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Solar pumping for rural water supply: life-cycle costs from eight countries

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Although interest in solar water pumping has been steadily growing, misconceptions persist about the applicability and cost-effectiveness of such systems in remote settings. The primary barrier to wide scale adoption of solar water pumping is that policy makers and practitioners at the local, national and international levels lack valid and transparent information on performance in a broad range of contexts and of the full life-cycle costs. In an attempt to fill this information gap, this paper presents upfront and recurring costs from 85 rural solar water pumping schemes of various sizes that have been designed, constructed and supported by Water Mission in eight countries. The average life-cycle costs associated with the reviewed schemes were within and on the lower end of IRC WASHCost benchmark ranges for both piped water schemes and boreholes fitted with handpumps. These findings indicate solar pumping is a viable and cost-effective intervention for rural water supply.

Motivation

The United Nations Sustainable Development Goals have brought about a renewed focus on sustainability of rural water supplies, particularly in terms of long-term financial viability of operation and maintenance or "service delivery" models. In this context, interest in solar water pumping has been steadily growing due to its capability of producing a high level of service while reducing energy costs, as well as to increasing affordability of photovoltaic modules, reliability of supply chains and overall technical viability.

Various attempts have been made to estimate the life-cycle costs of solar water pumping systems, most of which indicate that long-term power supply and capital maintenance savings render the systems more cost effective than alternative mechanized pumping systems (Bannister, 2000; Odeh et al., 2006; Meah et al., 2008). In addition, the WASHTech Technology Applicability Framework, a tool which can be used to evaluate technical and financial as well as institutional, environmental and social sustainability of technologies in a specific context, has been applied to solar pumping in Uganda, Ghana and South Sudan (NETWAS & WaterAid Uganda, 2013; TREND et al., 2013; VNG & IRC, 2014). However, misconceptions persist about the applicability and cost-effectiveness of solar pumping systems in remote settings and with surface or poor quality water sources. The primary barrier to wide scale adoption of solar pumping is that policy makers and practitioners at the local, national and international levels lack valid and transparent information on performance in a broad range of contexts and of the full life-cycle costs (NETWAS & WaterAid Uganda, 2013).

Since 2008, Water Mission has been involved in design, construction and support activities associated with more than 1,000 solar water pumping systems of various sizes in 15 countries. In an attempt to fill the information gap in sustainability of solar water pumping, this paper presents upfront and recurring costs from 85 of these schemes in eight countries.

Methodology

An initial scan of Water Mission's web-based data management system was conducted to identify all water supply schemes of those the organisation has designed, constructed and supported that included a solar powered surface or submersible pump and solar modules. Capital expenditure data was available from technical design and budget documents for 85 of the schemes, which were therefore selected for inclusion in this review. These schemes were installed over a period from July 2013 to November 2016 and could be characterized by size as small (serving less than 500 people), medium (serving between 500 and 5,000 people) and intermediate (serving between 5,000 and 15,000 people). Reliable operational and minor maintenance expenditure data as well as revenues from container-based collection fees and monthly tariffs paid by water users was available for 72 of the 85 reviewed schemes. The distribution of designed service populations and countries where the reviewed schemes are located is displayed in Figure 1.

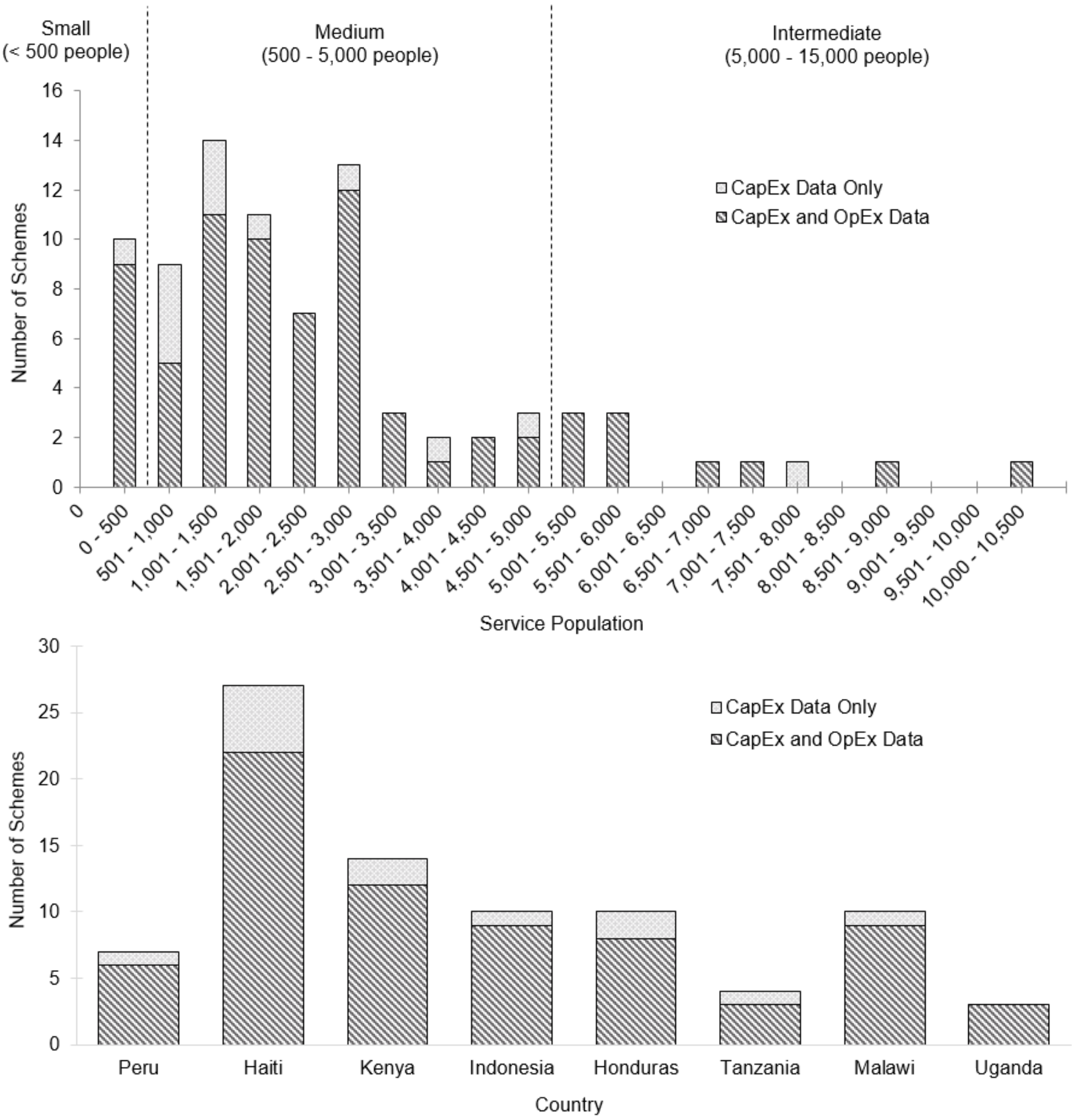

Figure 1. Population and geographic distribution of reviewed solar water pumping schemes

Source: Water Mission

A schematic of a typical solar water pumping scheme considered in this review is provided in Figure 2. Many of the reviewed schemes included piped distribution networks that feed to multiple public tapstands in strategic locations in the service area. None of the reviewed schemes utilized batteries, charge controllers or AC power backup. Instead, all of the schemes were designed to utilize pumps that are capable of receiving DC power directly from a solar array.

Relevant upfront and recurring costs were analysed for each reviewed scheme based on industry standard cost categories, definitions and benchmarks (Fonseca et al., 2011; WASHCost, 2012). Specific hardware and software elements that were included in each cost category are defined in Box 1.

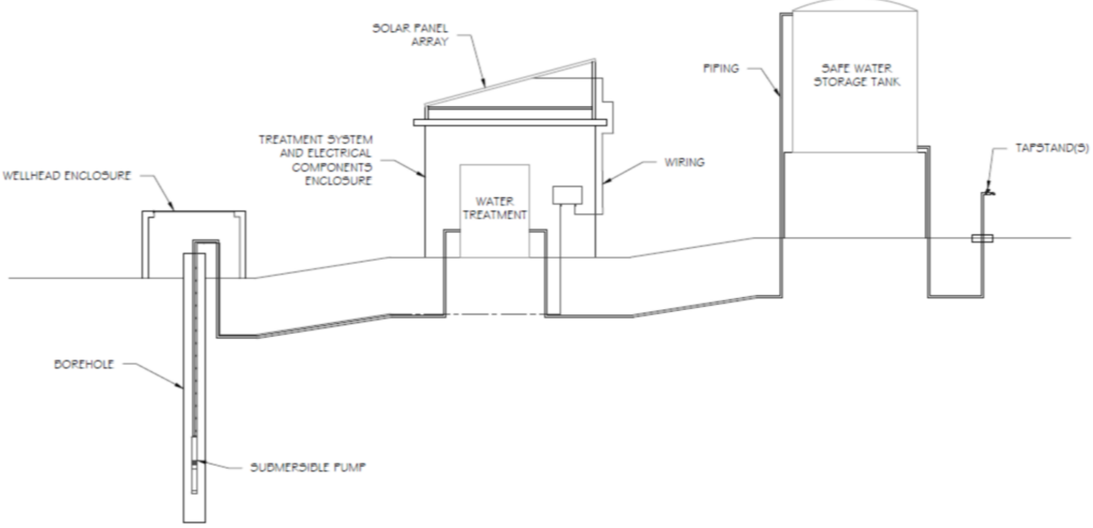

Figure 2. Schematic of typical solar water pumping scheme included in review

Source: Water Mission

Box 1. Hardware and software elements included in life-cycle cost analysis of solar water pumping schemes

For the purposes of this review, material, labour and travel expenditures associated with the following activities were included in the life-cycle cost analysis:

- Capital Expenditure (CapEx) – water quality and source yield testing; engineering design; water source development including drilling, protecting and/or securing ground and surface water sources; construction and installation of enclosures, solar arrays and associated wiring (typically 1.5 to 2 kW), surface or submersible pump and controls, water treatment equipment, elevated storage tanks (typically 5,000 to 10,000 L of total storage elevated 1 to 3 m above ground on pads or towers), supply and distribution piping, and tap stands (either at point-source kiosks or at multiple locations in the service area); stakeholder coordination and planning; community engagement and capacity building activities including assessment and mobilisation, leadership development, initial management and administration training, initial system operator training, community-led sensitization and promotion, and extended support of operation, maintenance and administration for a period of 1 to 3 years until operational and financial stability is achieved
- Operating and Minor Maintenance Expenditure (OpEx) – ongoing operation and minor maintenance of all water supply system components including purchase of water treatment and cleaning supplies; ongoing water quality monitoring; ongoing administration including tariff collection, money handling and record keeping; salaries and commissions; ongoing marketing, public relations and conflict resolution
- Capital Maintenance Expenditure (CapManEx) – ongoing repair and/or replacement of major system elements including procurement and installation, adjusted for inflation at 2.8% per year.

Limitations in the manner in which historical expenditures were allocated and tracked in Water Mission's accounting software prevented actual CapEx from being evaluated. Instead, budgeted expenses based on data found in scheme design documents were assumed to be an accurate representation of CapEx because significant variance from total actual expenses is not typically observed. In addition, volunteer labour and financial contributions provided by communities served by the reviewed schemes, which typically represent less than 10% of total CapEx, were not accurately recorded and are therefore not included in the estimates.

The reviewed schemes were all managed by community-based water committees that keep records of expenditures, allowing Water Mission to review and validate. OpEx was calculated based on data found in these logbooks and was assumed to represent long-term recurring cost of operation and minor maintenance even though the schemes had only been in operation for an average duration of 21 months (min three months; max four years) at time of review. CapManEx was evaluated based on all observed failures Water Mission has experienced in any solar water pumping scheme since 2008 and on estimated future cost of major scheme elements over assumed lifespans. Historical international exchange rates were used to convert all recurring financial data from local currency to USD. Cost of capital and expenditure on direct support were not evaluated in this review. Although such cost elements are likely to vary little across different water supply technologies, they are dependent on national and local policies and service delivery models.

Life-cycle costs for solar water pumping schemes

Capital expenditure (CapEx)

A summary of information that is relevant to CapEx of the reviewed schemes is provided in Table 1.

Table 1. CapEx summary for solar water pumping schemes

	Small schemes (<500 people)	Medium schemes (500-5,000 people)	Intermediate schemes (5,000-15,000 people)
Number of schemes reviewed	9	65	11
Avg. service population (min; max)	341 (204; 450)	2,168 (500; 5,000)	6,735 (5,100; 10,500)
Design water demand [L/person/day] (min; max)	9 (5; 13)	7 (2; 20)	7 (2; 20)
Avg. CapEx [USD] (min; max)	$46,733 ($30,968; $74,170)	$60,960 ($27,822; $274,354)	$60,769 ($25,125; $132,037)
Avg. CapEx [USD/person] (min; max)	$139.60 ($85.52; $188.31)	$39.17 ($7.38; $207)	$9.58 ($3.25; $25.39)
WASHCost CapEx Benchmark Range [USD/person]	$30 - $131		$20 - $152

Average CapEx per person was higher than the WASHCost benchmark range for small schemes and decreased with increasing scheme size. This trend indicates economies of scale are present to some extent, but it is also influenced by the fact that CapEx in USD was essentially equivalent between medium and intermediate schemes even though intermediate schemes were designed to serve greater than three times more people. This phenomenon was likely a result of incorporation of door-to-door vending in larger schemes which allowed for larger service populations without requiring additional costly infrastructure.

The majority (76%) of the reviewed schemes were medium in size (serving 500 – 5,000 people) and more than 50% of the schemes were designed to serve 1,000 to 3,000 people. Since schemes in this size range comprise the bulk of Water Mission's experience with solar water pumping, the reported life-cycle costs are likely to be the most reliable and transferrable compared to those of the small and intermediate ranges. For these schemes, a good rule-of-thumb is that costs associated with engineering, design and construction activities comprise approximately 75% of the total CapEx, and costs associated with community mobilisation and capacity building activities account for the remaining 25%.

Average CapEx per person for the reviewed medium-sized schemes was within and on the lower end of the WASHCost benchmark range for similarly sized schemes providing a basic level of quantity, quality, accessibility and reliability. These schemes were typically designed to meet water demand for consumption, providing an average of 7 L/person/day of chlorinated water to public or private access taps at least within one km and often within 100 m of residences. Although only 10% of the schemes were designed to produce the industry-accepted basic per capita quantity (20 L/person/day), all were designed to be capable of the highest level of quality, accessibility and reliability (Fonseca et al., 2011).

The capacity of the solar submersible and surface pumps installed in the reviewed schemes are typically maximized at service populations less than or equal to 5,500 people when designed to meet daily water demand for consumption, and they are capable of operating at no more than 100 to 150 m of total dynamic head. Producing a higher daily quantity of water in order to serve larger populations or pumping from deeper groundwater sources or longer distances necessitates multiple solar pumps or a larger AC pump with a DC/AC inverter system, which would in turn result in an increase in CapEx. Water Mission has installed and supported a limited number of schemes which included AC pumps and inverter systems, and these did not meet criteria for inclusion in this review.

Operating and minor maintenance expenditure (OpEx)

A summary of information that is relevant to OpEx of the reviewed schemes is provided in Table 2. As with CapEx, OpEx decreased with increasing scheme size. All but one scheme had a positive average net income, indicating the associated collection fees and tariffs were sufficient to recover OpEx. Average OpEx per person for medium sized schemes was within and on the lower end of the WASHCost benchmark range.

Table 2. OpEx summary for solar water pumping schemes

	Small schemes (<500 people)	Medium schemes (500-5,000 people)	Intermediate schemes (5,000-15,000 people)
Number of schemes reviewed	8	54	10
Avg. service population (min; max)	343 (204; 450)	2,106 (500; 5,000)	6,825 (5,100; 10,500)
Avg. OpEx [USD/month] (min; max)	$30 ($5; $61)	$83 ($1; $813)	$68 ($7; $355)
Avg. OpEx [USD/person/year] (min; max)	$1.09 ($0.17; $2.29)	$0.52 ($<0.01; $7.81)	$0.11 ($0.01; $0.41)
WASHCost OpEx benchmark range [USD/person/year]	$0.50 - $5.00		

Capital maintenance expenditure (CapManEx)

Of all the solar water pumping schemes Water Mission has designed and constructed since 2008, 29 instances of solar pump or control equipment failure have been reported. These failures almost always occurred within the manufacturer's warranty period and were resolved by replacing the failed equipment. Pumps failed in 11 instances and controls failed in 18 instances incurring an average cost of $1,500 and $250 to repair, respectively. Major maintenance issues due to improper handling, installation or user error have been reported 34 times in Water Mission's cumulative experience. The average cost of repair for these issues was $1,300 and was almost always covered by water committee savings.

Anticipated replacement costs for hardware elements at end of lifespan should be considered in addition to unanticipated repair costs when planning for CapManEx. Since none of the hardware elements in the reviewed schemes were in operation longer than the anticipated lifespan, these costs were estimated for a typical medium-sized scheme and presented in Table 3.

Conclusion

The majority of the schemes reviewed in this paper can be characterized as medium in size, with an average service population of 2,200 people. The average observed life-cycle costs associated with these schemes was within and on the lower end of IRC WASHCost benchmark ranges for delivering basic service via both piped water schemes and boreholes fitted with handpumps. A full and normalized comparison of life-cycle costs associated with solar water pumping schemes and boreholes fitted with handpumps was not conducted as part of this review. However, these findings indicate the reviewed solar schemes, particularly those in the medium and intermediate size categories, are at least as cost effective as boreholes fitted with handpumps while providing higher service level in terms of water quality, accessibility and reliability. The authors strongly recommend that national and international policy makers and practitioners begin to consider solar water pumping as a viable and cost effective intervention for rural water supply.

Table 3. Estimated CapManEx for Typical Medium Scheme Serving 2,200 People			
Hardware Element	**Current Cost [USD]**	**Estimated Lifespan [years]**	**Future Cost [USD]**
Water source (boreholes & surface water intakes)	$700	30	$1,603
Structures (enclosures & towers)	$7,000	30	$16,028
Power supply (solar array & electrical materials)	$2,500	20	$4,343
Pumping equipment (solar pump & controls)	$2,000	15	$3,026
Water storage tanks	$3,200	20	$5,559
Taps	$2,000	10	$2,636
Water treatment equipment	$8,000	20	$13,898
Piping	$8,500	20	$14,767
Miscellaneous materials and labour	$4,000	20	$6,949
Total Current Cost [USD]	$37,900	Total Future Cost [USD]	$68,809
Total Estimated CapManEx [USD/person/year]			$1.51
WASHCost CapManEx benchmark range [USD/person/year]			$1.50 - $7.00

As with CapEx and OpEx, the average CapManEx per person was within and on the lower end of the WASHCost benchmark range.

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