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Solar powered water pumping in refugee camps: lessons learnt from East and Horn of Africa

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Fuel powered boreholes are often the only option to provide potable water in refugee camps in East and Horn of Africa (EHA). Large fuel consumption, camp operations over decades and limited funding contribute to the fact that this type of water supply may not be sustainable. In recent years, several boreholes in refugee camps in EHA were equipped with solar powered water pumping systems to assess the feasibility of this alternative energy source. It could be shown that solar systems are a valuable option to replace or enhance fuel powered systems, and that higher investment costs of solar systems are outweighed by the reduction of fuel costs.

Introduction

The region of East and Horn of Africa (EHA) hosts several of the largest refugee camps around the world, at the same time, the region of EHA accommodates hot semi-arid zones where water can be scarce. Correspondingly, the provision of potable water in sufficient quantities for refugees is an essential but highly demanding task.

In many refugee camps in EHA water is provided through groundwater extraction, where water is pumped from boreholes to elevated storage tanks and is then fed into distribution systems using the force of gravity. Due to low groundwater tables and the requirement for large quantities of potable water, pumping of water is linked to high energy consumption. Fuel powered generators are the main source of energy leading to high fuel consumption and correspondingly to high operational costs for water supply.

In its global strategy for public health, the United Nations High Commissioner for Refugees (UNHCR) defined that water facilities have to be designed so that sustainability issues and long term considerations are properly addressed (UNHCR, 2014). Therefore, UNHCR tries to lower ecological footprint and costs while maintaining or even improving the provision of potable water to refugees. One approach to reach this goal is the implementation of solar powered water pumping instead of conventional fuel powered systems. Previous studies have shown that operational costs can be reduced by replacing fuel with solar power (Bannister, 2000; Odeh et al., 2006; Meah et al., 2008). Recent implementations of solar systems in refugee camps have been reported in Chad (Lorentz, 2014) as well as in Kenya and in Somalia (Runo and Muema, 2014). This study reports the findings from solar powered water pumping systems which have recently been introduced in refugee camps in EHA.

Context

Limited funding for the provision of water in refugee camps

In protracted refugee crises, which are common in EHA, it can take many years before refugees are able to safely return to their home country, or other durable solutions are found. This development can change the status of refugee camps from temporary to rather long-term (Perouse de Montclos and Kagwanja, 2000). Dadaab refugee camp for instance is reaching its 23rd year of operation in 2015 (UNHCR, 2012b), and Sudan is hosting Eritrean refugees since more than 40 years (UNHCR, 2015a). Depending on the host country policies, refugees are often not allowed to take part in paid work and cannot earn a living, which creates the need for free provision of basic services.

During the course of an emergency, the funding provided by the international community follows a distinctive pattern. In the beginning the available funding increases strongly, but as the situation stabilises and enters the 'protracted' phase, funding tends to steadily reduce. The demographics in refugee camps often do not follow this pattern leading to low available funding for a remaining large refugee population. In the case of Dadaab refugee camp, the UNHCR budget for water provision per person per year was almost halved from 2010 to 2014. In the same period, the population only decreased from around 464'000 (2011) to 356'000 (2014) (UNHCR, 2015b).

The combination of fluctuating funding, camp operation over decades with unchanged large refugee populations and the requirement for free provision of basic services can lead to challenging situations for both the host countries and UNHCR, as well as difficult living conditions for refugees.

Water pumping in refugee camps

Up to now, fuel powered generators are the main energy source for borehole motorization in refugee camps in EHA. Depending on borehole conditions, one litre of fuel can be used to pump 3-5 m^3 of potable water on average. Fuel is normally purchased and transported in bulk to camps by UNHCR, and then implementing partners responsible for camp operation are issued with adequate fuel for their operational needs. Depending on the local settings, the provision of fuel for refugee camps can be cost and energy-intensive. Additionally, there is a risk that fuel allocated for water pump generators may be misused or stolen. Investigations in Hagadera refugee camp, Kenya, have shown that by limiting generator accessibility, fuel theft of up to 20 litres per day per borehole can be prevented. At Hagadera after the UNHCR Partner (NRC) installed improved anti-theft devices for the system of 7 boreholes with pumping rates of 45-55 $m^3 \cdot h^{-1}$, they reported savings of 43'000 USD per year due to reduction in fuel theft (NRC, 2013).

When using photovoltaic panels for energy provision for water pumping, different setups are conceivable. This study investigates the implementation of purely solar powered systems and hybrid systems consisting of fuel powered generators as well as photovoltaic panels. The use of batteries is not discussed as it is linked to additional costs and loss in efficiency. The immediate use of solar power enables the storage of water in elevated tanks, and no further energy is needed for distribution. Not discussed in this study is the impact on required storage volume, as it depends on local settings such as distribution system, chlorination (batch-wise or continuous) and daily distribution pattern within the refugee camp. For this study, three boreholes equipped with solar powered water pumping systems have been selected due to the availability of performance data, their variety of pump capacity and the coverage of hybrid as well as purely solar powered systems.

Selected solar powered boreholes in refugee camps in EHA

Hagadera refugee camp (Kenya)

In Hagadera refugee camp in North-Eastern Kenya, a fuel powered borehole was converted to a hybrid system by adding photovoltaic panels (for more information cf. Runo and Muema, 2014). However the borehole has been operated exclusively on solar power since its commissioning in March 2014. Figure 1A depicts the water pumping performance which is based on daily water meter readings. It can be seen that in November 2014 the borehole was out of operation due to maintenance, and on July 29th and September 1st the water production were particularly low due to bad weather conditions. In case these two dates are not considered, the average daily water production for the observed period is 133 $m^3 \cdot d^{-1}$ with a standard deviation of 30 $m^3 \cdot d^{-1}$. Low monthly water productions have been observed during April, which marks the rainy season, and July which is together with June the month with the lowest solar irradiation in the region.

Ifo 2 refugee camp (Kenya)

Figure 1B depicts the performance of a purely solar powered borehole from Ifo 2 refugee camp located in North-Eastern Kenya. The data is based on daily water meter readings, whereas the recording started on January 15th and was interrupted in April due to the absence of staff. Unfortunately, the recording was not continued after June 2013 due to a change in implementing partners. For the observed period, the average daily water production is around 45 $m^3 \cdot d^{-1}$ with a standard deviation of 6 $m^3 \cdot d^{-1}$.

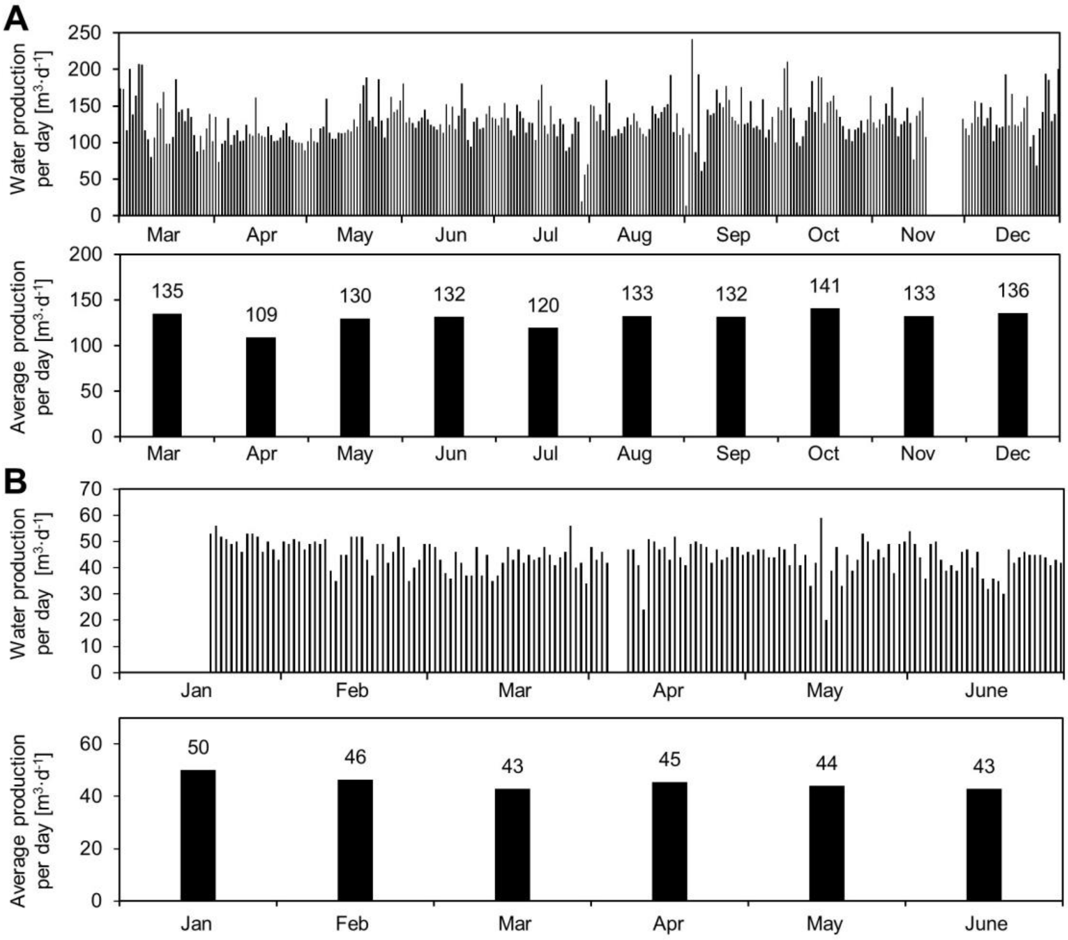

Figure 1. Solar powered water production of (A) borehole in Hagadera refugee camp (Kenya) from March - December 2014 and (B) borehole in Ifo 2 refugee camp (Kenya) from January - June 2013

Kaya refugee camp (South Sudan)

In Kaya refugee camp located in Upper Nile state in South Sudan water is provided via the exploitation of 5 boreholes located in around 7 km distance to the camp. In August 2014 four fuel powered boreholes were converted to hybrid systems, with an investment cost for the additional solar systems amounting to 24'000 USD per borehole.

Table 1. Performance of boreholes in Kaya refugee camp for arbitrary duration of 57 days before and 57 days after the conversion to hybrid systems

Parameters	**BH1 fuel powered** (for period of 57 days before conversion to solar-hybrid)	**BH1 hybrid powered** (for period of 57 days after conversion to solar-hybrid)	**BH2 fuel powered** (for period of 57 days before conversion to solar-hybrid)	**BH2 hybrid powered** (for period of 57 days after conversion to solar-hybrid)
Water production [m^3]	4434	6297	4005	3946
Fuel consumption [L]	1340	740	1580	730

Table 1 shows the performance of two of these boreholes for an arbitrary duration of 57 days before and 57 days after their conversion to hybrid systems. It can be seen that by converting BH1 and BH2 to hybrid systems, the fuel consumption could be reduced by 45% (BH1) and 54% (BH2), whereas the amount of pumped water could be maintained. In case of BH1, even an increase in water production of 42% could be achieved. The conversion to hybrid systems also lead to an increase in operating days for the observed period of time, as fuel powered systems need the presence of staff but solar systems automatically switch on as soon as the solar irradiation exceeds a predefined threshold.

Discussion

Fluctuating performance of solar powered boreholes

The system performance depicted in Figure 1 reveal fluctuating water production of solar powered boreholes. The fluctuation is caused by varying intensity of solar irradiation and shows the need for sufficient storage volume in order to capture the extracted water and to provide steady water provision. Especially for systems with larger capacities, the performance can vary strongly. In Hagadera, the standard deviation in regard to the average water production (22%) is almost doubled in comparison to the smaller system in Ifo 2 (13%) which pumps only a third of Hagadera's daily production. The reason can be found in the broader range of energy production of larger solar systems.

For both solar systems, the monthly average water production per day only shows a minor variation throughout the year (cf. Figure 1). The influence of rainy seasons and varying solar irradiation are reflected in the monthly variation, but do not contribute to vast differences in water production. It can be concluded that dimensioning of systems based on months with low solar irradiation should assure the provision of water throughout a majority of days per year. Considering the fluctuation of solar systems, one has to keep in mind that fuel powered water pumping in refugee contexts is also often linked to fluctuation due to lack of fuel or restricted accessibility to boreholes.

The use of hybrid systems

Hybrid systems including both solar panels and a generator are required when the required number of pumping hours exceed the number of daylight hours. In these cases solar power is used during daylight hours and the generator is switched on to power the pump during the hours of darkness. The results in Table 1 show that hybrid systems not only reduce fuel consumption and the need for supervision, in case of Kaya refugee camp where boreholes are located outside the camp and access might be restricted due to security issues, hybrid systems can even increase the water production due to the automatic start-up of solar systems.

In Kakuma refugee camp in Northern Kenya, pumping is conducted up to 15 hours per day, therefore conversion to solar-hybrid would mean generator running hours could be reduced by half.

The use of pure solar systems

Where pumping hours are able to be restricted to daylight hours only, then systems powered purely by solar energy should be considered. This is especially applicable in situations where it is not easy to make regular supplies of fuel due to logistical or security constraints such as South Sudan or Dadaab. The same is valid for boreholes with restricted accessibility or boreholes which are not operated on a daily basis. The removal of the generator and replacement with solar power also removes the possibility for fuel theft, which in some locations has been reported as a factor which has resulted in increased usage of the generator to enable increased volumes of fuel supply. On the other hand, the theft of solar panels can be mitigated by bolting panels to elevated steel structures and maintaining guards at the site. Using this strategy there have been no issues with theft of solar panels in any of the three locations described in this report.

The cost of water pumping

Experiences from the field have shown that one litre of fuel can provide 3-5 m3 of potable water on average. Using current fuel costs from Kenya of 1.26 USD·L-1, this equals to savings of up to 0.4 USD per m3 of water pumped with solar power instead of fuel. For the system implemented in Hagadera this leads to theoretical savings of 1'600 USD per month, whereas the smaller system in Ifo 2 allows monthly savings of 540 USD (cf. Table 2). For Kaya BH2, the reduced fuel consumption due to the conversion to a hybrid system leads to savings of around 570 USD per month. For all three systems, the savings only refer to fuel costs. Other savings, such as expendable materials needed for generator operation (oil, filters etc.) or servicing costs which become omitted when switching to solar powered operation, depend on local settings and have not been included in the calculation, however, they represent only a minor share of overall operation costs. In comparison, the operation of solar systems is virtually free of costs as no servicing or expendable materials are needed and cleaning can be conducted with small hoses connected to panels allowing regular automatic flushing with extracted groundwater. Staff costs are not likely to change as guards responsible for the security of borehole premises are also responsible for generator operation, and will be retained for both solar power and generator power systems.

Shown in Table 2 are investment costs for the solar water pumping system in Ifo 2, for a purely solar powered system comparable to the one installed in Hagadera (PowerGen, 2015), and for fuel powered systems comparable to the ones installed in Hagadera and Ifo 2 (Davis & Shirtliff, 2015). It can be seen that despite lower investment costs, the costs of fuel powered operation in Hagadera and Ifo 2 exceed the costs for solar systems within 4 years of operation. The same is valid for the conversion to hybrid system in Kaya, where costs for fuel powered operation exceed the costs for hybrid operation within 4 years.

Not considered in this study is the financial impact of the difference in lifespan of solar and fuel powered systems. Experience from the field shows that generators have to be replaced on average after 8-10 years, whereas solar panels usually have a warranty provided by the supplier of 25 years.

Table 2. Financial comparison of fuel and solar powered boreholes in Hagadera and Ifo 2, as well as for the conversion of a fuel powered borehole to a hybrid system in Kaya.

Costs	Hagadera		Ifo 2		Kaya BH2	
	Fuel	Solar	Fuel	Solar	Fuel	Hybrid
Investment costs [USD]	22'000	89'000	12'500	33'000	0	24'000
Fuel costs per month [USD]	1'600	0	540	0	1'060	490

Limitations of solar powered water pumping systems

Although the development of solar systems is advancing, there is still a limitation regarding their pumping capacity. The current upper limit regarding motor power is 30 kW AC, enabling pump capacities from pumping rates of 38 $m^3 \cdot h^{-1}$ at a head of 200 m to 241 $m^3 \cdot h^{-1}$ at a head of 15 m (Lorentz, 2015). The limited capacity hinders the replacement of large fuel powered systems by purely solar powered systems, or the shift to hybrid systems by adding solar systems with similar capacity. However, 72% of all fuel powered boreholes in Kenyan refugee camps providing 69% of the potable water are equipped with systems which are smaller than the current upper limit of solar systems. Therefore, the fuel powered pumping systems of these boreholes could be replaced by, or additionally equipped with solar systems. For countries with smaller refugee camps which potentially also have smaller water pumping infrastructure, it can be assumed that the potential for implementing solar systems is even higher compared to Kenya.

Conclusion

Although solar powered water pumping is not yet applicable on all scales, it is a very promising approach to reduce operating costs and to enable more sustainable water provision in refugee camps. Solar systems are a valuable alternative to conventional fuel powered system especially in the region of EHA where fuel can be expensive to transport, access to boreholes limited, but solar irradiation is fairly constant. This study shows that solar systems can reduce fuel consumption of water provision, or even fully replace fuel powered systems. Furthermore it could be shown that higher investment costs are outweighed by lowered fuel costs.

For further investigations, the performance documentation of solar systems has to be improved. Up to now, solar boreholes are often poorly recorded due to the fact that no staff is needed for the operation. A promising opportunity to improve performance analysis is the increasing use of remote control and monitoring applications integrated in pumping systems. Further insights on borehole performance could be used to optimize the dimensioning of solar installations and would allow better financial comparisons to fuel powered systems.

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Note
The views expressed herein are those of the authors and do not necessarily reflect the views of the United Nations.

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