EVALUATION OF THE SUSTAINABILITY OF SOLAR POWERED WATER SUPPLY SYSTEMS IN KENYA

European Union Civil Protection and Humanitarian Aid

IOM • OIM

OXFAM

NRC NORWEGIAN REFUGEE COUNCIL

Global Solar and Water Initiative

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AC -------------------Alternating Current
ATM ------------------Automated Teller Machine
CAPI -----------------Computer Aided Personal Interviewing
CDF ------------------Constituency Development Fund
DAC ------------------Development Assistance Committee
DC -------------------Direct Current
ECHO ----------------European Civil Protection and Humanitarian Aid Operations
EPD ------------------Empty Pipe Detection
ESMAP --------------Energy Sector Management Assistance Program
ESRI -----------------Environmental Systems Research Institute
GIS -------------------Geographical Information Systems
GSWI ----------------Global Solar-and-Water Initiative
HH -------------------Household
IDP -------------------Internally Displaced Persons
IOM ------------------International Organization for Migration
JMP ------------------Joint Monitoring Programme
KES ------------------Kenya Shillings
KIFFWA -------------Kenya Innovative Finance Facility for Water
KIIs-------------------Key Informant Interviews
NAS ------------------Nairobi Aquifer System
NGO -----------------Non-Governmental Organization
0NRC ----------------Norwegian Refugee Council
O&M -----------------Operations and Management
OECD ----------------Organization for Economic Co-operation and Development
PV -------------------Photo Voltaic
SDGs-----------------Sustainable Development Goals
TDH------------------Total Dynamic Head
ToR ------------------Terms of Reference
USD------------------United States Dollars
VSF-------------------Vétérinaires Sans Frontières Germany
WASH ---------------Water, Sanitation and Hygiene
WHO ----------------World Helath Organization
WSPs ----------------Water Service Providers
GAA ------------------German Agro Action
WVK -----------------World Vision-Kenya

Executive Summary

The Global Solar-and-Water Initiative (GSWI), funded by the European Civil Protection and Humanitarian Aid Operations (ECHO) and led by IOM, Oxfam and NRC, seeks to promote, advocate for and mainstream the use of solar energy in WASH projects for refugee and IDP camps as well as local communities. This is with the understanding that, for most of these communities, water pumping is dependent on generators powered by fossil fuels. The high cost of fuel coupled with maintenance needs of the generators translates to high recurrent costs, which are passed on to the water consumers. The initiative's goal is to reduce medium and long term recurrent costs of operating water supply systems by mainstreaming the use of solar energy. It is, however, noted that various factors have contributed to the limited adoption of solar energy as a solution to water pumping. Some of these include: shortage of relevant expertise, limited information, standards and tools required to drive growth and lack of demonstration of benefits of using solar power for water supply. GSWI commissioned this study to evaluate the sustainability of solar-powered water systems in Kenya. The evaluation was to look at existing solar schemes where different designs, approaches and uses of energy are being applied and document best practices, shortcomings, improvements and recommend models for sustainability of solar water schemes in refugee camps and communities.

This evaluation adopts the National Research Council's[1] definition of sustainability where "a sustainable water system is one that can meet performance requirements over the long-term [including] the technical, institutional and financial capacity to satisfy public health and safety requirements on a long-term basis". The evaluation methodology applied a three-step process: (i) desk review, (ii) field work and (iii) synthesis. The desk review resulted in a detailed evaluation plan (inception report), three structured questionnaires, and a set of key informant interview questions. Questionnaire pre-testing was carried out at two solar powered systems in Machakos County for the three structured questionnaires. Primary data was collected from 40 borehole sites with emphasis of the water point selection being in regional and implementing agency diversity. There was also a bias for systems older than 3 years as stipulated in the terms of reference. The selected sites were from six counties namely Wajir, Homabay, Turkana, Kajiado, Machakos and Kitui. The implementing agencies represented included World Vision Kenya, Oxfam, German Agro Action, Kenya Redcross, Grundfos Lifelink, Water Mission International, Vétérinaires Sans Frontières Germany (VSF), private entities, County governments and Constituency Development Fund (CDF) implemented sites. The following mix of powering technologies was evaluated: 29 standalone solar systems; 7 solar-diesel hybrid systems; 2 diesel powered systems; 1 electric system and; 1 solar-electricity system. A total of 532 surveys were conducted at the 40 sites: 469 household interviews, 23 institution interviews and 40 water point operator interviews. 12 key informant interviews were also conducted. The data synthesis focused on four key areas namely i) technical sustainability, ii) operations and management models, iii) financial sustainability models and iv) impact assessment.

Technical Sustainability

Parameters including system functionality and components breakdown, maintenance and repair, vandalism and theft, and system sizing were assessed. Functionality was defined as the ability of the water system to supply water at the time of the visit. 5 of the 40 systems evaluated (12.5%) were nonfunctional at the time of the evaluation. Component breakdown, on the other hand, is defined as the failure of a critical component of the system so that the system fails to deliver water for a period

[1] National Research Council, 1997, Safe Water from Every Tap: Improving Water Service to Small Communities.

of at least one day. The study found that 22 out of the 40 (55%) water points surveyed have experienced a component breakdown in the past (the time bound of 'past' varied with the experience of the respondent with the water point). The most frequent breakdowns (12 of the 22 systems) were water pipes related issues such as bursts and leakages which are easily resolved. Pump failure was the second most predominant breakdown at 8 out of 22 systems. 3 out of 22 systems reported theft of solar panels as a contributor to power source breakdown; only 3 of the 37 systems (8%) installed with solar systems indicated breakdown due to issues with the solar technology, and the issues were not technological, but rather due to theft. This may be contrasted to 5 of 9 systems (56%) fitted with diesel generators that indicated power source breakdown due to issues with the generator. Overall, it was concluded that 1) solar technology contributes to greater reliability of water systems as compared to diesel systems due to their much low probability of breakdown and 2) the main contributor to systems non-functionality over extended periods is pump-breakdowns, and this is agnostic to the power generating system. Pump failure was the cause of non-functionality for 4 of the 5 nonfunctional systems observed during the evaluation. Also, while it was the second most frequently observed component breakdown after water pipes, repair of water pumps often requires specialized skills and is costlier compared to fixing water pipes which is easily done at the local level. Frequent water pump failure should, however, not be the case as submersible pumps have a life-span of 10-15 years if properly installed and require very minimal maintenance. There is therefore need for heightened focus on proper system design and pump installation by implementing agencies.

Evaluation of pump sizing was carried out for only 14 out of the 40 systems because of data limitations. Only 3 of the 14 systems were seen to have pumps that are oversized while the remaining 11 are either correctly sized or inconclusive. Systems considered inconclusive were those that had undersized pumps from the evaluation analysis but it was unclear whether smaller pumps were deliberately selected (e.g. due to lower demand than borehole yield). 9 out of 13 systems have correctly sized power for the pumps installed while the remaining 4 were undersized. Undersized systems with regards to power tend to operate at a lower flow rate than desired leading to lack of adequate water to meet demand or longer wait times at the water points. The evaluation reveals the importance of correct pump selection, array layout and solar panel selection and the resulting economic efficiency that can be achieved.

Operations and Management Models

A one-size fits all approach cannot be adopted for the management of solar-powered water systems as different management models can be applied successfully in varied contexts. Different management models work in different settings and this evaluation does not find that there is a specific model that should be advocated for or admonished. Because a model is working in one setting does not mean it will work in all settings; that a model is not working in a different setting does not mean it's a bad idea. Good concepts may sometimes not work because they were either not executed well, their execution was wrongly timed or was in the wrong environment. The study identified three distinct water systems management models among the evaluated systems namely:

County implemented and managed water schemes implemented by the county government of Machakos. The model's key strength is that County resources are used in installation and management of systems including designated water engineers and county plumbers. Because water is provided for free, the models main weaknesses are financial: bureaucracies involved in spending of public resources lead to long durations of system downtime.

Private sector implemented and managed model implemented by Grundfos LIFELINK, Grundfos' inclusive business model for sustainable supply of safe drinking water at affordable prices. The model's key distinguishing features are 1) water dispensing ATMs and water ATM cards/keys designed to work on the M-pesa platform and 2) Grundfos LIFELINK signed 5-10-year service and maintenance agreements with communities. While the model had favorable reviews from all the beneficiary communities, only about 5 of 38 systems could consistently collect the agreed upon amount of about KES 215,000 p.a. based on at least 5 years of operation, disproving the model's business case. This has led Grundfos LIFELINK to discontinue the program. In its place, Grundfos has developed an improved model of the water ATM (AQTap) that transfers O&M and financial management to water committees.

Community water users group managed model whose generic attributes include implementation of systems under aid projects which are handed over to communities and; a committee appointed by the community to oversee day-to-day and the overall management of the system. Varied success rates were observed for systems under this model. The study identified some overarching characteristics of successful community managed schemes: i) Presence of at least one individual who is highly committed to the success of the project; ii) Absence of alternative sources of water, especially during the dry season; iii) High sense of community responsibility often displayed by a general perception that water collections held by the committee is community funds and iv) Presence of recurrent costs.

Recognizing that the different management models have varied merits and demerits, this study identifies three main factors that should be incorporated into any management approach to enhance its sustainability: financial accountability which could be achieved through registration of water users associations as legal entities and use of water ATMs; dedicated and salaried water point operators responsible for day-to-day operations and; availability of technical support for maintenance and repairs which could be achieved through engagement of the county water office (county engineers and plumbers).

Financial Sustainability Models

In efforts to mainstream the use of solar power for water pumping at community level, the focus of most aid agencies has been on the reduction in recurrent costs associated with water supply and consequent payback period for solar water systems against fossil fuel powered generators. This study finds that the focus on reduced recurrent costs and short payback periods, unfortunately, tends to be interpreted as no cost of energy for water pumping negating the need for making water payments by beneficiary communities. This conclusion is deduced from two key observations: 1) Among the solar-diesel hybrid systems evaluated, water pumped using the solar system was often provided for free; payment for water services is mostly for water pumped using the diesel generator. 2) There was a notable discrepancy between what people indicated to be paying for water services and actual revenues collected by the water points. The 2 diesel powered systems, the solar-electricity system and the operational solar-diesel hybrid systems indicated charging for water. 69% of the operational standalone solar system (n=25) also indicated charging for water services. While the cost of water per 20L jerrycan averaged at about KES 5 for all these systems, the monthly collections for the solar standalone systems were significantly lower compared to the other systems. The average monthly collections for solar standalone systems providing water at a fee was KES 20,085 compared to KES 142,667 among solar-diesel hybrid systems, KES 41,000 for solar-electricity hybrid systems and KES 43,000 for diesel systems.

With these observations, the evaluation finds that while the focus on reduction in recurrent costs associated with water supply and consequent payback period for solar water systems against fossil fuel powered generators is suitable for the supply side (development/aid agencies and government bodies), there needs to be a complete shift in the demand facing narrative (benefitting communities) from **'*tapping into a cost-free source of energy for water pumping*'** to **'*cumulating funds for system replacement*'.** Communities need to understand that while there are minimal recurrent costs in operating solar systems, there are significant one-off costs required to ensure continued long-term operation. Consequently, water must be provided at a fee to ensure funds for repairs, maintenance and replacement of parts. With the current approach, the sector faces the risk of having multiple scattered non-functional systems in 10-15 years.

Impact Assessment

This evaluation concluded that overall, solar powered water supply systems have the capability to provide accessible and reliable water to communities. A key impact that can be derived from solar-powered water supply systems that is still in its nascent stages in Kenya, is its ability to deliver the highest level on the JMP ladder for household drinking water services – safely managed drinking water. An example of this was 4 solar-diesel hybrid systems in Wajir county which had distribution networks that included household connections and communal water points.

It is also worth noting that many solar-powered boreholes assessed under the evaluation, particularly those in Kajiado, Kitui and Machakos, exhibited water quality issues due to high levels of salinity. The poor quality of water at these water points limits the uses of water to cleaning and watering of livestock and is a significant factor to why people rely on alternative sources of water: while 90% indicated relying on the evaluated systems as their main source of water, 58% also indicated relying on more than 1 source of water. Siting of solar powered water systems should therefore be deliberate in ensuring water quality to ensure target communities use the water for potable purposes.

Recommendations

Overall, the study has found that solar powered water supply systems (SPWSS) for communities is technologically ready for mainstreaming in the Kenyan setting. However, to ensure sustainability of the systems, financial and operations & management considerations outlined above MUST be addressed. Following evaluation of best practices at successful water points along with inputs from KIIS, the following two models of implementing solar powered community water access projects are recommended:

The enhanced water committee model recognizes that communities will continue to manage their water supply systems, at least in the interim and more so for supply schemes developed under aid projects. With this in mind, the model proposes the following enhancements: 1) Institute financial accountability measures including a) NGO funding should be extended to include pre-paid water meters (ATMs), particularly ATMs that channel money directly to the water point's bank account; b) NGOs should ensure that communities have bank accounts and multiple signatories identified prior to handing over systems to communities; 2) System liability should be shifted to borehole equipping companies for enhanced design and installation services. This may be achieved through staggered payment structures bound by the funding cycles (e.g. 80% upon equipping the borehole and 20% at the end of a two-year period upon confirmation of functionality); 3) Active county government engagement for financial accountability (e.g. being signatories to bank accounts) and technical support (systems maintenance and training of committees by county engineers and plumbers).

The Private entity management model is built on the premise of running a water point like business to ensure cost recovery and enhance sustainability. It involves engagement of a profit-making entity, preferably, a micro-enterprise, to oversee the management of water points including O&M. The model is anchored on aggregation and clustering of sites (>20) within a region whose management is outsourced to an identified company. The outsourcing agent could be the county government or an NGO/consortium of NGOs working within an area. This entity will work through salaried scheme operators eliminating need for water committees. Economies of scale and the revenues collected form the incentivizing factor for private sector (back of the envelope estimate assuming 250 households served by one waterpoint and paying a minimum of KES 250 per month would result in at least KES 62,500 per site; 1.25 million for 20 sites). As in the enhanced water committee model, it is recommended that funding entities 1) shift some liability to borehole equipping companies for enhanced system design and installation and; 2) extend funding to installation of water ATMs. The county governments on the other hand are engaged in contracting and regulating the private entity.

1.Introduction

1.1 Background

The Global Solar-and-Water Initiative(GSWI), funded by the European Civil Protection and Humanitarian Aid Operations (ECHO) and led by IOM, Oxfam and NRC, seeks to promote, advocate for and mainstream the use of solar energy in WASH projects for refugee and IDP camps as well as local communities. This is with the understanding that, for most of these communities, water pumping is dependent on generators powered by fossil fuels. The high cost of fuel coupled with maintenance needs of the generators translate to high recurrent costs, which are passed on to the water consumers. The initiative's goal is to reduce medium and long term recurrent costs of operating water supply systems by mainstreaming the use of solar energy. It is, however, noted that various factors have contributed to the limited adoption of solar energy as a solution to water pumping. Some of these include: shortage of relevant expertise, limited information, standards and tools required to drive growth and lack of demonstration of benefits of using solar power for water supply.

1.2 Objectives

GSWI commissioned this study to evaluate the sustainability of solar-powered water systems in Kenya. The evaluation was to i) be carried out on existing solar schemes where different designs, energy mixes and approaches are being used, ii) assess the cost-effectiveness of adopting solar water pumping systems and their efficiency, reliability and sustainability in ensuring community water access, iii) highlight the challenges facing the development of solar-powered water supply and, iv) document best practices and recommendations on models for the sustainability of solar powered water supply in communities.

1.3 Solar Powered Water Supply in Kenya

There has been a marginal increase in access to basic water supply in the country between 2000 and 2015, with the annual rate of change standing at a meagre 0.80%. The Joint Monitoring Programme (JMP) for Water Supply and Sanitation estimated that in 2015, 58% of Kenyans (83% in urban areas and 50% in rural areas) had at least a basic level of water supply, compared to 46% in 2000 (88% urban, 36% rural). This means that, 42% of the population, an estimated 19 million Kenyans, still source their water from unimproved sources including 23% relying on surface water sources like rivers, dams, lakes and irrigation channels[2]. These sources pose significant health risks as they expose individuals to a variety of water-related diseases. They are also intermittent and unreliable, particularly in arid and semi-arid areas. Efforts are being made to improve WASH access, especially in the rural, marginalized and remote areas of Kenya, through the provision of more technical assistance and donor contributions to rural water service providers and county water departments. There are also initiatives such as the Kenya Innovative Finance Facility for Water (KIFFWA) aimed at catalysing private sector investment in the improvement of water services.

Solar- Powered groundwater pumping systems are the fore front of pro-poor technologies being promoted for human, livestock and other remote watering applications because they are durable, can be mobile and exhibit long term economic benefits[3]. Kenya has abundant solar energy sources with an estimated insolation of 5-7 peak sun hours. The country can harness this resource as a cheaper alternative to diesel or electricity for groundwater abstraction.

[2] World Health Organization (WHO) and the United Nations Children's Fund (UNICEF), 2017, Progress on drinking water, sanitation and hygiene: 2017 update and SDG baselines. Geneva.

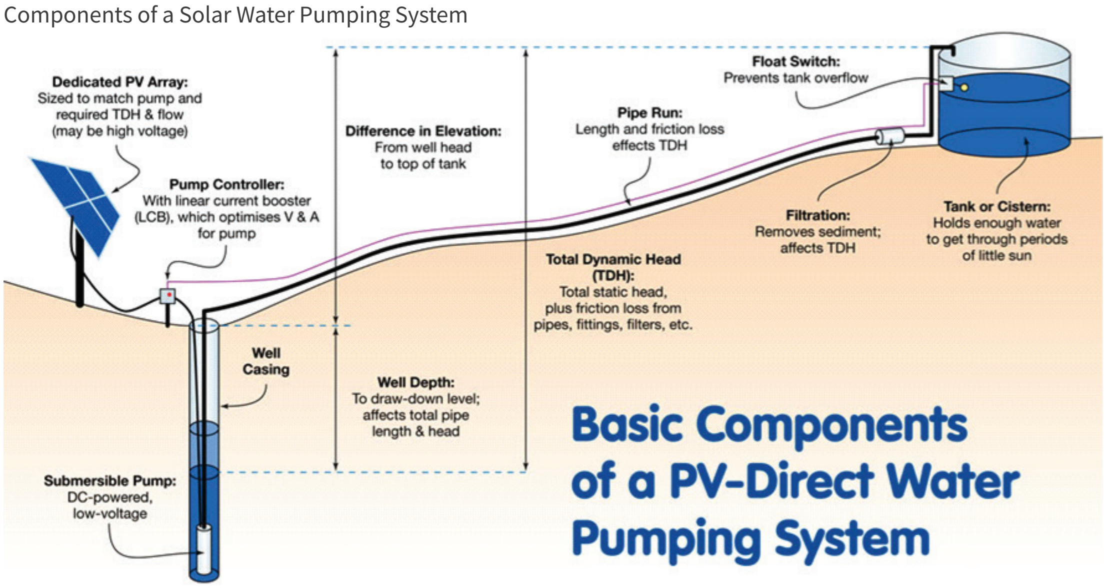
[3] R.V Pelt, C Weiner and R. Waksom, Colorado State University Solar-Powered Groundwater Pumping Systems- https://dspace.library.colostate.edu/bitstream/handle/10217/183597/AEXT_067052012.pdf?sequence=1

A solar water pumping system is like any other conventional water pumping system except that the power source is solar energy. The systems have, as a minimum, a PV array, a motor, a pump, and a water storage tank (See Figure 1). Water is more cheaply and effectively stored in a tank rather than storing electro-chemical energy with batteries. Pump motors are normally run directly from the PV array and can use maximum power point tracking controllers which optimize energy harvest from the solar PV array, increasing system reliability[4].

There has been a steady increase in the number of solar water pumping systems installed in Kenya primarily due to the declining prices of photovoltaic modules which have fallen rapidly from USD 5 per watt in 2000 to USD 0.5 per watt in 2014[5].

Other factors that have contributed to this increase in uptake include: advances in inverter technologies and its associated falling prices and an increase in the number of players within

Figure 1: Components of a PV-Direct Water pumping system



Source: Home Power Magazine

the solar water pumping market offering competitive services and more choices for consumers. About 50% of the solar water pumping systems in Kenya are used for irrigation while the remaining 50% are for community water supply[6].

Several conducive policy and regulatory frameworks around solar products put in place by the government have furthered this uptake. These include; i) the National Energy and Petroleum Policy 2015 which provides tax concessions for development of renewable sources of energy including solar, ii) the Energy (Solar Photovoltaics) regulation 2012 which is aimed at improving the quality of solar products in the market, iii) The sessional Paper No.4 of 2004, iv) the Energy Bill 2015, v) Kenya vision 2030 and vii) The Kenya National Climate Change Response Strategy[7].

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[4] Solar Water Pumping: Kenya and Nepal Market Acceleration https://www.researchgate.net/publication/284098829_Solar_Water_Pumping_Kenya_and_Nepal_Market_Acceleration [accessed Dec 11 2017].

[5] B.O. Muok, W. Makhoha and D. Palit Solar PV for enhancing electrical access in Kenya-What Policies are required?

[6] R.Foster, A.Cota- Solar Water Pumping Devices and Comparative Economics- https://www.researchgate.net/publication/259932006_Solar_Water_Pumping_Advances_and_Comparative_Economics

[7] Kenya Climate Innovation Centre(KCIC)-Kenya Solar PV Market Assessment- https://kenyacic.org/sites/default/files/publications/KCIC%20Solar%20Survey-3.pdf

1.3.1 Initiatives in Community Managed Water Supply

Water supply in the rural areas is evolving as more sector players begin to involve the private sector in the management of community water supply for the enhanced efficiency and promotion of sustainability. The two examples highlighted below give an outlook into current developments in the sector.

a) Fundi Fix Model

Fundi Fix is a community water point maintenance service that was established by Oxford University under the Reach project. It is currently being piloted in Kwale and Kitui Counties and is currently limited to the maintenance of hand pump systems. The mission of Fundi Fix is to provide quicker, cheaper and sustainable water maintenance services to rural communities. Typically, under the model, a community will sign a renewable maintenance contract with Fundi Fix which will then provide regular check-ups and status monitoring of the handpumps. Fundi Fix will also conduct repairs in less than 2 -3 days upon receiving an alert on system breakdown. The community in-turn pre-pay service charges every month to Fundi fix via mobile money. The model is based on four interconnected aspects; professional services, sustainable finance, smart monitoring and coordination. The professional services pillar describes how the Fundi Fix model seeks to promote local entrepreneurs by employing them on performance-based contracts to maintain water infrastructure, the sustainable finance pillar illustrates how the model applies financial instruments such as performance-based finance, mobile payments and a water services maintenance trust fund to effectively manage funds, the smart monitoring pillar describes how under the model, handpumps are fitted with sensors that continuously monitor their condition and flag down technical issues. The smart monitoring data is aggregated on cloud-based computing. The institutional coordination pillar simply reflects the need for organization among sector players and separation of policy, regulatory and delivery functions[8].

b) Service Delivery Models for Sustainable Water Supply

This is an initiative housed with the Water Sector Trust Fund and developed by the Netherlands Development Organization (SNV) in collaboration with Kenya Markets Trust. The three bodies piloted 5 different service delivery models in the Western Region of Kenya which they term as institutional options for water supply and subsequently developed a service delivery model toolkit as a guide. The basic premise of the 5 models is the incorporation of the private sector to professionalize the management of rural and peri-urban water systems. The models include; i) the lease operator model-where a private sector operator (lessee) takes over a water system for a period of 7-10 years and operates and maintains system with minimal investment in network expansion while paying the asset owner lease fees, ii) the delegated management model which involves a larger WSP allocating a portion of it's service area to a smaller operator to manage, iii) the private operator model where a private party (a legally registered enterprise), is contracted to provide all managerial and technical expertise at a water scheme for 3 to 5 years, iv) the operations and maintenance service contract where a body mandated to oversee water supply contracts a private entity to provide maintenance and repair support for their water assets on their behalf and the v) professional manager model which involves a Community water committee appointing a professional team to oversee day to day operations while it provides strategic oversight. In all the models the county and the regulator must provide consent and oversight[9].

1.3.2 Hydrogeology

Groundwater is a highly valuable resource in Kenya, which is classified as a water scarce country. It is particularly important in the arid and semi-arid areas which cover 80% of the country and support 34% of the country's population and 50% of livestock. There are five different categories of aquifers in Kenya depending on the yield of the aquifer system and the quality of water as illustrated in Figure 2 below.

There is no standard depth for the different aquifer categories as depth varies for individual aquifers within the categories. The Merti Aquifer, which is classified as strategic, is thought to be between 80m-280m thick with boreholes typically being dug between 105m and 150m. Nairobi Aquifer system, also falling within the strategic category, is a complex multilayered, aquifer system. Boreholes in this system are typically drilled

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[8] The FundiFix Model: Maintaining Rural Water Services-UNICEF, REACH, University of Oxford- https://reachwater.org.uk/wp-content/uploads/2016/11/Fundifix-booklet-WEB.pdf

[9] Service Delivery Model Toolkit for Sustainable Water Supply (2017)- Water Sector Trust Fund

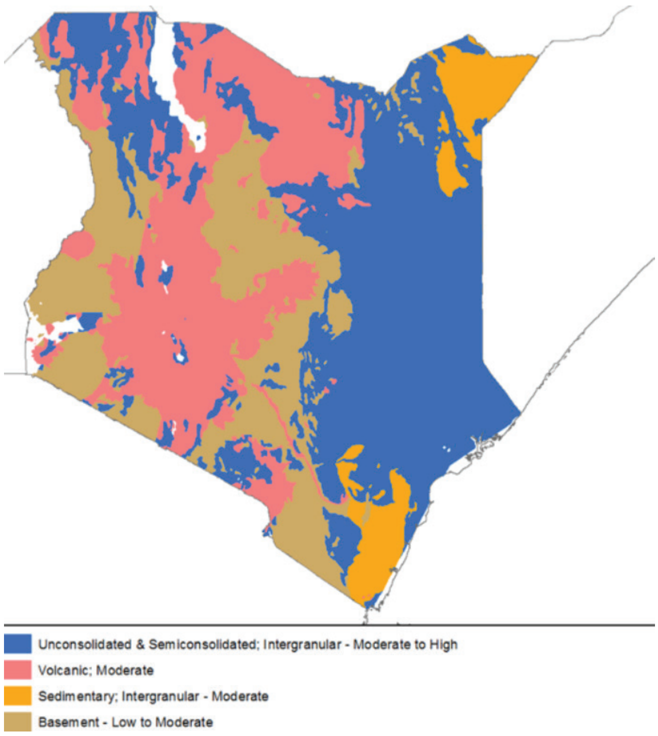
Figure 2: Classes of Aquifers in Kenya

Class	Description	Examples
Strategic aquifer	Aquifer used to supply significant amount /proportions of water in a given area and for which there are no alternative resources, which such resources would take time and money to develop, significant transboundary aquifers	Sabaki, Tiwi, Nairobi, Central Merti, Nakuru, Kabatini, Lake Naivasha, Lamu Island
Major aquifer	High-yields aquifer systems with good quality water	Daua and Elgon
Minor aquifer	Moderate-yield aquifer systems with variable water quality	Mandera Jurassics
Poor aquifer	Low to negligible yield aquifer systems with moderate to poor water quality	Aquifers in Basement Rocks
Special aquifer	Aquifers systems designated as such by WRMA	Isinya

Source: National Water Master Plan 1992

between 250m-450m.[10] Development of a database with comprehensive details on each aquifer within the prescribed categories should be undertaken to enhance understanding of Kenya's ground water resources and inform their exploitation through technologies like solar water pumping. Figure 3 below illustrates the interconnectivity and location of aquifers in Kenya. It indicates that high yielding unconsolidated and semi-consolidated intergranular aquifers are found in arid and semi-arid regions covering counties such as Wajir, Garissa, Turkana, Kitui and Tana River. These counties have the adequate levels of solar insolation required to support solar-powered pumping indicating potential for exploitation.

Figure 3: Aquifers in Kenya



Source: Earthwise-British Geological Survey

[10]British Geological Survey- http://earthwise.bgs.ac.uk/index.php/Hydrogeology_of_Kenya

2. Methodology

A three-step evaluation process was employed to meet the objectives of the ToR. This included (i) desk review, (ii) field work and (iii) synthesis. This enabled the assessment of the technological, economic, and social aspects associated with solar water pumping systems in Kenya. Figure 4 represents a summary of the approach.

2.1 Desk Review

The desk review had two main aims, the first was to understand the background and the context of GSWI as well as the current state of solar water pumping in communities. The second was to conduct a comprehensive desk and literature review on; i) the use of solar energy for water access and ii) WASH indicators and evaluations that would contribute towards the analysis of data collected during the fieldwork stage.

The step also informed the formulation of the sampling framework and the field data collection tools. This included the design of the institutional, household and water point operator survey questionnaires.

Figure 4: Study Approach

Desk Review

- Reviewing relevant GSWI documents to fully understand the intended intervention logic and partners' information needs.
- Identifying solar powered schemes, develope a concise evaluation framework and design data collection tools.
- Listing of potential relevant participants and partners to be consulted

Field Work

- Preparation for data collection
- Selection and training of enumerators
- Conduct the field study
- Data cleaning and analysis

Synthesis

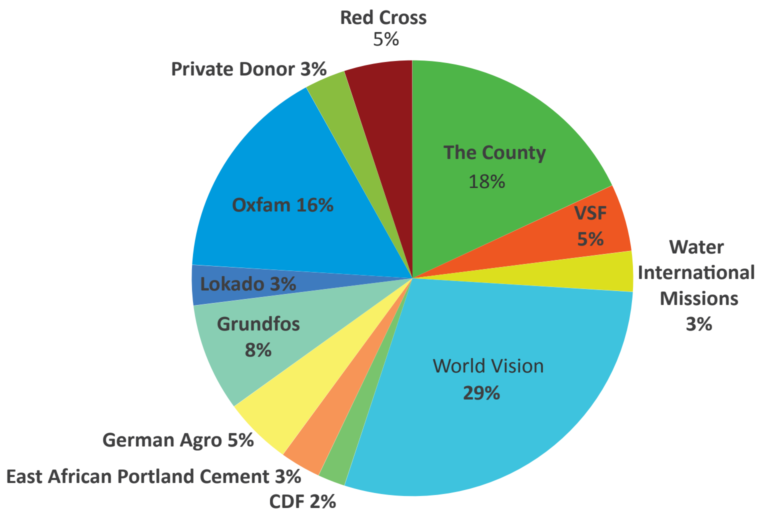
- Writing of draft report and validation of findings with evaluation stakeholders
- Integrate stakeholder comments into the evaluation report
- Produce an advisory document that highlights study finding and key lessons and recommendations on use of solar systems for sustainable community water supply.
- Development of best practices to be adopted for the management of solar-powered water pumping systems
- Produce an sustainability took-kit for solar powered boreholes

2.2 Field Work

2.2.1 Location Sampling

Primary data was collected from 40 borehole sites across six counties namely Wajir, Homabay, Turkana, Kajiado, Machakos and Kitui. The 40 borehole sites were selected from a database developed through collating data from a list of sites provided by GSWI with open source data from the water point data exchange. Emphasis of the selection was on regional and implementation agency diversity to ensure a representative survey. Some of the initial boreholes selected during the project inception were substituted following telephone verifications with the local contact persons as well as GSWI recommendations. The substitutions helped to augment the variety of the boreholes assessed. Figure 5 below illustrates the donor and system mix. The final borehole sites evaluated are listed in Annex 1.

Figure 5: Mix of selected sites



Powering System	No.
Diesel power	2
Electric power	1
Solar + Diesel hybrid	7
Solar+Electricity hybrid	1
Solar power	29
Total	**40**

Year of solar system installation	No. of sites
2007	1
2011	3
2012	3
2013	4
2014	7
2015	7
2016	9
2017	3
Total	**37**

The locations of the boreholes that were visited are also illustrated in Figure 6. A web map with interactive pop-up windows was developed on the ESRI ArcGIS online platform to provide detailed attribute information on the 40 sites and can be found on the following *link. {http://arcg.is/Du1HS}.*

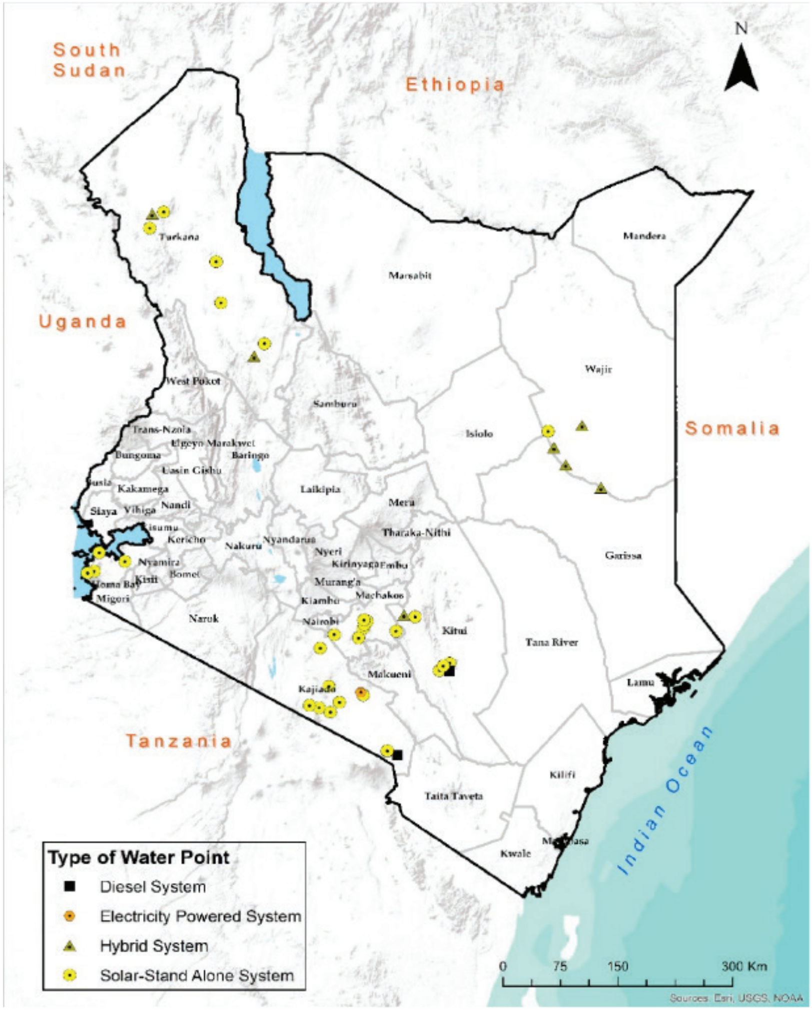
2.2.2 Respondent Sampling

Of the 40 borehole schemes assessed during the evaluation, 38 were community user schemes while 2 were private boreholes. To ensure a representative household sample at the 38 community user schemes, respondent selection was based on the random-walk technique. Institutions surveyed were selected on the advice of the water point operator or the water point committee. A total of 532 surveys were conducted at the 40 sites, surpassing the proposed target sample size of 484 as illustrated in Table 1 below.

Table 1: Sample size of primary data collection

Respondent Type	Intended Interview Sample	Achieved Interview Sample
Households	370	469
Institutions (Schools and Health Facilities)	74	23
Water Point Operators	40	40
Total	**484**	**532**

Figure 6: Location and Type of Sampled Sites



The institutional surveys fell short of the intended target because primary schools were closed during the survey period while access to secondary schools was limited due to ongoing national examinations. It was also observed that there were very few health centres and dispensaries at the surveyed sites. Extra household interviews were done to compensate for the deficit in institutional surveys.

2.2.3 Survey design and administration

Structured questionnaires were administered to scheme users, scheme operators and institutions. The questionnaires covered aspects on price per barrel of water, average volumes of water sold, system reliability, impact of vandalism and theft on solar systems, cost recovery mechanisms, number and technical characteristics of pumps and solar systems installed and % downtime of solar systems among other parameters.

The questionnaires were developed iteratively, incorporating comments from GSWI and observations from the pre-test exercise which was conducted at two borehole sites in Machakos County.

The survey interviews were conducted through Computer Aided Personal Interviewing(CAPI) using the Open-Data Kit (ODK) tablet-based survey platform. The android-based application provides a user-friendly interface for questionnaire administration and allows for interview inputs to be saved on an electronic device's memory or uploaded directly to a local server where data cleaning and analysis can be done.

The household and institutional surveys were administered by enumerators from the local communities with overall supervision and coordination from the EED team. The more complex scheme operator survey was conducted by EED supervisors.

2.2.4 Key Informant Interviews

Semi-structured questionnaires were developed for key informant interviews with relevant stakeholders identified during the literature review stage as well as during field work. Interviews were conducted with county water officers, water equipment supply companies, donor organizations and Water Service Providers (WSPs). The list of KIIs is provided in Annex 2.

2.3 Synthesis

Outputs from the desk review and field work stage were cleaned and analysed on excel and synthesized to develop a concise report acting as both an advisory document and performance report. The sections of the report on performance summarize the performance of the solar schemes on parameters of interest while the advisory components of the report discuss practices and shortcomings observed in the evaluation and offer recommendations on financial, capacity, policy, and technical approaches to promote adoption of solar-powered water supply in Kenya.

2.3.1 Limitations and Assumptions

1. Impact of solar powered water supply systems was performed against alternative sources of water used by target study respondents. Impact evaluations require baseline data which was unavailable due to the nature of this evaluation – water systems evaluated under this study were implemented by varied entities under different programs. To fill the gap in baseline information, the evaluation assumed that in the absence of the solar schemes, the alternative sources of water relied on would be the main sources of water.
2. In addition to comparing impact of solar powered systems against alternative sources of water, evaluation of the effectiveness of solar powered water supply systems was based on JMP recommended standards for water access. While the study could not conclude on whether the water users' situation had changed with the installation of the solar schemes, use of JMP standards allowed conclusions on level of drinking water services.
3. Only sources that were used by more than 10 respondents are used in the evaluation of the impact of solar powered water supply systems against alternative sources of water. The percentages reflected in the analysis are based on the number of people that indicated using a source of water.
4. There was inadequate data collected for education and health institutions because the survey was conducted at a time when primary schools were closed and there was limited entry to secondary schools due to ongoing national examinations. There were very few health centers and dispensaries at the visited sites.

3. Technical Sustainability

Technical sustainability in the context of this study looks at aspects pertaining to the functionality of solar water pumping components particularly the solar water pump and the solar PV module. The section is anchored on exploring the capability of solar-water pumping equipment to provide service for the stipulated life-span and the factors that affect and contribute to the longevity of equipment service including maintenance and repair, vandalism, theft and proper installation and system sizing.

3.1 Analysis of water point functionality rate

Functionality of the solar-powered water systems was based on the operational status of the system at the time of the visit – that is, was the system supplying water at the time of the visit? 5 of the evaluated systems (12.5%) were non-functional at the time of the site visits. 4 of these were due to broken pumps, while only one was not functioning due to theft of solar panels. The table below elaborates on causes of non-functionality for the five non-functional water points.

Table 2: Narrative for non-functional systems

#	Name of Borehole (cause of non-functionality)	Date of Borehole Installation	Date of Solar System Installation	Date of breakdown	Narrative on System Issues
1	Saremba Borehole **(Solar-Panel Theft)**	Aug 1996	Dec 2014	Jan 2017	***Ownership and System Security Issues***- Saremba borehole, located in Homabay County was retrofitted with solar power in 2014. The system however ceased to function due to the theft of several solar panels by community members. The theft can be traced back to lack of adequate system ownership by the community coupled with inadequate system security. The solar powered system was in a remote area far from community homesteads. Additionally, the panels were not welded securely onto the frame making it easy to remove the panels. The community has also exhibited over-reliance on the implementing NGO as they are unable to replace the missing panels themselves and are awaiting assistance from the NGO.
2	Lokori water supply system **(Pump Failure)**	Aug 1986	Jan 2014	Feb 2017	***Inadequate Maintenance Issues-*** Lokori Water supply system is a 31-year-old system that was retrofitted with solar power in 2014. The system, however, broke down due to suspected pump failure. The community attributes the breakdown to lack of scheduled maintenance of the pump.

#	Name of Borehole (cause of non-functionality)	Date of Borehole Installation	Date of Solar System Installation	Date of breakdown	Narrative on System Issues
3	Naibala Borehole **(Pump Failure)**	May 2016	May 2016	Aug 2017	***Installation and Warranty Issues-*** Naibala Borehole located in Kajiado county, is a solar stand-alone system that was installed in 2016. However, the pump broke down in 2017. The breakdown occurred less than two years after installation and should have been fixed under the system warranty- which for pumps runs up to two years. Suspected lack of knowledge by the community on how to go about repairs or on issues concerning warranty is the main reason why the system is currently still non-functional. Proper communication by the implementing NGO on possible avenues for repair as well as transfer of important documents such as the warranty certificate can deter this kind of situation from arising.
4	Inkisanjani Nasieku Growers Project Borehole **(Pump Failure)**	Feb 2014	Feb 2014	Sept 2014	***Installation and Warranty Issues-*** The Inkisanjani borehole is one of two systems that were set up for the sole purpose of providing water for an irrigation scheme called Inkisanjani Nasieku Growers Project near Oloitoktok town, Kajiado County. The system ceased to function 6 months after commissioning. Local technicians estimated that pump repair would cost about KES 350,000- 400,000. They community noted that they were not in possession of any warranty documents which would have allowed them to repair the system as it was less than two years old. Additionally, this community also exhibits dependency on the implementing NGO as they are unable to raise the funds required to replace the pump and are constantly reaching out for funding.
5	Leboo Borehole **(Pump Failure)**	June 2015	June 2015	Dec 2016	***Installation and Site Selection Issues-***Leboo borehole in Kajiado County, was reported to have been problematic right from installation. According to the system operator, the pump installers were forced to pause installation due to a pump malfunction and return it to their workshop for repairs. The pump failed an additional two times after installation, and was repaired by the installing company. Unfortunately, the pump failed a third time, less than two years after installation and has never been repaired since. The community is not too keen on fixing the system as: i) it is in an area with about 3 other boreholes in very close proximity; ii) the water produced from the system has an unpleasant taste. This speaks to the need for rigorous feasibility and hydrogeological studies prior to selecting a borehole site.

As can be seen, 3 of the 5 nonfunctional systems broke down within two years of installation of the solar system. This observation complements observations made during a national evaluation of solar powered schemes installed by UNICEF in Somalia that concluded that solar powered community water supply systems have a 2-year mortality period: probability of functionality is much greater beyond two years of operations[11]. To ensure systems operate beyond 2-years a phased payment approach between implementing NGOs bodies and borehole equipping companies may be adopted. This is further expounded in the recommendation section.

The findings of the study which highlight pump failure as the leading cause of non-functionality corroborate the results of a Water Aid study evaluating the use of Solar Technology at two Ethiopian water schemes, -Abete Barage and Yebabe Eyesus. The study revealed that at both sites failure was a direct cause of pump and inverter failure while the solar panels were reliable and experienced no issues. The system at Abete Barage was in fact not functioning because of pump failure[12]. Another study by UNICEF on a review of experiences with solar water supply systems, reiterates the fact that pump related issues such as a motor burnout are considered severe issues[13] whose repair could take several weeks.

It is understood that submersible pumps have a long life-span and are supposed to give 10 -15 years of service if care is exercised during initial installation [14]. However, conversations with sector players (donor organizations and equipping companies) revealed that incomplete or missing borehole completion reports and test pump documents are a major contributor to improper sizing of pumps which subsequently leads to failure of the borehole system. This is particularly the case for retrofitted systems where due to the age of the system, borehole reports may have been lost over the years. These reports contain important parameters such as the borehole depths, aquifer characteristics, tested yield, the static water level and the pumping water level that inform the selection of the correct pump[15].

Declining ground water levels are another contributor to submersible pump breakdown. For the pumps to work efficiently, they must maintain a level of water above them to stop them from running dry, a situation that can destroy the pump in a very short time[16]. It is important to conduct an initial aquifer test to determine the hydraulic characteristics of aquifers or water-bearing layers and identify potential local groundwater flow problems before setting up the pump system. Pumps can also be protected against low water flow using dry run protection in the form of low-water-level sensors that turn off the pump when water drops below the lowest sensor.

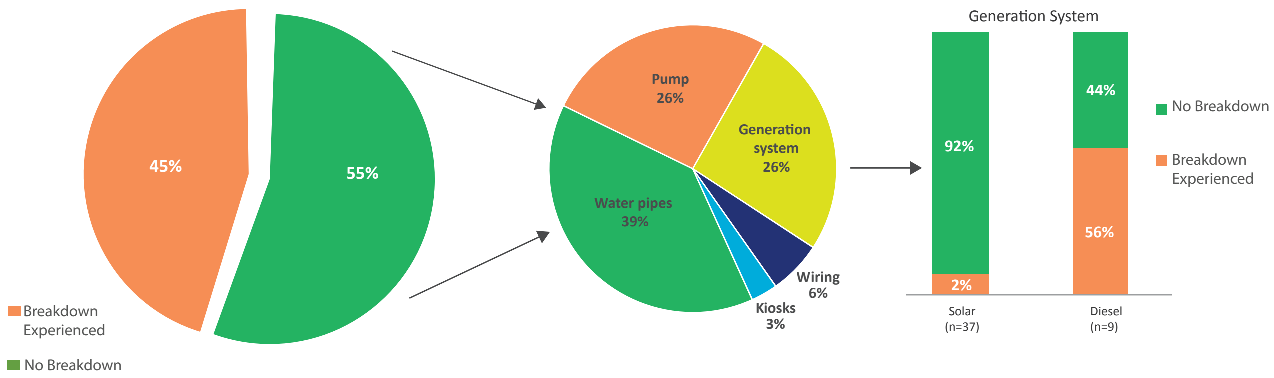
3.2 Analysis of Component Breakdown

Components breakdown was also evaluated. Component breakdown, in the context of the study, is defined as the failure of a critical component of the system so that the system fails to deliver water for a period of at least one day. It is differentiated from functionality in that it is not dependent on system status at the time of evaluation but rather historical events. The study indicated that 22 out of the 40 (55%) water points surveyed have experienced a breakdown in the past (the time bound of 'past' varied with the experience of the respondent with the water point). Analysis on system components breakdown indicates that most breakdowns (12 of the 22 systems) are water pipe related issues such as bursts and leakages which are easily resolved. Pump failure was the second most predominant cause of breakdown at 8 out of 22 systems. Generation system malfunction was also one of the major contributors to system breakdown with 8 of 22 systems having experienced a failure with the solar technology or the

[11] Study by EED Advisory Ltd for UNICEF – Somalia.
[12] Solar Technology: An Alternative Technology for Pumping Water http://soilandwater.bee.cornell.edu/publications/seifu-wateraid-note4.pdf
[13] Scaling Up Solar-Powered Water Supply Systems: a review of experiences (2016)-UNICEF- https://www.unicef.org/wash/files/UNICEF_Solar_Powered_Water_System_Assessment.pdf
[14] Water Group-Deep Well Submersible Pumps Operating and Installation Instructions for Dynaflo Pumps
[15] P. Munyoki, Equipping, Commissioning and Maintenance of Boreholes
[16] http://www.impress-sensors.co.uk/applications/borehole-level-measurement-using-pressure-level.html

diesel generator. Exploring this further, it was found that only 3 of the 37 systems installed with solar systems indicated breakdowns due to issues with the solar technology, and the issues were not technological, but rather due to theft. This may be contrasted to 5 of 9 systems fitted with diesel generators that indicated power source breakdown due to issues with the generator. This illustrates the reliability of solar technology as compared to diesel generators as a power source. Additionally, since solar technology experiences fewer breakdowns it is also more cost efficient as it requires less resources to maintain.

Figure 7: Systems that have experience component breakdown

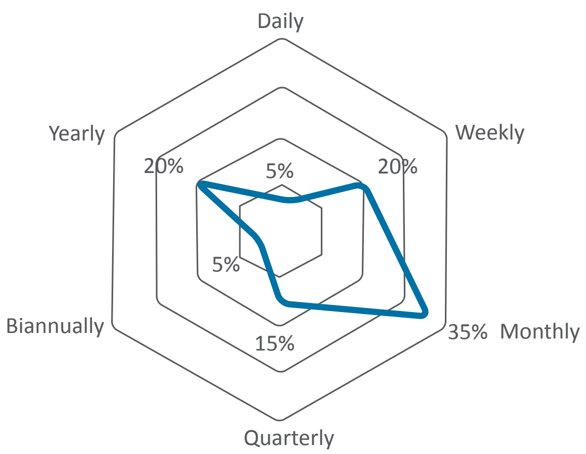


3.3 Maintenance and Repair

3.3.1 Maintenance

Solar-water pumping systems are advantageous in that they can operate without supervision and require very little maintenance compared to diesel set-ups. However, routine preventive maintenance is necessary to ensure a long-life cycle[17]. Queries into the different types of servicing plans in place at the 40 water points revealed that maintenance of the equipment was largely limited to cleaning of the panels with two isolated incidences of tank cleaning. 20 out of 37 (54%) of the solar-stand alone and hybrid systems assessed reported that they clean their panels, majority of these, 7 out of the 20, clean the panels monthly. The frequency of solar panel cleaning is dependent on a variety of factors including the location of the system, the tilt angle of the panels, the amount of windblown dust, the power required from the panels and the cost of cleaning the panels.

Figure 8: Frequency of solar panel cleaning



Some of the other maintenance measures that can be adopted to enhance the lifespan and improve the functionality of the solar panels include: regularly checking for a shadow on the panels - the WHO manual on water lifting devices, for instance, recommends checking for shadows every six months; trimming trees if necessary; checking the switches, fuse and connections and; inspecting the junction box on the back of the solar panels to ensure the wiring is right.

[17] Micro-Energy International-Solar Water Pumps 2015- http://www.e-mfp.eu/sites/default/files/resources/2015/07/Solar%20Water%20Pumps_2015.pdf

[18] World Health Organization(WHO)- Linking Technology Choice with operation and Maintenance Chapter 4-Water Lifting Devices- http://www.who.int/water_sanitation_health/hygiene/om/linkingchap4.pdf

Occasional maintenance for the submersible pump would involve annually taking the pump out of the well, cleaning the pump, checking motor status, replacing faulty components on the controller, and replacing worn out piping[18]. Frequency would depend on prevailing conditions.

The exhibit below highlights a market offering by one of the solar equipment providers interviewed. This presents one of the approaches that can be adopted for regular maintenance and repair of solar water pumping systems.

Market Offering: Service & Maintenance Contract by Davis & Shirtliff

Clients can enter into Service Contract Agreements with Davis & Shirtliff. Under the contract, Davis & Shirtliff is mandated to visit the system at least four times in the year to conduct regular maintenance checks. They are also required to visit the system when a problem arises.

Clients under the service contract agreement are charged annually. Consumers are charged based on their distance from the nearest Davis & Shirtliff Branch. The costs comprise of a per kilometer charge of Kshs 90 for each routine check and a technician cost of Kshs 10,000 per visit.

In case of equipment breakdown, the client pays for repair / replacement of components at a discounted rate. This expense is in addition to the annual service and maintenance fee.

3.3.2 Repair

Factors around repair including training of water committees and artisans, knowledge on where to access spare parts and technicians as well as charges for repairs were evaluated. It was found that members of the committee as well as community artisans lack adequate training: 15 out of 40 (37.5%) scheme operators reported having received training for minor repairs and 5 out of 40 (12.5%) reported having training for major repairs. Minor repairs include changing of taps or valves, fixing of leaking water pipes among others while major repairs include activities like replacement of pump mortars and repair of faulty wiring.

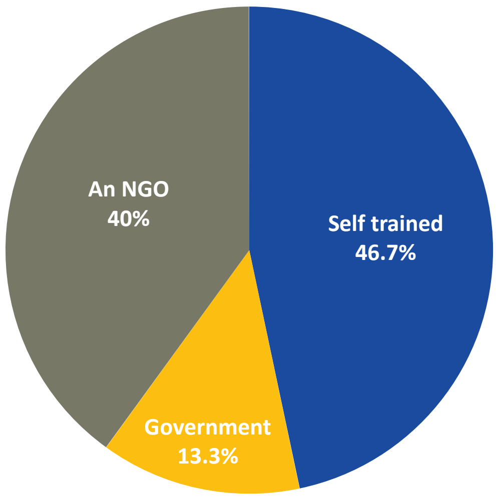
Table 3: Training of water point operators

Training Status	Training for Minor Repairs	Training for Major Repairs
Have Training	37.5%	12.5%
Lack Training	62.5%	87.5%

Further scrutiny revealed that of the 15 scheme operators and committee members who had received training, majority (46.7%) are self-trained or paid for their training. A significant percentage (40%) had been trained by Non-governmental bodies and donor organizations. Key informant interviews with donors and equipment suppliers indicate that the type of training offered to the water committees includes financial and management training. For more technical aspects, artisans are sometimes selected from the community to receive training on how to operate the system.

Some equipment suppliers also indicated that they conduct training sessions throughout the year and they encourage NGOs to send committee members of newly established boreholes to attend. Challenges with the training arise when trained individuals leave an area without passing on knowledge to other individuals to continue running the system. There is also a training gap for subsequent committees that take over from the initially trained committee. It is recommended that this training gap be met by engaging county governments as expounded on in the recommendations section.

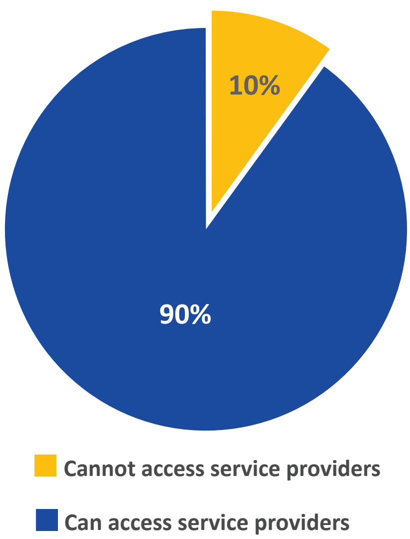
Figure 9: Source of training



Training on equipment warranty was also observed to be lacking particularly for the 3 systems that had ceased to function within two years of commissioning. The committees did not have the warranty documents required for system repair and were not aware of the duration of warranty. This situation points to incomplete hand-over procedures by implementing agencies.

36 of the 40 evaluated scheme operators reported knowing where to access technicians in case of system failure. Technicians in this context referred to local plumbers, electricians and artisans. While the question did not disaggregate for solar systems specific technicians, the data is encouraging as it is likely that the available technician would isolate the cause of the problem and advise the community of who to contact. In some counties like Machakos and Kitui, the sub-county water office deploys county water plumbers to the schemes to conduct repairs. This model is particularly useful when major equipment issues arise as the plumbers are trained mechanics and engineers. 24 out of 40 (60%) scheme operators indicated knowledge on where to access spare parts. The question did not disaggregate the types of spare parts and as such, all system components including taps, valves, piping, solar panels and meters are considered. It is worth noting that water committees for a significant number of systems indicated that they approach the implementing donor in case of major issues such as pump breakdown who links them up with the equipment suppliers.

Figure 10: Accessibility to technicians



It is encouraging to note that 33 out of 40 water points indicated that they mostly rely on charges on water and community contributions to meet their repair and maintenance costs. However, 7 out of 40 schemes still exhibit a dependency syndrome and believe that donors, the government or water service providers should meet the repair and maintenance costs. This perception was particularly prevalent in Machakos county where water from county installed systems is provided for free and the county shoulders all repair and maintenance costs. While the data on perceptions on who should meet the cost of repairs and maintenance is encouraging, conversations with water point operators/committees often revealed that often, communities turn to donors and well-wishers for costly repairs. This is elaborated further under Operations and Management Models.

Figure 11: Accessibility to spare parts

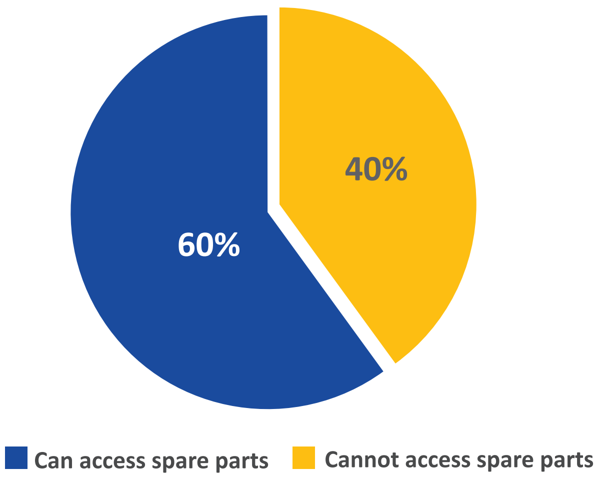
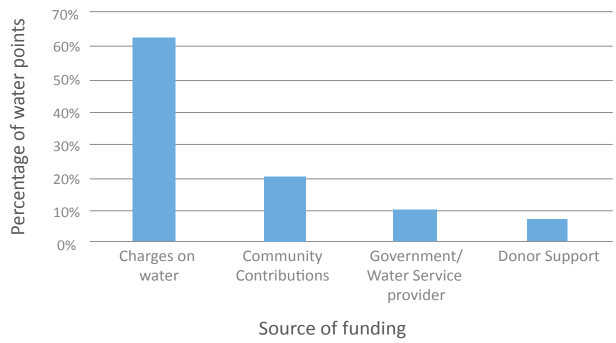


Figure 12: Perceptions on who should pay for repairs and maintenance costs



Insurance of pump sets is not common, even globally, however with the increasing diversification of the type of items that can be insured, this should be considered particularly to replace the pump motor. Interviews with leading equipment suppliers in Kenya confirm that they only offer a 2-year warranty for pumping equipment.

3.4 Vandalism and Theft

Security is a very important aspect that must be considered during installation of a solar-powered system. The PV array is one of the most expensive components of the system and it should be protected from theft, vandalism, wildlife and domestic animals. 10 of the 40 of the systems evaluated in the field (25%) had been vandalized while theft of the system equipment was less common at 17.5%(7 out of 40 systems). The main components prone to vandalism are the water pipes and water taps while the main components prone to theft are the solar PV modules.

Table 4: Vandalism Overview

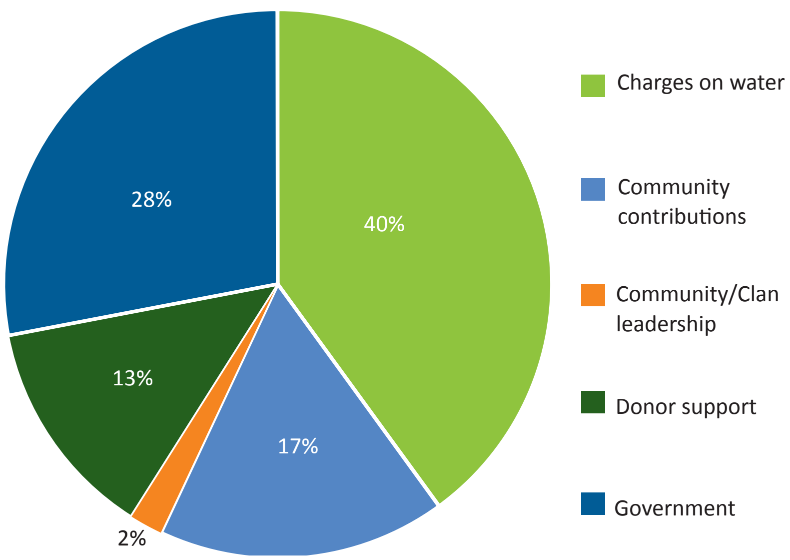
Parameter	Vandalism	Theft
Occurrences of Vandalism or Theft	25%	17.5%
Main Component prone to Vandalism/Theft	Water Pipes and Taps	Solar Panels

One of the key contributors to water pipe vandalism was seen to be community conflict. For instance, the piping network of two systems in Machakos was designed to provide water to certain areas leaving out others. Because of this design limitation, communities not receiving water have resorted to regularly vandalizing the system pipes to cut off water supply to their neighbors. This example highlights the importance of stakeholder participation in the entire system installation process to mitigate such risks.

Some of the systems located close to game reserves also experienced vandalism from elephants particularly during drought seasons. The elephants, in their search for water, often ruin pipes and taps at the waterpoints. The situation is so extreme that one system, Enkeju Errap has installed an electric fence around its Solar PV array that is powered from a battery system fed by the solar array. Some communities have also resolved the issue of vandalism by elephants by constructing dedicated elephant troughs.

Water committees in collaboration with the communities being served by the water systems have put several measures in place to ensure that the systems are secure. These range from raising the solar panels, fencing the borehole abstraction point and the solar panels, putting up security lights, hiring a watchman to guard the system, creating a schedule for

Figure 13: Who should pay for vandalized or stolen parts/ equipment?



the committee to man the system, setting up a vigilance system whereby community members take turns guarding the system. Some communities also construct the system in an individual's home as a security measure. The solar panels should also be properly installed and tightly welded to counter theft.

A perception analysis conducted at the water systems indicates that 40% of scheme operators and committees understand that payments for vandalized or stolen equipment should be sourced from charges on water. Combining that with 17% of water point operators who believe the cost of such incidences should be met by community contributions gives an encouraging statistic of communities that have claimed ownership of the systems. The remaining 43% of systems need to be sensitized on the importance of owning the systems and running them profitably to cater for any arising eventualities.

Exhibit 1: Case of Saremba Borehole

One of the non-functional systems assessed during the study in Homabay County, Saremba Borehole was a showcase of the detrimental effects of theft on solar-powered water pumping systems. The water committee reported that a few members of the community had stolen the solar panels as well as the pump controller. Probing further, it became evident that the only security measure that had been put in place for the system was the installation of security lights. The system had no fencing and was in an isolated area far from community homes. The committee, further highlighted that the panels had not been properly welded onto the frames, thus it was very easy to unmount them.

The incidence highlights three important issues that must be addressed to counter theft and ultimately vandalism.

- *Proper installation of the solar panels*
- *Ownership of the water systems by the community*
- *Instituting the required security measures*

Figure 14: Stolen solar panels at Saremba borehole

3.5 System Sizing

3.5.1 Pump and Power Sizing

The appropriateness of the system pump was evaluated by determining the total dynamic head (TDH) and yield and carrying out a systems parameter match against the manufacturer's pump performance curve. This was performed for sites that had provided data on the pump model, yield and TDH; 14 sites out of 40 were evaluated. The accuracy of the power sizing for the system was also evaluated by comparing the power provided by the solar panels and the power required by the pump motor.

Many factors influence the design and sizing of a submersible pump, however, the two key factors that that determine the duty point of the pump are the TDH and the flow rate of the borehole. Additional factors that are taken into consideration and whose importance varies on a case by case basis include water demand, the location of the water point, the borehole conditions, safety factors for AC and DC pumps among others.

Total Dynamic Head

The standard formula used to compute the total dynamic head of the borehole sites is outlined below.

TDH= (Sum of the vertical lift+ pressure head +friction loss)

- Vertical lift- This consists of the Water Pumping Level, the elevation difference between the top of the well to the top of the storage tank and the gradient between the top of the well and the bottom of the storage tank.
- Pressure head- This is the pressure at the delivery point in the tank
- Friction loss- This is the loss of pressure due to the flow of water through pipes and fittings.

Values of the total dynamic head for the 14 boreholes were derived from the implementing agencies. The average head for the 14 evaluated systems was 119 meters with range of 58m to 253m.

Borehole Yield

This is the amount of groundwater that can be obtained from a borehole measured in cubic meters per hour. The accurate yield of a borehole is determined by means of a pumping test (aquifer test). Aquifer tests are valuable in determining optimum abstraction rates, which in turn allow for correct sizing of the pump (prevent over abstraction and pump burn out) and in determining optimum pumping schedules. Borehole yields used in the evaluation were derived from scheme operators and implementing agencies.

Systems Parameter Match

7 of the systems (50%) have the right pump while 3 of the pumps are oversized and 4 pumps are undersized. Undersized pumps have been termed as inconclusive in table 1 below due to the variety of factors that go into consideration during design other than yield which the evaluation is based on. For instance, a small pump may be deliberately installed when the community demand is significantly less than the yield.

9 out of 13 systems (69%) have correctly sized power for the pumps installed while 4 of 13 systems have undersized power. Undersized systems with regard to power tend to operate at a lower flow rate than the desired flow rate leading to lack of adequate water to meet demand or longer wait times at the water points.

The evaluation reveals the importance of correct pump selection to ensure pumps operate within their optimal specifications; this also helps to ensure economic efficiency in setting up solar powered pumping systems. Additionally, oversizing poses a risk to the borehole due to over pumping. For boreholes with oversized pumps like Mbusyani, Saremba and Kikambuani the same amount of water can be abstracted using smaller pumps.

Another highlight of the evaluation is the impact of the array layout on the power size. When multiple panels are required, they must be wired in series, parallel, or a combination of series-parallel to meet both the voltage, amperage and power requirements of the pump[1]. With the diverse range of solar panels currently available in the market, sizing engineers should seek achieve economic efficiency in their selection of solar panels and arrangement of modules. For instance, Kaluni borehole uses 34 panels of 195W (17 in series X 2 strings) to give a total power of 6,630kW. In contrast, use of 17 panels of 265W (17 in series x 1 string) would yield a similar voltage but optimize on the power installed resulting in financial savings.

[19]Design of small Photovoltaic(PV) Solar-Powered Water Pump Systems- United Stated Department of Agriculture(USDA)- https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_046471.pdf

Table 5: Water Point Sizing

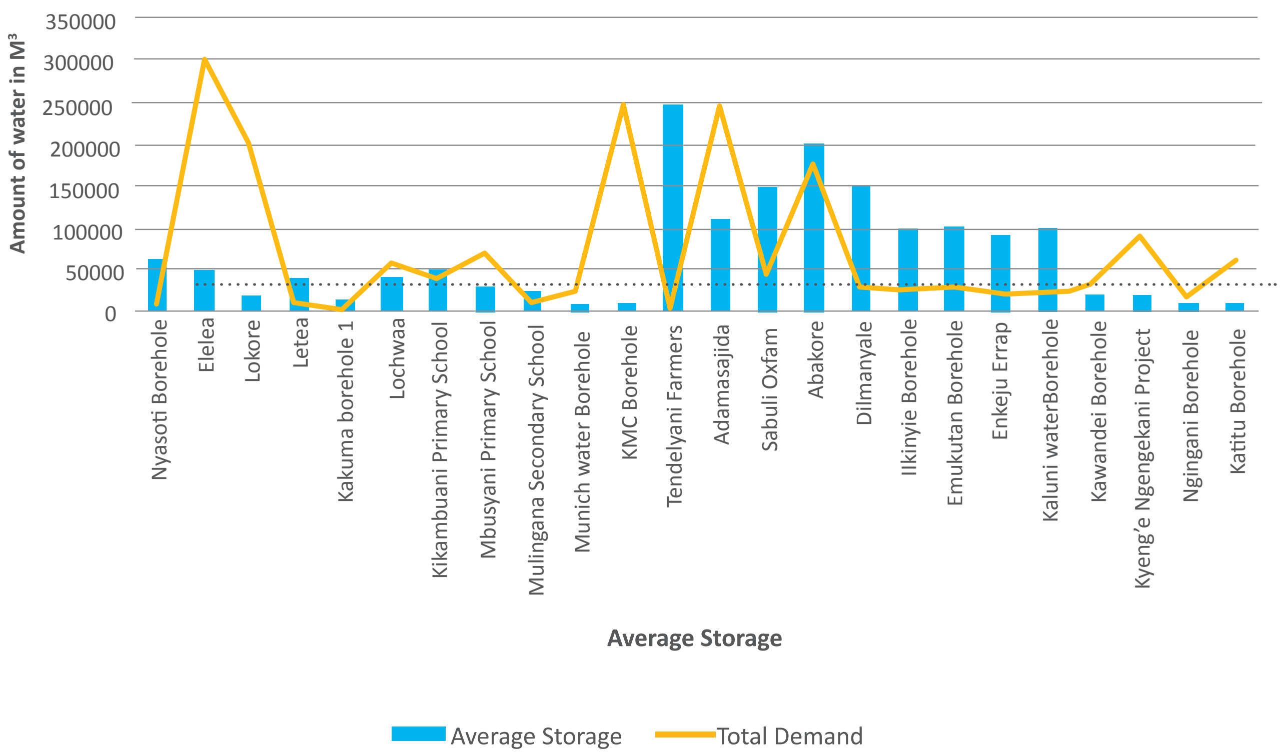
Name of Borehole	Type of Borehole	Total Dynamic Head	Borehole yield (m^3)	Recommended design yield (70% of tested yield)	Pump Brand	Pump Model	Number of Solar Panels	Solar Panel Rating	Total Solar Power (KW)	Power required by motor	Pump Evaluation	Power Evaluation	Comments
Nyasoti Borehole	Solar Stand-Alone	140	6	4.2	Lorentz	PS 4000-CSJ5-25	24	n/a	4	4	Inconclusive	Undersized Power	Comments
Saremba Borehole	Solar Stand Alone	75	4.5	3.15	Lorentz	PS 4000-CSJ5-25	0	n/a	2.01	4	Incorrect pump (Oversized)	Correctly Sized	The PV size provided is correct for the duty required. However, a smaller pump would be more efficient in this case.
Elelea	Solar-Stand Alone	100	15	10.5	Grundfos	SP 8A-44	34	125	4.25	7.5	Correct Pump	Undersized Power	
Kikambuani Primary	Solar-Stand Alone	112	9.6	6.72	Grundfos	SP 9-55	21	250	5.25	11	Incorrect Pump(Oversized)	Undersized Power	
Mbusyani Primary	Solar-Stand Alone	82	8.2	5.74	Grundfos	SP 9-25	21	250	5.25	5.5	Incorrect Pump (Oversized)	Correctly Sized	The PV size provided is correct for the pump. However, a smaller pump would be more efficient in this case.
Mulingana Secondary School	Solar-Stand Alone	73	3.3	2.31	Grundfos	SQF 1.2-2	5	250	1.25	1.4	Inconclusive	Correctly Sized	
Kwa Munuvi water borehole	Solar-Stand Alone	112	3.6	2.52	Grundfos	SQF 1.2-2	5	255	1.275	1.4	Inconclusive	Correctly Sized	
KMC Borehole	Solar-Stand Alone	125	8.2	5.74	Grundfos	SQF 1.2-3	18	80	1.44	1.4	Inconclusive	Correctly Sized	
Tendelyani Farmers' cooperative society ltd	Solar-Stand Alone	58	1.2	0.84	Grundfos	SQF 1.2-2	4	250	1	1.4	Correct Pump	Correctly Sized	
Ali Dumal (Hybrid System)	Hybrid	253	21.6	15.12	Dayliff	DS 30-26	80	235	18.8	22	Correct Pump	Undersized Power	
Emukutan Borehole	Solar Stand Alone	160	9	6.3	Lorentz	PS9k C-SJ8-44	74	120	8.88	7.5	Correct Pump	Correctly Sized	
Enkeju Errap	Solar Stand Alone	110	9.5	6.65	Grundfos	SP 8A-25	35	160	5.6	4	Correct Pump	Correctly Sized	
Kaluni water Borehole	Solar Stand Alone	160	5	3.5	Grundfos	SP 5A-33	34	195	6.63	3	Correct Pump	Correctly Sized	In this case the power sizing is assumed to be correct to achieve correct parallel-series module arrangement. Use of bigger panels could have improved power efficiency.
Kawandei borehole	Solar Stand Alone	106	10	7	Lorentz	PS 9K	48	not given	not given	n/a	Correct Pump	Inadequate information	

3.5.2 Storage Sizing

Water storage is an essential element for an economically viable solar powered water pumping system. The tanks should be sized on a case by case basis in consideration of water demand and variable pumping rates (e.g. cloudy weather vs peak sunlight availability) with the goal of ensuring continuous flow of water. Based on field observations, this evaluation recommends that storage should be optimized to the borehole yield. In this way, water flow is optimized to technical feasibility by pumping as much water as can be sustainably abstracted. There were at least 7 instances (17.5%) where water point operators noted that they either delay water collection times in the morning (open kiosks at 10am) or close as early as 4pm to allow water pumping into the tanks. This often contributed to long wait times at the water point as majority of consumers interviewed, 55%, collected water in the morning. This situation arose because limited pumping was done during periods of low demand due to storage limitations thus water in the tanks was rapidly depleted during high demand periods and had to be replenished either in the late afternoon or early morning.

A comparison of average storage capacity against one-day household demand was made for 24 out of the 40 systems assessed. 13 of the systems (54%) have adequately sized storage that meets demand while 11 of the systems (46%) have inadequate storage with a one-day household demand that exceeds available storage. However, it is important to note that 6 out of the 13 solar powered boreholes with adequate storage supply water to large herds of livestock. Since livestock demand has not been factored into the demand equation, there is a likelihood that the demand could be much higher and exceed the storage capacity. 14 out of the 40 remaining systems did not have adequate data on system storage amounts and the average number of households using the system while 2 systems were private boreholes.

Figure 15: Average storage against one-day household demand



The lack of adequate data for 14 of the systems coupled with the inadequate storage phenomenon at 11 of the water points is indicative of the need to improve storage design when installing solar powered water systems. Conversations with sector stakeholders also reveal that financing is a limiting factor when designing the systems and as such emphasis is placed on procurement of solar powered water pumps and PV modules over storage tanks. Borehole equipping companies also confirmed that they do not size the storage and work with

4. Evaluation of Operations and Management Models

the quote provided by the donor organization.

Water systems operations and management (O&M) is identified as crucial to long-term sustainability, and inadequate O&M is a frequent cause of system failure. Three distinct water systems management models were observed during this study, with some waterpoints having a combination of models. The following discussion presents the key attributes of each model observed along with the model's strengths and weaknesses.

4.1 County Implemented and Managed Water Schemes

This management model was observed in Machakos County, where the county government is implementing solar powered water supply systems at the community level. The following are the model's key attributes:

1. The county identifies areas of intervention, designs systems, procures and funds system installation. As much as is technically feasible, systems are installed in public premises e.g. primary schools. Water is distributed through a series of standpipes.
2. The county provides overall management of the water scheme through the Sub-county water offices. This includes designated water engineers and county plumbers who are called upon in case of system breakdown.
3. Water users' committees are formed for the day-to-day management of the system. This includes issues such as water distribution schedules, replacement of small components such as taps among others.
4. Water is free.

Table 6: Analysis of county implemented and managed schemes

#	Strengths	Weaknesses
1.	Availability of technical skills through county employees who are trained in and dedicated to management of community water supply schemes. These include engineers, plumbers and persons with water management knowledge.	Bureaucracies involved in spending of public resources lead to long durations of system downtime. For instance, procurement of replacement pumps or pipes requires submission of requests to the County Water office which is followed by official county procurement procedures.
2.	Availability of county resources for operation and maintenance of systems. The county follows up on warranty for broken systems or procures new system components.	As water is provided for free, the sub-county water office has no operational finance kitty to meet basic maintenance and repair needs. Purchase of repair materials has to go through the County ministry. This is unsustainable in the long run, especially considering the risk of changing political interests.
3.	Coordination of water access efforts in the county. The county's water office has a bird's eye view of water needs across the county. As such, projects are prioritized on a needs basis.	The water schemes are viewed as '*Mutua's*' (the current governor of Machakos County who has greatly promoted installation of solar powered water systems at community level). Consequently, there is little community ownership of the systems and people expect the County to be responsible for continued operation of systems.
4.		Political influence e.g. in what areas receive a standpipe, have led to conflicts within some communities. This was seen to result in increased cases of vandalism.

4.2 Private Sector implemented and Managed Models

The observed model was implemented by Grundfos Lifelink under the 'water kiosk with water supply' model. Grundfos Lifelink seeks to provide a holistic model to sustainable water solutions through a combination of Grundfos' innovation in pump technology, revenue collection and water management. The model in discussion was implemented across 40 sites in Kenya with the first systems installed about 10 years ago. The following is our understanding of the model's key attributes based on key informant interviews and conversations with community water users group at four beneficiary communities:

1. Grundfos Lifelink identified target communities and managed the end-to-end installation of solar powered water supply systems. The systems include a water dispenser that combines a water ATM and Grundfos remote monitoring technology.
2. The water ATMS are designed to work on the M-pesa platform. Community members are issued with a water ATM card/key which they can load water credit through mobile money payments. Grundfos Lifelink maintained control of the system back-end and accounts. Water prices are set at KES 3 / 20L.
3. Grundfos Lifelink signed 5-10-year Agreements with communities where among other things; communities would pay KES 215,000 annually to Grundfos Lifelink for maintenance; any collections above the KES 215,000 would be credited back to the communities; Grundfos would cover all operations and maintenance costs including salaries to water point operator and watchman and system repairs regardless of whether the KES 215,000 limit was reached.
4. The KES 215,000 collected from all the sites forms a cost recovery mechanism for Grundfos Lifelink for the costs incurred in maintenance and repairs.
5. Community water users' committees were formed for the day-to-day management of the systems.

Table 7: Private Sector implemented and Managed Schemes

#	Strengths	Weaknesses
1.	Some of the oldest solar systems reviewed that reported never having a technical problem were under the Lifelink program. It was inferred that Grundfos' oversight on end-to-end installation of water schemes ensured quality of technical aspects of projects.	The model assumes that community water schemes can raise at least KES 215,000 a year. Based on at least 5 years of operating 38 systems, only about 5 systems could consistently collect this amount. This, according to Grundfos Lifelink is unsustainable given the costs associated with repairs and maintenance thus disproving the business case behind the management model.
2.	The water ATMs enable direct depositing of funds to a bank account thus reducing avenues of fraud. Also, the water ATMs reduce community – committee conflicts by removing the direct interaction of water user committees with collected funds.	The model has a high risk of severed community relations. As most communities did not receive any funds from the water collections (only the surplus of KES 215,000 is credited back to communities), communities viewed Grundfos to be benefiting from their money.
3.	The KES 215,000 collected and retained by Grundfos through the water ATMs provides a cost recovery mechanism for the repairs and maintenance.	
4.	Remote monitoring and service and maintenance activities by Grundfos minimize system downtime.	

Following the disproving of the business case of this management model, Grundfos Lifelink has discontinued the program – they no longer sign service and maintenance agreements with communities and are not renewing agreements with currently engaged communities. Instead, Grundfos has developed an improved model of the metered dispensers known as AQTap that transfers financial management to the committees. The AQTap is still based on the M-Pesa platform and money is deposited to accounts directly associated with the communities. Communities may still contact Grundfos for repairs and maintenance, but at a fee.

4.3 Community Water Users Group Managed Model

This model was most commonly observed among NGO implemented water supply systems and adopted various unique aspects depending on the implementing agency. Generic attributes of this model are:

1. The solar powered water supply system was installed as an aid project and handed over to the community. The implementing agency is barely, if at all, involved in the day-to-day and the overall management of the system.
2. A committee appointed by the community oversees the day-to-day and the overall management of the system.

While extensive literature exists on the merits and demerits of community managed water supply systems, this evaluation is inconclusive on whether they should be advocated for or against. Some very successful and some very poorly managed schemes were observed, all of which followed the general precepts of community managed schemes. Some overarching characteristics of successful community managed schemes were, however, observed – these systems had a combination of at least two of the attributes described in Figure 16 below:

Figure 16: Commonalities observed in successful community managed schemes

Presence of at least one individual who is highly committed to the success of the project:
For instance, in Adamasija, Wajir County, the committee chairman has taken it upon himself to ensure that meters are read, has set up a shop where people can come settle their water bills, ensures that electricity bills are paid and oversees the system water distribution schedule.

Absence of alternative sources of water:
Lack of alternatives, especially during the dry season, causes communities to be better stewards of their water systems. This includes having a higher willingness to pay for water to ensure availability of funds for maintenance. This is especially the case where the main source of livelihood (e.g. livestock) is highly dependent on availability of water.

High sense of community responsibility:
A general perception that water collections held by the committee is community funds was expressed by committees of the more successful projects evaluated. Some of these committees had contributed towards the construction of classrooms in schools within their communities, extended distribution networks to key institutions or provided water at subsidized costs during the dry season.

Presence of recurrent costs:
Diesel and solar-diesel hybrid systems were seen to have a higher understanding of financial management, which is key to the sustainability of water schemes. Also, these schemes enjoyed a higher sense of willingness to pay for water services by consumers unlike in stand-alone solar systems which had a general perception that water should be free as the energy is free.

A major area of concern for community managed water schemes is their ability to meet significant one-off O&M costs like repair or replacement of pumps and generators. Three approaches to raising such funds were observed:

#	Approach	Examples
1	Use of water point savings	Several water points indicated relying on their savings for various O&M activities including replacement of solar panels blown off by strong winds, rehabilitation of the storage tank elevation structures, replacement of pumps, and repair of generators. Incidentally, except for one site, all sites indicating meeting significant O&M costs from savings also indicated having at least KES 100,000 in their savings. This may be seen as evidence good understanding of financial management.
2	Community contributions	Community contributions to meet a one-off large repair cost was observed at only 1 of the 40 sites evaluated. Members raised a total of KES 450,000 over 7 months towards the replacement of a broken pump. While it took a relatively long time to raise the money, the initiative is indicative of a sense of community ownership of the water scheme.
3	Reliance on external assistance	As indicated in Figure 14, most operators noted that repairs costs should be met by water charges or community contributions. However, further probing in some instances revealed reliance on an external party for large repairs. The parties often included an NGO, the county or a well-wisher (mostly political aspirants). In one hybrid site for instance, the community turned to Red Cross to help repair their generator while in another, the community relied on the county to change the borehole pipe casing biannually due to pipe corrosion.

4.4 Comparative discussion of O&M Models

Different management models work in different settings and this evaluation does not find that there is a specific model that should be advocated for or admonished. Because a model is working in one setting does not mean it will work in all settings; that a model is not working in a different setting does not mean it's a bad idea. Good concepts may sometimes not work because they were either not executed well, their execution was wrongly timed or was in the wrong environment. Further, Article 93 of the Water Act of 2016 gives room for various water systems' management models noting that systems:

"may be managed by the community associations, public benefit organizations or a private person under a contract with the county government"

This study, however, finds that there are key factors that should be incorporated into any management model to ensure its sustainability. Table 8 highlights these factors and gives practical examples on how the various management models have implemented them.

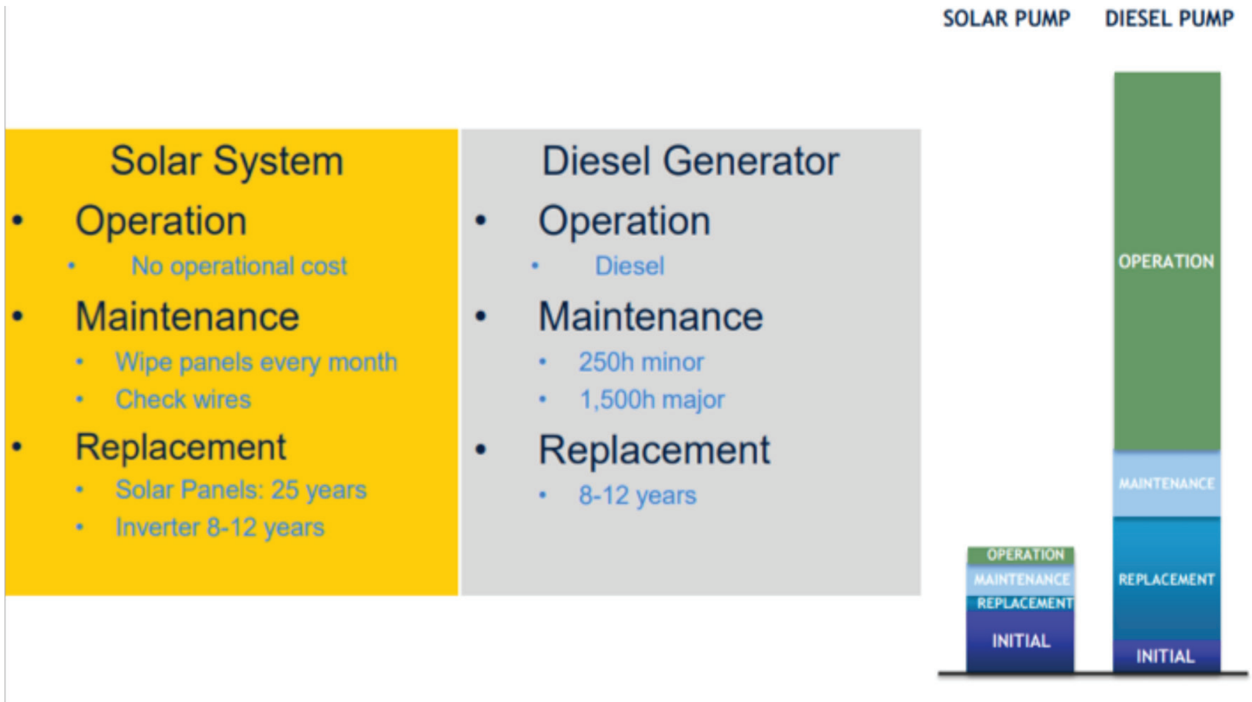
Table 8: Key factors to O&M Models

Factor	Implementation Examples
Financial accountability	***Registration of Water Users Associations as legal entities*** This approach was observed among most World Vision-Kenya implemented projects where beneficiary communities come together under a registered association and select a committee to represent them. The committee is then governed by legal requirements including obligations to maintain a bank account and keep financial records, holding of annual general meetings where among other things, financial records are presented, and agreeing on signatories needed for bank withdrawals. ***Use of water ATMs*** Water ATMS promote transparency in water collections by making water transactions cashless. Two systems were observed under this evaluation including the AQTap (implemented by Grundfos Lifelink and also adopted by World Vision-Kenya) and SUSTEQ (implemented by Oxfam-Kenya). As one water committee chairman noted, water ATMs reduce committee – community conflicts by removing committee interactions with community funds. By keeping a record of water credits against sales, water ATMs minimize instances of fraud.
Dedicated Personnel	***Salaried water point operators*** All highly performing water systems had at least one person dedicated to overseeing the day-to-day running of the system. Based on this observation this study concludes that having a person who is contractually obligated to oversee the operations of the system is key to its success. This ensures that there is someone answerable to the community in case of system non-functionality. Having the person salaried ensures they are sufficiently motivated as water management is their source of livelihood.
County Involvement	***Engage the County Water Office*** With water being a devolved function, county governments play an integral role in service delivery and their involvement will increasingly be critical to the long-term sustainability of water systems. Some practical ways of involvement observed included: i. County water representatives serving as signatories to water committees for increased financial accountability. These may be representatives from the county or sub-county levels. ii. County providing technical personnel (plumbers and engineers) for system maintenance and repairs. In Mivuni, Kitui County, for instance, the committee calls on the county engineer to service their generator at a discounted price.

5. Financial Sustainability Models

Closely tied to management models is financial sustainability mechanisms in considering the long-term sustainability of solar powered water systems. The Energy Sector Management Assistance Program (ESMAP) of the World Bank, for instance, estimates the payback period of a solar system operated for the estimated lifespan of the solar panels (25 years) to be 1-3 years compared to operating a diesel system for the same duration (see Figure 17[20]).

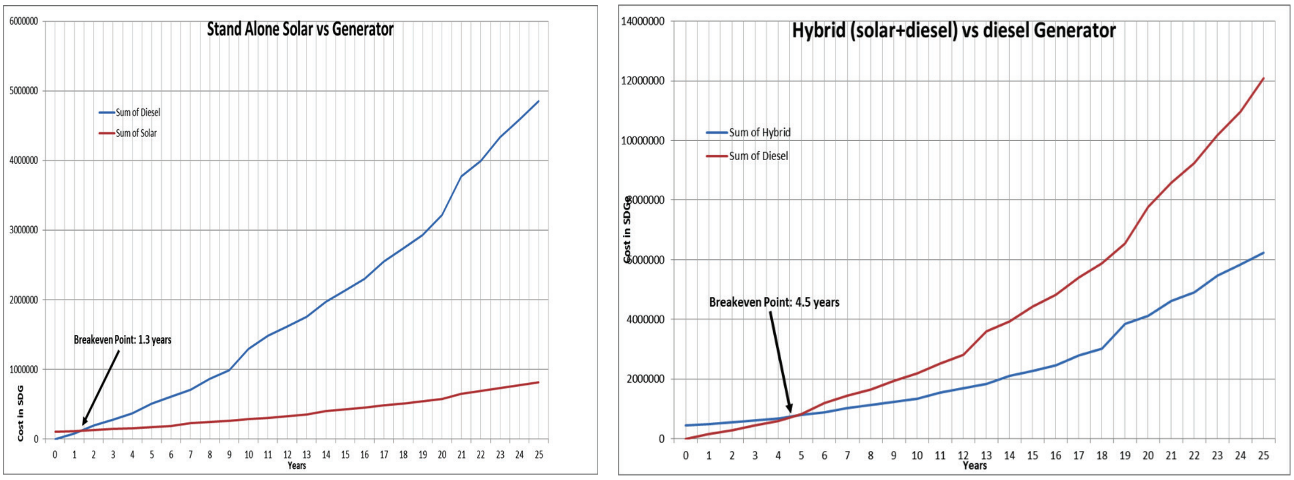
Figure 17: Lifecycle costing comparison of diesel vs solar pumping (ESMAP)



These findings complement those collected by the Global Solar and Water Initiative in several countries in East and Horn of Africa, showing an average payback period of 0-4 years and a cost reduction over life of the systems of -40% to -90% when compared to diesel generators. Figure 18 summarizes the GSWI findings.

[20]ESMAP, 2017, Solar water pumping for sustainable water pumping, http://www.worldbank.org/en/topic/water/brief/solar-pumping

Figure 18: Lifecycle costing comparison of diesel vs solar pumping (GSWI)



Some of the most cited finance related benefits of using solar power for water pumping include:

1. Solar has the benefit of minimal recurrent costs. This is especially with respect to the source of energy where the recurrent cost of fossil fuels (the most common alternative) fluctuates with market forces and servicing costs for diesel/petrol powered generator systems can get quite expensive.
2. The falling prices of solar PV technology has greatly reduced the capital investment required for installation of solar systems, making their use in water pumping more viable.
3. Unlike other solar PV technology applications that require investment in energy storage, the water sector has the advantage of use of water tanks circumventing the need for energy storage and increasing feasibility for solar power for water pumping.

With these financial benefits, the use of solar energy has been fronted as the pro-poor choice for advancing water access. While this study agrees with that general conclusion, it finds that there are aspects of use of solar energy for water pumping that are often ignored and that need to be addressed to ensure the long-term sustainability of systems. These are:

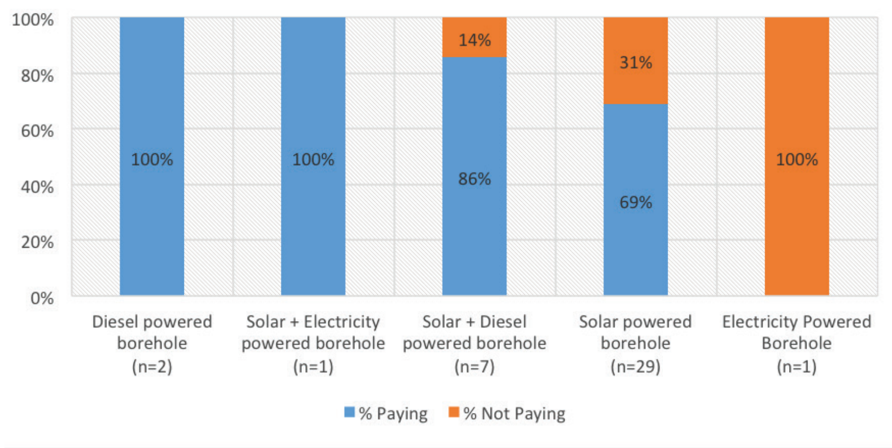
1. Addressing the perception that water should be free as the energy for pumping is free;
2. Raising funds for replacement of system components and;
3. Raising funds for improved delivery of water services.

The following section presents observations made during the study on financial sustainability and makes recommendations for ensuring long term sustainability.

5.1 Payment for water services

Payment structures observed in the field varied with region, powering systems and management models. Figure 19, highlights the rate of payment for water services as observed among the visited sites.

Figure 19: Payment for water services at mechanized systems



Key observations to be considered in interpretation of Figure 19 include:

- Water is free at County installed systems in Machakos County. These systems were all standalone solar powered systems and Machakos respondents represent a significant proportion of those not paying for water under the solar stand-alone systems category in Figure 19.

- One stand-alone electric powered borehole was evaluated under this study, and was operated and managed by East African Portland Cement. The company covers all the operations and maintenance costs associated with the borehole as part of their corporate social responsibility program. Consequently, the benefiting community access water for free.

- 14% of respondents not paying for water under solar-diesel hybrid systems represents respondents from Dilmanyale. The borehole, which was initially a diesel-only system that charged for water services, had been retrofitted with a solar system and fitted with a reticulation system within a month of the evaluation. The change-over switch to allow for use of diesel and solar was also yet to be installed at the time of the evaluation, hence the system was operating as a solar stand-alone system. The community was also still in discussions on how charge for water going forward in consideration of those developments.

Five approaches to payments for water services were observed and are summarized in Table 9 and Table 10. A specific waterpoint could apply more than 1 of the approaches as discussed.

Table 9: Average water charges – Household use

	Every time you collect water (20L)	Daily	Weekly	Monthly
Solar + Diesel borehole	4.25			654.80
Water pan	5.00			
Electric powered borehole	5.08			
Diesel powered borehole	5.21			397.00
Solar powered borehole	5.79	48.89	55.00	369.18
Hand-pump operated well/borehole	6.00			100.00
Open well	10.20			
Water vendors	14.00	30.00		

Table 10: Average water charges – Livestock

Animal	Every time you collect water	Monthly
Camels	13	-
Cows	3	63
Donkeys	0	100
Goats / Sheep	1	70

1. Pay as you go

This was the most commonly observed model where people pay for water collected at a communal water point, often in either 20L jerry cans or 100L water drums. As seen in Table 9, there isn't a significant difference in the cost of a *mtungi* (20L) from the various mechanized systems. Stand-alone solar powered systems have the highest average rate among these mechanized systems – this is, however, inflated by data from one system in Kitui County where respondents indicated paying KES 15-20 shillings per *mtungi*. Excluding this waterpoint brings the average down to KES 4.57 per *mtungi,* making it comparable to the solar-diesel systems. Animals are also charged on a pay per consumption basis. Table 10 shows the average charges per animal.

2. Metered monthly payments

10 systems had household metered connections, where water charges are monthly based on meter readings. Table 11 shows the average charges per unit and highlights the maximum and minimum rates observed for the different systems. This system was seen to work best for systems that have personnel dedicated to the operation and maintenance of the system. These persons were responsible for overseeing the reading of meters, sending out bills and following up on payments.

3. Flat monthly payments

Flat monthly payments were based on community agreement on what rate to pay for water services. The charges ranged from KES 50 to KES 500 for household use. Table 10 highlights the average monthly charges for cows, donkeys and goats. This approach was most commonly observed at stand-alone solar powered systems and applied to systems with household connections as well as systems using communal water points. Sabuli and Dilmanyale water points in Wajir County, both of which are solar-diesel hybrids, were exemptions.

Table 11: Water charges per unit (m^3)

System	# of sites evaluated	Average rate (KES/m^3)	Min. Rate (KES/m^3)	Max Rate (KES/m^3)
Solar + Diesel powered borehole	2	80	60	80
Solar + Electricity powered borehole Total	1	100	100	-
Solar powered borehole	7	88	33	125

Sabuli

While water at this site is distributed through household connections and water kiosks, households are charged a flat rate of KES 500/month. Community members have opposed any efforts to introduce metering with the view that this will be more expensive. The proposed charges for metered connections is KES 100/m^3.

NB: Diesel pumping is mostly for livestock, where they are fed through community water troughs and are charged on a per consumption basis.

Dilmanyale

Reticulation of the Dilmanyale System had been completed about two weeks to this evaluation. Prior to reticulation, water sales were from a communal water point and payments based on a pay as you go approach. At the time of this evaluation, the community was yet to agree on an approach to payment collection going forward with community members indicating that they were charged a flat rate while the management committee expressed an intention to install meters.

4. Need-based payments

Under this approach, community members don't pay for water and are only asked to contribute finances with the need for repairs. This was only observed at solar powered and hand-pump water systems.

5. Livestock-only approach

This approach was mainly observed in Kajiado county where only livestock are charged for water. Water for human use is provided for free. Table 10 summarizes the average charges for livestock.

5.2 Implications for financial sustainability

While the data highlighted above indicates that people pay for water regardless of the system (solar vs diesel vs hybrid), interrogating responses on water payment collections and water point savings reveals inconsistencies in actual collections, and especially for the solar standalone systems.

Table 12 summarizes the reported average monthly collections (minimum and maximum collections) along with the average current savings (including maximum and minimum reported savings). As seen, solar powered boreholes have the lowest collections and savings contrasted to solar-diesel hybrid systems which have the highest collections and savings, yet water is provided at an almost similar cost especially among pay-you-go approaches. While it is recognized that various factors, including water point catchment size and poverty levels, may influence collections and savings practices, it is concluded that water systems with recurrent costs have a better understanding of financial management based on collected data and conversation with the different water point operators / committee representatives. Additionally, a general perception that energy from the sun is free and, consequently, water pumped using the solar system should be free was observed. This perception was most evident at solar-diesel hybrid systems where it was common observation that water pumped using the solar system is free; a fee for water is only charged when the generator is used for pumping. This perception is also seen as a contributor to the low savings at solar standalone systems. For instance, a water users committee member in one of the sites in Kitui county that had household water connections alongside water kiosks noted that it was very difficult to get residents with HH connections to pay for water citing negligible costs to operate the system.

In contrast, the standalone solar system with the highest savings was one that charges a monthly flat rate for livestock only – water for domestic use is provided for free.

Table 12: Water Collections and Savings

Source	Monthly Average: Max. Collections	Monthly Average: Min. Collections	Max. Reported Monthly Collection	Min. Reported Monthly Collection	Average Current Savings	Max. Savings	Min. Savings
Solar powered borehole	20,085	9,850	100,000	Free	23,304	150,000	0
Solar + Diesel powered borehole	142,667	66,500	300,000	20,000	484,833	2,500,000	0
Solar + Electricity powered borehole	41,000	25,000	41,000	25,000	200,000	200,000	n/a
Electricity Powered Borehole	Free	Free	-	-	-	-	-
Diesel powered borehole	43,000	5,500	70,000	1,000	152,000	300,000	4,000

Studies on mainstreaming use of solar power for water pumping at community level have often focused on reductions in recurrent costs associated with water supply and consequent pay-back periods for solar systems. This perspective makes a business case for solar water pumping from the supply side (implementing agencies, governments). However, given the nature of implementation of solar water systems for communities, which are often through aid or government projects (no cost to benefiting communities), it can be argued that the message tends to be interpreted as no cost for energy for water pumping thus negating the need for water payments. There is therefore need for a deliberate shift in focus for the demand side from reduced recurrent costs and short pay-back periods to system replacement periods. The following are suggested as ways to make the shift:

1. Shift in narrative

There needs to be a complete shift in the demand facing narrative of solar powered water systems for communities from 'tapping into a cost-free source of energy to pump water' to 'cumulating funds for system replacement'. Communities need to understand that while there are minimal recurrent costs in operating solar systems, there are significant one-off costs required to ensure their continued long-term operation. For instance, waterpoint operators / committee representatives at 12 of the 29 (41%) stand-alone solar systems evaluated noted that what they like the most about the systems is that they are cost free. Implementing agencies need to be very deliberate in altering this viewpoint.

2. Water must be provided at a fee

For long-term sustainability of systems, water must be provided at a fee to ensure funds for repairs, maintenance and replacement of parts. In one of the sites visited in Wajir County for instance, where the committee indicated having about 2.5 million in savings from water collections, the committee met the cost of replacing solar panels blown by strong winds, ensuring the functionality of the system. Box 1 provides estimate calculations for system replacement / replication periods.

3. Promotion of safely managed water delivery services

In a bid to realize SDG 6 through promotion of safely managed water delivery systems, financial sustainability mechanisms should be aligned with management models to promote use of water collection savings to set up reticulation systems. As seen in Box 1, providing water at a fee can lead to savings large enough to extend distribution systems to households.

Box 1: System Replacement / Replication Periods

The estimated components cost of setting up a system with a yield of 8m³/h and a total dynamic head of about 200m is KES 2 million. The table below highlights two approaches to charging for water services. Minimal fees of KES 1 per mtungi, or a flat monthly rate of KES 250 per household would ensure that communities have funds for system repairs and replacement. They would even have funds for replication of their existing system in as short a duration as three years.

Scenario 1: Flat rate payments		Scenario 2: Pay-as-you-go Payments	
Cost of solar system	2,000,000	Cost of solar system	2,000,000
Target # of HH	250	Target # of HH	250
Monthly flat rate	250	Cost of water (20L)	1
Life-cycle of components (years)	10	Borehole yield (m^3/hr)	8
Est. cost of system operator (@9,000p.m)	1,080,000	Hours of pumping per day	7
Funds accumulated (10 years)	6,420,000	System loses	30%
System Replacement Period (years)	***3***	Life-cycle of components (years)	10
		Pumped volume (per day, L)	56000
		Water available for sale (per day, L)	39200
		Equivalent # of 20L jerrycans	1960
		Water collections per day	1,960
		Est. cost of system operator (@9,000p.m)	1,080,000
		Funds accumulated (10 years)	6,074,000
		System Replacement Period (years)	***3***

Considering these estimates are made using rather conservative numbers, for instance KES 1 per mtungi while the current market average is about KES 5 per mtungi, these calculations demonstrate the potential benefit that communities would gain from adequate financial management of waterpoints. Applying KES 5 per mtungi to Scenario 2 yields about KES 3.4 million per year after water point operator costs. These are funds that communities could direct towards extension of pipelines to households even as they save towards system replacement or replication. It can therefore be concluded that, with financial accountability measures in place, financial sustainability of solar water systems can be easily achieved.

6. Impact Assessment

This impact review evaluates the relevance and effectiveness of using solar powered water supply systems to meet the water demands of target communities in Kenya. While the ToR requests for an evaluation of the efficiency of using solar powered water systems, this assessment did not have enough information for data-backed conclusions. According to the DAC Criteria for Evaluating Development Assistance, efficiency is a measure of how economically resources/inputs (funds, expertise, time, equipment, etc.) are converted into results. Because of the nature of this evaluation, evaluating varied specific water points and not the projects they were implemented under, there was inadequate project specific information for an efficiency evaluation.

6.1 Relevance

Relevance looks at the extent to which the objectives of an intervention are consistent with recipients' requirements, country needs, global priorities and partners' policies[21]. Due to a lack of baseline data and documented needs assessments[22] to use as a basis for evaluation, this discussion looks at respondent's water use behavior, interpreted in consideration of the JMP ladder for household drinking water services reflected below:

Figure 20: JMP Ladder for Household Drinking Water Services

Service Level	Definition
Safely managed	Drinking water from an improved water source which is located on premises, available when needed and free of faecal and priority chemical contamination
Basic	Drinking water from an improved source provided collection time is not more than 30 minutes or a roundtrip including queuing
Limited	Drinking water from an improved source where collection time exceeds over 30 minutes for a roundtrip to collect water, including queuing
Unimproved	Drinking water from an unprotected dug well or unprotected spring
No service	Drinking water collected directly from a river,dam, lake, pond, stream, canal or irrigation channel

This study deliberately targeted areas that have mechanized boreholes for community water access. Most respondents indicated relying on these systems as their main sources of water, placing access to an improved water source at about 90% (see Figure 21). There is, however, a retained high reliance on unimproved water sources as summarized in Table 13 below:

[21] DAC Criteria for Evaluating Development Assistance

[22] Systems evaluated were implemented under varied projects by different implementing agencies.

Figure 21: Main Sources of water

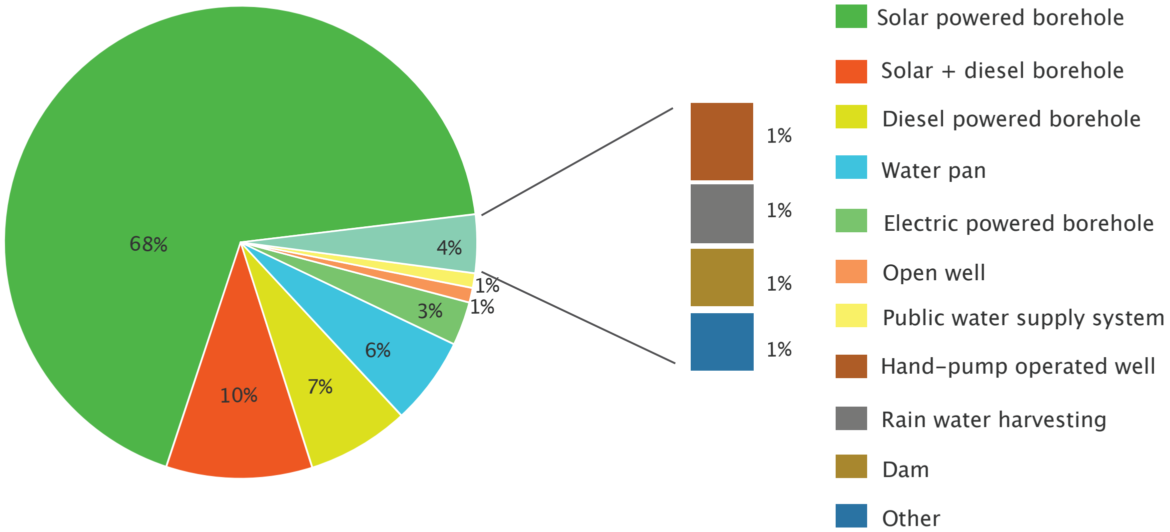
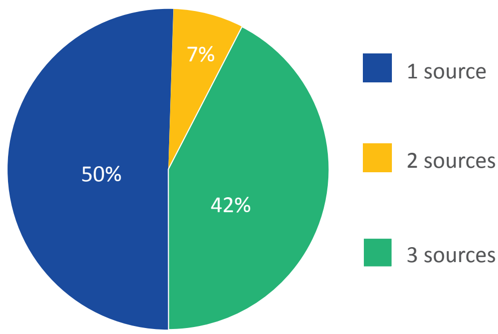


Table 13: Alternative sources of water (n = 469)

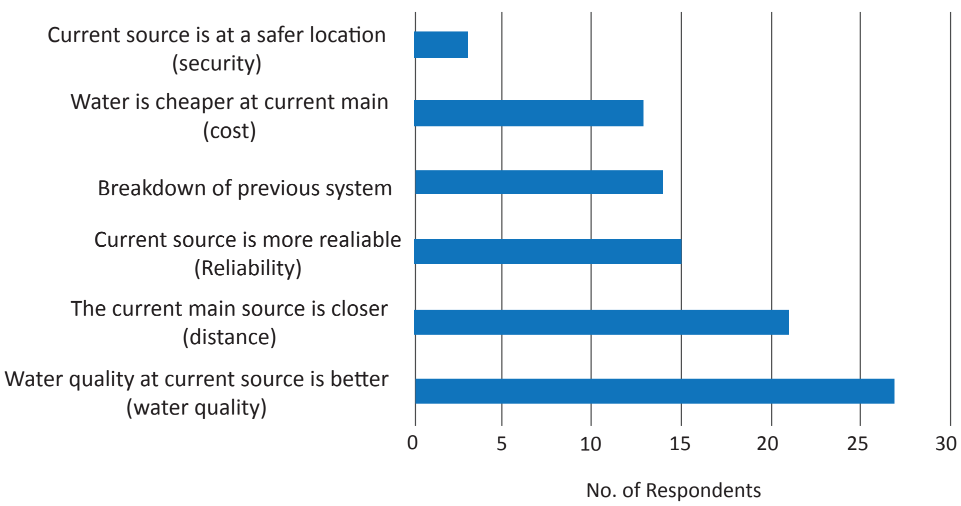
Source	Persons using the water source	Persons using water source as main source
Dam	18	4
Open well	24	7
River stream	91	2
water pans	26	26
water vendors	14	2

Figure 22: Water sources per HH



It is also noted that of the 72 persons that indicated having changed their water point over the last three years, 60 respondents had switched from using unimproved water sources (water vendors, water pans, rivers and dams) as their main water sources to solar powered schemes. Figure 23 summarizes the reasons most frequently cited as reasons for switching from relying on unimproved sources of water to the solar powered schemes. As can be seen, water quality is a key driver closely followed by distance travelled to water point.

Figure 23: Reasons for changing the main source of water



Also, as discussed under the Effectiveness section below, most respondents spend less than 30 minutes to collect water from solar powered systems. As such, solar powered water systems are seen to have the potential to provide, in the minimum, basic levels of water services to communities.

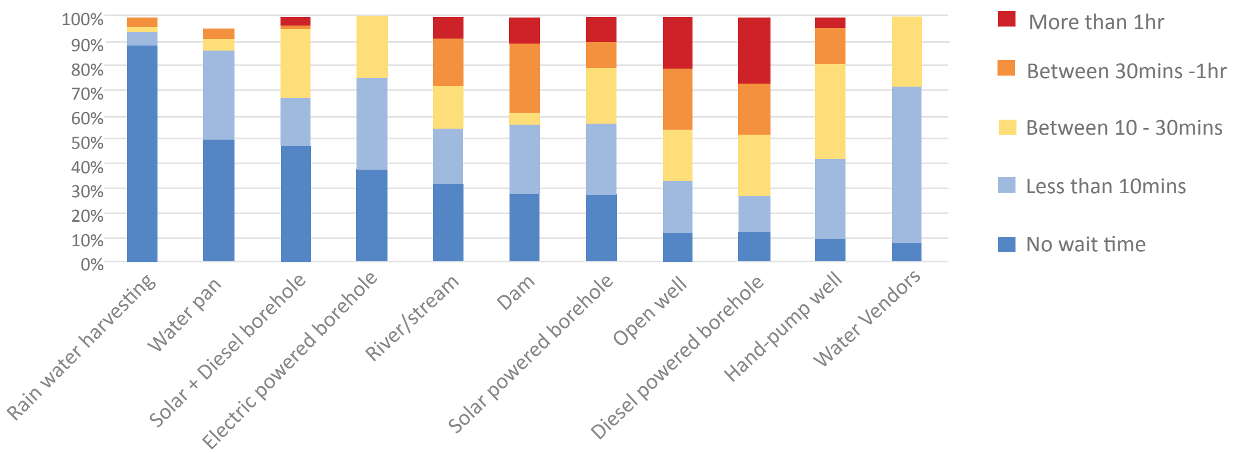
6.2 Effectiveness

The OECD – DAC Criteria for evaluating Development Assistance defines Effectiveness as "a measure of the extent to which an aid activity attains its objectives". Given the context of this evaluation, where the sampled water supply systems were installed by different entities under different projects, specific project objectives cannot be ascertained. As such, effectiveness is evaluated under an assumed overall project objective of providing water access to communities. Evaluation is based on the elements of safely managed drinking water services during the SDGs era as outlined by the JMP[23]: Accessibility, Availability and Quality. An additional factor considered is gender.

6.2.1 Accessibility

Accessibility looks at the time taken to collect water, including distance travelled and time it takes queuing. A water source is said to be accessible if it takes less than 30 minutes to collect water. Figure 24 below reflects the waiting times observed for the various water sources evaluated.

Figure 24: Waiting times for water collection at different water sources



A key factor affecting waiting times, especially among mechanized systems, was the system's distribution network where systems with household connections experienced less waiting time/ a shorter waiting time. As seen in Figure 25, most respondents collect water at communal water collection points which include standpipes and water kiosks. It may therefore be inferred that mechanized water systems in general, and solar powered systems in specific, have in most efforts been used to deliver basic levels of drinking water services.

Systems evaluated in Wajir County, however, showed that solar powered water systems can be used to deliver the highest level of safely managed drinking water services. 4 of the 5 systems evaluated in Wajir county were solar-diesel hybrid systems with distribution networks that included household connections and communal water points. As seen in Figure 26, 52% of Wajir respondents have household water connections which also explains why the solar-diesel hybrid systems have the shortest waiting times among mechanized systems in Figure 24.

Distances travelled are another factor affecting accessibility. Table 14 summarizes the various distances travelled by respondents to different water sources. According to WHO, a water source should be within 1,000 metres of the home,

[23] World Health Organization, 2017, Safely managed drinking water - thematic report on drinking water 2017. Geneva, Switzerland: License: CC BY-NC-SA 3.0 IGO.

Figure 25: Water collection points

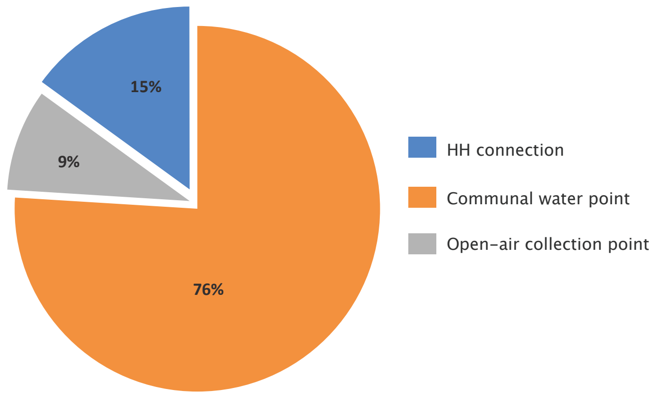
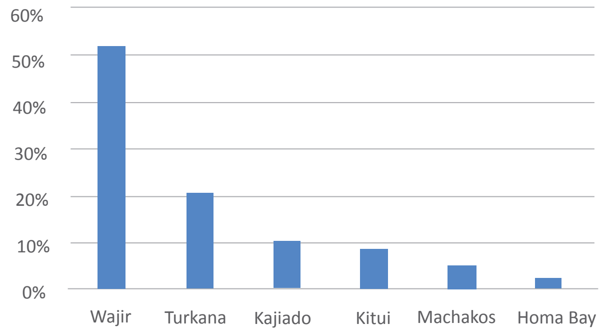


Figure 26: HH Connections per County



indicating that most standalone solar water systems visited under this study are appropriately sited. These average distances are biased by intervention designs. The solar powered systems in Machakos County for instance have standpipes distributed across the waterpoint catchment, so that most consumers are within at least 500 meters of a standpoint. The diesel borehole in Kitui in contrast is a single water kiosk serving an entire sub-location.

Table 14: Average distances travelled to water point

Source	Distance (km)
Dam	2.47
Solar + Diesel borehole	2.38
Open well	2.32
Diesel powered borehole	1.59
River/stream	1.56
Hand-pump operated well/borehole	1.51
Solar powered borehole	0.99
Water pan	0.75
Electric powered borehole	0.64
Rain water harvesting (tanks)	0.47
Water vendors	0.27

6.2.2. Availability

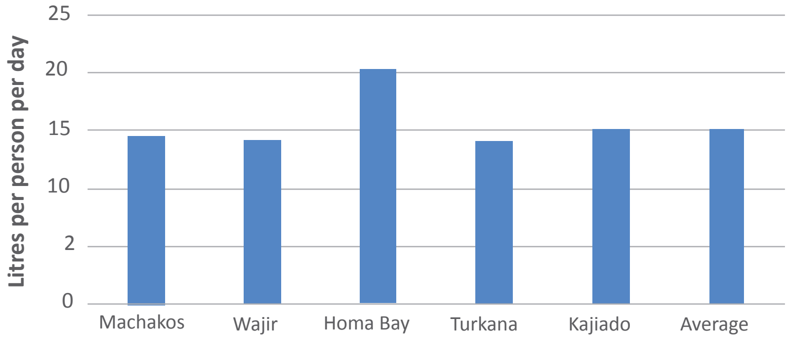
The human right to water recognizes that "water supply for each person must be sufficient and continuous for personal and domestic uses". The World Health Organization puts the volume needed at between 50 and 100 litres of water per person per day[24] while the Sphere Handbook, which provides minimum standards in humanitarian response[25], put the water needs at least 15 liters per person per day. Figure 27 shows averages of self-reported consumption volumes for households[26]. As seen, the volumes are barely at the minimum levels proposed for humanitarian response.

[24]The human right toe water and sanitation, http://www.un.org/waterforlifedecade/human_right_to_water.shtml

[25]The Sphere Handbook, http://www.spherehandbook.org/en/water-supply-standard-1-access-and-water-quantity/

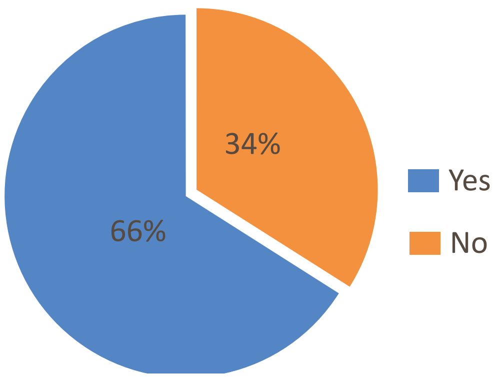
[26]Consumption volumes were mostly reported by persons collecting water from communal waterpoints. These averages may therefore not be representative of persons with household connections.

Figure 27: Volume consumed per person per day



In contrast, however, 66% of water point operators believe that their respective water points meet the community's water needs. Asked the question, '*Does this water point meet the community's demand?*', one operator noted that it did as that was the only water source the community had and they had therefore learnt to adjust their water demand to the available supply.

Figure 28: Does this water point meet the community's water demand?

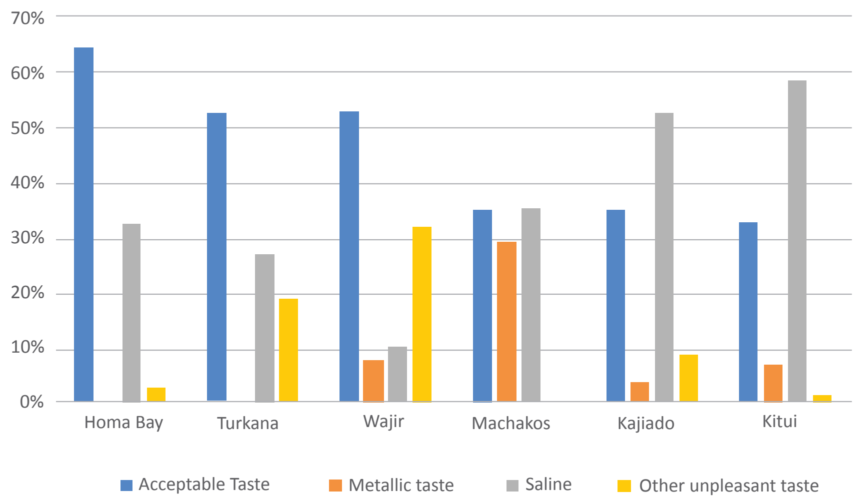


6.2.3 Quality

Drinking water should be free from pathogens and its chemical constitution should not include elements (e.g. fluoride and arsenic) at concentrations harmful to humans. The scope of this study did not cover detailed water quality analysis. No incidences of diarrhea were reported by all respondents in response to the question '*Has anyone in this household experienced diarrhea in the last 6 months?*'

Water salinity was a major concern, especially among residents of Kitui, Kajiado and Machakos as reflected in Figure 29. Consequently, it is a significant factor on why people rely on more than one water source. In Katitu, Kitui County for instance, water sourced from the solar powered boreholes is mainly used for livestock and brick making. Conversation with residents revealed that during the dry season, people walk about 5km to collect water for drinking and cooking.

Figure 29: Views on taste of water



There were also cases of metallic taste in water, most of which talk to the need for appropriate design systems. In Machakos and Kitui counties for instance, some of the exposed parts of the casing were seen to be severely rusted and the plastic storage tanks often had lines of rust at leak points. As most of these boreholes had either been capped prior to solar installation or were retrofitted with solar systems, it is likely that the borehole casing had rusted over time leading to the undesired taste and odor. It is recommended that in such instances, a system overhaul is carried out before solar installation including use of non-corrosive casing.

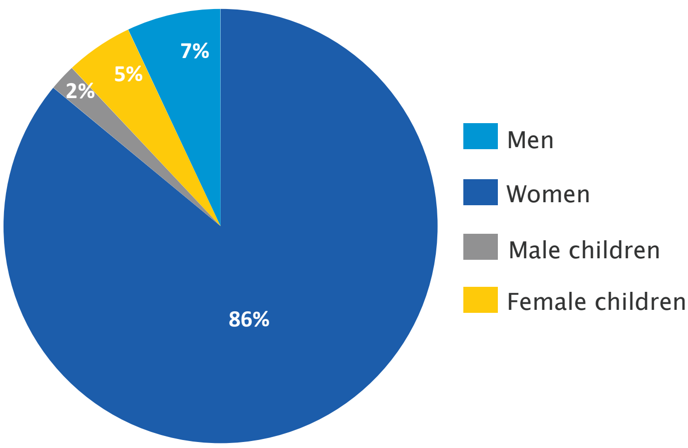
In general, it is recommended that correct siting of boreholes be done to guarantee that water is acceptable to target communities and ensure the use of the system once installation and handing over are completed.

6.2.4 Gender

Water collection is predominantly carried out by women. Conversations with various respondents at the water point often pointed to this being a culturally assigned gender role with many noting that *"hiyo huwa ni kazi ya wanawake"* (that is a woman's role). The only instant when a water point operator noted that more men than women are involved in water collection was in Katitu, Kitui County where the borehole water is mainly used for livestock and brick making.

Women involvement in water management is also lacking, despite them being the ones most involved in water collection. Only two of the 40 sites visited had a female water point operator. Also, only two sites had female headed water point committees.

Figure 30: Water collection - gender



7. Conclusions

7.1 Pillars of Sustainable SPWSS

Solar-powered systems are a cost-effective means of delivering basic and safely-managed water supply to remote communities. Overall, the evaluation finds that solar powered water supply systems (SPWSS) for communities are technologically ready for mainstreaming in the Kenyan setting. This evaluation also finds that sustainable water supply systems inherently display three critical features. Such systems are characterized by proper technical design, grounded operational structures and self-generated financial replenishment. The choice of solar power generation largely addresses aspect of design which must be supported by the other two critical pillars, irrespective of the technology. These considerations are seen to be the three pillars of sustainable SPWSS as summarized below.

Figure 31: Pillars of Sustainable SPWSS

7.1.1 Design

Design, as a sustainability pillar, addresses technical aspects involved in setting up and operationalizing a water system. This includes choice of technology and equipment, siting of the system, type and quality of water and design specifications. By assessing various parameters including system functionality, maintenance and repair mechanisms, vandalism and theft, and system sizing, various lessons can be drawn. For instance, the value of proper system design and pump installation cannot be understated. Overall, it was found that the main contributor to non-functionality of systems (where water was not available at the time of the evaluation) was pump-breakdowns. This, however, should not be the case as submersible pumps typically have a life-span of 10-15 years if properly installed and require very minimal maintenance.

Additionally, evaluation of storage type and size reveals repeated incidences of undersized storage which often led to long waiting times at some water points while the solar-diesel hybrid systems often defaulted to using diesel generators in times of high water demand, negating the contribution of the solar component. In contrast, cases of vandalism and theft of the system components were very rare among the evaluated systems due to implementation of security measures such as construction of systems close to households, raising and welding in of solar panels, hiring of night guards, fencing of the systems, and installation of security lights.

7.1.2 Operations and Management (O&M)

O&M Models look at the systems in place to ensure the day-to-day running of the waterpoint. Various models of O&M with varied levels of success were observed at the water points evaluated. This study emphatically concludes that a one-size fits all approach cannot be adopted for management of solar-powered water systems as different management models can be applied successfully in varied contexts. The failure of an O&M model within a stated context also does not necessarily mean that it was a bad model but it could have been a good idea that was poorly timed, poorly sited or poorly implemented. It was, however, found that there are three main factors that should be incorporated into any management approach to enhance its sustainability. These include:

- Measures for financial accountability as elaborated on in the third pillar below;
- Employment of dedicated and salaried water point operators and system personnel. These are people whose source of livelihood is dependent on the operational success of the water system and are therefore vested in ensuring system functionality;

- Availability of technical support for system maintenance and repairs. The engagement of county water offices in water point management was identified as a viable option as these have dedicated water professionals.

7.1.3 Finance

While the capital costs of installing community solar water pumping are often borne by implementing aid agencies or county government, most of these systems are managed by communities. In efforts to mainstream the use of solar power for water pumping at community level, focus has been on the reduction in recurrent costs associated with water supply and consequent payback period for solar water systems compared to alternatively powered systems. While this outlook makes a business case for the supply facing entities (development agencies and NGOs), it is often interpreted as no cost of energy for water pumping negating the need for water charges by benefiting communities (demand facing entities). This evaluation identifies a need to make deliberate efforts to shift this narrative among communities to ensure that they understand that while there are minimal recurrent costs in operating solar systems, there are significant one-off costs to ensure their continued long-term operation. Measures including setting up bank accounts and training on financial accountability need to be put in place to ensure that communities are saving towards these costs.

7.2 Best Practices in the management of solar powered water supply

Table 15 below elaborates key best practices observed from an analysis of commonalities of success across the evaluated systems and supplemented by additional information from secondary data sources. They have been categorized to reflect pre-installation, installation and operation phases of a solar water pumping system.

Table 15: Summary of Best Practices

Category	Best Practice
Pre- Installation	**Regulated use of Ground Water** Solar water pumping relies on groundwater resources and as such it is important to sustainably utilize this resource. This is particularly important in areas where there are no alternative sources of water. More emphasis therefore needs to be placed on monitoring of ground water abstraction and aquifer recharge to ensure borehole health and minimize incidence of dry boreholes.
	Regulation of drillers Stricter enforcement must be established in the drilling sector to curb the activities of rogue borehole drilling companies. Due to lack of customer knowledge, drilling companies may skip important steps such as the hydrogeological survey which may result in the borehole drying up after a short period of time. Additionally, drilling companies should provide customers with full documentation including the test pumping report and the borehole completion report.
Installation of borehole	**Correct System Design** Conversations with sector players as well as donor organizations indicated that incomplete or missing borehole completion reports and test pump documents are a major contributor to incorrect design of systems. This includes improper pump selection and system power sizing which subsequently leads to failure of the borehole system. This is particularly the case for retrofitted systems, where the age of the system makes it difficult to trace the borehole completion reports. These reports contain important parameters such as the borehole depths, aquifer characteristics, tested yield, and the static and pumping water levels, all of which inform the selection of the correct pump and power sizing.

Category	Best Practice
	Maintenance of borehole data Borehole equipping companies should ensure that they place permanent, legible labels detailing pump and solar equipment specifications. This is important for repair and maintenance purposes as well as providing information during impact surveys. Additionally, it was observed that over time, the permanent labels become illegible and it thus becomes important to find additional means of storing borehole data. Among observed approaches to this is Oxfam's phone application that is under development and that will be shared with agencies for the ease of collecting data and mapping sites. Alternatively, the use of Radio Frequency Identification(RFID) tags could be explored as a means of storing equipment details. Use of RFID is already being practiced by water utilities in countries like Germany and the USA as a means of inventory management and water use data collection among other uses.
	Community Sensitization Instilling a sense of ownership of the water point cannot be over-emphasized. This should be done prior to, during and after the installation of the systems. Failure to do this often leads to high prevalence of vandalism and theft as well as overreliance by the community on donor assistance. There is also need for communities to be trained on system management with the option of additional guidance and supervision after the installation of the borehole (e.g. 6 months) before they are left to run it.
	Training of committee members or Scheme Operators Some equipment suppliers reported that they conduct training sessions throughout the year on use of solar-powered equipment. Such entities should liaise with development bodies of newly established boreholes for scheme operators to attend training sessions.
Operation and Maintenance	**Securing of the System** Systems should be adequately secured to prevent incidences of theft and vandalism. This includes welding of solar panels onto a reinforced mounting frame, fencing of equipment, hiring a night-guard, installing security lights among others.
	Regular Cleaning of Solar Panels Solar panels should be regularly cleaned with water and a soft sponge to reduce soiling losses that arise due to accumulation of dust and other particles like bird droppings on the panels. Equipping companies should provide communities with solar panel cleaning poles and brushes.
	Maintenance of Compound There is general neglect of the compounds where the solar water pumping equipment is located. Overgrown grass, plastic bags and spoilt fencing are a common sight. This reduces accessibility to system equipment and can promote theft and vandalism. Routine clearance of the site around the Solar Water Pumps and panels should be encouraged.
	Providing Water at a Fee Water at solar-powered pumping systems should be provided at a fee. Repairs, part replacement and eventual replacement of solar panels and pumping equipment is dependent on the monies collected and saved over time. Lack of collection at solar-powered water points may compromise the long-term sustainability of systems.

Figure 32: Case Study of an effectively operated water system

KMC Borehole in Athi River, Machakos County offers a great example for application of a multi-faceted approach to the various issues affecting solar water systems for community water access. Installed in 2007, the system was among the first systems installed under the Grundfos Lifelink 'water kiosk with water supply' Model. Beside borehole deepening due to sinking water levels, the borehole has been in operation since installation. The table below highlights the actions carried out or measures in place to ensure long-term sustainability of the water system.

Issue	Solution	Description
System Design	End-to-end installation by a private entity; Service and maintenance contracting	Grundfos Lifelink oversaw the site identification, feasibility studies, drilling and equipping at this site. Based on the business model, Grundfos Lifelink was also responsible for the repairs and maintenance of the system for the duration of the agreement with the community. This approach ensures that the equipping entity carries out quality installations and regular preventative monitoring as they bear any repairs and maintenance costs.
System Management	Engagement of the county water office	The water point committee was selected by and is overseen by the sub-county water office. The selection process was competitive and included: 1) groups bidding for waterpoint management must be registered entities; 2) groups must have existed and operated a bank account for more than 6 months to qualify. Contracts with non-performing water committees can be terminated by the county water office. This ensures the continued performance of committees.
Financial management	Use of water ATMs	Grundfos Lifelink installed an automated water dispenser (AQTap) at the water kiosk. The system, which uses water keys/cards credited with money to dispense water, is based on the M-pesa platform and allows for direct money transfers to a bank account. During the validity of the Service agreement with the community, Grundfos retain KES 215,000 to cater for costs of repairs and maintenance and credited any surplus money to the water committees. As an additional money earning opportunity for the water committee, a fulltime water point operator with a master vending card sold water to persons without the ATM cards as KES 5/20L while the system charges KES 3/20L, thus making the community a profit of KES 2 per 20L dispensed.

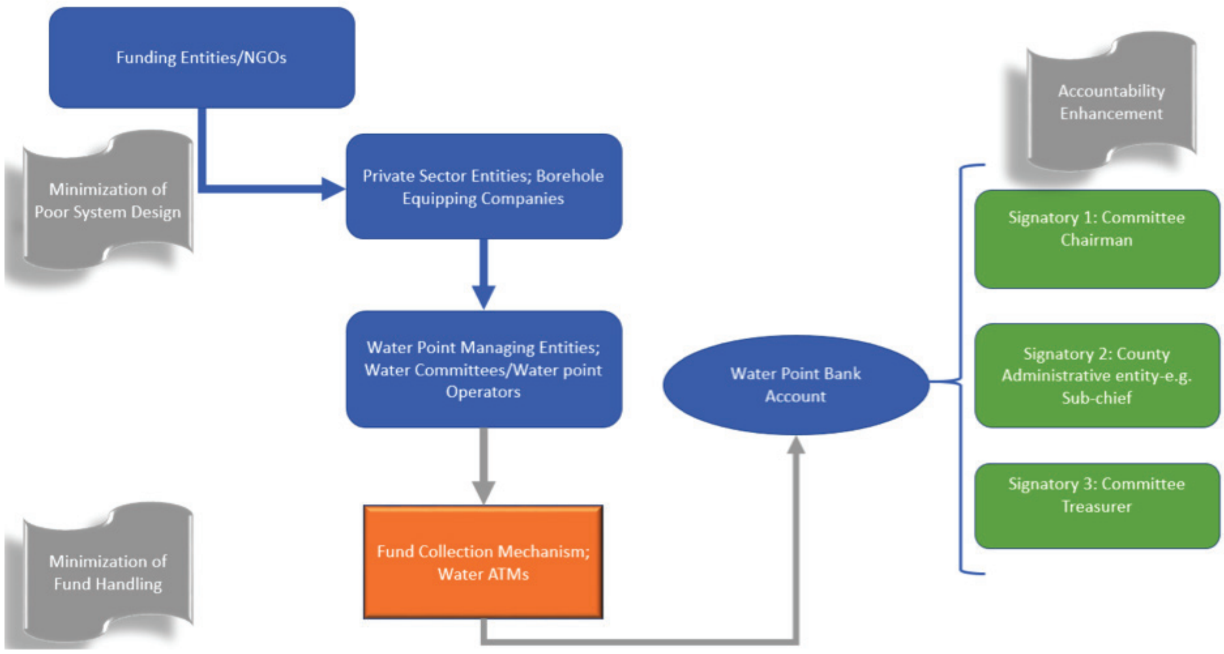
8. Recommendations

As noted in the conclusions, this study observes that solar powered water pumping systems are technologically ready for mainstreaming in Kenya. However, the sustainability of these systems is dependent on system design, O&M mechanisms in place and financial management. As such, the recommendations of the study are presented as two multi-stakeholder implementation models that have been developed based on lessons learned and best practices observed during the evaluation.

8.1 The Enhanced Water Committee Model

The first model recognizes that water users' committees will remain an integral component of community water schemes for most systems implemented in Kenya in the near term. It therefore seeks to enhance the current management structures of these committees by adopting and combining strategies that were observed at successful water points. The model involves 4 key solar water pumping sector players namely; i) Private Sector Borehole Equipping Companies ii) Non-Governmental Organizations and developmental bodies iii) Water Committees and iv) County Administrative Entities and is illustrated in Figure 33.

Figure 33. The Enhanced Water Committee Model



This model is anchored on the following key factors:

i. Liability anchorage to enhance system design and operation

Under this model, NGOs and other funding entities continue in the role the of conducting hydrogeological and feasibility studies, overseeing borehole drilling, financing borehole equipping and training water committees and scheme operators. However, to enhance system design and installation, the model proposes a staggered payment structure where borehole equipping companies receive some payment after the system has been operational for a stated number of months. Recognizing that funding cycles for different donors vary, this payment structure could be bound by the project funding cycle. For instance, instead of making full payments to borehole equipping companies upon completion of works, payments can be made in instalments with 80% upon equipping the borehole and 20% at the end of the funding cycle (for cycles less than 2 years, though this should be longer than the warranty period), after-sales support period or after 2 years (for funding cycles longer than 2 years) upon confirmation of the system functionality. With such structures in place, funding entities leverage on the expertise of borehole equipping companies to confirm designs and sizing plans. Additionally, this shift in liability pushes the equipping companies to carry out their due diligence on borehole specifications and ensure proper installation for reduced risk of system non-functionality.

ii. County involvement to promote accountability

The Kenya Constitution 2010 mandates county governments with water services provision and as such, puts the counties at the core of any water access interventions. This evaluation identifies three key areas for county engagement that can contribute to enhanced community water committees:

1. Implementing agencies should engage the county in registering benefitting communities as legal entities (water users' associations). This would require communities to implement key financial accountability measures including maintaining books of accounts, minuting and sign-off of any expenditures and holding annual general meetings.
2. The committees should be trained on accountability measures such as funds withdrawals procedures that involve at least three signatories. Having county representatives (e.g. persons from the ministry of water, chiefs or village administrators) as account signatories can promote accountability in usage of funds collected from the system.
3. The county water department should oversee training of new water committees to mitigate the training gap that arises when there is a transition in water point leadership.
4. County resources should be used to ensure the maintenance and repair of water systems. A practical example would be equipping the water point committees with contacts of county plumbers and engineers who may be engaged in case of system malfunction. This is especially relevant for major system breakdowns where the availability of specialized skills would help with identifying the main cause of system breakdown and advising on appropriate actions.

iii. Technology Adoption to minimize fund handling

This study recommends that funding should cover the equipping of water points with automated payment devices such as Water ATMs to facilitate collection of funds. It was observed that there were lower levels of savings among stand-alone solar powered systems yet these systems will inevitably face significant one-off costs for components replacement. Maintaining the status quo in handling finances at these water points presents a risk of multiple failed systems within a few years.

The adoption of water ATMs at water points presents an avenue for minimized the handling of money at the water committee level which can lead to more sustainable systems. Water ATMS observed in the field included AQ Tap and SUSTEQ. Both systems allow users to channel funds directly to the bank account limiting avenues for fraud and mitigating the mismanagement of funds that plagues water committees. Coupling use of water ATMS (that deposit funds directly to bank accounts) with financial accountability measures suggested earlier (e.g. multiple signatories) will improve on financial sustainability of community managed water schemes.

8.2 Private Entity Management Model

The second model promotes the running of solar powered water supply systems as enterprises. This is realized through engagement of private entities to oversee the management and operations of a cluster or clusters of water schemes for a fee to support cost recovery and enhanced sustainability.

For this model to work, three key factors form the basis of success:

1. Provision of water services at a fee: the model is only viable where water is provided at a fee.
2. Aggregating and clustering of sites for economies of scale: For instance, this could be realized by a group of NGOs working within a certain region forming a consortium and outsourcing the management of >20[27] solar-powered boreholes to a private entity which oversees water payments collections and funds management for operations and management.
3. The water schemes under management must be the only source of water in the community, or at the very least, the main source of water.

The key players in this model are the funding entities, the private company engaged in system management and county governments. A description of their roles within this model is given below:

1. Funding entities

As in the enhanced water committees model, funding entities provide funding for the feasibility studies, borehole drilling and equipping of the selected sites. They should also seek to: 1) shift some liability to borehole equipping companies based on funding cycles as a way of enhancing system design and installation; 2) Extend funding to installation water ATMs to minimize actual handling of monies.

Additionally, for the model to work, implementing entities should aggregate sites within a region (either projects they have implemented or projects by a consortium of NGOs and developmental bodies) and outsource the management of >20 to a private entity.

2. The Private Limited Water Point Management Company

Operations of water supply systems will be handed to the private entity during commissioning. The role of this private company is to oversee the day-to-day management of the scheme – water pumping, system maintenance and repairs, payments collection, security provision among others. The presentation of the private managing entity to the benefitting community by the implementing NGO helps mitigate the risk of lack of community support to the private entity. The engaged private entities should:

1. ***Ideally, be micro-enterprises*** - This model is considered lucrative for micro-enterprises due to the economies of scale and the revenues likely to be generated. A back of the envelope estimate assuming 250 households served by one waterpoint and paying a minimum of KES 250 per month would result in at least KES 62,500 per site (the highest grossing solar-standalone system evaluated under this study had an average of KES 100,000 monthly collections). Clustering 20 of such sites yields about KES 1.25million a month making a business case for micro-enterprises. However, as discussed below, measures must be put in place to ensure that these private entities are regulated.

2. ***Be entities with experience in running a business*** – In identifying the private entities, the NGO / consortium of NGOs should seek already existing micro-enterprises (e.g. businesses with an operational account for at least 12 months) and whose operations span the area covered by the clustered water supply schemes.

Under this model, scheme operators serve as the primary community link. The scheme operators are engaged under performance contracts with the private management entity and work at the water supply systems on a full-time basis. To ensure efficient service delivery, the system operators should receive technical training on operating the water scheme including but not limited to meter reading, equipment maintenance and system diagnostic analysis.

Additionally, in recognition of the fact that access to drinking water is a human right in Kenya, measures must be put in place to ensure that water remains affordable for all. It is therefore recommended that the community is engaged in setting the water tariff. Also, for community buy in, it is recommended that the following measures are discussed, put in place and communicated to the community:

[27] This number could vary depending on the size of the systems and potential revenue per system.

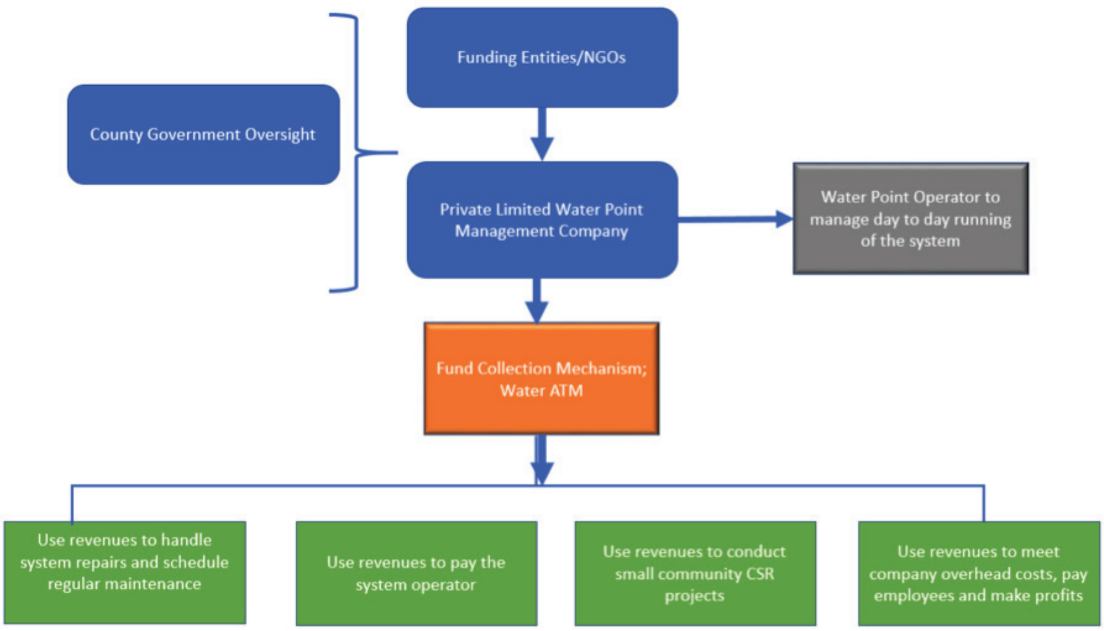
i. Establishment of a development kitty – a percentage of all collections is saved for future repairs and maintenance needs. This is critical as solar powered water systems have significant one-off costs for component repairs.
ii. Establishment of a community kitty – an agreed percentage of collections is given to the community for development initiatives (e.g. development of a school or dispensary). The money should be directed to a community bank account and the responsibility of managing these funds given to a community appointed committee.
iii. Surplus funds go to the day-to-day management of the scheme including salaries for the scheme operators and profit to the private entity.

Any of these three components of the collection can be a percentage, fixed amount or a combination of the two.

3. The County Government

As mentioned earlier, Article 93 of the constitution gives room for various water system management models if they are under contract with the county government which has the overall mandate of water supply. Thus, the NGO / Consortium of NGOs and the private management entities must rigorously engage county governments and sign binding contracts before initiating the model. Additionally, the county should provide regulatory oversight to the private entity.

Figure 34: Private Entity Management Model



ANNEX 1: LIST OF BOREHOLES

Borehole Name	County	Type	Implementing Agency	Date of Borehole Installation	Date of Solar Panel Installation	Functionality Status	Management Model
Nyasoti Borehole	Homabay	Solar Stand-Alone	World Vision	Apr-1994	May-2012	Functional	Community Management
Saremba Borehole	Homabay	Solar Stand-Alone	World Vision	Aug-1996	Dec-2012	Not Functional	Community Management
Kager Borehole	Homabay	Solar Stand-Alone	World Vision	Sep-2013	Sep-2013	Functional	Community Management
Kisui Borehole	Homabay	Solar Stand-Alone	County Government of Homabay	Dec-2013	Jan-2016	Functional	Community Management
Nabulon borehole 9	Turkana	Solar Stand-Alone	Oxfam	Nov-2014	Sep-2015	Functional	Water Service Provider
Elelea	Turkana	Solar Stand-Alone	World Vision/County Government of Turkana	Dec-2013	Dec-2014	Functional	Community Management
Lokori water supply system	Turkana	Hybrid (Solar/ Diesel)	The County Government of Turkana	Aug-1986	Jan-2014	Not Functional	Community Management
Lokore	Turkana	Solar Stand-Alone	Vétérinaires Sans Frontières Germany	Nov-2002	Dec-2015	Functional	Community Management
Letea	Turkana	Solar Stand-Alone	The County Government of Turkana/Lokado	Jan-2015	Jan-2015	Functional	Community Management
Kakuma borehole 1	Turkana	Hybrid (Solar/ Diesel)	Lutheran World Foundation/Oxfam	Dec-1994	Mar-2016	Functional	Community Management(CBO)
Lochwaa	Turkana	Solar Stand-Alone	Vétérinaires Sans Frontières Germany	Oct-1987	Dec-2015	Functional	Community Management
Kikambuani Primary	Machakos	Solar Stand-Alone	County Government of Machakos	Apr-2016	Dec-2016	Functional	County Managed Scheme
Mbusyani Primary	Machakos	Solar Stand-Alone	County Government of Machakos	Mar-2016	Dec-2016	Functional	County Managed Scheme
Mulingana Secondary School	Machakos	Solar Stand-Alone	County Government of Machakos	Jun-2016	Aug-2016	Functional	County Managed Scheme
Munich water borehole	Machakos	Solar Stand-Alone	County Government of Machakos	May-2003	Sep-2016	Functional	County Managed Scheme
KMC Borehole	Machakos	Solar Stand-Alone	Grundfos	Jan-2007	Aug-2007	Functional	Private Sector Managed Scheme
Tendelyani Farmers cooperative society ltd	Machakos	Solar Stand-Alone	County Government of Machakos	Jul-2016	Oct-2016	Functional	County Managed Scheme
Katangi Special School	Machakos	Solar Stand-Alone	Private Donor	Nov-2015	Nov-2015	Functional	Institutional Management
Adamasajida	Wajir	Solar Stand-Alone	Oxfam	Jan-2011	Jan-2011	Functional	Community Management
Ali Dumal	Wajir	Hybrid (Solar/ Diesel)	World Vision	Nov-2011	Nov-2011	Functional	Community Management

Borehole Name	County	Type	Implementing Agency	Date of Borehole Installation	Date of Solar Panel Installation	Functionality Status	Management Model
Sabuli Oxfam	Wajir	Hybrid (Solar/ Diesel)	Oxfam	Sep-2013	May-2015	Functional	Community Management
Abakore	Wajir	Hybrid (Solar/ Diesel)	Oxfam	Apr-2001	Oct-2013	Functional	Community Management
Dilmanyale	Wajir	Hybrid (Solar/ Diesel)	Oxfam	Jan-2006	Sep-2017	Functional	Community Management
Ilkinyie Borehole	Kajiado	Solar Stand-Alone	World Vision	Aug-2013	Aug-2013	Functional	Community Management
Emukutan Borehole	Kajiado	Solar Stand-Alone	World Vision	Apr-2012	Aug-2012	Functional	Community Management
Kisaju Private Borehole	Kajiado	Solar Stand-Alone	Private Owner	Apr-2014	Apr-2014	Functional	Community Management
Naibala Borehole	Kajiado	Solar Stand-Alone	German-Agro Action	May-2016	May-2016	Not Functional	Community Management
Elerai Community Borehole	Kajiado	Electricity-Powered	East African Portland Cement	Jan-1978	n/a	Functional	Community Management
Inkisanjani Nasieku Growers Project Borehole	Kajiado	Hybrid (Solar/ Electricity)	Red-Cross	Feb-2014	Feb-2014	Not Functional	Community Management
Enkeju Errap Borehole	Kajiado	Solar Stand-Alone	World Vision	Jun-2016	Aug-2016	Functional	Community Management
Leboo Borehole	Kajiado	Solar Stand-Alone	German-Agro Action	Jan-2015	Jun-2015	Not Functional	Community Management
Elerai Private Borehole	Kajiado	Solar Stand-Alone	Private Owner	Dec-2016	Jul-2017	Functional	Community Management
Samai Water point	Kajiado	Diesel	County Government of Kajiado	May-2010	n/a	Functional	Community Management
Enkutoto Borehole	Kajiado	Hybrid (Solar/ Electricity)	Red-Cross	Nov-2017	Nov-2017	Functional	Community Management
Kaluni water Borehole	Kitui	Solar Stand-Alone	World Vision	Sep-2014	Sep-2014	Functional	Community Management
Kawandei borehole	Kitui	Solar Stand-Alone	World Vision	Nov-2013	Jan-2014	Functional	Community Management
Kyeng'e Ngengekani Project	Kitui	Hybrid (Solar/ Diesel)	World Vision / Grundfos /County Government	Sep-2009	Oct-2011	Functional	Community Management
Ngingani Borehole	Kitui	Solar Stand-Alone	World Vision/ Grundfos	Aug-2009	Aug-2014	Functional	Community Management
Mivuni Water Users Association	Kitui	Hybrid (Solar/ Diesel)	World Vision	May-2011	n/a	Functional	Community Management
Katitu Borehole	Kitui	Solar Stand-Alone	World Vision	May-2013	Jul-2013	Functional	Community Management

ANNEX 2: LIST OF KEY INFORMANT INTERVIEWS

#	Organization	Type of Organization	Contact Person	Type of Interview
1	World Vision Kitui	Donor	Kennedy Ayua	Telephone
2	Oxfam Wajir	Donor	Abdulrizak Kontoma	Telephone
3	German Agro Action(Kajiado)	Donor	Milicent Mbidhi	Telephone
4	Red cross	Donor	James Musyoka	Telephone
5	Water missions	Donor	Vivian	Telephone
6	East African Portland Cement	Donor	Paul Parseloi	Telephone
7	KAWASEPRO (Kakuma Water Service Providers)	Water Company/Manager	Evans Okore	Telephone
8	World Vision Kenya	Donor	Francis Huhu	Physical Visit
9	Grundfos Lifelink	Borehole Equipping Companies	Patrick Oketch	Physical Visit
10	Davis & Shirtliff	Borehole Equipping Companies	Eng. Philip Holi	Physical Visit
11	Machakos County – Water Office	County Government	Jones Mwaka	Physical Visit
12	Davis & Shirtliff	Borehole Equipping Companies	Reuben Kinuthia	Physical Visit

European Union
Civil Protection and
Humanitarian Aid

IOM • OIM

OXFAM

NRC
NORWEGIAN
REFUGEE COUNCIL

Global Solar and
Water Initiative