Title: A pilot study of a combined energy and water hub in The Gambia

Short title: A pilot study of a combined energy and water hub in The Gambia

Dr Andrew Swan[1], Daniel Ballam [2], Isobelle Logan [2]

[1] *Senior Lecturer, School of Built Environment & Engineering, Leeds Beckett University, Leeds, LS2 9EN United Kingdom*

[2] *Mobile Power Ltd, Parkhead House, Sheffield S1 4FS, United Kingdom*

Abstract:
Many people across the developing world live 'off-grid' in terms of access to mains electricity, and therefore depend upon alternative power sources to recharge their mobile phones. These recharging facilities are typically located in shops/informal businesses, and often powered by a diesel generator or solar panel. Many of these rural communities are also served by local water infrastructure that has fallen into a state of disrepair. It has been reported that many individuals are prepared to pay a small regular fee to recharge their mobile phone, whilst their wider communities may often claim to lack sufficient funds to keep their water infrastructure maintained.
This paper introduces a pilot study in Gambia that combines an off-grid recharging hub with a community water point. It is proposed that a proportion of the income generated by this enterprise could be retained and used to fund the on-going maintenance costs of the recharging hub and the local water infrastructure.

Keywords:
Off-grid power, Maintenance funding, Mobile phone ownership, Rural water supply, Solar community pumps

1 Background

This paper presents a pilot study from The Gambia that combines an off-grid recharging hub with a community water point. The study explores whether this arrangement could help meet growing energy demands, whilst simultaneously providing an innovative funding stream to support on-going water maintenance costs.

There has been significant growth in both mobile phone ownership and usage across Africa. But a large proportion of the population served by a mobile network still lack other key infrastructure, such as electricity or clean water. For example, 360 million Africans are covered by mobile networks but lack access to mains electricity; similarly, 125 million people in this region could access a mobile network but not an 'improved water source' (GSMA, 2014).

Many communities served by an improved water source, such as a borehole, still experience operational challenges. When such infrastructure malfunctions, users will often resort to less protected water-sources, increasing their exposure to water-related diseases. The problem of broken water pumps is well documented, with studies reporting between 20% and 65% of hand pumps installed across the region as broken or out of use (RWSN, 2010). The operational problems associated with such water infrastructure have been partially attributed to insufficient local financial resources for repairs/maintenance (Chowns, 2015). Many water stakeholders consider that local communities (typically via their water point committees) should save regular 'maintenance installments' towards the on-going costs of their water points. But the large numbers of broken water pumps indicate that many are unable, or unwilling, to save the funds required to implement such repairs. It has been suggested that 'pay-as-you-go' water systems (See Appendix 1) may represent a better method of collecting maintenance installments from local communities. Such technologies enable users to purchase credit for water, these payments then facilitate water to be delivered from smart-taps. Smart-taps are typically equipped with Near Field Communication (NFC) technologies that enable users to place a pre-paid token near the tap head to facilitate water flow. The proponents of these systems argue that commoditization of water can promote responsible usage and help harness more sustainable revenue streams to support the associated on-going maintenance costs.

In contrast to the aforementioned deficits in water maintenance funding, many local community members seem prepared to pay a small regular fee to recharge their mobile phones at local shops or businesses. It is reported that some individuals spend around 10% of their annual income keeping their phones recharged (GSMA, 2011; UN, 2013). These energy demands have lead to the emergence of new technologies that provide power for off-grid communities. Notable examples include the BuffaloGrid, M-KOPA Solar, ReadyPay Solar and Mobile Power systems (see Appendix 2).

2 Methods

The pilot study used a small solar array to run a water pump, as well as Mobile Power's off-grid battery 'Charging Station'. The *modus operandi* of the system (see Figure 1) involved local users paying a small fee to rent portable battery packs for periods of 24 hours. These batteries could then be used to power mobile phones or other low power electrical equipment, such as LED light bulbs. A small, refundable deposit was taken from each customer prior to initial rental, creating an incentive to return the packs. However, water was available from the community pump without a financial charge. It was intended that a proportion of the income generated by this enterprise would be retained, and used to fund the on-going maintenance costs of both the recharging hub and the local water infrastructure.

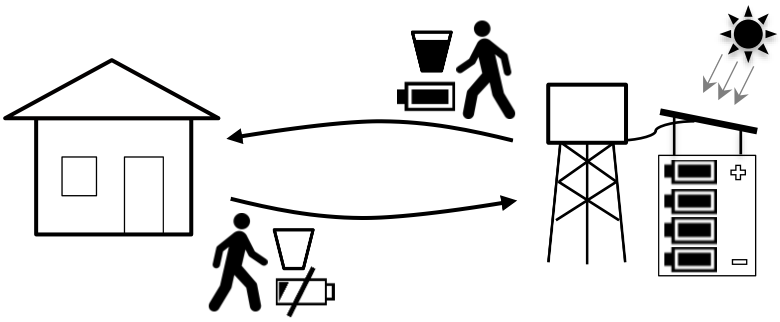

Fig 1: *Modus operandi* of combined solar powered water pump and battery recharging station

The study was conducted at a rural site in the west of Gambia. This site was 200m from the edge of the settlement of Kunkujang-Gunjur, and provided water for drinking and irrigation purposes. A community survey exercise was undertaken at the start of the project by Kenny *et al*. (2015). The water-point typically served between 50 to 100 users, with survey investigations indicating there were approximately 60 regular users (Kenny, 2015). The local population lacked access to grid electricity at the start of the field trial and were considered to be large enough to provide an adequate battery rental market. Much of the local community were non-salaried, and relied on farming as their main source of income. A typical local income was 150 Dalasi (£2.52) per day. The study area, like the rest of Gambia, has a sub-tropical climate with a wet season that generally lasts from June to October and a dry season from November until May.

The water system consisted of an 18m deep concrete-lined sealed well (A on Figure 2), a solar pump and a 2000 litre water storage tank (B on Figure 2) that was elevated approximately 4m above ground level. Water from this header tank was piped to a stand pipe beyond the site's perimeter. A concrete structure (C on Figure 2) was constructed to support the tank and solar array (D on Figure 2), and to house the equipment associated with Mobile Power's combined Charging and Activation Station (E on Figure 2). Further details are presented in Appendix 3.

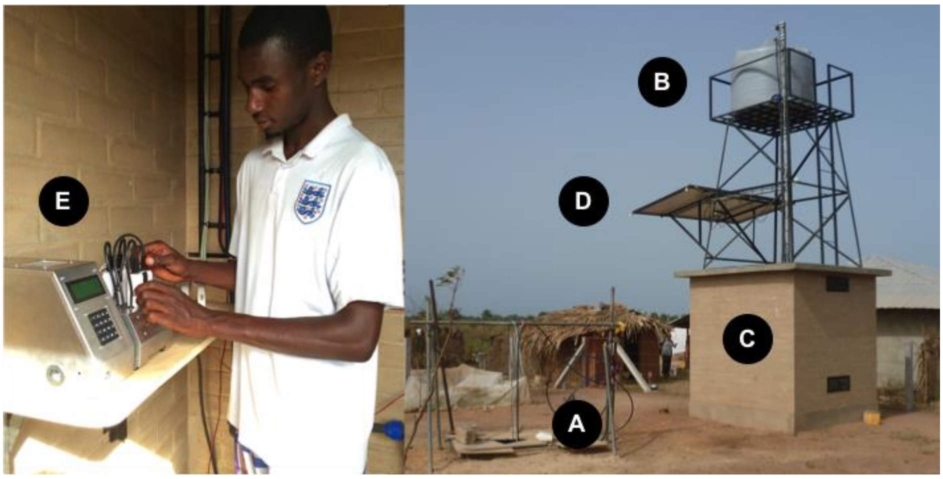

Fig. 2 Pilot combined solar powered community water pump and battery recharging/activation station

The initial smart-battery rental cost of 15 Dalasi (£0.25) per day was proposed by local project partners, and deemed appropriate given the costs of comparable services. For example, water is available for 14.88 Dalasi (£0.25) per $1m^3$ from a number of the PAYG-SW systems that have already been installed in Gambia (AWE, 2017).

3 Results

The pilot system was monitored during the initial months of the field trial both in relation to: *i.) the amount of water pumped and ii.) the number of 'smart' battery packs recharged and rented.* Figure 3 presents field data collected from the pilot system between June and August 2015. The daily volume of pumped water is presented as a line graph. Whilst, the daily number of battery packs recharged is represented as a bar chart. The number of batteries recharged at the facility typically ranged between 4 and 8 units per day. The mean average volume of water pumped during this period was 1227.3 litres per day. The maximum, and minimum daily volumes during this period were 3273 litres and 64.6 litres per day respectively. It should be noted that this minimum value occurred on the 3rd of August, after 7 consecutive rainy days (see Figure 4).

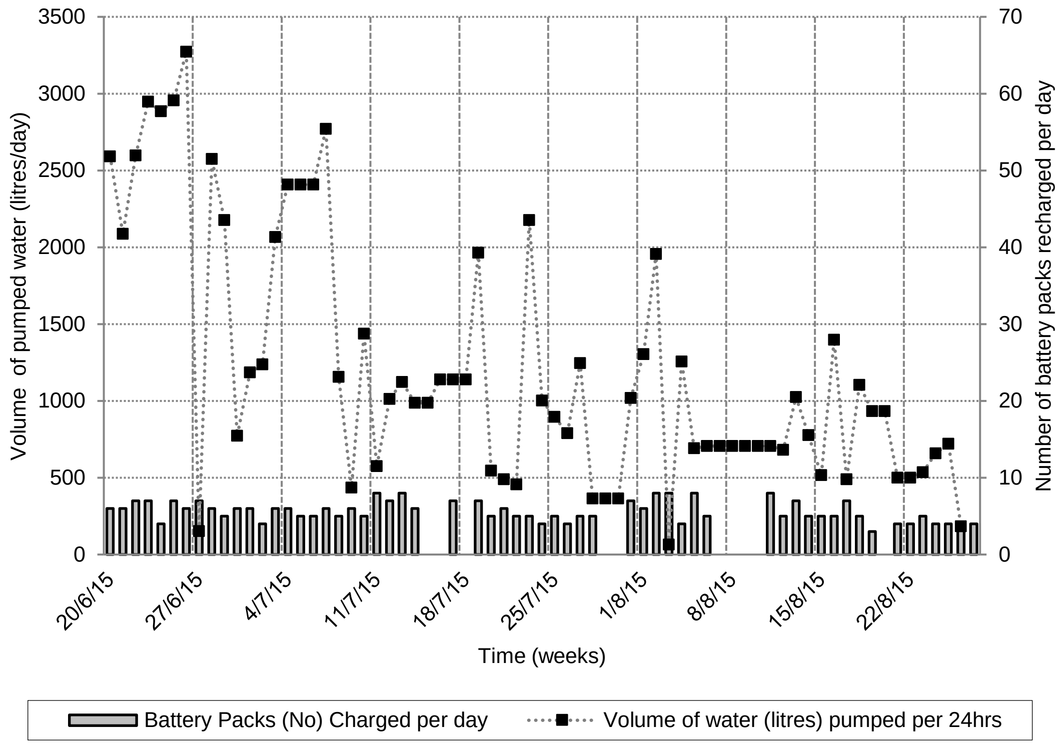

Fig. 3 Daily volume of pumped water and number of battery packs recharged at the Kunkujang pilot study

The water usage patterns (Figure 3) were relatively stable during the first 3 weeks, but there was a marked reduction in the water used as the trial continued. The rationale for this is clearer once daily rainfall patterns are considered (see Figure 4). Historical rainfall records were obtained from a local weather station at Banjul airport (WU, 2017), which is located approximately 23km North East of the Kunkujang site. As the impacts of the country's rainy season are felt, and daily rainfall depths increase, there was a notable drop in water demand from the pilot scheme.

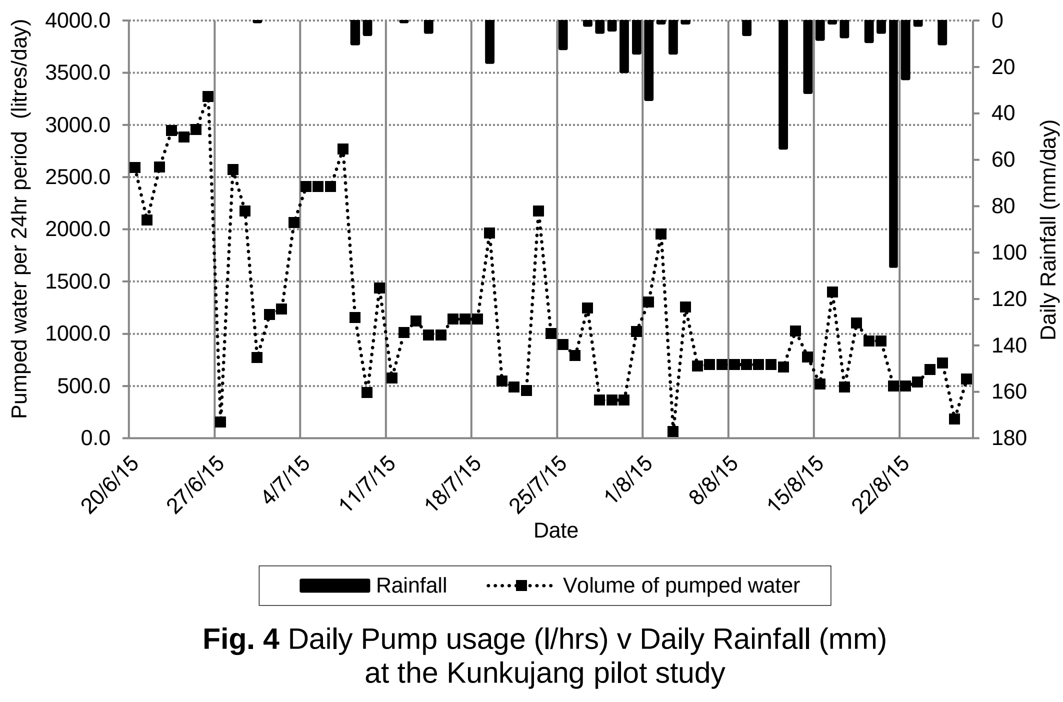

Fig. 4 Daily Pump usage (l/hrs) v Daily Rainfall (mm) at the Kunkujang pilot study

It was calculated from the data presented in Figure 4 that the daily average volume of water delivered and the daily average number of battery packs recharged were 1.23m^3 and 4.83 respectively. These daily values equate to monthly averages of 37.42m^3 and 146.93 battery rentals per month (i.e. assuming 30.42 days in an average month).

4. Discussion

The average monthly revenue generated by the pilot battery rental scheme (Case 1 in Table 1) was compared with those of two water maintenance funding strategies (See Cases 2 and 3 in Table 1). The battery rental income was calculated by applying the rental price, of 15 Dalasi (£0.25) per pack per day, to the monthly average number of battery rentals (i.e. 146.93). The second mechanism (Case 2) hypothetically applied reported local 'pay as you go' water rates of 14.88 Dalasi (£0.25) per cubic metre of water (AWE, 2017) to the monthly average volume of water pumped from the pilot system (37.42m^3); whilst the third approach (Case 3) applied a conventional monthly 'water point user maintenance' contribution (i.e. of 2.31 Dalasi or £0.04 per month per capita) for the 60 regular users of this pump. It should be noted that this figure of 2.31 Dalasi was based upon reported discussions with a local NGO (Walker *et al.*, 2017).

Table 1: Income generated at Kunkujang pilot compared to other water funding mechanisms

Funding Mechanism	**Reported Cost**	**Citation**	**Calculation of corresponding monthly income based on observed usage at Kunkujang pilot**	**Average monthly income**	**Potential water levy** *(i.e. income per monthly average no. of battery rental [(a)])*
Case 1: MobilePower Smart battery rental fee	**15 Dalasi** *(£0.25)* per 24hr	*n/a*	**= 15 Dalasi (£0.25) x 146.93** [(a)] *(a) where monthly average number of battery rentals = 146.93*	**2203.95 Dalasi** *(£37.03)*	*n/a*
Case 2: Pay as you go water fee	**14.88 Dalasi** *(£0.25)* per 1m	AWE (2017)	**= 14.88 Dalasi (£0.25) x 37.42** [(b)] *(b) where the Monthly Average volume of water delivered =37.42m^3*	**556.81 Dalasi** *(£9.36)*	***3.79 Dalasi*** *(£0.06)*
Case 3: Conventional 'water point user maintenance charge'	**2.31 Dalasi** ***(£0.04)*** per user per month	*Walker et al. (2017)*	**= 2.31 Dalasi (£0.04) x 60** [(c)] *(c) where the regular number* of pump users = 60 people	**138.6 Dalasi** *(£2.33)*	***0.94 Dalasi*** *(£0.02)*

Given the observed monthly average number of battery rentals of 146.93; it would appear that a 'water levy' of 0.94 Dalasi (£0.02) applied to each battery rental fee would generate the equivalent monthly income of the conventional 'water point user maintenance charge' (Case 3 in Table 1). Likewise, an alternative 'water levy' of 3.79 Dalasi (£0.06) applied to every battery rental would match the total monthly 'pay as you go' water revenue (Case 2 in Table 1). These water levies could either be added to, or deducted from, the initial battery rental price of 15 Dalasi (£0.25). If the first approach is employed, then the overall battery rental fee would increase from 15 Dalasi (£0.25) up to 18.79 Dalasi (£0.32) in order to generate the same 'water income' as Case 2, or 15.94 Dalasi (£0.27) to match the 'water income' associated with Case 3. These initial field trials had indicated that a fully charged smart battery pack could recharge three smartphones, or up to seven non-smartphones. Therefore, the initial pricing structure (i.e. of 15 Dalasi) would effectively equate to a 'non-smart' phone recharging fee of 2.14 Dalasi (£0.04); whilst the increased prices of 18.79 Dalasi (£0.32) and 15.94 Dalasi (£0.27) would yield equivalent 'non-smart phone' recharging fees of 2.68 Dalasi (£0.05) or 2.28 Dalasi (£0.04). The equivalent 'smart phone' recharging fees would be 6.26 Dalasi (£0.11) and 5.31 Dalasi (£0.09) respectively. Even these higher charges would seem viable given reports that some phone users are prepared to pay 10% of their income on keeping their phones recharged (GSMA, 2011; UN, 2013). Ten percent of the typical daily local income (i.e. of 150 Dalasi) equates to 15 Dalasi (£0.25), which is still significantly higher than either the equivalent 'smart' and 'non-smart' phone recharging fees described above (i.e. that incorporate the aforementioned 'water levies').

5 Conclusions

This paper has introduced a field trial that combines a water point with a smart-battery rental service, which enables local communities to power their mobile phones and other low energy devices. The off-grid power service shares a combined solar array with a community water pump. It is interesting to note that the field data demonstrates the impact of external influences on the usage patterns observed. For example, localised rainfall can be clearly seen to impact the daily volumes of water collected from the pump. This suggests that the local community use this water for both drinking, washing and irrigation purposes. The influence of such external factors highlights the importance of continued community engagement/dialogue to help assess the wider range of issues that will impact the long-term viability and success of this, and any subsequent pilot schemes.

The early analysis presented in this paper indicates that there may be potential to collect a 'water maintenance levy' via the pilot scheme's smart battery rental income. It is evident that the merits of this strategy will need to be assessed by on-going field trials. The robustness of this combined technology still needs to be assessed over the longer term, and at other locations. Furthermore, the local community's willingness to pay a battery-recharging fee that subsidises the maintenance of the associated water infrastructure still needs to be fully assessed via community engagement and surveys conducted over a longer period – especially if there are other (cheaper or comparable) recharging facilities available within the locality.

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SUPPORTING INFORMATION

Appendix 1: Pay As You Go Solar Water (PAYG-SW) Pumps

Recent years have seen the emergence of a number of PAYG-SW systems across sub-Saharan Africa. For example, the 'eWATER' pay as you go system is currently being used at a number of locations across Gambia (AWE, 2017). This system utilises the eWATER tap with NFC (Near Field Communication) technology that enables users to purchase credit for water from local agents on a small disc. Placing this pre-paid disc near the 'smart' tap allows water to flow. These water credits may also be purchased via mobile phone payments. Africa Water Enterprises, the 'not for profit organisation' behind this system report that 1m^3 of water costs 14.88 Dalasi (£0.25) in Gambia (AWE, 2017). Similarly, Grundfos (2016) have developed the 'AQtap' system that seeks to deliver sustainable water sales via the use of: Smart cards that store water credits; the AQtap dispenser unit, which delivers water and manages credit; and an overarching 'Water management system' that handles the associated data.

It should be noted that some PAYG-SW systems will not deliver water unless a corresponding payment has been received – and as such some stakeholders have expressed concerns regarding the 'ethical issues' related to withholding water from those who cannot afford such payments.

Appendix 2: 'Pay As You Go' (PAYG) Power systems

There have been a number of notable recent developments towards the formal provision of power for off-grid communities. The **BuffaloGrid** system is a portable recharging hub that can be used to charge up to 10 individual mobile phones simultaneously (BuffaloGrid, 2015). The hub itself can then be recharged by a 60-watt solar panel. The BuffaloGrid system has been field-trialled in Uganda (Ananthaswamy, 2013). This system employs an innovative payment mechanism, in which the customer sends an SMS (costing 110 Ugandan shillings or US$0.04) to the hub. When the hub receives the SMS, an LED light appears above the socket to indicate that it is ready to charge a phone. A single SMS will enable a phone to be recharged for up to 90 minutes. Field trials have indicated that a fully charged BuffaloGrid hub should last up to three days, and should be capable of charging between 30 and 50 phones a day.

The **M-KOPA Solar** initiative offers 'pay-as-you-go' solar home systems for the African market (M-KOPA, 2015). M-KOPA users pay an initial deposit of around $35 to have a solar panel and ancillary system installed at their property. Using mobile payment protocols on their phones, customers must regularly top up their account in order to continue to receive energy. The on-going costs of this system approximately equates to US$0.45/per day of energy. After an initial 12-month payment period, full ownership of the system reverts to the customer, from which point they can access free solar energy. Fenix International have developed a similar portable solar panel system called **ReadyPay Solar** (Fenix, 2015). Its users can access solar energy from a ReadyPay solar panel by making micro-payments via their mobile phone of approximately US$0.35 per day. BBOXX have also developed the **SMART Solar system** for individual households in emerging markets (BBOXX, 2015). The SMART Solar energy service can be controlled and monitored remotely. This system can also be remotely switched-off should customers fail to maintain their monthly payments. System usage information is collected and relayed through mobile networks.

The **Mobile Power system** is designed to allow users to take portable battery packs back to their home in order to power a range of low energy domestic appliances. This system is aimed at lower income communities than many of the aforementioned approaches. The Mobile Power system comprises a central 'Charging Station', which can be powered by a range of generation technologies including solar panels, a diesel generator or mains electricity, and a number of 'Activation Stations' located at local shops. Small, portable battery packs are charged at the Charging Station and distributed to Activation Stations once fully charged. These can be rented directly to customers for an allotted period (typically 24 hours). A smart security system ensures that the battery packs remain 'locked' until payment has been received. Activation can be achieved via cash payment to the local operator or via mobile payment. Once activated, a battery can be used to power a range of DC devices via its two USB ports, including mobile phones, LED lights, fans and radios. When the allotted rental period has elapsed, the battery de-activates automatically leaving the customer unable to use or recharge it. Battery packs must then be returned to the Activation Station and a new pack rented; depleted packs are sent back to the Charging Station for re-charge. Initial field trials have indicated that a fully charged battery pack can recharge 3 smartphones, or up to 7 non-smartphones.

Appendix 3: Pilot system: Key design considerations

The pilot system (See Figure A3 and Table A3) was designed to reliably deliver both the required volume of water* and the required number of charged battery packs. As such it was crucial for adequate power to be readily available for both the pump and the battery-charging infrastructure, both on a daily and seasonal basis. Since the pilot system includes a new water-point and a novel battery rental enterprise (i.e. without historical field data on demand and usage patterns), a number of design assumptions were made in regard to these parameters. This initial demand uncertainty directly informed the design of the energy-delivery architecture, and as such, demand estimates were incorporated into a rudimentary design model to aid the sizing of system components.

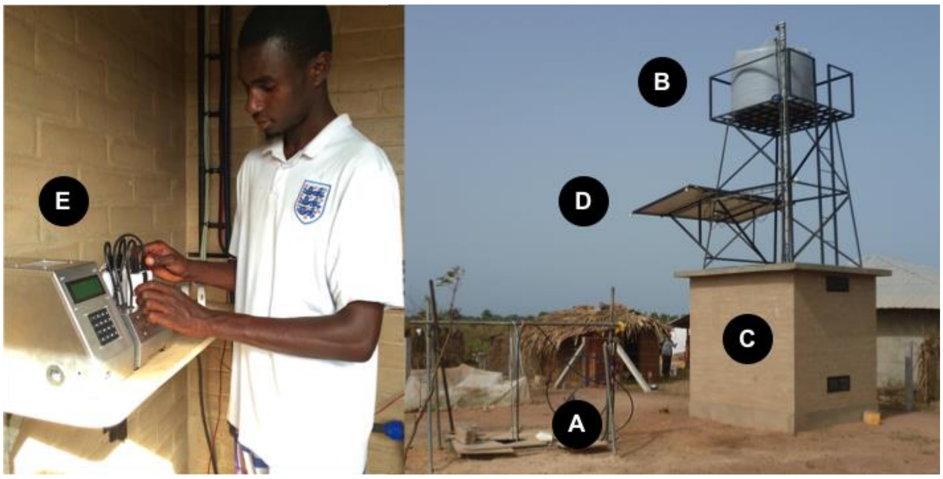

Fig. A3 Pilot combined solar powered community water pump and battery recharging/activation station

Table A3 Description of main system components and location

Component	Description	Location	Further details
Solar pump	Shurflo 9300 series 24 V	**A**	Located in hand dug well
Water tank	2000 L	**B**	Mounted on steel structure on 4m^2 roof
Charge controller	2 x 20 A MPPT	**C**	Within concrete structure
Lead-acid batteries	4 x 12 V 110 Ah	**C**	Within concrete structure
MP battery packs	60 x 26 Wh	**C**	Charged within concrete structure; distributed to customers for use
Solar array	750 W = 3 x 250 W panels	**D**	Mounted on steel structure on 4m^2 roof. Orientation: 180° Inclination: 14°
Charging Station	Mobile Power charging station	**E**	Within concrete structure

The pilot scheme utilised a semi-integrated system, with the pump powered directly by a single 250W solar panel and the Charging Station fed by two 250W panels, This system was designed to support a minimum of 8 hours of pumping at 100W and the charging of up to 30 battery packs in each 24 hour period. The system's energy requirements were met by a combination of direct power from the solar panels (for daylight hours), and stored energy from the shared lead acid batteries (for night-time hours). During periods of insufficient sunshine the system was designed to operate autonomously for 1.4 days (i.e. with full water pumping and battery charging capacity).

** It appears that the Kunkujang water-point typically serves between 50 to 100 users, with benchmark survey work (Kenny, 2015) indicating there were approximately 60 regular users. These users indicated that they were utilising the collected water for both drinking and irrigation purposes. The average daily volumes observed from the pilot system (Figure 3) would seem to support this assessment. Assuming each of the Kunkujang users is using 20 litres per capita per day in line with WHO (2013) guidelines; then the approximate number of users can be assessed by dividing the mean average daily amount of pumped water (1227.3 litre/day) by 20 litres/per capita per day. This approach yields an estimate of 61.4 users for the water point.*

Appendix 4: Pilot system: Operational details

Mobile Power (https://www.mobile-power.co.uk/#home) installed and managed this field study in partnership with Leeds Beckett University and Africa Startup (https://africastartup.org). The pilot study sought to explore the technical and commercial viability of this combined system. Battery packs were recharged by a local agent and rented to the local community via a network of venders and shops. The original battery rental pricing structure (of 15 Dalasi) was modelled around a CAPEX pay-back period of 2 years, and sought to support the ongoing OPEX and OPMANEX costs associated with the battery rental scheme. Given that this was a novel combined pilot study – the project team initially chose to consider the OPEX costs for the system's water component separately. These were considered by exploring the costing impacts of two alternative water maintenance funding strategies that had already been employed at similar solar water projects in Gambia.

The complete rationale for the adopted price point has not been published at this stage. In any case, the authors do not consider that the CAPEX costs associated with this pilot system would be reflective of those associated with a mass produced 'commercially readied' product. Similarly, the OPEX and OPMANEX are still being assessed via this, and ongoing parallel studies. For example, the authors consider that there might be some regional variations linked to local materials and labour costs that could impact the OPEX calculations at different sites. It is hoped that these issues will be expounded within subsequent project outputs.'

Appendix 5: Pilot system: Water Quality

The pump described in this study, like many other local water points, accesses the shallow aquifer that lies beneath much of Gambia. Discussions with local water stakeholders (Walker et al, 2017) highlighted that the top of this aquifer can typically be reached at depths of between 6 and 20m (i.e. dependent upon the specific location and its local geology). This aquifer reportedly suffers contamination and subsequent water quality problems. This has been highlighted by regular monitoring exercises undertaken by the country's Rural Water Resources Department; with high turbidity and coliform counts measured from shallow wells. This problem is particularly evident during the rainy season. The shallow aquifer is typically reached via open hand-dug wells, but it is worth noting that hand pumps and solar systems are also widely used to accessed this aquifer. The open wells were reported to experience greater contamination during the rainy season - as they clearly offer less protection against the wash-off of surface pollutants than a covered well, or a sealed well served by a solar or hand pump.'

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