Field findings of an action research pilot

MODULAR BUILDING PROJECT

How data-driven and disruptive technologies can improve the sustainability of water services in rural Africa

November 2021

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Introduction

An estimated 25% water points in sub-Sahara become dysfunctional after 5 years. This dysfunctionality rate increases to about up to 30% after 10 years[1]. As a result, a considerable portion of the capital-intensive water infrastructures fails to deliver the envisioned social impact.

One major root cause of this high failure rate is the imbalance between revenue generated by water sales and expenditure needed to maintain and operate the water infrastructure, which requires reliable post-installation maintenance structures. The imbalance is particularly present in rural Africa, where scale of economy and lower water consumption per capita face unfavourable conditions compared to urban settings. Moreover, the willingness and ability to pay for water is often limited and unlocking payment behaviour is one of the 'wicked rural water challenges'.

In the past years both Practica Foundation as well as Project Maji have been exploring ways to close the gap between operational expenditure and income in water projects focussed on rural Africa. One of our key questions is whether a different approach to hardware design and hardware set-up can bridge this financial gap. Therefore, both parties decided to partner and pilot a novel approach in water hardware implementation.

The newly developed setup as tested in the pilot–*referred to as modular building in this paper* - is a small network of prepaid water kiosks fitted with a mechanical prepaid device. The system itself is adaptive: it can grow or decrease in size depending on the uptake or changing demographics. Thereby creating the ability to optimize the business case during the operational phase. Moreover, the system as a whole is sized based on field monitoring of existing water points in rural settings – ensuring an optimum balance between service levels versus costs.

The newly developed concept is based on the following hypotheses:

1. Paid water services transform beneficiaries into customers. Value creation – by higher service levels – will increase the uptake of the service and the willingness to pay.
2. The uptake of newly introduced paid water services in newly targeted communities is hard to predict. Novel technical concepts – focussed on agility and adaptability - can help to reduce the entrepreneurial risk and optimize the business case.

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[1] What's working, where and for How long: a 2016 Water point update (nov 2016), Sean Furey.

3. Data-driven and disruptive designs have the ability create more appropriate water infrastructure for rural setting - thereby supporting sustainable hardware implementation.

The novel concept has been piloted in Ghana in the first quarter of 2021. This paper describes the findings. It starts with a more detailed explanation of the concept of modular building, followed by the novelties that have been integrated in this pilot. The paper is concluded with the results and conclusions, where the hypotheses are compared to the field findings.

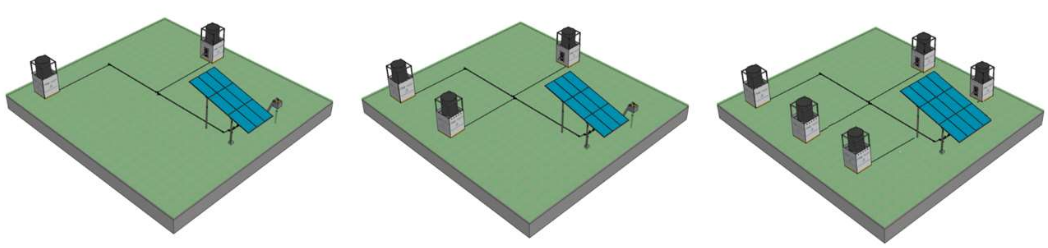
Explanation of modular building

Before highlighting the results of testing our hypotheses, this chapter describes the concept of modular building that has been put to the test during the pilot project in detail. The pilot project area was rural Ghana, a remote community with an estimated population size of 1,500 people. At the time of intervention there was a non-functional water kiosk and a sub-optimal functional hand pump present in the village.

The core of the concept is a standardized, compact mini water kiosk that can be connected to a central grid. It is designed with rural, remote communities in mind. It serves as a public water point – able to reach about 500 people. Depending on the water needs, this grid can be expanded or reduced by adding or removing the small water kiosks.

Photo: compact kiosk

The project includes fit-for-purpose technologies using solar pumping and custom designed mechanical payment systems with data monitoring capacity. These mechanical prepaid systems ensure that freeriding is avoided and the system can be tracked from a distance.



Conceptual overview of expanding network

The system design consists of a network that is fed by a pressure pump in a single well, leveraging existing water infrastructure such as a tube well. The pressure in the network is generated by the central solar powered pump, rather than a more traditional gravity-generating water tower.

In the pilot site three kiosks were installed– each strategically located so it can serve its own user group.

Figure 1 Overview of implementation location

The modular concept proving multiple small water kiosk in a village was named 'the Maji Plus' distribution system. It forms an alternative to the Maji Mini kiosk in the concept range of Project Maji. This Maji Maji kiosk - with more than 50 systems installed up to date - is a single water kiosk providing a paid water provision service in rural Africa.

The following paragraphs discusses the novelties of the modular piped system as implemented in the pilot.

Novelty 1: Risk reduction by Standardisation and Adaptability

To achieve financial sustainability, the water consumption of a paid water service needs to be over a certain threshold to ensure the operational costs can be covered through the water revenue.

However – based on experience– the uptake of a newly introduced water system proves hard to predict. Surveying indicators such as water scarcity, alternative water sources, level of income, population density, willingness to pay provide some insight, yet are only indicative for the success and uptake of rural water services. Results vary considerably from site to site – even in a situation where the indicators show a clear demand, willingness and ability to pay.

Our technical setup reduces the entrepreneurial risk by using a staged approach during the introduction. The setup of the systems allows the system to adapt – by adding or removing the compact standardized water kiosks - depending on the demand. The system can be introduced with a minimal layout and can expanded when the uptake is high.

Subsequently, this adaptability in the service provided enables utilities to improve the overall business case and ensure long-term sustainability of the facility and service to the community. Given the limited costs of the small, compact water kiosks, a self-expanding economic model supporting sustainable access to safe water can become a reality, resulting in a breakthrough in the rural safe water service delivery models.

Novelty 2: Income optimisation via value creation

To ensure financial sustainability – which amongst other factors is achieved through technically sound systems – service levels need to be elevated to maximize income. In this quest to elevate the service levels one should be aware that there is an optimum[2].

Field observations suggest that an average single kiosk has a service reach of about 300-400 meter radius. On average, this service reach translates in a water sale in the range of 1,500-2,500 litres per day. Consumption peaks during the dry season and reduces in the wet season as the availability of alternative water sources has a significant effect on the sales of paid water services.

Creating a small network of water kiosks – as is possible in the concept developed by Practica - each serving their own catchment area (in the range of 500 customers each) can result in higher demand via improved value creation, therefore leading to improved revenue.

[2] Note: Higher service levels, generally, come at a higher cost. And – ideally – consumers pay more for a better service. This however has an optimum. This is the point where the additional costs of the service level increase are higher than the additional revenue created by this service level increase. From a business case perspective, one should therefore aim at the optimum service level, not the highest.

This network arrangement of kiosks therefor allows the system to optimize the service level (reducing distance of the water point to the customer, resulting in extra income) in relation to costs.

This concept is made possible by using a single solar pump directly linked to the distribution network which provides pressure to feed the kiosks, contrary to the commonly used gravity-fed systems. By installing a pressurized delivery system, water can be dispensed at a number of different sites up to a kilometre from a single well point, even uphill. Using a single borehole to serve multiple community groups improves the utility of this borehole.

Novelty 3: TokenTap

All small kiosks are fitted with a 'TokenTap' - designed by Practica Foundation. A low-cost and easy to maintain token-based re-payment system designed with demanding rural settings in mind.

Electronic payment systems, also known as water ATMs, have gained popularity in the rural water arena, but unfortunately, they are expensive, both in terms of investment as well as operation.

Moreover – in very remote, rural areas, high-tech electronic versions of different prepaid alternatives proved to be difficult to maintain by local technicians. Also, the supply chain of spare parts can be found to be a challenge.

Practica's TokenTap is truly a fit-for-purpose payment system, only integrating essential technology. Its particular aim is to reduce the operating cost, whilst simultaneously increasing reliability. Fully mechanical, it is a robust system that delivers a fixed amount (e.g. jerry can or bucket) of water to the user when a token is inserted.

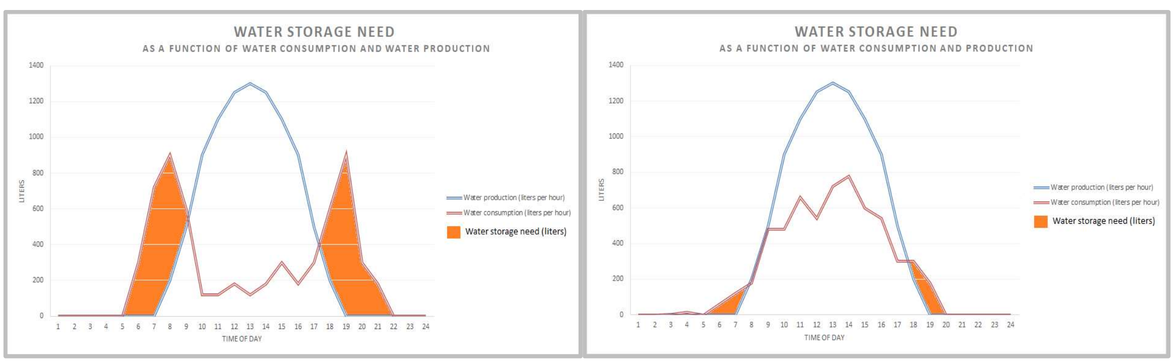
TokenTap system meets all the objectives of a cashless payment system (enhance revenue collection, financial security, and accountability, 24/7 access, remote monitoring, eliminate information asymmetries, improved uptime, freeing time for labour or schooling) while introducing a mechanical solution reducing the payment solution cost significantly.

Novelty 4: Sizing of tanks

To optimize the infrastructure cost, the concept uniquely matches water production with actual demand, resulting in an overall much smaller, more efficient and cheaper system, while having the same water sales capacity of an equivalent centralised system.

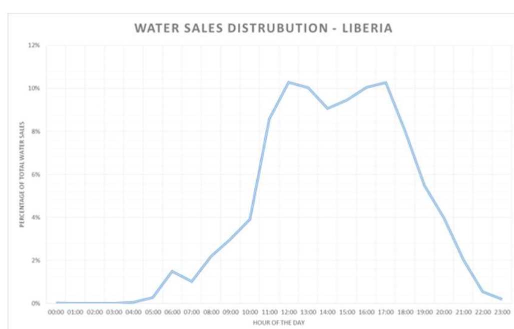
The popular assumption in the rural water sector is that collection peaks are early morning, - starting at dawn - and late afternoon. Most systems have been designed in accordance with these two demand peaks. This notion is confirmed by user statements. Our pre-impact survey relating to the pilot shows that 73% water fetchers are convinced they collect water in the early morning.

The consumption behaviour is relevant as it dictates the size of the tank. A water tank is a buffer between water production and water consumption. The more similar these patterns are, the smaller the tank can be. With a consumption pattern with peaks at dawn and late afternoon, and a solar pump peaking around noon, a relatively large water buffer is needed. However, if the water consumption peaks at noon too, the water buffer (being the tank) can be significantly reduced. The principle can be observed in the graphs below.



Graphs: water storage needs

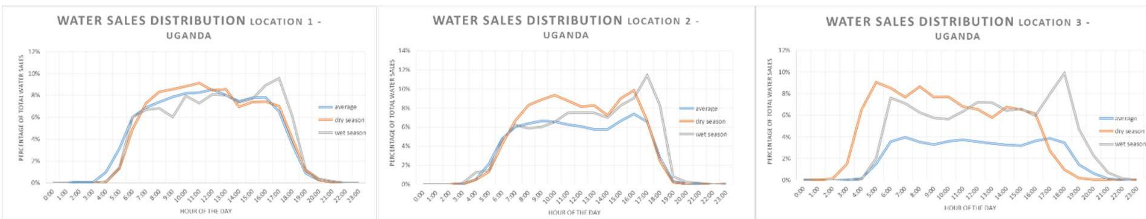
Practica Foundation conducted a study in 2019 to challenge the widely accepted collection pattern assumptions to develop a supply system that meets actual demand (in litres) rather than presumed, which requires large water storage capacity. The data showed a surprisingly clear pattern of water collection across the day, rejecting the original notions of fetching water at peak times.



Graph: water sales as a percentage of daily sales during the day

An independent study by Ingram and Memon (2020) reviewing rural water collection patterns combining smart meter data with user experiences in Tanzania, presented similar conclusions. Collection occurs through the daylight hours with slightly greater volumes dispensed in the afternoon–evening due to free time from economic activities and children returning from school.

This same pattern is also observable in data (based on multiple years) received from WaterCompass, a Uganda-based NGO with multiple kiosks located in the western part of Uganda. Interestingly enough – the patterns appear to differ according to the season. With a clear consumption peak in the late afternoon during the wet season. A potential explanation – suggested by WaterCompass – is that consumers wait during the day for rain. And when no rain falls, the customers fetch water at the paid water point.



Graphs: water consumption patterns Uganda - WaterCompass

Data-driven decisions can now be made to reduce the size of the tank capacity at each water dispensing point, resulting in better customer service performance and cost-reduction. As a result – and if the data in the pilot proves to be consistent with the current field data - a single kiosk of 5,000 litres (as used in the Maji Mini kiosk) can be reduced to 1,000 litre tank while not reducing the average daily sales capacity. Consequently, the small kiosks were fitted with a 1,000 litre tank.

It is also noteworthy that when designing a piped system in a conventional way, the water storage capacity would be in the range of $35m^3$ – more than 10 times the storage capacity used in this pilot[3].

[3] 1000 inhabitants at time of construction, 3% annual population growth, 20 liters per person per day – resulting in an expected water demand of (1753 inhabitants after 20 years x 20 liters per person per day) = 35 m3/day. Assumed storage capacity = daily demand. Often even larger storage capacities relative to daily demand are suggested. 20 liters per person day is a figure that is used in design standards. (e.g. Small towns sector guidelines, volume 3, dec 2010 of the community water and sanitation agency of Ghana & Water Supply design manual of Uganda 2nd Edition), but also WHO refers it as a basic service level (https://www.who.int/water_sanitation_health/publications/2011/9789241548151_ch05.pdf).

Results

The tentative results of the pilot are analysed per hypothesis mentioned in the introduction. The pilot is has started at the beginning of April. Long-term data combined with a higher pilot scale will need to confirm the conclusion.

First hypothesis

'Paid water services transform beneficiaries into customers. Value creation – by higher service levels – will increase the uptake of the service and the willingness to pay.'

The following table shows the service level perception of the customers before and after the introduction of the pilot. The pre-impact situation consisted of a single hand pump serving the same population with free water.

Variable	Classification of variables	%	%
Survey post-implementation		**Post impact (22 May21)**	**Pre impact (30 March 21)**
I fetch more water because the source is closer to home	Yes	100	N/A
	No	0	N/A
	Same	0	N/A
Satisfaction rate	Very satisfied	86.7	11.5
	Satisfied	13.3	53.8
	Neutral	0	3.8
	Dissatisfied	0	23.1
	Very dissatisfied	0	11.5
Reliability (i.e. water availability)	Very satisfied	60	0
	Partially Satisfied	33.3	23.1
	Neutral	6.7	0
	Dissatisfied	0	76.9
Opinion TokenTap system	Strongly in favor	80	54.5
	In favor	20	45.5
	Not in favor	0	0

Table: survey post and pre implementation.

As can be seen in the table, the satisfaction rate regarding the water provision increased significantly. This is likely to be a result of increased reliability compared to a hand pump. All customers state that more water is fetched as a result of a reduction of distance between their dwelling and the water point.

The following table shows the water consumption of the newly introduced system in the end of the rainy season in Ghana[4]. Generally, the rainy season is faced with lower water sales due the availability of alternative water sources. Also, the average water consumption of the Mini Maji (being the single water kiosks in the project range of Project Maji) in the same time period is shown. The averages of the Mini Maji kiosks are based on 50+ systems in the same country (Ghana).

[4] peak of rainy season is May/June - given the tropical sub-tropical conditions the peaks in rain are less profound than can be found elsewhere in sub-Sahara Africa.

Month	Tap 1 liter (litres)	Tap 2 liter (litres)	Tap 3 liters (litres)	Total (litres)	Average per day (litres)	Average PM Mini Maji Ghana (litres)	Factor increase (sales mini Maji divided by sales modular system)
may	47.190	42.702	46.508	136.400	5.052	1.653	3
jun	21.296	37.334	24.156	82.786	3.066	1.790	1.7
jul	30.646	44.220	30.800	105.666	3.914	1.468	2.6
Average					4011	1637	2.5

Table: water sales of pilot project

The table above shows that

- The water sales of the new system as a whole increases significantly compared to an average Mini Maji (single kiosk) in the same month. For the three months monitored the sales more than doubled, reaching an average increase factor of 2.5
- Each kiosk sold - in the network of the pilot site - sold about 1.336 litres average per day. Being only 20% less than a Mini Maji.

Given the observations mentioned above the hypothesis that value creation results in higher uptake and willingness to pay appears to be true. The newly introduced concept has considerable higher uptake than an average single water kiosk. And, furthermore, allowed a successful introduction of a paid water service in a context where a hand pump was providing free water.

The financial consequences of this observation will be discussed in the next paragraph.

Second hypothesis

'The uptake of newly introduced paid water services in targeted communities is hard to predict. Novel technical concepts – based on agility and adaptability - can help to reduce the entrepreneurial risk and optimize the business case.'

To analyse the results of the pilot the modular design approach will be compared to the Maji Mini.

The following table shows the differences between the two concepts.

	Maji Mini **Central water kiosk**	**Modular piped system** **Small, piped distribution system with three dispensing points (kiosks)**
CapEx (total system cost / per standalone kiosk)	$15,000 / $15,000 (incl. pump, solar panels, pipes, fitting work, etc. Excluding well). Prices do differ per site and country.	$24,000 / $8,000 (incl. pump, solar panels, pipes, fitting work, etc. Excluding well). Prices do differ per site and country.
Population avg.	500-1,000	1,500-2,250
CapEx per customer	15,000/750=20 USD	24,000/1,875= 12.8
Kiosk system	1 kiosk: Central hub in heart of community	3 kiosks: 1 central solar pumping hub with 3 satellite kiosks up to 1km from hub
Storage capacity	1 x 5,000L poly tank	3 x 1,000L poly tanks
Consumption average Ghana	1,650 L per day	4,000 L per day (measured over 3 month period in pilot)
Payment system	E-pay: Digital payment system RFID technology	TokenTap: Mechanical with coins
Revenue ($0.001/per liter)	Day: 1.65 USD / Month 50 USD Year: $600	Day: 4 USD / Month 120 USD Year: $1,440

The table above shows the following:

- **At system level:** When the total system costs are compared (15.000 vs 24.000 USD) a small, piped network is more capital intensive but also has a higher revenue. The hardware cost increase is about *60%*, yet the measured sales increase by a factor 2.5.

  An indication of the maintenance cost can be calculated as a percentage of the construction cost. Consequently, the maintenance cost of the Modular piped system is higher than the Maji Mini. However, maintenance cost only forms one part of the total operation cost. Other factors, like overhead, transport cost, operator cost will not significantly differ between the two setups.

  The total operational cost increase - of the modular piped system compared to the Mini Maji will therefore remain well below the 60% while the income increase is 145% considerable higher. Therefore, concluding that a substantial competitive financial advantage is created in the pilot.

- **At kiosk level:** The investment per kiosk (of similar sales capacity) in this pilot is nearly 50% cheaper than a single, central water kiosk (Maji Mini). While having the same customer reach.

  Adding an extra kiosk to the network is expected to cost around 5,000 USD. While using a central – single – water kiosk, this would cost 15,000 USD. The financial competitive advantage of the modular piped system compared to the Maji Mini will therefore further increase in case of a system expansion. Furthermore, the combination of an improved business case combined with lower investment costs per water kiosk compared to a single water kiosk approach, also reduces the financial gap of a self-expanding service model where the water system can not only sustain itself, but also show growth financed by water revenues.

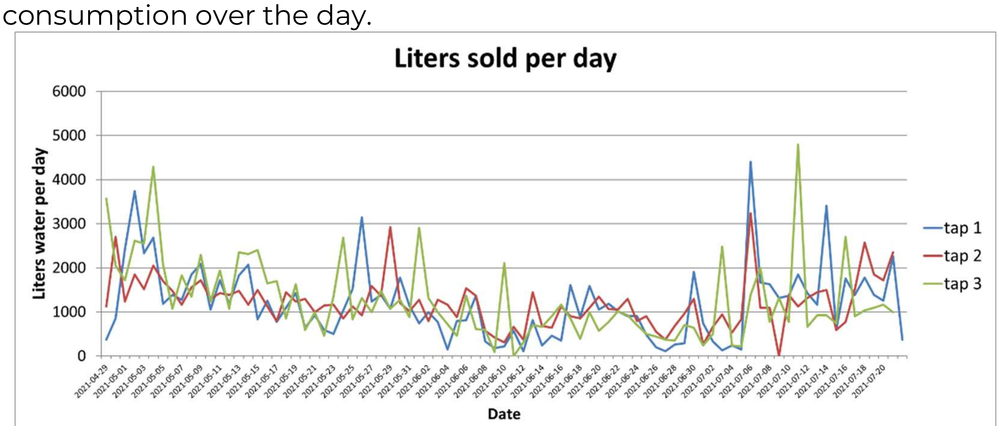
- **At customer level;** the investment per customer is reduced from 20 USD per customer to 12.8 USD per customer. Allowing a greater reach per invested donor dollar. And, even more important from the financial perspective, the operational expenditure needed per capita (see analysis at system level) to maintain the system decreased resulting system that is more likely to be financial sustainability.

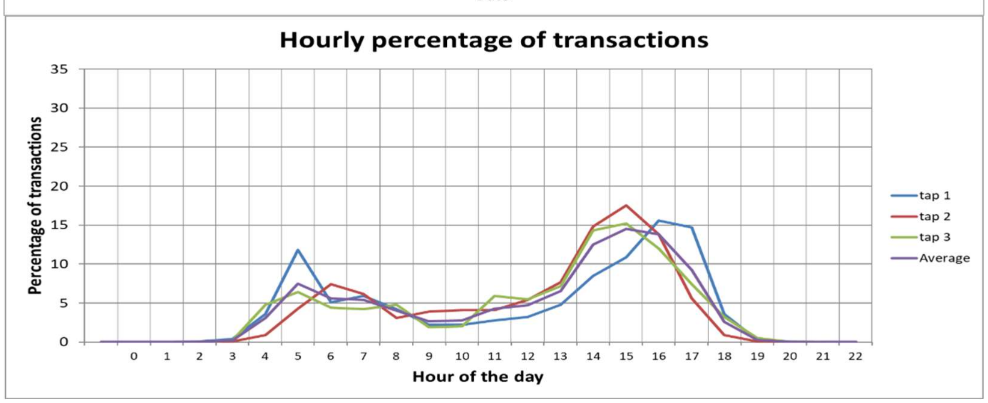
Third hypothesis

'Data-driven and disruptive designs have the ability create more appropriate water infrastructure for rural setting - thereby supporting sustainable hardware implementation'

This hypothesis is particularly applicable for two innovation aspects: the sizing kiosks and the introduction of a novel prepaid system.

The following graphs show the litres sold per kiosk (tap 1-2-3) and distribution of water consumption over the day.





Graphs: water sales (top) and water consumption patterns (bottom)

The graphs show that:

- The consumption pattern as initially expected – being a bathtub shaped form - is not observed in this pilot project. The graph shows distinct peaks, particular at the end of the afternoon, around 15,00 hrs /16,00 hrs. Part of the explanation might be in the fact that it is the wet season. Data suggests that water consumption tend to peak at the afternoon in this season as observed in the data from Uganda.
- The storage capacity does currently not form a technical constrain. Although it seems contradictive to the observation above – it is a result of the fact.
    - Only (in the range of) 15% of the water is sold at a moment where the water production (starting at 7 and ending at 17.00) is lower than the water consumption. The mismatch between production and consumption particularly happens in the morning.
    - The total storage capacity of the system as a whole (3 m^3) is still substantial to the total number of sales (4 m^3/day).
- On the sales peak of a *single* small water kiosk with a storage capacity peaks nearly 4,500 litres – being about the same as the previously expected sales capacity of a large single water kiosk fitted with a 5 m^3 tank.

Lastly, also the TokenTap, being an alternative to electronic prepaid systems, was piloted. The following table shows the opinion of the users of the token tap.

Variable	Classification of variables	%	%
TokenTap rapid survey post-implementation		Post impact (22 May21)	Pre impact (30 March 21)
Opinion TokenTap system	Strongly in favor	80	54.5
	In favor	20	45.5
	Not in favor	0	0

Table: customer satisfaction TokenTap use

As can be seen, the initial scepticism of users at the pre-implementation phase has reduced considerably. With even 80% of the users being strongly in favour of the system.

Further observations during the pilot are as follows:

- The TokenTap behaved as per the design. The main strength of the device is its simplicity: it is easy to install and maintain. This lower complexity is likely to results in lower operational cost. Downside of the simplicity it the loss of more complex functions that come with electronic devices. In particular, RFID technology allows the tracking of consumption behaviour on token level. And allows the consumer to purchase water in different volumes, whereas the TokenTap sales one 22 litre jerry can per token. This, however, did not appeared to have affected water sales.
- Cycle time reported was timed at approximate 1 minute from insertion of token to filling up a 22L bucket - making the theoretical sales volume per hour over 1,300 litres. Meaning, queuing in unlikely to happen with the observed water sales of the kiosks.

- According to the Caretaker observations, the reservoirs consistently supply the expected volume (22L) and pans / buckets are filled to the rim and are therefore perceived as reliable.
- According to the Caretaker the system had not been sabotaged by the villagers and no foreign objects have been used as alternative tokens. Some community members have reported that their tokens were 'stuck' for a short while, but the Caretaker has independently solved those issues.
- Thus far, no incidents of theft of tokens within the community have been reported.
- Improvements could be found in improving in the monitoring box and the data handling. Based on the findings the design of the tracker (both in terms of hard and software) of the TokenTap has been updated and fitted with a small solar panel.

Conclusions and recommendations

Given the observations above, it can be concluded that novel concepts in the right setting:

- *Can increase the uptake of the service and the willingness to pay;*
- *Can help to reduce the entrepreneurial risk and optimize the business case;*
- *And can create more appropriate water infrastructure for rural setting.*

Key in this all is data-driven design and re-evaluate conventional approaches. Yet, this pilot shows only the start of this potential. To fully optimize this potential the following is recommended.

- *Operational expenditure per capita*: while investment cost per capita is a widely used figure in the funding of water infrastructure, the operational expenditure (ideally including capital maintenance expenditure, cost of capital, and support costs) per capita appears to be hardly used. While this figure –in combination with the revenue per capita - is key in the financial and the directly related technical sustainability of water infrastructure. When aiming for a sustainable introduction of hardware it is recommended to strongly focus on this aspect – from idea to design to implementation and operation.

- *Improve uniform performance tracking of infrastructure*: Data is needed to understand what works in the field and what not. This applies to both new and existing infrastructure.

  Systems and communal water points that rely on irregular functionality spot-checks – either in person or digitally - show the tentative functionality results, but do not provide any insight beyond that observation. This common practice does not provide a clear picture on the long-term financial and technical sustainability or causes of possible failure. Nor does it allow a comparison of systems to analysed what works best.

  It is therefore recommended to invest in and focus on uniform and data-rich performance tracking that allows a more in-depth analysis and comparisons of water infrastructure performances, both technically as well as financially; an investment that benefits from a systematic maintenance and service provision scheme to support water point sustainability.

- *Static to dynamic*. Water infrastructure should not be seen as a static. It is recommended to introduce hardware that allows to deal with changes – such as demonstrated in this pilot. Critically, also apply this logic to existing hardware. Previous constructed infrastructure can be optimized by changing layout or design. Thereby capitalizing on already made investments. To allow optimisations, the financial/technical performance tracking of the system is – again – key. Carefully recording the performance of systems can also unlock funding in forms of loans as transparent and uniform data will reduce the risk for loans.

- *Disruptive approaches:* Awareness that disruptive approaches are needed to overcome the current water challenge – and investing in applied action research is as important as reaching the unserved with appropriate concepts at scale.