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Title: **A pilot study from The Gambia to improve access to water, energy, and mobile phones**

Short title: **A pilot study from The Gambia to improve access to water, energy, and mobile phones**

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Abstract:
Across Sub-Saharan Africa many communities lack reliable access to mains electricity, and therefore depend upon unconventional power sources to recharge their mobile phones. Many of these informal recharging centres are powered by a diesel generator or solar panel. Furthermore, many of these same communities are frequently served by broken water pumps. Previous reports indicate that many individuals are prepared to pay a small regular fee to recharge their mobile phone, whilst their local water point committee lacks sufficient funds to keep their water infrastructure maintained. This paper presents a novel funding strategy aimed at helping communities cover the maintenance costs of their local water supply. This premise was demonstrated using a pilot system in Gambia which combined a solar powered community water point with an off-grid smart battery rental hub for everyday electricity needs such as mobile phone charging. The paper presents preliminary field data from this site and explores the wider context surrounding the pilot system.

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

1 Introduction

This paper describes field trials in Gambia of a ‘Sustainable Water and Power’ (SWAP) pilot system that combined a solar powered off-grid recharging hub with a community water pump. The SWAP pilot system was designed to address growing energy requirements, whilst concurrently delivering an innovative maintenance funding stream. This initial study has demonstrated the viability of the smart battery rental business model that sought to retain a proportion of the generated income in order to fund the ongoing maintenance costs associated with both the water and energy infrastructure. The authors consider that this premise now needs to be assessed through further field trials that explore the robustness of the pilot over the longer term and in other contexts (i.e. in different locations and for different communities). This case study may have wider relevance beyond the immediate context, as some of Gambia’s key infrastructural issues are representative of those experienced in many other African countries. If widely adopted, this approach may therefore have the potential to improve the operational reliability of rural water infrastructure across Africa, which is reported to frequently malfunction, and remain out of service, due to a range of issues, including insufficient local resources.

1.1 Access to mobile phones and networks

There has been significant growth in both mobile phone ownership and usage across Africa. A recent survey conducted in 23 Sub-Saharan African countries, indicated that two-thirds (65%) of households had access to at least one mobile phone in 2013 (Gallop, 2014). In terms of network coverage, the ‘GSM (Global System for Mobile communications) per capita’ coverage of the African population reached 76% in 2012 (GSMA, 2014). It is reported that, in the same year, Gambia had ‘GSM per capita’ coverage of 93% (GSMA, 2014). A significant proportion of the population who are served by a GSM network may still lack access to other key infrastructure, such as electricity or clean water. It has been reported that over 360 million Africans are covered by mobile networks, but lack direct access to electricity within their home (GSMA, 2014).

1.2 Limited access to mains electricity

Limited provision of mains electricity is an issue for many rural communities in Gambia, and across much of Africa. It is reported that 65% of Gambia’s population lack a mains electricity supply (World Bank, 2016). Other studies indicate this figure is between 68% and 74% in terms of the overall sub-Saharan African population (El Bassam *et al.*, 2013; GSMA, 2014).

1.3 Off-grid power solutions

Many people who lack mains electricity engage in considerable efforts to recharge their phones. Some phone users in rural areas may travel significant distances to the nearest recharging facility. A previous study in rural Malawi indicated that some inhabitants regularly travelled 2 km to visit the nearest recharging facility (Swan and Cooper, 2013). Recharging a mobile phone at such facilities may cost around US$0.15 to US$0.20 (Manchester *et al.*, 2013). In Kenya and Uganda, countries where Gross Domestic Product (GDP) per capita is less than US$800 (UN, 2013), it is reported that some individuals may spend up to US$80 a year keeping their phones charged (GSMA, 2011). A number of novel solutions for recharging mobile phones are emerging across Africa. Many of these have been specifically designed and developed by, and for, rural mobile phone users.

1.3.1 ‘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. A number of emerging technologies (e.g. the BuffaloGrid, BBOX, M-KOPA Solar and ReadyPay Solar systems) are briefly discussed within Appendix A1.

1.3.2 Mobile Power smart-battery rental system

Mobile Power’s system has been developed to enable users to rent small portable battery packs for powering low energy domestic appliances within the home. This approach has been designed for lower income communities than many of the other systems highlighted in Appendix A1. The Mobile Power system incorporates a ‘Charging Station’ that can be powered by various generation methods (i.e. including solar arrays, diesel generators or mains electricity), together with a number of ‘Activation Stations’ located at local shops/businesses. The portable battery packs are recharged at the Charging Station and then delivered to the Activation Stations when fully charged. The batteries can then be rented by customers for an allotted period (normally for a 24 hour period). A smart security system effectively ‘locks’ these battery packs until a payment has been received. This activation process can either be facilitated via a cash payment to the local operator or via mobile payment. Upon activation, the battery can be used to power a range of direct current (dc) devices via its two USB ports, including mobile phones, LED (light-emitting diode) lights and radios. When the apportioned rental period has elapsed, the battery will automatically de-activate (i.e. so the user is unable to use or recharge it). These ‘locked’ battery packs can then be returned to the Activation Station and a new pack rented; depleted packs are delivered to the Charging Station for re-charge. Early field deployments have indicated that a fully charged battery pack can recharge three smartphones, or up to seven non-smartphones.

1.4 Limited access to ‘improved water’ sources

The disparity between mobile phone coverage and clean water access in Sub-Saharan Africa is becoming increasingly significant. It was recently reported that 125 million people in this region are covered by mobile networks but do not have access to an ‘improved water source’ (GSMA, 2014). This developmental challenge is one of many covered by the Sustainable Development Goals (SDGs) adopted by UN member states in 2015. Despite recent progress towards SDG6, which aims to deliver universal access to safe and affordable drinking water by 2030, many Sub-Saharan Africans still do not have access to ‘improved water’ sources. WHO-UNICEF (2013) report that only 63% of the population in this region has access to improved water. The situation is reportedly better in urban parts of Sub-Saharan Africa, where 84% of people can access an improved water source, but in rural areas this figure drops to 51%. Coverage in Gambia is slightly better than other parts of the continent, with a reported 70% of the rural population able to access a safe water supply (AFDB, 2011).

1.5 Broken water infrastructure

Many rural communities served by water pumps experience operational/reliability problems. It is obvious that all types of water pumps will deteriorate and exhibit worsening performance over time. When this water infrastructure fails, communities may revert to the use of less protected water-sources, with the risk of exposure to a wide range of water-related diseases. The problem of broken water pumps in Sub-Saharan Africa is well documented, with previous studies reporting that between 20% and 65% of hand pumps installed in a number of African countries are broken or out of use (RWSN, 2010). It is difficult to source relevant published data from the Gambian context, but there are reports of this being an issue across the country’s rural areas (RWSS, 2016). For example, the authors interviewed a Gambian pump mechanic – who indicated that 15 pumps (23.1%) of the 65 units in his region were currently out of action. This small sample is consistent with the failure rates reported by larger studies from across sub-Saharan Africa (RWSN, 2010). Such maintenance issues are not only limited to hand pumps, but are also experienced in relation to other water infrastructure, including solar powered community pumps. If broken pumps remain in a state of disrepair then some of the progress made as a result of the SDG targets, especially those relating to access to safe water, could be diminished. Furthermore, broken pumps represent a capital loss in terms of the investment that is represented by this infrastructure.

1.6 Lack of maintenance funding

The aforementioned reliability problems have been partly attributed to a lack of local financial resources for repairs or regular maintenance (Chowns, 2015). However, it is evident that there are a range of other contributory factors, including: limited access to spare parts; limited technical capacity within the user community; inappropriate project implementation and/or technology choice; limited post-construction monitoring and support from external agencies (Moriarty *et al.*, 2004). 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 own water points. However, the large proportion of broken water infrastructure, described within Section 1.5, indicates that in practice many local communities are unable, or unwilling, to save the funds required to implement such repairs.

1.6.1 Overview of Gambian Context

A series of interviews with key Gambian water stakeholders highlighted that local communities are typically expected to raise a monthly contribution of 3000 Dalasi (approximately US$70) towards the maintenance costs associated with their hand water pumps (Walker *et al*, 2017). These monthly contributions are considered sufficient to fund most common repairs when required (such as the replacement of bearings, washers and chains). These ‘small repairs’ are typically viewed as being the responsibility of the local communities to fund and instigate the remedial action. In most cases such repairs will actually be undertaken by the local area mechanic, but funded by the local water committee. Governmental and/or charitable help is often sought in conjunction with ‘larger’ remedial works, such as the replacement of broken pump cylinders, which can amount to 35,000 Dalasi (approximately US$800).

Similar funding arrangements are typically adopted to help maintain other types of water points, such as solar powered community pumps. The authors interviewed a local non-governmental organisation (NGO) that had installed a number of solar powered community pumps across Gambia. This NGO expects local communities to raise the associated maintenance costs. As such, these local communities are required to raise maintenance contributions of 3000 Dalasi (approx. US$70) per month for larger schemes (i.e. serving approximately 2500 people) and 1500 Dalasi (approx. US$35) per month for smaller schemes (i.e. that serve approximately 600 people), however, the NGO indicated that there is often a significant shortfall in the maintenance contributions actually paid by the local communities (Walker *et al*, 2017). With some community members claiming that they do not have sufficient resources to make these regular payments. The NGO disputes this argument, pointing to the 'fact' that many community members own mobile phones and can afford the regular payments required to keep their 'Pay As You Go' SIM cards topped up. Similar water maintenance funding shortfalls have been reported elsewhere in Africa. For example, Chowns (2015) reports that many water point committees in Malawi fail to collect sufficient contributions from their local communities to implement repairs when required. It is evident that there may be an array of different reasons for these funding problems – including the effects of poverty, dependency culture and local corruption (Chowns, 2015).

In response to such issues, there appears to be an emerging viewpoint from many within the local ‘developmental’ water sector that ''Pay As You Go' water systems may represent a viable solution to this problem. The proponents of these ‘Pay As You Go’ systems argue that commoditisation of water (through such payments) should help promote responsible usage and help harness more sustainable revenue streams to support the associated on-going maintenance costs. However, some other stakeholders have expressed concerns regarding the efficacy of withholding water from vulnerable people who cannot afford such payments.

1.6.2 Pay As You Go Solar Water (PAYG-SW) Pumps

A number of different PAYG-SW systems have been developed for the African market. For example, the ‘eWATER’ 'Pay As You Go system has been employed across The Gambia (AWE, 2017). This system utilises the eWATER tap with NFC (Near Field

Communication) technology, which allows consumers to buy credit for water from local agents on a small disc. Holding the pre-paid disc near the 'smart' tap enables the delivery of water. Water credits can also be procured via mobile phone payments. Africa Water Enterprises, the 'not for profit organisation' behind this system report that 1m^3 of water costs £0.25 (or 14 Dalasi in Gambia) (AWE, 2017). A similar technology, called the 'AQtap' system has been developed by Grundos (2016). This system aims to yield sustainable water sales via the use of: Smart cards that store water credits; the AQtap dispenser unit, which distributes water and manages credit; and 'Water management system' that handles the associated data.

1.7 Novel funding mechanisms for rural communities and their water points

There are various examples of alternative solutions for addressing the funding shortfall for pump repairs (Swan and Cooper, 2013). For example, a number of local communities and support agencies have explored income generation activities connected to the operation of their water point – including the use of borehole run-off, and other excess water to irrigate crops that are then sold, with a portion of the income retained for the borehole's maintenance costs.

2 Methods

A field trial was undertaken to assess the merits of the SWAP pilot system, which used solar panels to power a water pump, in addition to Mobile Power's off-grid battery 'Charging Station' (see Section 1.3.2). This arrangement involved local community members paying a small fee to hire portable battery packs for a 24 hour period. These batteries could either be rented directly from the Charging Station or from participating local shops (Figure 1). A refundable deposit was collected from each user prior to their initial rental (i.e. to provide an incentive to return the battery packs). However, water could be collected from the associated community water point without a financial charge. It was anticipated that some of the income produced by this enterprise would be retained in order to fund the ongoing maintenance costs associated with both the water and energy infrastructure.

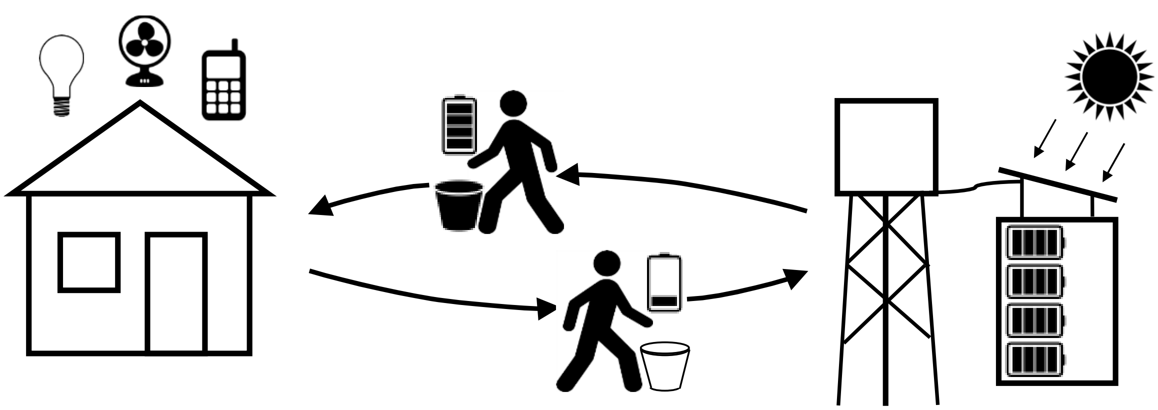


Fig 1: *Modus operandi* of the SWAP pilot system

2.1 Profile of case study area

This study was undertaken at a rural location in western Gambia to test the social, commercial and technical viability of the combined system. The case study site was approximately 200m from the Kunkujang-Gunjur settlement, and supplied water for drinking and irrigation purposes. This pump generally supported between 50 to 100 users, with local survey work indicating there were approximately 60 regular users. The water pump and solar array were located in a secure location with a watchman living on the premises. The local populations of Kunkujang and N'Yofelleh 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 (approximately US$3.50) for a day of labouring. The case study site, 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 country is one of the smallest in Africa, and forms a small, relatively flat, strip (approximately 50km wide and 740km long) around the Gambia River.

2.2 Key design considerations

The SWAP pilot system was designed to reliably supply adequate volumes of water in addition to meeting the local demand for battery packs. It was therefore essential that sufficient power was available for both the pump and the battery-charging infrastructure, both on a daily and seasonal basis. Given that the pilot system comprised a new water-point and a novel battery rental enterprise (i.e. lacking historical field data on demand and usage patterns), a series of design assumptions were made with respect to these parameters. These initial demand uncertainties influenced the design of the energy-delivery architecture, and as such, estimated demand patterns were incorporated into a rudimentary design model (Swan *et al*., 2018) to aid the sizing of system components.

2.3 Technical overview

The adopted water infrastructure comprised of a 18m concrete-lined well (Figure 2 – A), a solar pump and header tank (Figure 2 - B), from which water was piped to a collection point outside the site compound. A small building (Figure 2 - C) supported both the tank and solar array (Figure 2 - D), and housed Mobile Power's combined Charging and Activation Station (Figure 2 - E). Further details are presented in Table 1.

The pilot employed a semi-integrated system, with the pump directly powered by a 250W solar panel and the Charging Station supplied by two 250W panels. This arrangement was intended to support at least 8 hours of pumping at 100W and the recharging requirements for 30 battery packs per 24 hour period. The system's energy demands were supplied via a combination of direct power from the solar panels (i.e. during daylight hours), and stored energy from the shared lead acid batteries (i.e. during the night). The system was designed to operate autonomously for 1.4 days (i.e. at full water pumping and battery charging capacity) during periods of inadequate sunshine.

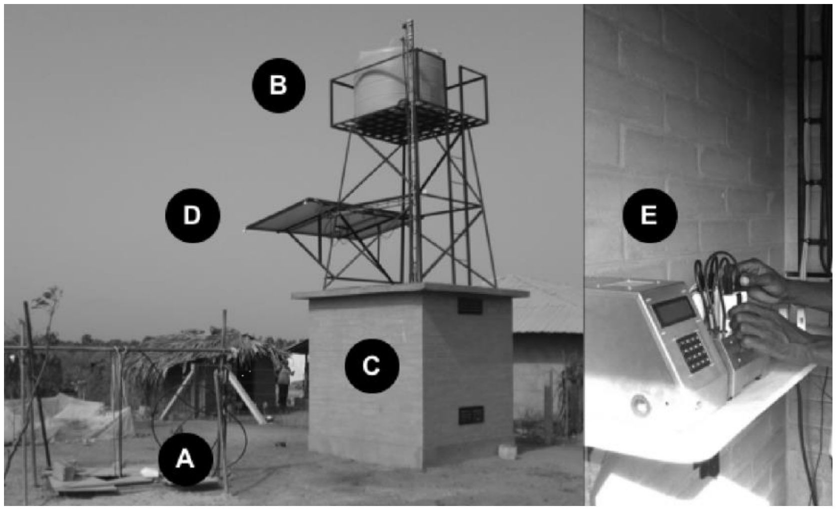


Fig. 2 SWAP pilot system comprising a combined solar powered community water pump and battery recharging/activation station

Table 1 Description of SWAP system's main components and locations

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

The smart-battery target rental cost of 15 Dalasi (approximately US$0.35) was initially adopted for an activation period of 24 hours. This target price was proposed by the local project partner (Africa Startup), and was deemed appropriate given the costs of comparable services (e.g. 14 Dalasi for 1m^3 of water – see Section 1.6.2).

3 Results

The performance of the SWAP pilot system was observed during the initial months of the field trial both in relation to: *i.) the volumes of water pumped* and *ii.) the number of recharged battery packs that were rented*. The following graph (Figure 3) presents field data collected from the Kunkujang pilot system during the second and third quarters of 2015. The water usage readings were manually recorded from a water meter by a local field operative. The battery data was collected in a similar manner. The daily volume of water (litres per 24 hour period) pumped from the Kunkujang borehole, via the system's standpipe, is presented on the bottom axis. Whilst, the inverted 'top axis' presents the daily number of SMART battery packs recharged. It is worth noting that the number of batteries recharged at the facility generally ranged between 4 and 8 units per day, with a small number of inactive days. These inactive days generally related to staffing issues (i.e. the local agent being away) rather than technical problems. The field data collected from the Kunkujang pilot system indicated the mean average amount of water pumped during this period was 1227.3 litres per day. The median, maximum, and minimum daily volumes of pumped water during this period were: 1002.5 litres; 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).

Further analysis of the average daily volumes delivered from the pilot system would seem to support the initial assessment that the pump has 60 regular users. Assuming each of the Kunkujang users is using 20 litres per capita per day*; then the approximate number of users could be estimated by dividing the mean average daily amount of pumped water (1227.3 litres/day) by 20 litres/capita per day. This approach yields an estimate of 61.4 users for the water point.

** Note: WHO (2013) guidelines indicate that a quantity of 20 litres per capita per day should be sufficient to take care of basic drinking, hygiene needs and basic food hygiene.*

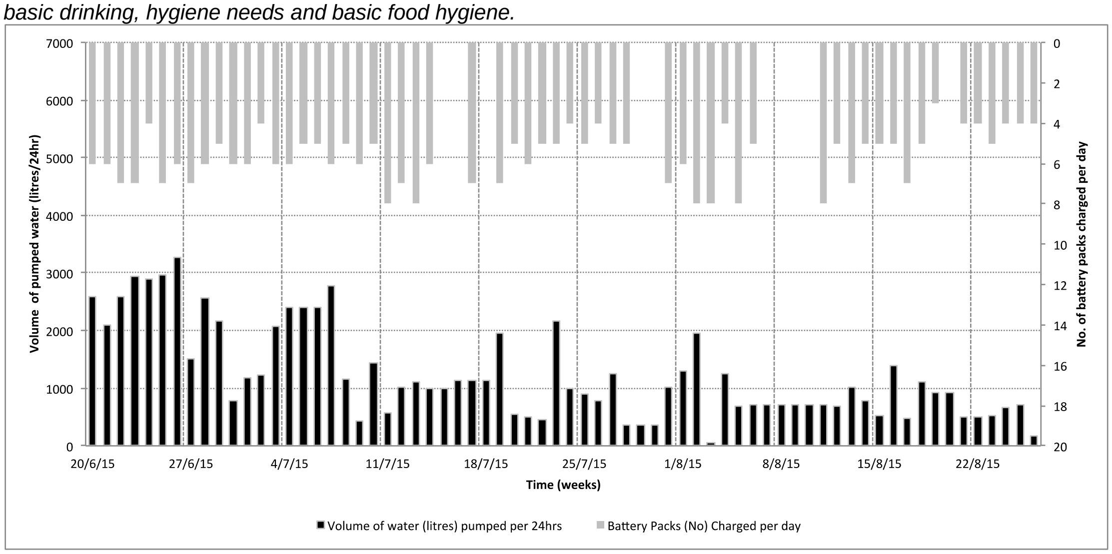


Fig. 3 Daily volume of pumped water and number of battery packs recharged at the Kunkujang pilot study

The water usage patterns presented in Figure 3 appear to remain relatively similar during the first three weeks. However, from this point onwards, there is a marked reduction in the daily volume of water used, as the trial continued. The reasons behind this reduced water usage become clearer once daily rainfall records are considered (see Figure 4). Rainfall data was obtained from a local weather station at Banjul airport (WU, 2017), which is located approximately 23km to the North East of the Kunkujang site. As the impacts of the country's rainy season are felt (i.e. and daily rainfall depths increase), there is a notable drop in water demand from the Kunkujang scheme. This would seem to confirm the findings of community survey work, outlined in Appendix 2, which indicated water was being collected from the pilot systems for both drinking and irrigation purposes.

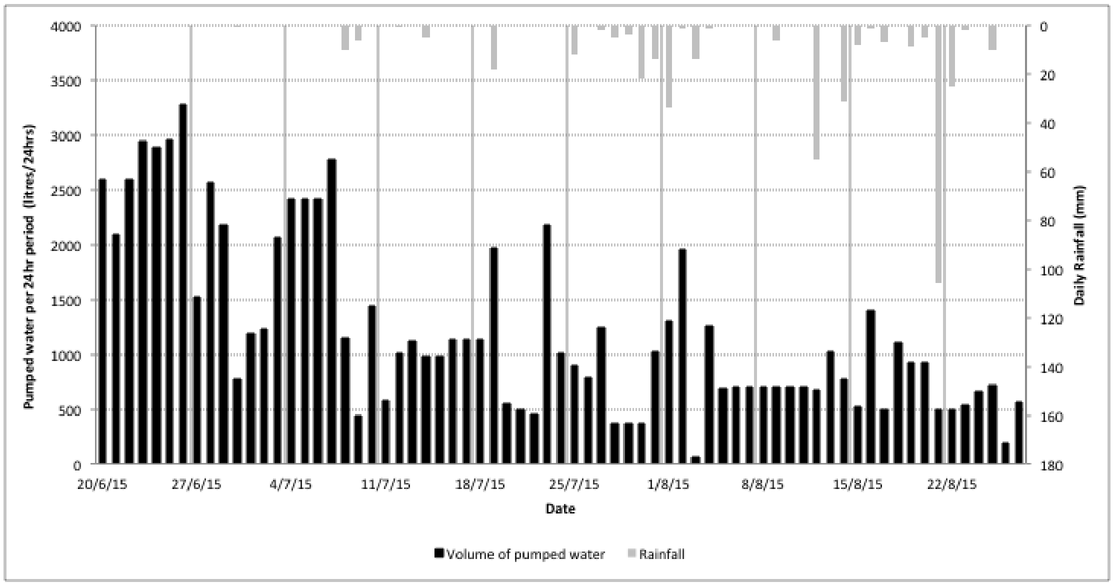


Fig. 4 Daily Pump usage (l/hrs) v Daily Rainfall (mm) at the Kunkujang pilot study

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).
It is important to reflect how and why local residents are collecting this water (e.g. how many people use the pump; how much water they collect; and whether it is used for drinking, irrigation or other purposes). Similarly, other social issues such as the local rates of income, phone ownership and typical recharging patterns will also influence the operational performance of the pilot system. To this end, the preliminary results presented in this section should be considered in conjunction with the insights obtained from a range of community-based investigations described in Appendix A2.

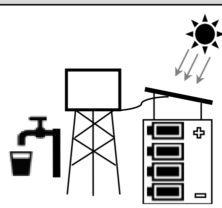
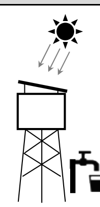
4 Discussion

The following section explores the revenue generated by the SWAP pilot system with comparable maintenance funding mechanisms associated with other local water schemes. For instance, local stakeholders indicated that a conventional 'water point maintenance contribution' of 2.5 Dalasi per user per month was typically requested for small solar powered community water systems in the Gambia (i.e. that serve up to 600 people) (Walker *et al*., 2017). The survey work presented in Appendix 2 indicated that the Kunkujang system has 60 regular users, so its equivalent total maintenance contribution (using the aforementioned maintenance formula) would hence be 150 Dalasi per month. If a broader range of between 50 to 100 water point users were considered (to allow for temporal population changes and surveying uncertainties); then the corresponding monthly maintenance contributions would equate to 125 and 250 Dalasi per month respectively.

The field data presented in Figure 3 indicates 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 (assuming there are 30.42 days in an average month). If there were 60 regular users of the Kunkujang pump, it follows that the corresponding daily water usage per capita of this pump was 20.5 litres per person per day. Similarly, the per capita rental rate of the smart battery packs was 0.08 packs per person per day.

The aforementioned usage patterns were then analysed to calculate the monthly, and monthly per capita income that could potentially be raised at the SWAP site using three alternative funding mechanisms (See Table 2). The first mechanism relates to the income generated by Mobile Power's target rental pricing structure of 15 Dalasi per battery pack (per day) when applied to the observed battery rental patterns shown in Figure 3. The second mechanism hypothetically applies reported ''Pay As You Go' water rates (See Section 1.6.2) of 14 Dalasi per cubic meter of water to the volumes pumped from the Kunkujang project; whilst the third approach relates to the conventional flat rate 'water point maintenance contribution' of 2.5 Dalasi per pump user per month.

Table 2: Income generated at SWAP pilot compared to conventional water funding mechanisms (assuming regular 60 water point users)

	FUNDING MECHANISM		
	 **SWAP Pilot:** **Mobile Power battery rental** *(No charge for water & battery rental: 15 Dalasi per pack)*	 **EWater:** **'Pay As You Go' water** *(Water charge of 14 Dalasi charge per 1m^3)*	 **Conventional 'water point maintenance charge'**
Average monthly income	**2203.95 Dalasi**	**523.88 Dalasi**	**150 Dalasi**
Average Monthly income per capita	**36.73 Dalasi**	**8.73 Dalasi**	**2.5 Dalasi**

The income generated from the SWAP pilot scheme's battery rental service (Table 2) is over four times higher than the projected revenue that might have been generated if a Pay As You Go (PAYG) system had been fitted to the Kunkujang site (i.e. based on the volume of water pumped over the corresponding period). It is noted that this assumption relies on the same water usage rates under both free to access (as is currently the case at the pilot study) and a hypothetical 'PAYG' scenario. It is conceivable that the introduction of a 'PAYG' approach could lower the levels of water being pumped, and the subsequent revenue generated. Similarly, the average monthly income associated with the Smart battery rental scheme is significantly higher (i.e. over fourteen times greater) than the conventional 'water point maintenance fee' (of 150 Dalasi) that is typically applied to similar water points across Gambia.

This exercise helped derive an appropriate water point maintenance levy/fee that could be applied to the battery rental pricing structure. It would appear that there is potential to incorporate this amount, as an equivalent rate to the conventional ‘water point maintenance charge’ (i.e. 2.5 Dalasi per month per capita) – and to hence collect this amount via the pilot scheme’s smart battery rental income. Based on the battery rental patterns highlighted in Figure 3, applying a water maintenance levy of 1.02 Dalasi to every battery rental charge would appear to be sufficient to cover the water point maintenance requirement. This might either be taken from the initial rental price of 15 Dalasi (i.e. reducing the battery income to 13.98 Dalasi per rental) or by increasing the overall rental fee from 15 to 16.02 Dalasi. The initial pricing structure (i.e. of 15 Dalasi) effectively equates to a mobile phone recharging rate of 2.14 Dalasi (USUS$0.05); whilst the increase price, which adds the water maintenance levy, would equate to a mobile phone recharging rate of 2.29 Dalasi (US$0.05). The supporting rationale for the calculation of these values is outlined in Appendix A3. This analysis was also repeated for a broader range of user populations (i.e. 50 and 100 users). The revised water maintenance levy for the 50-user scenario would drop to 0.85 Dalasi; whilst for the 100-user scenario this would rise to 1.7 Dalasi. It is notable that even these alternative scenarios would generate phone recharging fees that are comparable to alternative rates quoted in this paper.

5 Conclusions

This paper has highlighted a number of infrastructural issues that are taking place across much of Sub-Saharan Africa. There has been significant growth in terms of both mobile phone ownership and usage across this region. However, the widespread access to mobile phone coverage is contrasted by relatively poor access to other key infrastructure, such as clean water or mains electricity. These infrastructural problems appear to be more significant within rural areas. Some mobile phone users in such rural areas regularly travel significant distances to recharge their devices at shops or informal businesses. It has been reported that whilst many individuals are prepared to pay a small regular fee to recharge their mobile phone, their wider communities may often lack sufficient funds to keep their water infrastructure maintained.

This paper has introduced a field trial that is exploring the merits of a smart-battery rental service that enables local communities to power their mobile phones and other low energy devices. In this novel SWAP pilot system, the off-grid power service shares a combined solar array with a community water pump. The paper has presented field data from this case study, and demonstrated the technical viability of the combined system. It is interesting to note that the collected 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 indicates that the local community use this water for both drinking and irrigation purposes. It is clear that less water is drawn from the water point during, and shortly after rainy periods. 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 analysis presented in this paper indicates that there is potential to collect a ‘water maintenance levy’ via the SWAP pilot scheme’s smart battery rental income. However, it is evident that the merits of this strategy will need to be assessed by further field trials.

The robustness of this combined technology still needs to be assessed over the longer term, and at other contexts (i.e. in conjunction with different communities, locations and markets). For example, a 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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Appendix A1. Review of ‘Pay As You Go’ (PAYG) power systems

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 US$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. BBOX have also developed the **SMART Solar system** for individual households in emerging markets (BBOX, 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.

Appendix A2: Community analysis for Kunkujang pilot study

A2.1 Community surveys: Overview

A benchmarking visit to the study area was undertaken at the start of the research project. These preliminary investigations adopted informal survey methods and a conversational tone, in an attempt to put respondents at ease in the spirit of rapid and participatory rural appraisal (PRA) (Chambers, 2012). Local community members were interviewed at the pilot study site, and at nearby homes and shops. Discussions were undertaken with key individual stakeholders (e.g. informants, agents, shopkeepers, field workers) and with focus groups of men, women and young people living close to the project site. It is considered that the groups interviewed were reflective of the local community in Kunkujang-Gunjur. Aggregation of data from focus groups is well established in development research and their findings have been influential across a range of policy and practice (Chambers, 2012). The surveyed focus groups broadly related to the distinct cohorts highlighted in Table A2.1.

Table A2.1: Details of Surveyed Groups

Surveyed Focus group	Sub groups	No of participants	Comment
Service providers	*Agents*	**1**	Operated the pilot system and distributed battery packs
	Shop keepers	**5**	Retail/distribution outlets of battery packs to local community
	Community workers	**3**	Work with local community of Kunkujang-Gunjur
Community members	*Adult males*	**15**	Reside in vicinity of pilot study site in Kunkujang-Gunjur
	Adult females	**25**	As above. Many also oversee vegetable gardens in adjacent areas close to Kunkujang-Gunju
	Youth males	**8**	Reside in vicinity of pilot study site in Kunkujang-Gunjur
	Youth females	**5**	As above

The discussions with these focus groups, individuals and households were based around the questions presented in Table A2.2:

Table A2.2: Mobile phone related questions used in community interviews

No.	Question
1	Do you have a mobile phone and when was it acquired?
2	Who else in your household has a mobile phone and when were they acquired?
3	What type(s) of mobile phone do you have? (e.g. Smart phone or Non-Smart phone)

4	How often, and where, do you recharge your mobile phone?
5	How much does it cost to recharge your mobile phone?
6	How far do you travel to recharge your mobile phone?
7	How often do you recharge your mobile phone?
8	What do you use your mobile phone for?

In addition to these mobile phone related questions, general discussions were undertaken with the community member focus groups that explored the quality of their water source, as well as their current usage and collection patterns (e.g. the distance travelled to collect water and time taken; how much water is collected; who collects water). Similar discussions explored how community members might respond to a closer, more abundant and safer water supply.

Informal and unstructured or semi-structured interviews were deemed the best way to elicit the views of the participants in this case. This methodology was adopted in preference to more formalised approaches; as such formal surveys have been reported to sometimes miss the realities of rural deprivation (Chambers, 2014). By choosing this type of 'Quick and Dirty' approach (Chambers, 2012), the researchers had to rely on previous field experience and the practice of development using rapid and participatory rural appraisal (PRA).

A2.2 Community surveys: Key observations

A2.2.1 Capacity and Demand

The benchmarking visit was undertaken during the pilot scheme's first operational quarter. However, the trial already appeared to be popular to the point of oversubscription, as evidenced by a shopkeeper in N'Yofelleh setting up an additional battery-based system to cope with the growing demand. A range of 'Quick and Dirty' survey investigations indicated widespread ownership of mobile phones among young and old, male and female with some differentiation in their usage. Some of the men interviewed described that they used their mobiles to save themself an unnecessary long walk (i.e. to avoid walking significant distances only to be told that their friend or family member 'had travelled elsewhere' when the person they sought was not at home). Whilst some of the women interviewed, described how they regularly take calls from market traders with orders for vegetables (interestingly they did not immediately identify this as business use). Some of the adult users emphasized the importance of mobiles for keeping in touch with the rest of the household and for summoning assistance. A number of young people, in common with their peers elsewhere, used their mobiles to go on Facebook and access YouTube. There was very little use of texting by the surveyed groups; although people knew this was cheaper than calls. There was also good knowledge of the relative benefits of different mobile phone service providers.

A2.2.2 Literacy and mobile phone use

When talking to focus groups, it was observed that several people asked others to record their names (for research ethics purposes) indicating a level of illiteracy. The fact that most people used their phones mainly for calls and seldom for texting may relate to this.

A2.2.3 Gender equity and mobile phone use

The gender balance of mobile phone ownership was fairly even, though women had usually acquired their phones some time after their husbands. In this short visit during the dry season, an impression was gained that women are using their phones for business more than men but this needs to be further investigated.

A2.2.4 Water use

It appeared that Kunkujang water-point typically served between 50 to 100 users, with the benchmark survey work indicating there were approximately 60 regular users. These users indicated that they were utilising the collected water for both drinking and irrigation purposes.

A2.2.5 Potential benefits for local communities

It is considered that this field trial has potential to deliver many benefits to the local community. By itself, the water point will enable access to clean water in an area with few wells so reducing the drudgery of water collection for the local community. Closer access to improved water supplies can bring a range of benefits. For example the ability to meet minimum standards for water consumption produces better health status which in turn enables people to be more economically active; time saved from water collection enables women (who are often the main water collectors) to engage in other productive activities; the reduction in the drudgery of carrying water reduces the incidence of neck and back problems for women; if girls are not required to collect water it reduces a constraint on their school attendance. However, the benefits of improved water quality may only be realised with additional attention to how water is managed in the home to prevent contamination from multiple users accessing water stored in the house.

There is also potential for irrigation of locally grown vegetables during the dry season, this would benefit household nutrition as well as sales. The wider context, is that the Gambia currently imports significant amounts of food as it's domestic production is insufficient to cover it's consumption requirements. Furthermore, the operation of agricultural markets might be enhanced by the use of mobile money (WFP, 2011). The livelihoods of poor communities are considered to be more secure when they have a more diverse range of income stream (Carney, 1998, Ellis, 1999). This diversity should mean that communities are less vulnerable to shocks, such as adverse weather or severe ill health and hence unexpected costs as well as inability to work. Thus, if one enterprise among several has a bad year, other income streams can compensate. Livelihood potential depends on peoples' capital endowments and entitlements i.e. ownership of or access to natural, social, human (skills and knowledge), physical (infrastructure) and financial capital. It is recognised that there is a risk that the scheme might prompt an excess of petty traders competing with each other (Little, 1999) and it is hence evident that local communities should be encouraged to diversify in order to provide added value to their agricultural produce (e.g. by preserving fruits and vegetables for sale in the dry season to avoid this as far as possible). Greater income from farming vegetables could also lead to purchases of motorised and non-motorised transport (in the latter case creating employment to produce e.g. carts and trailers locally) to deliver produce to market.

The availability of this solar power should create employment opportunities both directly (e.g. agents), and indirectly via the greater use of mobile phones enabling people to access: information to improve their incomes; and to access health/transport to health facilities. There is also potential for using solar power for processing of agricultural produce to enhance value and longevity. The availability of solar-powered light when battery packs are taken home should improve domestic air quality and reduce accidents from candles and kerosene lamps.

Appendix A3: Calculation of water maintenance levy for battery rental fee

The paper highlighted the potential to incorporate a water maintenance levy on the battery rental fee, as an equivalent rate to the conventional 'water point maintenance charge' (i.e. 2.5 Dalasi per month per capita) – and to hence collect this amount via the pilot scheme's smart battery rental income. Assuming the pilot scheme has 60 regular users, it is possible to calculate that a water maintenance levy of 1.02 Dalasi applied to every battery rental charge would be sufficient to cover the water point maintenance requirement. As indicated this might either be taken from the initial rental price of 15 Dalasi (i.e. reducing the battery income to 13.98 Dalasi per rental) or by increasing the overall rental fee from 15 to 16.02 Dalasi. The supporting rationale for the calculation of this value is outlined below.

Assuming there are 60 regular users of the Kunkujang pump, the corresponding conventional monthly 'water point maintenance' charge would be 125 Dalasi (i.e. based on 2.5 Dalasi per month per capita). If this amount is then divided by 146.93 (i.e. the average number of battery rentals per month), this would give the levy of 1.02 Dalasi required from each individual battery rental in order to cover the whole communities' overall monthly water point maintenance requirements. Similarly, it can be demonstrated that the revised water maintenance levy for the 50-user scenario would fall to 0.85 Dalasi; whilst for the 100-user scenario this would rise to 1.7 Dalasi.

Table A3: Income generated at Kunkujang pilot compared to conventional water funding mechanisms

Scenario	Water point maintenance contribution	Mobile Power contribution	Battery rental price	Equivalent price per phone	Equivalent price per phone smartphone charge
Existing price structure including water point fee (for 60 users)	1.02 Dalasi	13.98 Dalasi	15 Dalasi	2.14 Dalasi	5 Dalasi

Existing price structure + water point fee (for 60 users)	1.02 Dalasi	15 Dalasi	16.02 Dalasi	2.29 Dalasi	5.34 Dalasi
Existing price structure including water point fee (for 50 users)	0.85 Dalasi	14.15 Dalasi	15 Dalasi	2.14 Dalasi	5 Dalasi
Existing price structure + water point fee (for 50 users)	0.85 Dalasi	15 Dalasi	15.85 Dalasi	2.26 Dalasi	5.28 Dalasi
Existing price structure including water point fee (for 100 users)	1.7 Dalasi	13.3 Dalasi	15 Dalasi	2.14 Dalasi	5 Dalasi
Existing price structure + water point fee (for 100 users)	1.7 Dalasi	15 Dalasi	16.7 Dalasi	2.39 Dalasi	5.57 Dalasi

Table A3 highlights a number of pricing scenarios; the first retains the existing 15 Dalasi rental price; whilst the second adds a water levy to the initial rental price to give a revised battery rental value of 16.02 Dalasi (i.e. if there are 60 regular users of the water point). The same scenarios are then repeated for the 50 and 100 user scenarios. For all cases the equivalent costs for charging both normal and 'Smart' phones are presented. These are based on the assumption that a fully charged battery pack can in turn recharge three smartphones, or up to seven non-smartphones. For the 60 user scenario, the initial pricing structure effectively equates to a mobile phone recharging rate of 2.14 Dalasi (US$0.05); whilst the revised price, which adds the water maintenance levy, would equate to a mobile phone recharging rate of 2.29 Dalasi (US$0.0503).

Additional References (used in within Appendices):

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