one (01) for the AUMN and (01) for the smallholder.

Thiès, 30 April 2018

Pour the AUMN

Mohamed Dia, President

Thiès, 30 April 2018

For the smallholder

Mr Ngagne Gadiaga

Appendix 19 Terms of reference of the study "Intermediate-depth solar pumping solutions for irrigation for smallholders in the Niayes region"

A. PROJECT BACKGROUND AND OBJECTIVES

Preamble

The activity that requires the services described in the present ToRs benefits from the financial assistance of a specific externally funded operation (EFO) centered on technical assistance, capacity building, and knowledge product development and dissemination under the umbrella of water security. The activity is carried out by Water in Agriculture Global Solution Group (WiA GSG) of the World Bank and must be fully completed by the end of November 2018.

Context

The agriculture sector is the single largest employer in the world, sustaining the livelihood of 40% of the population, many of whom live in poverty (United Nations, 2015). Increasing productivity in the agriculture sector is widely recognized as one of the most effective ways to fight poverty and stimulate socio-economic development.

In African drylands, irrigation is one of the most essential measures that can improve land productivity, reduce farmers' vulnerability, stabilize and increase their income, enhance food security and nutrition diversity, as well as create jobs by allowing multiple cropping practices, particularly during the dry season, when horticultural products can be grown and sold on the market. Besides, the land area under irrigation represents a marginal share of total cultivated area in sub-Saharan Africa, where only 5% of farmland is irrigated (International Water Management Institute, 2010) and where water scarcity is an impediment to economic growth and welfare.

Solar pumping is considered a very promising avenue to allow farmers to reduce production costs and therefore improve their lives. At present, let aside time-consuming hand-powered pumps, almost the total area irrigated from groundwater is pumped using affordable petrol surface pumps at a depth not exceeding 7 meters (physical limitation of all surface pumps). However hydrogeological maps reveal vast productive aquifers that are slightly deeper (intermediate depth, from 7 to 20 m) but that can only be reached using immerged pumps. However, the costs of immerged manufacturers' pumps are prohibitive with approximately 5,000 Euro for 0.5 hectares against 350 Euros for a motor pump (suction pump) and the same area.

Several affordable solar pumps solutions for intermediate depths are under development or at a testing phase, usually by non-profit organizations but they have not yet penetrated the West African market. One of such organizations, the PRACTICA Foundation, has, in association with Global Good,[49] conducted an initial assessment of suitable locations where intermediate depth pumps could be used and meet the needs while addressing the constraints (mostly financing if capital) of farmers in two countries: Senegal and Ethiopia. In Senegal, the Niayes

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[49] Global Good is a collaborative effort between Bill Gates and Intellectual Ventures to address some of humanity's toughest problems through the power of invention. http://www.intellectualventures.com/globalgood

appeared to be a very promising area to pilot intermediate depth solutions for smallholders, with prospects of scaling up in other areas in Africa.

Senegal is a very dry country with a fast-growing population, an already large share of which is found in cities, notably the capital city of Dakar, which exceeds 2,4 million inhabitants. The Niayes area is a piece of land of 10 km width and 150 km length consisting of dunes and depressions covering productive aquifers. There, some 17,500 smallholder farmers grow vegetables on individual plots that do not exceed 1 hectare and are usually smaller than ½ hectare but altogether amount to some 5,000 ha. These market oriented dynamic farmers supply 80% of the vegetables consumed in neighboring Dakar. Almost all of them abstract water using surface petrol or diesel surface pumps. This explains why (a) their production costs are quite high, preventing them from clearly coming out of poverty even though they are market oriented, and (b) the area under irrigation using this pumping technology cannot be expanded any further since surface pumps cannot physically tap water below 7 meters.

During its assessment, PRACTICA found that, based on the local hydrogeological maps, an additional 13,000 ha could be irrigated if it was possible to pump up at intermediate depths (between 7 and 20 m deep). In addition, the assessment showed that the range of price of the various intermediate depth solar pumps was compatible with significant margins. Lastly, interviews carried out with farmers confirmed a strong interest in intermediate depth solar irrigation solutions and farmers organizations' representatives who represent their collective interests and plays an efficient role in regulating the area mentioned they would be keen to play a role in trying the technology out. So far, no such pump and associated water application technology has been tested in the Niayes area.

Objectives of the activity

The objective of the activity is to pilot the feasibility of smart intermediate depth solar pumping solutions for the farmers of Niayes that can meet farmers' requirements, expectations, and constraints (current absence of supply of such equipment, associated watering technology, possibility of repairs), can suit the local physical environment (steeper slopes on dunes, impact on the aquifer and existing plots, etc…) and commercial environment (possibility to establish a supply chain, risk of market saturation for agricultural products). Piloting the feasibility requires:

- Field testing of the solution: manual drilling combined with installation of a number of intermediate depth pump models (to be supplied) and various water application technologies;
- Immediate lessons learned from observing farmers' responses;
- Confirmation of feasibility of supply chain of affordable solar pumping solutions;
- Characterization of the impacts (positive and negative) if at scale
- Overall lessons learned and dissemination.

B. SCOPE OF WORK

As a follow-up to the initial assessment carried out by the Practica Foundation and Global Goods on intermediate depth solar pumping solutions in Senegal[50], which was solely based on site visits and documentation, and in view of its promising results, the World Bank is recruiting a firm to carry out the field-testing phase in the Niayes area of Senegal of two or more models of pumps in two or more different locations (different setting, different people). This involves the following activities:

<u>Elaboration of a methodology and detailed work breakdown</u>

The consultant shall present a methodology and detailed workflow. This shall include a protocol of field testing, confirmation of site access, parameters monitored, approach used before, during and after the test, a detailed schedule and key milestones, resources engaged, including those used to procure and supply the pumps to be tested, but considering that the latter will be provided outside the assignment's budget. At that stage (or earlier), the consultant shall give a proof of free access to the plots where the pilots shall be installed (authorization from owner, etc…).

<u>Field testing of potential solutions</u>

Selection of manual drilling combined with installation of a number of intermediate depth pump models (to be supplied) and various water application technologies

At macro level (Niayes zone or above): from surveys, literature, mapping

- Identification of sites and stakeholders

At site / farmer level

- Contracting artisans specialized in manual drilling:
  - Tubewell installation using manual drilling with test
  - lessons in terms of cost and reliability
- Water abstraction:
  - Justification of the pumps to be tested
  - Installation and testing of several intermediate depth pump
  - Showcasing the pumps
  - Comparing pumps in field situation (to be done during project) and on measurement bench (already done)
- Water application:
  - Test of various water application technologies, possibly mini-sprinkler under low pressure or Californian irrigation, drip irrigation (with crops that are familiar to farmers)
  - Measure yields.
  - Assess the response of the land and the environment.
  - Framing (with discussions with farmers and observations of current practices) and showcasing the watering technologies)

<u>Immediate lessons learned from observing farmers' responses</u>

[50] Intermediate depth solar pumps - Scoping study - Country assessment Senegal, by Global Good & Practica Foundation, 2016. 24 pages.

At site / farmer level

- Observe farmers and collect their feedback from the showcasing (using a behavioral change approach)
- Administer questionnaires or focus group discussions
- Interpretation: Analysis of the barriers to the adoption of solar pumping technologies

Confirmation of feasibility of the supply chain

At site / farmer level

- Refined financial and economic analysis (based on the initial one carried out in Practica Foundation and Global Goods), knowledge of and appetite for financial mechanisms;

At macro level (Niayes zone or above): from surveys, literature, mapping.

- Conditions for establishment of a supply chain:
  - Identification of potential champions (including the organized union of horticultural products irrigators)
  - Identification of factors that hinder or favor (customs, counterfeit, trust relationships between stakeholders, …) and assessment of these factors and how to address them.
- Assessment of market saturation risk of vegetables due to potential incremental production (Dakar region)

Characterization of the impacts (positive and negative) if at scale

At a macro level (Niayes zone in experimentation sites and beyond)

- Environmental: Assessment of potential incremental hazards (or improvements) from extrapolation and existing literature
- Land use:
  - analysis of land rights for areas that are currently of low value (dunes): current situation and prospects.
  - Recommendation for securing land rights

Overall results, lessons learned

- Results:
  - Performance of intermediate depth solar pumps as constituents of solar pumping solutions for intermediate depth;
- Lessons learned:
  - The ability of the solution to address needs, constraints, requirements of smallholder commercial farmers
  - Possibility to establish a supply chain and action plan to do so.
  - Possible changes needed to intermediate depth solar pumps
  - The process used during the pilot test
  - What lessons can be drowned from the pilot test beyond the Niayes, in Senegal and other West African countries.
- Organization and financial responsibility of a one-day debriefing workshop in Dakar or a neighboring locality:
  - Presentation of draft final report to local stakeholders

- with a maximum of 40 people, including 5 people from the consulting firm, 2 from the World Bank, and other key stakeholders to be selected during the assignment (to be costed separately with a detailed breakdown)