A multi-criteria assessment of water supply in Ugandan refugee settlements

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SUPPLEMENTARY MATERIAL A

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SM A.1 Ugandan government guidelines for building new water supply systems in refugee settlements in the West Nile region

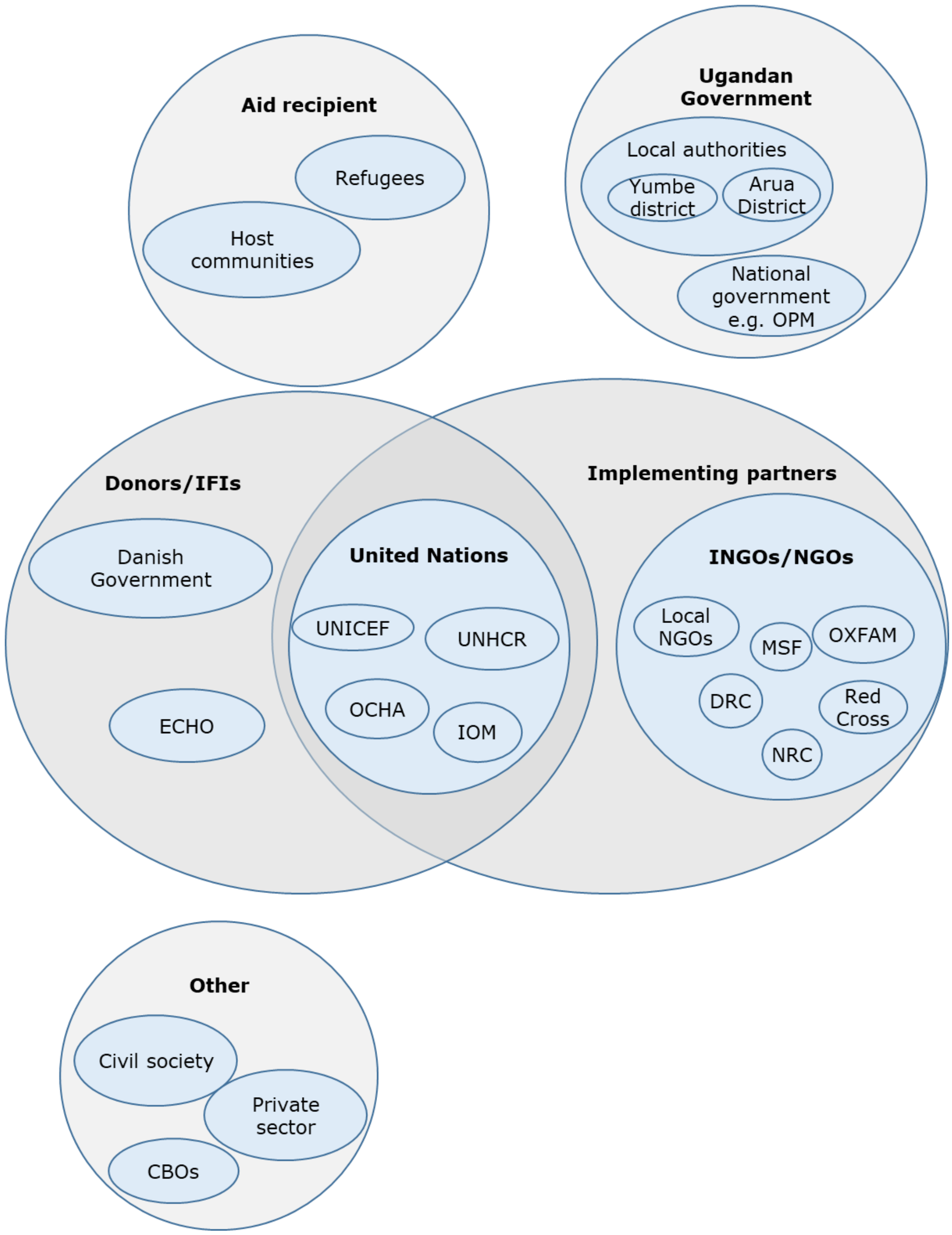
By November 2017, the government of Uganda provided the following guidelines to build new water supply systems in refugee settlements in the West Nile region:

- All the water tanks need to be made of steel instead than HDPE.
- The water production from boreholes should be maximised (if there is a borehole with a high yield, a large system should be implemented).
- The authorities are discouraging drilling of many shallow boreholes and the use of hand pumps. On the contrary, they are encouraging the use of deep wells and the maximisation of the yield found, meaning that hand pump should not be used if the pumping yield is high enough to motorise it. If the NGO does not have the money for motorization, it should make the borehole as a permanent one and then have added a motorised pump when possible.
- The boreholes should be at least 6'' and cased at the bottom.
- In order to avoid over pumping, they are pushing for a constant groundwater monitoring.

SM A.2 Stakeholder mapping and settlements

This annex shows the simplified stakeholders mapping in the emergency situations in Uganda (adapted from UNHCR (2018) Tange (2017) with the support of the Danish Refugee Council).

Generally, UNHCR and the Office of Prime Minister (OPM) are responsible for coordinating humanitarian refugee response in Uganda together with the UN and NGO partners. Furthermore, there are many other key partners in the coordination and funding such as ECHO, the EU Trust Fund, DFiD and the US Department of state. In order to achieve an integrated emergency response, local authorities, relevant line ministries, members of the refugee and host community are also involved [1].



SM A.3 Location of the settlements

Figure 1 and Figure 2 show the location of the West Nile region and of the three settlements mentioned in this study: Bidibidi, Rhino and Imvepi settlements.

Figure 1: Map of Uganda showing the West Nile region [3]

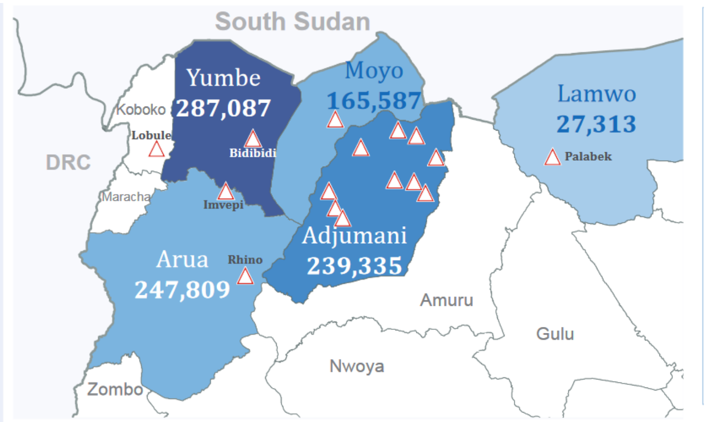


Figure 2: Map of the refugee camps in the North West region that shows the location of Bidibidi, Rhino ad Imvepi settlements.

SM A.4 Pictures of some of the systems – field trip 2017

This paper focused on data mainly collected from three refugee settlements of the North West region of Uganda: Bidibidi located in Yumbe district, Rhino and Imvepi settlement both in the Arua district. This Annex shows the pictures of some sites visited during the field trip in November and December 2017.

Hand pumps

Motorised pumps

Water trucking

Artesian spring

Water storage and distribution

Surface treatment water

SM A.5 Description of the alternatives

Types of pumping systems:

- Hand pump: 0.8 m^3/h used per 12 hours.
- Motorised borehole: modelled with different pumping yields (2, 5, 10, 25, 50 m^3/h) in order to observe conclusions that are independent by the individual technical characteristics (more information on each system can be found in Table 1):
    - Solar powered system, assumed 7 hours of full capacity a day. The cost of one solar panel is between 255 and 355 USD depending on the system.
    - Diesel powered system (short), assumed 7 hours of full capacity a day (meaning that the daily water produced is the same as the solar powered system)
    - Hybrid systems, 7 hours powered by solar energy and 3 hours (for the 2 and 5 m^3/h) and 5 hours (for the 10, 25 and 50 m^3/h) by diesel
    - Diesel powered system (long), pumping assumed 10 hours a day if small yield (2 and 5 m^3/h) and 12 hours a day for all the larger yield. This distinction was made because pumps used in low yield boreholes are not designed to run so many hours in a day.

How were the alternatives modelled?

- The costs for the hand pump and all the solar powered systems were based on real costs for systems that have been designed by DRC in three refugee settlements in Uganda (Bidibidi, Rhino and Imvepi).
- The diesel-powered systems were built respecting the following rules:
    - When running only for 7 hours per day, we assumed the same distribution system (length of the transmission and distribution pipes) as the solar
    - When running for more hours (10 or 12) per day, the distribution system was assumed to be proportional to the quantity of water delivered
    - The costs for the genset were based on the data given by a very common private supplier in the area. The genset synonym of generator set that is used to generate electricity.

Table 1: Summary of the design of the alternatives

Alternative	Pumping yield	Daily time and power for pumping	Pumped water per year	Water pump		Solar panels	Genset		Pipes*	Storage
	[m³/h]		[m³/year]	[kW]	USD	USD	[kVA]	USD	[m]	[m³]
HP	0.8	12h, Manual	2,738	N/A	1,073	N/A	N/A		N/A	
2_S	2	7h, Solar	5,110	SQ 2.5N/A2, 1.4 kW	1,656	4 pc 260 SW	N/A	N/A	300	10
2_Ds	2	7h, Diesel	5,110	〃	〃	N/A	3.5kW/4.4kVA	7,336	300	10
2_Dl	2	10h, Diesel	7,300	〃	〃	N/A	〃	〃	364	10
5_S	5	7h, Solar	12,775	SP 7N/A27, 4 kW	2,732	19 pc 250/300 Wp	N/A	N/A	4,102	40
5_Ds	5	7h, Diesel	12,775	〃	〃	N/A	5.5kW/6.9kVA	7,601	4,102	40
5_H	5	Hybrid: 7h Solar + 3h Diesel	18,250	〃	〃	As solar	〃	〃	5,860	40
5_Dl	5	10h, Diesel	18,250	〃	〃	N/A	〃	〃	5,860	40
10_S	10	7h, Solar	25,550	SP9N/A36, 7.5 kW	4,051	57 pc 250/300 Wp	N/A	N/A	6,140	60
10_Ds	10	7h, Diesel	25,550	〃	〃	N/A	18.8kW/23.4kVA	13,655	6,140	60
10_H	10	Hybrid: 7h Solar + 5h Diesel	43,800	〃	〃	As solar	〃	〃	10,525	60
10_Dl	10	12h, Diesel	43,800	〃	〃	N/A	〃	〃	10,525	60
25_S	25	7h, Solar	63,875	SP30N/A26, 22 kW	11,179	114 pc 250/300 Wp	N/A	N/A	5,383	120
25_Ds	25	7h, Diesel	63,875	〃	〃	N/A	55kW/68.8kVA	20,355	5,383	120
25_H	25	Hybrid: 7h Solar + 5h Diesel	109,500	〃	〃	As solar	〃	〃	9,229	150
25_Dl	25	12h, Diesel	109,500	〃	〃	N/A	〃	〃	9,229	150
50_S	50	7h, Solar	127,750	SP46N/A20, 30 kW	16.163	190 pc 250/260/265/280 Wp	N/A	N/A	7,128	150
50_Ds	50	7h, Diesel	127,750	〃	〃	N/A	75kW/93.8kVA	22,499	7,128	150
50_H	50	Hybrid: 7h Solar + 5h Diesel	219,000	〃	〃	As solar	〃	〃	12,219	250
50_Dl	50	12h, Diesel	219,000	〃	〃	N/A	〃	〃	12,219	250
50_S2	50	7h, Solar	127,750	SP46N/A20, 30 kW	16.163	190 pc 250/260/265/280 Wp	N/A	N/A	2,024	150
50_Ds2	50	7h, Diesel	127,750	〃	〃	N/A	75kW/93.8kVA	22,499	2,024	150
50_H2	50	Hybrid: 7h Solar + 5h Diesel	219,000	〃	〃	As solar	〃	〃	3,470	250
50_Dl2	50	12h, Diesel	219,000	〃	〃	N/A	〃	〃	3,470	250

* Transmission + distribution line

SM A.6 Operation and maintenance data

Conversion rate: 1 UDX = 0.000278 USD.

Hand pump

- Yearly operation and maintenance
  - 1 mechanic every 6 hand pumps
  - Spare parts (30% of the value of the pump)
- Major maintenance
  - Flush of the borehole every 2 years
  - Change of the pedestrian stand every 3 years

Motorized systems

- Yearly operation
  - Guards and attendants
    - 3 pump attendants for small systems (2 and 5 m^3/h)
    - 4 pump attendants and 3 pump guards for large systems (10, 25 and 50 m^3/h)
  - Protective gears for guards
  - Chlorine use (1 mg/l)
  - Cleaning and repainting of the steel tanks (200 USD for a 10-20 m^3 tank, 250 USD for a 40-100 m^3 tank, 500 USD for a 100-150 m^3 tank)
  - Diesel consumption: the cost of diesel in the baseline is 0.834 USD (3,000 UGX)
- Yearly maintenance
  - Genset
    - Every 150 hours, you need to change the oil (5 litres for 2, 5 and 10 m^3/h systems and 10 litres for 25 and 50 m^3/h systems)
    - Every 150 hours, you need to change the oil filter and the diesel filter
    - Every 500 hours you need to change the air filter
  - Generic maintenance solar (20 USD/ month for 2m^3/h, 30 USD/ month for 5 m^3/h, 50 USD/month for 10 m^3/h, 100 USD m^3/month for 25 m^3/h and 200 USD /month for 50 m^3/h)
  - Contingencies (see Table 2 for the actual costs)
- Major maintenance
  - Lifetime of the submersible pump (100% of the capital investment of the pump):
    - 5 years if used 10 or 12 hours per day,
    - 7 (for 2 and 5 m^3/h systems) and 8 years (for 10, 25 and 50 m^3/h) if used only 7 hours per day.
  - Genset
    - Overhaul of the genset (30% of the capital investment for the genset):
      - 5,000 hours for small systems (2 and 5 m^3/h) → 2 years if used 7 hours per day and 1.4 years if used 10 hours per day
      - 7,500 for large systems (10, 25 and 50 m^3/h) → 2.9 years if used 7 hours per day, 1.7 years if used 12 hours per day
    - Lifetime of the genset (100% of the capital investment for the genset):
      - 15,000 hours for small systems (2 and 5 m^3/h) → 5.9 years if used 7 hours per day, 4.1 years if used 10 hours per day
      - 25,000 for large systems (10, 25 and 50 m^3/h) → 9.8 years if used 7 hours per day, 5.7 years if used 10 hours per day
  - Solar panels
    - Replacement of the inverter every 7 years, 100% of the capital investment for the inverter
  - Hybrid systems
    - Replacement of the switch every 5 years, 100% of the capital investment for the switch between solar and diesel

Table 2: Detailed data and costs for O&M

		Pump		Genset					O&M costs		
Name	Pumping yield	Power and hours	Lifetime	Overhaul		Lifetime		Diesel consumption, 75% load	Cleaning and repainting of the tanks	Maintenance solar	Contingencies
	$[m^3/h]$		[years]	Hour	year	Hour	year	l / h	USD / year	USD / month	USD/year
HP	0.8	12h, Manual	-	-	-	-	-	-	-	-	-
2_S	2	7h, Solar	7	-	-	-	-	-	200	20	300
2_Ds	2	7h, Diesel	7	5,000	2	15,000	5.9	1.4	200	N/A	500
2_Dl	2	10h, Diesel	5	5,000	1.4	15,000	4.1	1.4	200	N/A	500
5_S	5	7h, Solar	7	-	-	-	-	-	250	30	400
5_Ds	5	7h, Diesel	7	5,000	2	15,000	5.9	1.4	250	N/A	600
5_H	5	Hybrid: 7h Solar + 3h Diesel	5	5,000	1.4	15,000	4.1	1.4	250	30	600
5_Dl	5	10h, Diesel	5	5,000	1.4	15,000	4.1	1.4	250	N/A	600
10_S	10	7h, Solar	8	-	-	-	-	-	250	50	500
10_Ds	10	7h, Diesel	8	7,500	2.9	25,000	9.8	4	250	N/A	750
10_H	10	Hybrid: 7h Solar + 5h Diesel	5	7,500	1.7	25,000	5.7	4	250	50	750
10_Dl	10	12h, Diesel	5	7,500	1.7	25,000	5.7	4	250	N/A	750
25_S	25	7h, Solar	8	-	-	-	-	-	500	100	750
25_Ds	25	7h, Diesel	8	7,500	2.9	25,000	9.8	10.4	500	N/A	1,000
25_H	25	Hybrid: 7h Solar + 5h Diesel	5	7,500	1.7	25,000	5.7	10.4	500	100	1,000
25_Dl	25	12h, Diesel	5	7,500	1.7	25,000	5.7	10.4	500	N/A	1,000
50_S	50	7h, Solar	8	-	-	-	-	-	500	200	1,200
50_Ds	50	7h, Diesel	8	7,500	2.9	25,000	9.8	14	500	N/A	1,800
50_H	50	Hybrid: 7h Solar + 5h Diesel	5	7,500	1.7	25,000	5.7	14	750	200	1,800
50_Dl	50	12h, Diesel	5	7,500	1.7	25,000	5.7	14	750	N/A	1,800
50_S2	50	7h, Solar	8	-	-	-	-	-	500	200	1,200
50_Ds2	50	7h, Diesel	8	7,500	2.9	25,000	9.8	14	500	N/A	1,800
50_H2	50	Hybrid: 7h Solar + 5h Diesel	5	7,500	1.7	25,000	5.7	14	750	200	1,800
50_Dl2	50	12h, Diesel	5	7,500	1.7	25,000	5.7	14	750	N/A	1,800

SM A.7 System component: which activities and processes are included?

Table 3 describes which activities and processes are included in each system component for both hand pumps and motorised systems.

Table 3: Explanation of which processes are included in each system component

	Hand pump	**Motorised system**
Borehole	Hydro-geological investigation, drilling the borehole (6’’), borehole drilling, pipes screen casting, cement grouting, gravel park, compressor, concrete	Hydro-geological investigation, drilling the borehole (6’’ if low yield, 8’’ if high yield), borehole drilling, pipes screen casting, cement grouting, gravel park, compressor, concrete
Site	Hand pump platform (including pedestal)	Concrete platform, construction of the security fence, chain link, gate, columns, guard’s house, generator cage (if diesel powered or hybrid), water borne toilet, dosing house,
Pump	Hand pump and stainless-steel pipes and rods	Submersible pump, chlorination system, power supply system (if solar powered system, including solar panels, metallic structure and inverter), genset (if diesel powered system) and switch between the two systems (if hybrid).
Distribution and storage		Excavation and pipe laying for transmission and distribution line, taps, steel storage tanks.

SM A.8 Questionnaire for the end-user survey

A questionnaire was designed in collaboration with DRC to understand the context related to the use of water by the South Sudanese refugees in Uganda. In May 2017, 400 households in Zone 1 of the Bidibidi settlement were surveyed as a representative sample for the total population of 51,000 people in that zone. A draft questionnaire was tested and adjusted for the final survey, based on three household visits. After adjustment, 16 enumerators conducted each 25 surveys among households in different villages of zone 1. These enumerators all had experience with executing a survey and were familiar with the survey format. Before executing the survey, two training sessions were held to ensure a uniform understanding of the questions and agreement on the translation into Arabic. The survey included the topics: demographics data and each household's water source; quantified water demand, water collection means, water use patterns; perceived quality of water, time spent at the pump; distance and time spent in travelling to and from the household to the water source. Results were compiled into a spreadsheet file for data processing, especially regarding the statistical significance of the results for different water sources.

Table 4 shows the original form of the end user survey.

Table 4: Original form of the end user survey.

1. Introduce your **NAME, REASON** for the **ASSESMENT** and mention that the beneficiary should be honest and there is **NO MONETERY/INCENTIVE/REGISTRATION** benefit from the discussion/session.
2. Ask for **PERMISSSION** to continue with the questions
3. **DO NOT** make any promises/commitments, simply mention that you are just collecting data
4. Only mention the options if it is stated in the question, or if no answer is given
5. You can always check off more options if nothing else is stated in the question
6. **Thank the beneficiary** after finishing the questionnaire.

Interviewer / team no:									
Location		**Zone**____________ **Village**____________ **Block**____________							
Headed House Hold Male/Female/Child	**Total people in household**	**Total**		**0-18 yrs.**		**19-59 yrs.**		**60 + yrs.**	
		M	F	M	F	M	F	M	F

N°	**Question and Filter**	**Answers**
1.	Who collects the water	**Man** ☐ **Woman** ☐ **Children** ☐
2.	Where do you get your water?	☐ **Tap stand tank (trucking)** ☐ **Tap stand** ☐ **Handpump** ☐ **Surface water (pond or river)**
3.	How many jerrycans do you collect per day? (Fill in number of jerrycans used to collect water) Can I see the type of jerrycans that you use?	**< 5 l** ________________ **10 l** ________________ **20 l** ________________ **>20 l** ________________
4.	How far do you walk to the water source?	**<u>Answer provided in meters:</u>** ☐ **Less than 500 m** ☐ **Between 500m and 1km** ☐ **More than 1km** **<u>Answer provided in minutes:</u>** ☐ **Less than 15 minutes** ☐ **Between 15 and 45 minutes**

		☐ **More than 45 minutes**
5.	How much time do you spend waiting at the water point?	☐ **Less than 5 minutes** ☐ **Between 5 and 30 minutes** ☐ **Between 30 and 60 minutes** ☐ **More than 60 minutes**
6.	When do you need the most water? (Only check one option)	☐ **Morning** ☐ **Afternoon** ☐ **Evening** ☐ **Night**
7.	When do you collect the water? (Only check one option)	☐ **Morning** ☐ **Afternoon** ☐ **Evening** ☐ **Night**
8.	How is the quality of the water?	☐ **Good** ☐ **Bad, it smells** ☐ **Bad, it tastes like chlorine** ☐ **Bad, it looks dirty** ☐ **Bad: ________________________________ (fill in)**
9.	What do you use the water for?	☐ **Drinking** ☐ **Cooking** ☐ **Cleaning (household)** ☐ **Personal hygiene** ☐ **Washing cloth** ☐ **Farming (growing crops)** ☐ **Farming (breeding animals)** ☐ **Construction materials (bricks, clay…)** ☐ **Other uses: ___________________________ (fill in)**
10.	Do you have enough water	☐ **Yes** ☐ **No**
11.	If the answer is no: Why don't you have enough water?	☐ **There is not enough water at my water source** ☐ **It is too difficult to pump the water** ☐ **It is too hard to carry the water** ☐ **We don't have enough containers to either store or carry water** ☐ **The water is not good (taste, smell, quality)** ☐ **The water source is too far** ☐ **The waiting time is too long** ☐ **We don't feel safe going to the water point** ☐ **Other: _________________________________ (fill in)**
12.	If you had more water, what would you use it for?	☐ **Drinking** ☐ **Cooking** ☐ **Cleaning (household)** ☐ **Personal hygiene** ☐ **Washing cloth** ☐ **Farming (growing crops)** ☐ **Farming (breeding animals)** ☐ **Construction materials (bricks, clay…)** ☐ **Other uses: ___________________________ (fill in)**
13.	How much water do you need? (Fill in number of jerrycans the user needs)	**< 5 l ________________** **10 l ________________** **20 l ________________** **>20 l ________________**

LIVELIHOOD		
14.	What is your main source of income for the household?	☐ **Selling food/animals** ☐ **Selling products/items** ☐ **Pastoral** ☐ **Brewing and selling alcohol** ☐ **Irregular labour for NGOs** ☐ **Irregular labour to community (e.g. farming for others, washing cloth, construction…)** ☐ **Regular employment** ☐ **None**
15.	What was your main source of income before becoming a refugee?	☐ **Selling food** ☐ **Selling products/items** ☐ **Pastoral** ☐ **Irregular labour (e.g. farming for others, washing cloth, construction…)** ☐ **Regular employment** ☐ **None**
16.	What do you need to become self-reliant/independent?	☐ **More water** ☐ **Regular employment** ☐ **More land for farming/animals** ☐ **Better access to trading/market** ☐ **Education/training** ☐ **Electricity** ☐ **Better housing** ☐ **Other: ________________________________ (fill in)**

SM A.9 Mathematical equations used in the Life cycle costing

Net Present Value (NPV)

The Net Present Value or Present Worth is used in economy to compare expenditures and revenues that happen in different times and to quantify the fact that "a dollar today is better than a dollar tomorrow". The unit of NPV is the currency used during the analysis, in this case USD. Equation 1 illustrates how NPV was calculated for the different timeframes without assuming any revenues. In the paper, we modelled 10 different timeframes (or years of operation): from 1 to 10 years.

Equation 1: Net Present Value (NPV), where E_t is the expenditure at year t, i is the discount rate, t the time and N is the defined timeframe

$$NPV_{(i,t)} = \sum_{t=1}^{N} \frac{E_t}{(1+i)^{(t-1)}}$$

When the discounting rate is equal to 0%, NPV just indicates the cumulative total costs of the systems for the timeframe i (Equation 2). This means that the cumulative costs of a system at the year 2 is calculated by summing all the cost of the first and the second year. Table 5 and Table 5: Example of calculation of the NPV for different timeframes.

Timeframe	How the NPV was calculated
N=1 → 1st year	$NPV_{(0\%,\ t)} = \sum_{t=1}^{1} \frac{E_t}{(1+i)^{(t-1)}} = \frac{E_1}{(1+0)^{(1-1)}} = E_1$
N=2 → 2nd year	$NPV_{(0\%,\ t)} = \sum_{t=1}^{2} \frac{E_t}{(1+i)^{(t-1)}} = \frac{E_1}{(1)^{(1-1)}} + \frac{E_2}{(1)^{(1-2)}} = E_1 + E_2$
N=3 → 3rd year	$NPV_{(0\%,\ t)} = \sum_{t=1}^{3} \frac{E_t}{(1+i)^{(t-1)}} = \frac{E_1}{(1)^{(1-1)}} + \frac{E_2}{(1)^{(1-2)}} + \frac{E_3}{(1)^{(1-3)}} = E_1 + E_2 + E_3$

Table 6 shows the simplified calculation for the first 3 years of operation with a discount rate equal to 0%.

Equation 2: NPV calculation in case the discounting factor is 0%, where t is the time

$$NPV_{(0\%,\ t)} = CAPEX + \sum_{t=1}^{N} (OPEX)_t$$

Table 5: Example of calculation of the NPV for different timeframes.

Timeframe	How the NPV was calculated
N=1 → 1st year	$NPV_{(0\%,\ t)} = \sum_{t=1}^{1} \frac{E_t}{(1+i)^{(t-1)}} = \frac{E_1}{(1+0)^{(1-1)}} = E_1$
N=2 → 2nd year	$NPV_{(0\%,\ t)} = \sum_{t=1}^{2} \frac{E_t}{(1+i)^{(t-1)}} = \frac{E_1}{(1)^{(1-1)}} + \frac{E_2}{(1)^{(1-2)}} = E_1 + E_2$
N=3 → 3rd year	$NPV_{(0\%,\ t)} = \sum_{t=1}^{3} \frac{E_t}{(1+i)^{(t-1)}} = \frac{E_1}{(1)^{(1-1)}} + \frac{E_2}{(1)^{(1-2)}} + \frac{E_3}{(1)^{(1-3)}} = E_1 + E_2 + E_3$

Table 6: Example of calculation of the NPV for different timeframes when considering capital expenditures (CAPEX) and operation and maintenance expenditures (OPEX)

Timeframe	How the NPV was calculated
N=1 → 1st year	$NPV_{(0\%,\ t)} = CAPEX_1 + \sum_{t=1}^{1} \frac{OPEX_t}{(1+i)^{(t-1)}} = \frac{OPEX_1}{(1+0)^{(1-1)}} = CAPEX + OPEX_1$
N=2 → 2nd year	$NPV_{(0\%,\ t)} = CAPEX_1 + \sum_{t=1}^{2} \frac{OPEX_t}{(1+i)^{(t-1)}} = CAPEX + \frac{OPEX_1}{(1)^{(1-1)}} + \frac{OPEX_2}{(1)^{(1-2)}} = CAPEX + OPEX_1 + OPEX_2$
N=3 → 3rd year	$NPV_{(0\%,\ t)} = CAPEX_1 + \sum_{t=1}^{3} \frac{OPEX_t}{(1+i)^{(t-1)}} = CAPEX + \frac{OPEX_1}{(1)^{(1-1)}} + \frac{OPEX_2}{(1)^{(1-2)}} + \frac{OPEX_3}{(1)^{(1-3)}}$ $= CAPEX + OPEX_1 + OPEX_2 + OPEX_3$

Unit NPV or NPV per m^3 of water

In order to compare water supply systems with a different water demand, we calculated the NPV per m^3 of water delivered. This parameter indicates how much a certain quantity of water (e.g. m^3) should cost to the final consumer in order to achieve cost recovery after a certain amount of time (the timeframe) while considering the discount rate for both expenses and earnings. Full cost recovery means that in each timeframe the sum of the expenditures (CAPEX and OPEX) is equal to the sum of revenues (potential fees consumers have to pay for each m^3 of water) (Equation 3). The unit NPV of water is the same concept as levelized water cost (LWC) in Parajuli et al. (2014).

Equation 3: Unit cost or unit NPV, where E_t is the expenditure at year t, R_t is the revenue at year t i is the discount rate, t the time and N is the defined timeframe

$$\sum_{t=1}^{N} \frac{R_t}{(1+i)^{(t-1)}} = \sum_{t=1}^{N} \frac{E_t}{(1+i)^{(t-1)}} \rightarrow \sum_{t=1}^{N} R_t = \sum_{t=1}^{N} \frac{E_t}{(1+i)^{(t-1)}} * \sum_{t=1}^{N} (1+i)^{(t-1)} \rightarrow$$

$$\left[\frac{USD}{m^3}\right] * m3\ delivered = NPV_{(i,N)} \rightarrow \frac{NPV_{(i,N)}}{m^3} = \frac{\sum_{t=1}^{N} \frac{E_t}{(1+i)^{(t-1)}}}{\sum_{t=1}^{N} \frac{m_t^3}{(1+i)^{(t-1)}}}$$

When the discounting rate is equal to 0%, the unit NPV just indicates the cumulative total costs of the systems for the timeframe N divided the total amount of water produced in the entire timeframe N (Equation 4). This means that the unit NPV at year 5 is simply the ratio between the sum of all the costs from year 1 to year 5 and the sum of the water delivered in the 5 years. Table 7 shows the simplified calculations for the first 3 years of operation with a discount rate equal to 0%.

Equation 4: Unit cost (or unit NPV) NPV calculation in case the discounting factor is 0%

$$\frac{NPV_{(0\%,\ i)}}{m^3} = \frac{\sum_{i=1}^{N} (CAPEX + OPEX_i)}{\sum_{i=1}^{N} (water\ delivered)_i}$$

Table 7: Example of calculation of the NPV for different timeframes when considering capital expenditures (CAPEX) and operation and maintenance expenditures (OPEX)

Timeframe	How the unit NPV was calculated
N=1 → 1st year	$unit\ NPV_{(0\%,\ t)} = \frac{CAPEX + OPEX_1}{water_1}$
N=2 → 2nd year	$unit\ NPV_{(0\%,t)} = \frac{CAPEX + OPEX_1 + OPEX_2}{water_1 + water_2}$
N=3 → 3rd year	$unit\ NPV_{(0\%,\ t)} = \frac{CAPEX + OPEX_1 + OPEX_2 + OPEX_3}{water_1 + water_2 + water_3}$

SM A.10 Water rates in the West Nile region

The following water rates were found in the West Nile region during the field trip (with a conversion rate of 0.000278 USD/UGX) and assuming that 1 m^3 of water = 40 jerrycans:

- Between 0.28 and 0.56 USD (1,000 to 2,000 UGX) per month per household in some rural areas with hand pumps. It means between 0.124 0.248 USD / m^3 (or between 444 and 888 UGX per m^3) assuming 15 l/person/day and 5 persons/household
- Between 0.556 – 0.834 USD (2,000 to 3,000 UGX) per m^3 in some rural areas with motorised systems
- Between 0.556 – 0.973 USD (2,000 to 3,500 UGX) per m^3 in the city of Arua
- Around 0.0278 USD (100 UGX) per jerrycan in Arua equal to 1.11 USD (4,000 UGX) per m^3
- 0.14 USD (500 UGX) per jerrycan in the town of Yumbe equal to 5.56 USD per m^3 (20,000 UGX) per m^3
- Between 0.14 to 0.28 USD (500 and 1,000 UGX) per month per household in the Lobule settlement that host Congolese refugees. The settlement is already few years old. → Between 0.062 - 0.124 USD (222 and 444 UGX) per m^3 assuming 15l/person/day and 5 persons/household

SM A.11 Life cycle inventory of the carbon footprint

This annex describes which processes were included in the carbon footprint analysis and the comparison between the data available in the carbon footprint and the Life Cycle Costing. The majority of alternatives have similar processes that have been modelled based on the ecoinvent database (Table 8). The following paragraphs illustrate the detailed life cycle inventory for the carbon footprint.

Table 8: how did we model some of the process common to the majority of alternatives.

Process	How did we model the process
Low-alloyed steel: fencing of the site, roof of the generator plinth and of the guards' house, structure of the solar panels, steel storage tank, structure for the storage tank	ecoinvent process: "steel production, low-alloyed, hot rolled; RoW"
Stainless steel: hand pump, motorised submersible pump,	ecoinvent process: "steel production, chromium steel 18/8, hot rolled, RoW"
Cement and concrete production	ecoinvent process: "unreinforced concrete production, with cement CEM II/A; RoW"
Gravel production	ecoinvent process: "market for gravel, crushed, RoW"
PVC pipes production	ecoinvent process: "extrusion production, plastic pipes; RoW" + "polyvinylchloride production, suspension polymerisation"
inverter production	ecoinvent process: "inverter production, 2.5kW; RoW". We assumed a linear relationship between the size of the inverter and its environmental impact (to model a 5.5 kW inverter we just multiplied the process per 2).
Genset production	"diesel-electric generating set production 18.5 kW, RoW". We assumed a linear relationship between the size of the Genset and its environmental impact (to model a 9 kW genset, we just divided the process per 2).
HDPE pipes production	ecoinvent processes: "Polyethylene production, high density, granulate; RoW" + "Extrusion production, plastic pipes; RoW".
Chlorine production for the diesel genset	ecoinvent processes: "sodium hypochlorite production, product in 15% solution state; RoW"
Oil production for the diesel genset	ecoinvent processes: "lubricating oil production; RoW"

Hand pump

LCA	Sources LCA	LCC
	Construction	
Borehole drilling		
N/A*		Performance bond Hydro-geophysical investigation
N/A*		Setting up and dismantling at every site
Diesel for boring: 1.75 l / m	Diesel consumption based on [5]	Drilling from 0-25m overburden; from 25-50m fractured zone or hard rock; from 50-75m fractured zone or hard rock.
PVC pipes with a density of 3.5 kg/m (process: production PVC from suspension + extrusion pipes): 60m + 0.6 m	Length consistent with the LCC. Average density between Schedule 40 = Schedule 80. [6]	Screen casings and plain casing
Assumed the cement grouting is used in the first 3m of the borehole (H = 3m) and thick 10 cm. The borehole of the hand pump is 6''.	Assumption based on similar borehole drilling.	Cement grouting
Gravel 1,200 kg	Quantity consistent with the LCC	Gravel park 100 kgx12
N/A*		Casting of sanitary seal

N/A*		Well development using development compressor.
N/A*		4 hours aquifer test pumping of constant discharge.
N/A*		Water quality analysis in a Government lab and on site.
Site		
Concrete platform with a diameter of 1 m with a high of 0.2 m + additional 0.2 m^3 (for the place where people stand to use the pump + short drainage system). Unreinforced concrete, with cement CEM II/A	Dimensions based on the field trip.	Construction of hand pump platform (concrete mix 1:2:4) including the installation of pedestal.
Pump		
15 kg of low-alloyed steel	Data collected during the field trip	u- 2 hand pump complete with above mount supper structure**.**
25 kg stainless steel pipes (chromium steel 18/8)	Data collected during the field trip	32mm stainless steel pipes and rods of 3m length
Distribution and storage		
-		-
	Operation & Maintenance	
Yearly maintenance		
N/A*		Salary for the hand pump mechanics
30% of the low-alloyed steel of the pump + 30% of the rods	30% consistent with the LCC	Spare parts (equal to 30% of the capital investment of the hand pump)
Capital maintenance (every 3 years)		
N/A*		Flush of the borehole
20% of the low-alloyed steel of the pump	20% consistent with the LCC	Change of the pedestrian stand

N/A* covers activities that are negligible in the carbon footprint

Motorised pumps

LCA	Sources LCA	LCC
	Construction	
Borehole drilling		
As in the hand pump, but with a depth of 75m and a borehole diameter of 8''	Consistent with the LCC.	As in the hand pump, but with a depth of 75m and a borehole diameter of 8''
Site		
Concrete pump platform: 3mx2.5mx0.2m around the borehole + additional 0.2 m^3 (for the place where people stand to use the pump + short drainage system).	Based on the construction design of the 2 m^3/h systems in Bidibidi settlement.	Construction of the pump platform.
• <u>For the 2 m^3/h systems:</u> Steel zinc coated net (2m high x 39.2m long) + 16 metallic posts to support the net (4.5 kg/post) = 310 kg unalloyed steel the net with a unitary weight if 4.5 kg / post • <u>For all the other diesel systems:</u> the site was assumed to be double than the one for the 2 m^3/h systems (620 kg of steel for the fencing) • <u>For all the solar and hybrid system:</u> the size of the site was based on the 2 m^3/h and assumed to be proportional to the number of solar panels.	Length of the metallic fencing from the construction design of the 2 m^3/h systems in Bidibidi settlement. Weight of the metallic fence was 3 kg/m^2 [7]. The weight of the metallic post was 4.5 kg per post [8]	Metallic fencing
Guards' house: assumed a building of 8 m^2: 9.4 m^3 cement + 14.4 m^2 of corrugated iron for the roof (modelled as low alloyed steel + zinc for the coating) – present in all the systems but the 2 m^3/h	Designed based on similar buildings visited during the field trip.	Guards' house

IF DIESEL		
Plinth for the generation: assumed a building of 8 m^2: 9.4 m^3 cement + 14.4 m^2 of corrugated iron for the roof (modelled as low alloyed steel + zinc for the coating) – present in all the systems but the 2 m^3/h	Designed based on similar buildings visited during the field trip. Assumed to be the same as the guards' house.	Plinth for the generator
Pump		
Stainless steel (chromium steel 18/8)	Weight based on the technical specification of the pump	Submersible pump
N/A*		PVC pipe riser and pipe discharge
N/A*		Automatic chlorine dosing
2 kg of generic electronic components	Assumed	Control unit, switch box, antenna, array to box, etc.
IF SOLAR		
Solar panels. Each solar panel has a dimension of 1.7m^2	Number of panels and dimensions based on the information given in the LCC. Dimensions of the panels based on the SW 260: 17 m^2/panel [9]	Solar panels
Inverter	Consistent with the LCC.	Inverter
Structure for the solar panels. Assumed 100kg / kW	Assumed based on similar designs	Structure for solar panels
IF DIESEL		
Genset	Consistent with the LCC.	Genset
Distribution and storage		
Low alloyed steel for the steel storage tank. The weight of the tank was calculated having an average density of 7,740 kg/m^3 and a thickness of 6 mm. The tanks were designed as following: • 10 m^3 as a cylinder (H: 2m, diameter of the base: 2.32m) • 40 m^3 as a parallelepiped (L: 5m, D: 4m, H: 2m) • 60 m^3 as a parallelepiped (L: 6m, D: 5m, H: 2m) • 120 m^3 as a parallelepiped (L: 8m, D: 5m, H: 3m) • 150 m^3 as a parallelepiped (L: 10m, D: 5m, H: 3m)	Density of steel as an average of stainless steel found in literature [10]	Steel storage tank
The structure for the steel tower was designed based on similar structures. The following structures were modelled for the study: • Structure for the 10 m^3 storage tank: 8m height; tot 2,566 kg • Structure for the 40 m^3 storage tank: 10m height; tot 9,035 kg • Structure for the 60 m^3 storage tank: 10m height; tot 9,035 kg • Structure for the 120 m^3 storage tank: 12m height; tot 13,213 kg • Structure for the 150 m^3 storage tank: 12m height; tot 17,516 kg	Based on similar structure visited	Structure of the steel storage tank
0.19 l diesel/m^3 excavated. The dugs are 1 m deep and 0.40 m large.	The dimensions of the dug are based on sites visited during the field trip. The diesel consumption was an average	Excavation of trenches for the distribution + transmission lines

	of values found in literature [11].	
HDPE pipes with a density of 0.45 kg/m	Density of HDPE pipes. 0.45 kg/m [12]	Supply and installation of transmission and distribution pipes
N/A*		Water meters
Concrete structure for the taps: 2m x 1.5m x 0.3m for the platform + 0.2 m^3 for the drainage Neglected the steel for the taps.	Dimensions based on taps visited during the field trip	Concrete structure for the taps x2
Operation & Maintenance		
Yearly maintenance		
1 mg/l of sodium hypochlorite per litre of water treated	Based on the field trip	Chlorine
N/A*		Payment of pump attendants and guards
N/A*		Cleaning and repainting of steel tanks
N/A*		Generic maintenance
N/A*		Contingencies
IF DIESEL		
Yearly diesel consumption including the impacts due to the production of diesel and the emissions during the combustion in the Genset (Table 9).	Consistent with the LCC	Diesel consumption
Yearly oil consumed with a density of 0.882 g/ml	Consistent with the LCC. Density of the oil 0.882 g/ml [13]	Oil consumption
N/A*		Oil filter, diesel filter and air filter
Capital maintenance		
stainless steel	Consistent with the LCC. Same quantity as needed for an original pump	Pump replacement
IF SOLAR		
New inverter	Consistent with the LCC	Inverter replacement, every 7 years
IF DIESEL		
Genset overhaul: 30% of a new Genset	Consistent with the LCC	Genset overhaul
Genset replacement: 100% new Genset	Consistent with the LCC	Genset replacement

N/A* covers activities that are negligible in the carbon footprint

Direct emissions of diesel combustion in the diesel genset

The emissions of diesel combustion in the genset are based on the data for a diesel generator set of an average power of 35 kW and an average load factor of 0.5 [14]. The emissions per litre of fuel are assumed to be the same in all the alternatives (Table 9).

Table 9: Average emissions of Generator sets per litre of diesel, diesel in Finland in 2016 [14]

Substance		Quantity [g/l fuel]
Carbon monoxide	CO	17
Hydrocarbons	HC	5
Nitrogen oxides	NO_x	25
Particulate matter	PM	2.2
Methane, fossil	CH_4	0.15
Dinitrogen monoxide	N_2O	0.043
Sulphur dioxide	SO_2	0.0081
Carbon dioxide, fossil	CO_2	2,656

Water truck

The emissions of diesel combustion in a water truck were modelled as a EUR III, semi-trailer, gross vehicle mass, urban driving fully loaded [14]. The emissions of heavy metals were based on a EURO III truck present in the EASETECH database. The emissions per tkm are assumed to be the same in all the alternatives.

The emissions per litre of fuel are assumed to be the same in all the alternatives (Table 10).

Table 10: Average emissions to air of "Semi trailer combination - Gross vehicle mass 40t, pay load capacity 25t - Urban driving, streets" [15]

Name	Amount	Unit	Comment
Nitrogen oxides	0.50	kg / tkm	from LIPASTO
Sulphur dioxide	0.00023	kg / tkm	from LIPASTO
Carbon monoxide, fossil	0.062	kg / tkm	from LIPASTO
Hydrocarbons, aliphatic, alkanes, unspecified	0.025	kg / tkm	from LIPASTO
Carbon dioxide, fossil	67	kg / tkm	from LIPASTO
Arsenic	3.53E-13	kg / tkm	EASETECH database
Cadmium	1.68E-13	kg / tkm	EASETECH database
Chromium	5.56E-12	kg / tkm	EASETECH database
Copper	2.52E-10	kg / tkm	EASETECH database
Nickel	4.45E-12	kg / tkm	EASETECH database
Lead	1.56E-11	kg / tkm	EASETECH database
Selenium	1.18E-12	kg / tkm	EASETECH database
Zinc	6.22E-10	kg / tkm	EASETECH database
Particulates, < 2.5 um	0.011	kg / tkm	from LIPASTO
Methane, fossil	0.0011	kg / tkm	from LIPASTO
Dinitrogen monoxide	0.00036	kg / tkm	from LIPASTO

SM A.12 Hazard Analysis Critical Control Point (HACCP) approach

The Hazard Analysis Control Point (HACCP) approach is a systematic preventive approach developed in the 1970s by the World Health Organisation (WHO) and used for decades to ensure food safety. HACCP has been applied on drinking water production in 1994 in Havelaar (1994). HACCP leads “process control away from end-point testing and towards control of the critical operations earlier in the process” by emphasizing the importance of not relying only on treatments as a barrier to water contamination [17]. HACCP could be performed both by NGOs (e.g. DRC) or responsible for the refugee settlements (e.g. local authorities in Uganda) to find where the major risks are. HACCP is composed originally of 7 steps: 1) conduct a hazard analysis, 2) determine the Critical Control Points (CCPs), 3) establish critical limits, 4) a monitoring system, 5) corrective actions for when a CCP is not under control, 6) verification procedures and 7) documentation. All the alternatives can be grouped in three large groups: hand pump, motorised systems with distribution piping, water trucking. This paper analyses the main risks and the Critical Control Points.

SM A.13 Results from the end-users survey

Table 11 summarises the main findings of the end user survey for each question in the questionnaire. *Figure 3* to Figure 19

Table 11: Results of the end users survey

Object	**Results and comments**
Gender and age of the interviewees	The interviewees were 46% male and 54% female (Figure 3) and 67% of the interviewees were less than 19 years old (Figure 4). These results well represent both the distribution of gender and age in Bidibidi settlement, where 53% of the refugees are female and 71% is between 0 and 17 [18]
Responsible for collecting water	Women (68%) and children (26%) (Figure 5).
Source of income of refugees	The majority of refugees don't have any source of income or earn some money by selling food and animals (Figure 6).
When do people use and collect water	The great majority of the people use and collect water in the morning for various reasons – i.e. temperature of the day or water supply (Figure 7). This peak demand could put pressure on the water system.
Water source	31% at a handpump, 27% at a tap stands supplied by water trucking and 42% at a tap stand supplied by a motorised system (solar or diesel) (Figure 8)
Water accessibility	Large variability. Almost 50% states to have less than the minimum of 15 litres per person per day as is required by the Sphere standards (Figure 9). 3 out of 4 households express they would like more water than is currently supplied. The average is 17.9 (similar to the results found in UNOPS 2017) and the median is 16
Quality of water	Only half of the interviewees think that the water is of good quality (Figure 11). Chlorine is the major issue for 20% of the refugees that are using tap stands – supplied by trucking or generators. This indicates that there is either too much chlorine in the water, or not enough awareness concerning chlorine. Other reasons like the colour of the water and the presence of salt take up between 30 and 45% of the interviewees per type of pump.
Waiting time at the water source	55% of the people declared to wait for more than 60 min at the water source (Figure 12 and Figure 13), longer than required by the Sphere standards – there is no significant difference between the type of pumps.
Distance from household to a water source	Only 60% of the refugees state to live within the minimum standard of 500m from a water source (Figure 14 and Figure 15). As it is hard for some refugees to estimate the distance, they were also allowed to express distance in time (Figure 16 and Figure 17). Interpreting the data of the distance between the household and the water source is a challenge – since their walking speed remains also an estimation. For this survey the walking speed in the specific context and with jerry cans is set at 2 km/h.
Reasons for an insufficient amount of water	The three major reasons for the insufficient amount of water cover 75% of the answers (Figure 10): not enough jerry cans to either store or carry the water, too long queuing times and not enough water at the source. Naturally, physical labour is only an issue for the hand pump.
Comparison between desired and current use of water	Refugees wish to use more water for farming - growing crops and breeding animals - and construction materials (Figure 18).
Wished livelihood opportunities	The most common wished livelihood opportunities in order to become self-reliant are: demand for more education, more land for farming and animals, a better access to markets for trading. The top 4 is completed with the demand for more water (Figure 19).

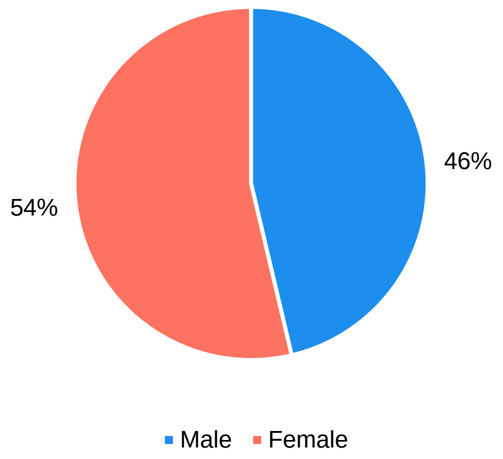


Figure 3: Gender of the sample group

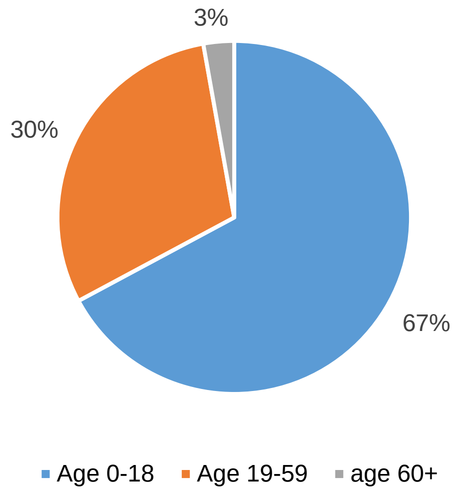


Figure 4: Age of the sample group

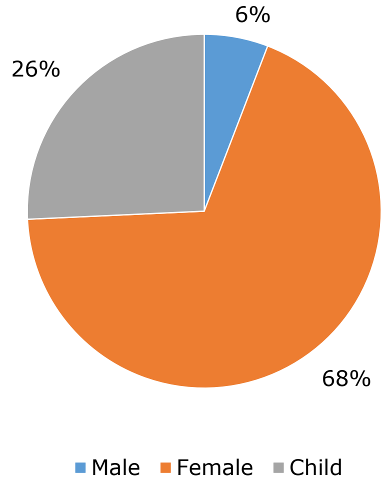


Figure 5: Work division of the sample group

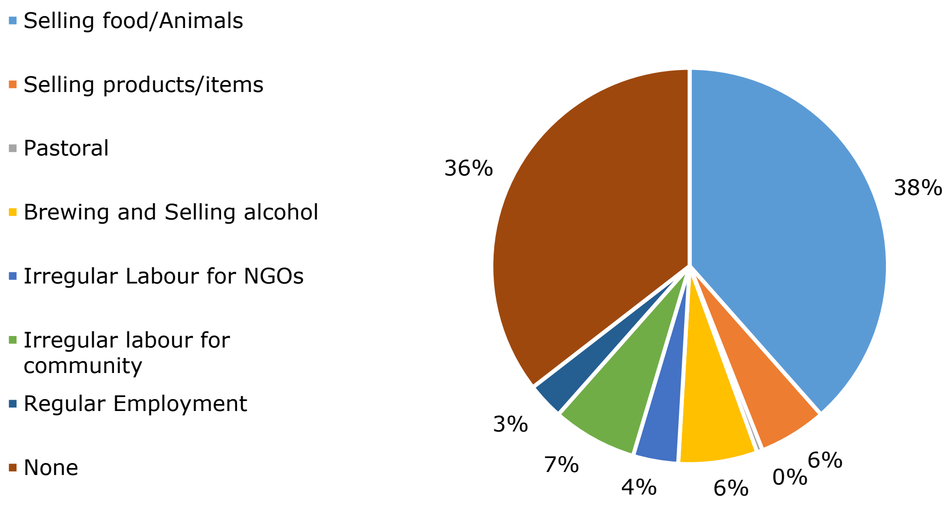


Figure 6: Main source of income for the households

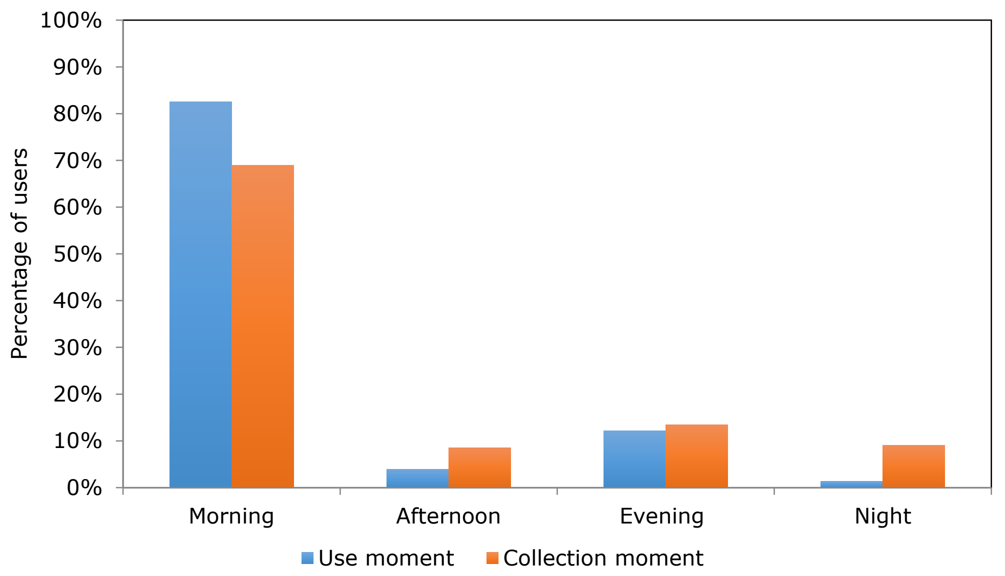


Figure 7: Water collection and use moment of the refugees

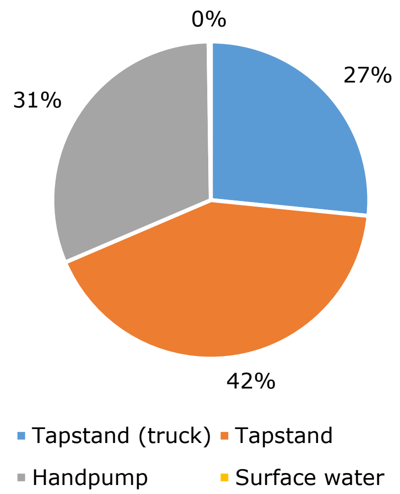


Figure 8: Type of water source

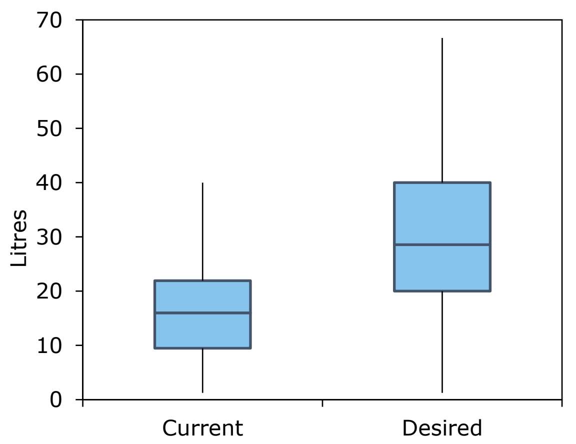


Figure 9: Boxplot of the amount of water declared per person per day

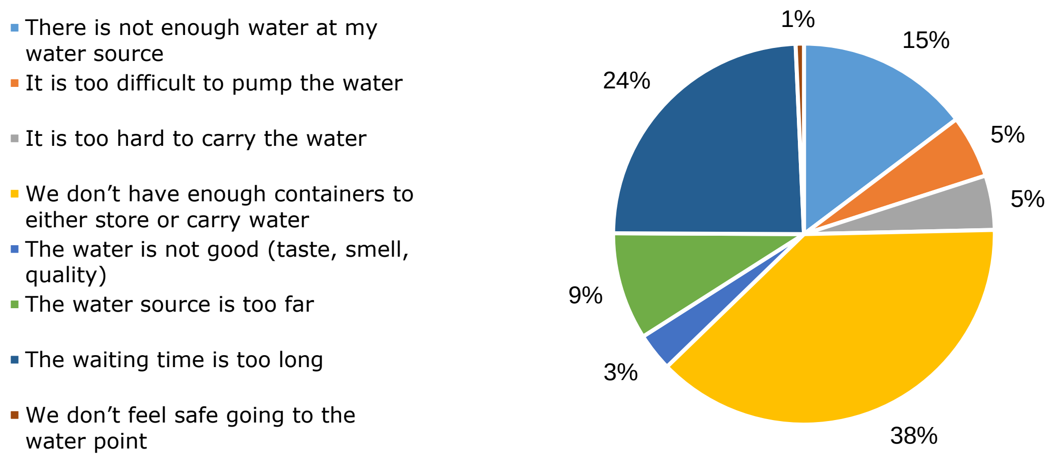


Figure 10: Reasons for an insufficient amount of water. People could choose more than one option.

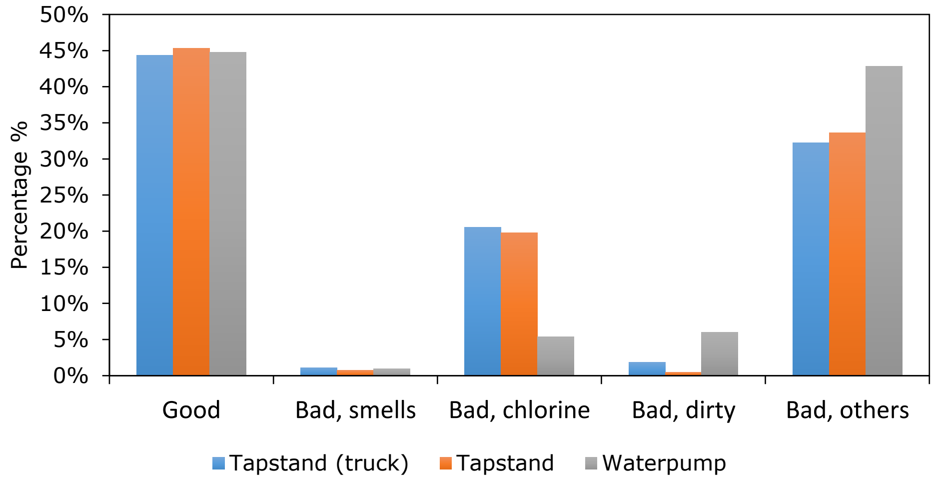


Figure 11: Quality of water per type of pump. Only the differences for chlorine are significant.

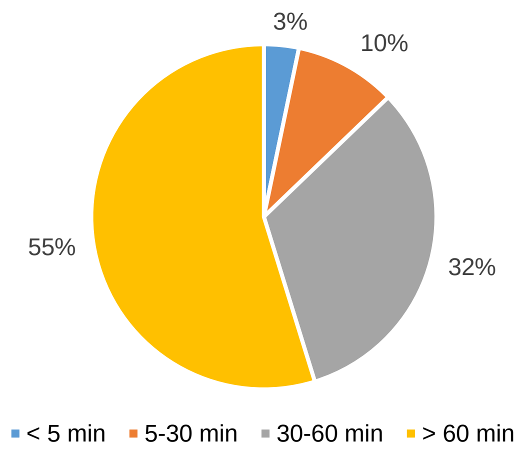


Figure 12: Time spent at the pump

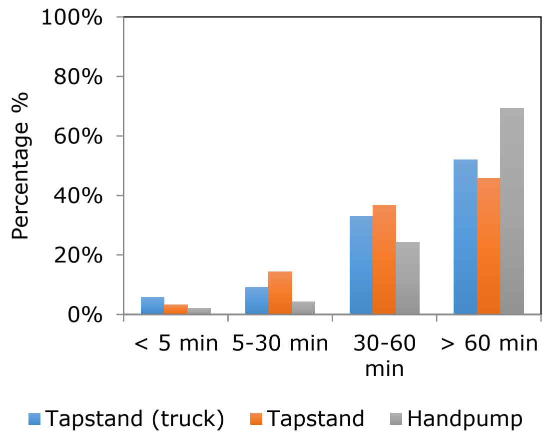


Figure 13: Time spent at the pump per type of pump

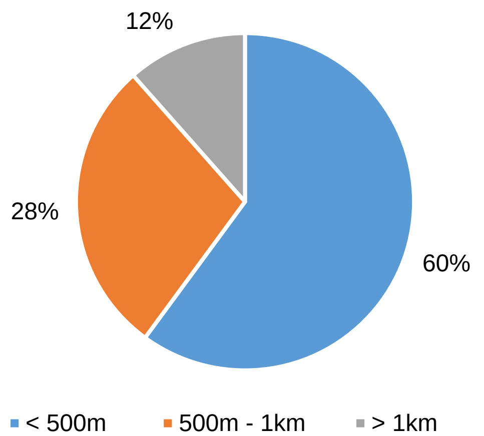


Figure 14: Travel distance

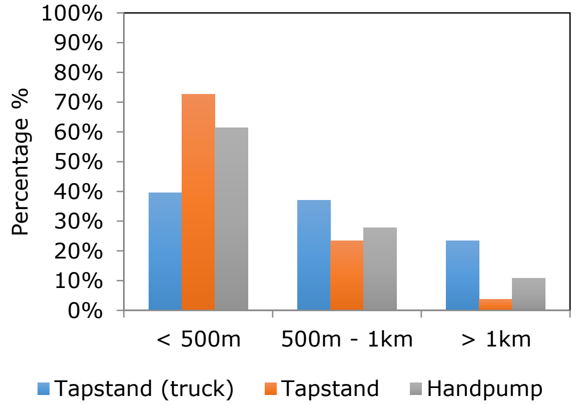


Figure 15: Travel distance per type of pump with a significant difference for the systems at < 500m.

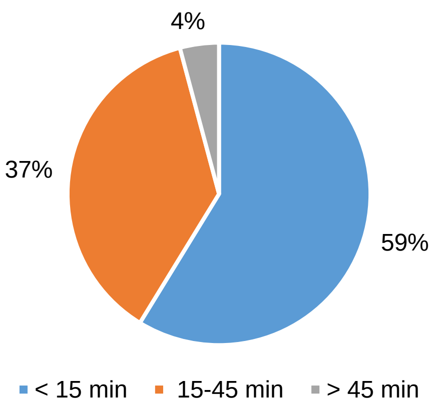


Figure 16: Travel time to the pump

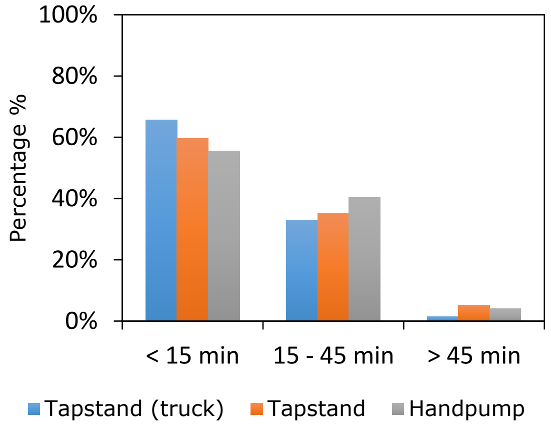


Figure 17: Travel time per type of pump

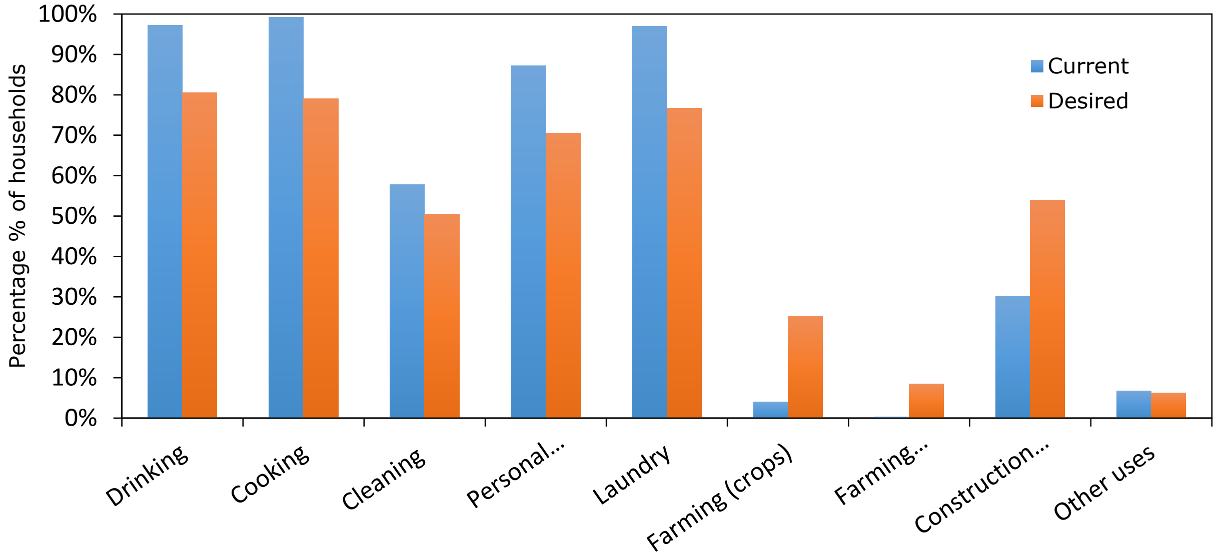


Figure 18: Current and desired usage of water

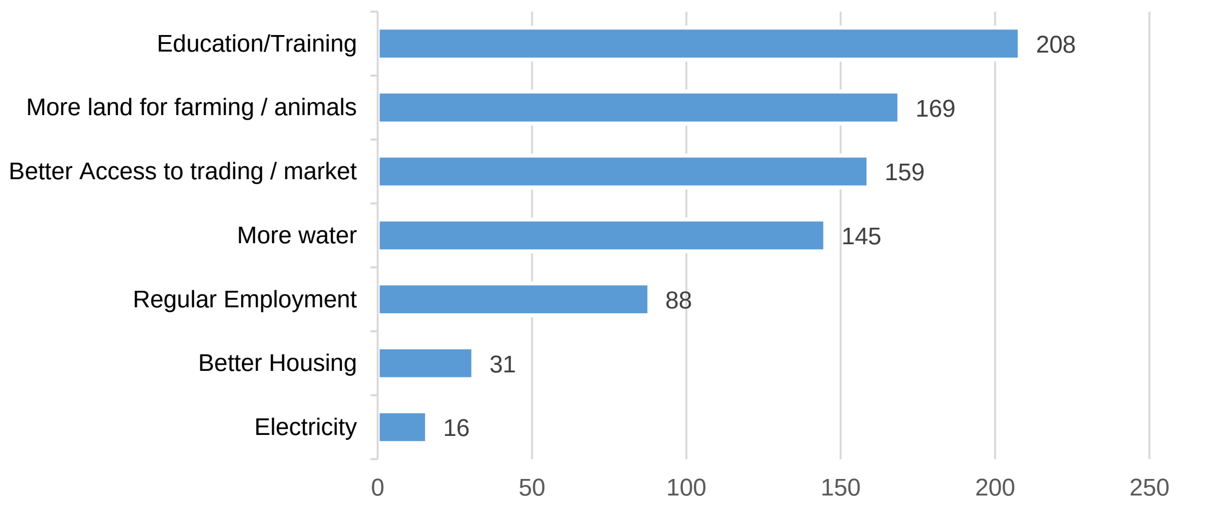


Figure 19: Self-reliance of the refugees. Answer to the question: "What would you need to become self-reliant?"

SM A.14 Results of the LCC: total costs [USD] encountered during the first year of operation (CAPEX + first year OPEX)

Table 12 and Table 13 show the total costs in USD encountered during the first year of operation (capital expenditure and O&M costs in the 1st year).

*Table 12: total expenditures encountered during the first year (CAPEX + 1st year O&M) for the hand pump and the motorised systems with a pumping yield of 2, 5 and 10 m³/h. *The hand pump should serve maximum 500 people (SPHERE standards)*

	HP	2_S	2_Ds	2_Dl	5_S	5_Ds	5_H	5_Dl	10_S	10_Ds	10_H	10_Dl
m³/day	7.5*	14	14	20	35	35	50	50	70	70	120	120
m³/year	2,738*	5,110	5,110	7,300	12,775	12,775	18,250	18,250	25,550	25,550	43,800	43,800
[Borehole]	4,879	11,932	11,932	11,932	18,328	18,328	18,328	18,328	18,328	18,328	18,328	18,328
[Site]	289	3,740	6,127	6,127	16,265	18,652	18,652	18,652	21,757	24,144	24,144	24,144
[Pump]	1,266	8,481	15,651	15,651	48,769	34,486	59,378	34,486	78,629	45,038	98,022	45,038
[Distribution]	0	24,769	24,769	27,652	105,619	105,619	138,400	138,400	137,892	137,892	201,355	201,355
TOT Capex	6,433	48,922	58,479	61,362	188,982	177,086	234,759	209,867	256,606	225,402	341,850	288,865
1st year O&M	485	4,132	7,686	9,243	4,461	8,004	6,291	9,634	9,037	18,015	16,091	24,819
TOT capex + 1st year O&M	6,918	53,054	66,166	70,606	193,444	185,090	241,050	219,500	265,643	243,417	357,941	313,685

Table 13: total expenditures encountered during the first year (CAPEX + 1st year O&M) for the motorised systems with a pumping yield of 25 and 50 m³/h and the water trucking

	25_S	25_Ds	25_H	25_Dl	50_S	50_Ds	50_H	50_Dl	50_S2	50_Ds2	50_H2	50_Dl2	Truck (1)
m³/day	175	175	300	300	350	350	600	600	350	350	600	600	300
m³/year	63,875	63,875	109,500	109,500	127,750	127,750	219,000	219,000	127,750	127,750	219,000	219,000	109,500
[Borehole]	22,832	22,832	22,832	22,832	22,832	22,832	22,832	22,832	22,832	22,832	22,832	22,832	22,832
[Site]	36,235	38,622	38,622	38,622	36,235	38,622	38,622	38,622	36,235	38,622	38,622	38,622	38,622
[Pump]	130,862	66,552	157,571	66,552	239,168	110,541	268,504	110,541	232,015	102,143	261,352	102,143	66,552
[Distribution]	196,592	196,592	285,627	285,627	293,270	293,270	504,369	504,369	216,958	216,958	370,729	370,729	0
TOT Capex	386,521	324,597	504,652	413,632	591,504	465,264	834,327	676,364	508,040	380,555	693,534	534,326	128,005
1st year O&M	10,433	33,029	27,854	50,200	12,083	42,265	36,023	65,105	12,683	42,265	36,023	65,105	788,738
TOT capex + 1st year O&M	396,954	357,626	532,506	463,833	603,587	507,530	870,350	741,469	520,723	422,821	729,557	599,431	916,743

Table 14 and Table 15 show a detailed analysis of the capital expenditures for all the alternatives, where:

- Pump includes the installation of the submersible pump, of the slicing kit, cable and control unit, of the riser mains and well head plumbing material, etc.
- Pipes excavation includes the general clearance along the pipeline, drainage channel, excavation of the trenches, a deposit of the excavated material, etc.
- Pipes supply includes supply, lay and set the distribution and installation pipes, marker posts for pipeline, taps, etc.

*Table 14: Detailed analysis of the capital expenditures of the hand pump and of the motorised systems with a pumping yield of 2, 5 and 10 m^3/h. *The hand pump should serve maximum 500 people (SPHERE standards)*

	HP	2_S	2_Ds	2_Dl	5_S	5_Ds	5_H	5_Dl	10_S	10_Ds	10_H	10_Dl
m^3/day	7.5*	14	14	20	35	35	50	50	70	70	120	120
m^3/year	2,738*	5,110	5,110	7,300	12,775	12,775	18,250	18,250	25,550	25,550	43,800	43,800
[Borehole]	4,879	11,932	11,932	11,932	18,328	18,328	18,328	18,328	18,328	18,328	18,328	18,328
[Site]	289	3,740	6,127	6,127	16,265	18,652	18,652	18,652	21,757	24,144	24,144	24,144
Generator plinth	-	-			-	13%	13%	13%	-	10%	10%	10%
[Pump]	1,266	8,481	15,651	15,651	48,769	34,486	59,378	34,486	78,629	45,038	98,022	45,038
Pump		49%	27%	27%	19%	27%	16%	27%	15%	26%	12%	26%
Solar panel	-	14%	-	-	15%	-	12%	-	30%	-	24%	-
Structure for solar panels	-	23%	-	-	6%	-	5%	-	12%	-	10%	-
Generator	-	-	55%	55%	-	26%	15%	26%	-	36%	16%	36%
[Distribution]	0	24,769	24,769	27,652	105,619	105,619	138,400	138,400	137,892	137,892	201,355	201,355
Pipes excavation	-	6%	6%	8%	22%	22%	29%	29%	31%	31%	24%	
Pipes supply	-	24%	24%	31%	33%	33%	37%	37%	35%	35%	42%	
Storage tank & structure	-	68%	68%	61%	34%	34%	26%	26%	31%	31%	21%	
TOT Capex	6,433	48,922	58,479	61,362	188,982	177,086	234,759	209,867	256,606	225,402	341,850	288,865

Table 15: Detailed analysis of the capital expenditures of the motorised systems with a pumping yield of 25 and 50 m^3/h and of the water trucking

	25_S	25_Ds	25_H	25_Dl	50_S	50_Ds	50_H	50_Dl	50_S2	50_Ds2	50_H2	50_Dl2	Truck (1)
m^3/day	175	175	300	300	350	350	600	600	350	350	600	600	300
m^3/year	63,875	63,875	109,500	109,500	127,750	127,750	219,000	219,000	127,750	127,750	219,000	219,000	109,500
[Borehole]	22,832	22,832	22,832	22,832	22,832	22,832	22,832	22,832	22,832	22,832	22,832	22,832	22,832
[Site]	36,235	38,622	38,622	38,622	36,235	38,622	38,622	38,622	36,235	38,622	38,622	38,622	38,622

Generator plinth	-	6%	6%	6%	-	6%	6%	6%	-	6%	6%	6%	6%
[Pump]	130,862	66,552	157,571	66,552	239,168	110,541	268,504	110,541	232,015	102,143	261,352	102,143	66,552
Pump	19%	37%	15%	37%	13%	29%	12%	29%	16%	37%	15%	37%	37%
Solar panel	36%	-	30%	-	31%	-	27%	-	32%	-	28%	-	-
Structure for solar panels	14%	-	12%	-	12%	-	11%	-	13%	-	11%	-	-
Generator	-	36%	15%	36%	-	24%	10%	24%	-	26%	10%	26%	36%
[Distribution]	196,592	196,592	285,627	285,627	293,270	293,270	504,369	504,369	216,958	216,958	370,729	370,729	-
Pipes excavation	11%	11%	13%	13%	11%	11%	11%	11%	6%	6%	6%	6%	
Pipes supply	36%	36%	31%	31%	49%	49%	49%	49%	45%	45%	45%	45%	
Storage tank	37%	37%	30%	30%	29%	29%	29%	29%	39%	39%	39%	39%	
TOT Capex	386,521	324,597	504,652	413,632	591,504	465,264	834,327	676,364	508,040	380,555	693,534	534,326	128,005

SM A.15 Results of the LCC: unit cost [USD / m³] of all the alternatives

Table 16, Table 17 and Table 18 illustrate the unit costs per m3 of water delivered in all the systems with a discount rate of 0%, 6% and 12%. The costs include CAPEX and OPEX for all the timeframes. To be noted that these are cumulative unit cost: at the year 3 the values indicate how much each m3 of water produced in the 3 years should cost to have full cost recovery of all the expenditures happened in the first 3 years; at the year 10 the values indicate how much each m3 of water produced in 10 years should cost to obtain full cost recovery of all the expenditures happening in the 10 years.

Table 16: Costs in USD/m³ of water for all the alternatives calculated with a discount rate of 0%. When the cells of Ds (only diesel-powered systems running for 7 hours per day) are green, it indicates that the system is more expensive than the only solar-powered systems. When the cells of Dl (only diesel-powered systems running for 10/12 hours per day) are green, it indicates that the system becomes more expensive than the only solar system. When the cells of Dl (only diesel-powered systems running for 10/12 hours per day) are green, it indicates that the system becomes more expensive than the hybrid systems.

	HP	2_S	2_Ds	2_Dl	5_S	5_Ds	5_H	5_Dl	10_S	10_Ds	10_H	10_Dl	25_S	25_Ds	25_H	25_Dl	50_S	50_Ds	50_H	50_Dl	50_S2	50_Ds2	50_H2	50_Dl2	Truck (1)	Truck (2)
1	2.53	10.38	12.95	9.67	15.14	14.49	13.21	12.03	10.40	9.53	8.17	7.16	6.21	5.60	4.86	4.24	4.72	3.97	3.97	3.39	4.08	3.31	3.33	2.74	8.37	6.74
2	1.50	5.60	7.48	5.65	7.75	7.66	6.78	6.35	5.38	5.12	4.27	3.93	3.19	3.06	2.56	2.38	2.41	2.15	2.07	1.86	2.09	1.82	1.75	1.54	7.82	6.74
3	1.22	4.00	5.49	4.31	5.28	5.32	4.63	4.46	3.70	3.72	2.97	2.81	2.18	2.25	1.79	1.74	1.64	1.57	1.43	1.34	1.42	1.35	1.22	1.12	7.62	6.74
4	1.03	3.20	4.62	3.55	4.05	4.20	3.56	3.48	2.86	2.96	2.32	2.28	1.68	1.82	1.41	1.44	1.25	1.26	1.12	1.09	1.09	1.09	0.96	0.93	7.53	6.74
5	0.86	2.72	4.00	3.38	3.31	3.48	2.99	3.02	2.36	2.51	1.98	1.96	1.37	1.56	1.22	1.27	1.02	1.07	0.95	0.95	0.89	0.94	0.82	0.82	7.49	6.74
6	0.88	2.40	3.86	3.09	2.81	3.12	2.55	2.63	2.03	2.24	1.71	1.79	1.17	1.40	1.06	1.17	0.87	0.96	0.82	0.86	0.76	0.85	0.71	0.75	7.48	6.74
7	0.78	2.27	3.58	2.88	2.54	2.80	2.26	2.35	1.81	2.02	1.53	1.63	1.04	1.28	0.95	1.07	0.78	0.87	0.74	0.78	0.69	0.78	0.64	0.69	7.44	6.74
8	0.74	2.09	3.38	2.68	2.26	2.56	2.02	2.12	1.65	1.88	1.38	1.51	0.96	1.21	0.86	1.00	0.72	0.82	0.67	0.72	0.64	0.74	0.58	0.64	7.42	6.74
9	0.73	1.95	3.18	2.65	2.05	2.34	1.84	2.00	1.51	1.78	1.28	1.41	0.87	1.14	0.80	0.94	0.65	0.77	0.62	0.68	0.58	0.70	0.54	0.61	7.40	6.74
10	0.70	1.83	3.06	2.58	1.88	2.19	1.72	1.89	1.39	1.74	1.20	1.34	0.80	1.12	0.76	0.91	0.59	0.75	0.58	0.65	0.53	0.69	0.51	0.59	7.40	6.74

Table 17: Costs in USD/m³ of water for all the alternatives calculated with a discount rate of 6%. When the cells of Ds (only diesel-powered systems running for 7 hours per day) are green, it indicates that the system is more expensive than the only solar-powered systems. When the cells of Dl (only diesel-powered systems running for 10/12 hours per day) are green, it indicates that the system becomes more expensive than the only solar system. When the cells of Dl (only diesel-powered systems running for 10/12 hours per day) are green, it indicates that the system becomes more expensive than the hybrid systems.

	HP	2_S	2_Ds	2_Dl	5_S	5_Ds	5_H	5_Dl	10_S	10_Ds	10_H	10_Dl	25_S	25_Ds	25_H	25_Dl	50_S	50_Ds	50_H	50_Dl	50_S2	50_Ds2	50_H2	50_Dl2	Truck (1)	Truck (2)
1	2.53	10.38	12.95	9.67	15.14	14.49	13.21	12.03	10.40	9.53	8.17	7.16	6.21	5.60	4.86	4.24	4.72	3.97	3.97	3.39	4.08	3.31	3.33	2.74	8.37	6.74
2	1.53	5.73	7.64	5.76	7.96	7.86	6.96	6.52	5.52	5.24	4.38	4.02	3.28	3.13	2.63	2.44	2.48	2.20	2.12	1.91	2.15	1.86	1.79	1.57	7.84	6.36
3	1.25	4.19	5.71	4.46	5.57	5.59	4.88	4.68	3.90	3.88	3.12	2.93	2.30	2.35	1.88	1.82	1.73	1.64	1.51	1.40	1.50	1.40	1.28	1.17	7.64	6.00
4	1.08	3.42	4.87	3.73	4.38	4.50	3.85	3.73	3.09	3.16	2.49	2.42	1.81	1.93	1.51	1.52	1.36	1.34	1.20	1.16	1.18	1.16	1.03	0.98	7.56	5.66
5	0.92	2.95	4.27	3.55	3.66	3.82	3.29	3.28	2.60	2.72	2.16	2.11	1.52	1.68	1.32	1.35	1.13	1.16	1.04	1.02	0.99	1.01	0.90	0.87	7.51	5.34
6	0.92	2.65	4.12	3.28	3.19	3.46	2.87	2.91	2.28	2.46	1.90	1.95	1.32	1.53	1.17	1.26	0.98	1.05	0.92	0.93	0.86	0.92	0.79	0.81	7.50	5.04

7	0.83	2.51	3.85	3.08	2.91	3.15	2.59	2.64	2.07	2.25	1.73	1.79	1.20	1.41	1.07	1.16	0.90	0.96	0.84	0.86	0.79	0.85	0.72	0.75	7.47	4.75
8	0.80	2.34	3.67	2.90	2.65	2.92	2.36	2.43	1.91	2.12	1.59	1.68	1.11	1.34	0.98	1.10	0.83	0.92	0.77	0.81	0.74	0.81	0.66	0.71	7.45	4.49
9	0.78	2.20	3.48	2.86	2.45	2.72	2.19	2.31	1.78	2.01	1.49	1.58	1.03	1.28	0.93	1.04	0.77	0.87	0.72	0.76	0.68	0.78	0.62	0.67	7.43	4.23
10	0.76	2.10	3.37	2.78	2.29	2.58	2.08	2.20	1.67	1.97	1.42	1.52	0.97	1.25	0.89	1.01	0.72	0.85	0.69	0.74	0.64	0.76	0.59	0.65	7.42	3.99

Table 18: Costs in USD/m³ of water for all the alternatives calculated with a discount rate of 12%. When the cells of Ds (only diesel-powered systems running for 7 hours per day) are green, it indicates that the system is more expensive than the only solar-powered systems. When the cells of Dl (only diesel-powered systems running for 10/12 hours per day) are green, it indicates that the system becomes more expensive than the only solar system. When the cells of Dl (only diesel-powered systems running for 10/12 hours per day) are green, it indicates that the system becomes more expensive than the hybrid systems.

	HP	2_S	2_Ds	2_Dl	5_S	5_Ds	5_H	5_Dl	10_S	10_Ds	10_H	10_Dl	25_S	25_Ds	25_H	25_Dl	50_S	50_Ds	50_H	50_Dl	50_S2	50_Ds2	50_H2	50_Dl2	Truck (1)	Truck (2)
1	2.53	10.38	12.95	9.67	15.14	14.49	13.21	12.03	10.40	9.53	8.17	7.16	6.21	5.60	4.86	4.24	4.72	3.97	3.97	3.39	4.08	3.31	3.33	2.74	8.37	6.74
2	1.56	5.87	7.79	5.87	8.16	8.05	7.14	6.67	5.66	5.37	4.49	4.11	3.36	3.20	2.69	2.49	2.54	2.25	2.18	1.95	2.20	1.90	1.84	1.60	7.85	6.02
3	1.29	4.37	5.93	4.61	5.85	5.85	5.13	4.90	4.09	4.05	3.27	3.06	2.41	2.44	1.97	1.89	1.82	1.70	1.58	1.46	1.58	1.46	1.34	1.22	7.66	5.38
4	1.12	3.62	5.11	3.91	4.70	4.80	4.13	3.98	3.31	3.35	2.66	2.56	1.94	2.04	1.61	1.60	1.46	1.42	1.28	1.22	1.27	1.22	1.10	1.03	7.58	4.80
5	0.97	3.18	4.54	3.73	4.01	4.14	3.59	3.54	2.84	2.93	2.34	2.27	1.66	1.80	1.43	1.44	1.24	1.25	1.13	1.09	1.08	1.08	0.97	0.93	7.54	4.29
6	0.97	2.89	4.38	3.47	3.56	3.80	3.19	3.19	2.53	2.68	2.10	2.11	1.48	1.66	1.28	1.35	1.10	1.14	1.01	1.01	0.96	1.00	0.87	0.87	7.53	3.83
7	0.89	2.75	4.13	3.28	3.29	3.51	2.93	2.94	2.33	2.49	1.93	1.96	1.36	1.54	1.19	1.26	1.02	1.06	0.94	0.94	0.90	0.93	0.80	0.81	7.49	3.42
8	0.86	2.59	3.96	3.12	3.05	3.29	2.72	2.74	2.19	2.36	1.80	1.86	1.28	1.48	1.11	1.20	0.96	1.01	0.87	0.89	0.84	0.89	0.75	0.77	7.48	3.05
9	0.84	2.47	3.79	3.07	2.87	3.11	2.56	2.63	2.06	2.26	1.72	1.77	1.20	1.42	1.06	1.15	0.90	0.97	0.83	0.85	0.79	0.86	0.71	0.74	7.46	2.72
10	0.82	2.38	3.69	3.01	2.73	2.98	2.45	2.53	1.96	2.21	1.65	1.72	1.14	1.39	1.02	1.12	0.85	0.95	0.80	0.83	0.75	0.84	0.69	0.72	7.45	2.43

SM A.16 Results of the LCC: unit costs [USD/m³], economy of scale

Figure 20, Figure 21, Figure 22 and Figure 23 shows the unit cost [USD/m³] including CAPEX and OPEX for all the solar powers systems, short running diesel powered systems (7 hours a day), hybrid systems and long-running diesel powered systems (10/12 hours per day) for all the timeframes with a discount rate: 0%.

The costs include CAPEX and OPEX for all the timeframes. To be noted that these are cumulative unit cost: at the year 3 the values indicate how much each m³ of water produced in the 3 years should cost to have full cost recovery of all the expenditures happened in the first 3 years; at the year 10 the values indicate how much each m³ of water produced in 10 years should cost to obtain full cost recovery of all the expenditures happening in the 10 years.

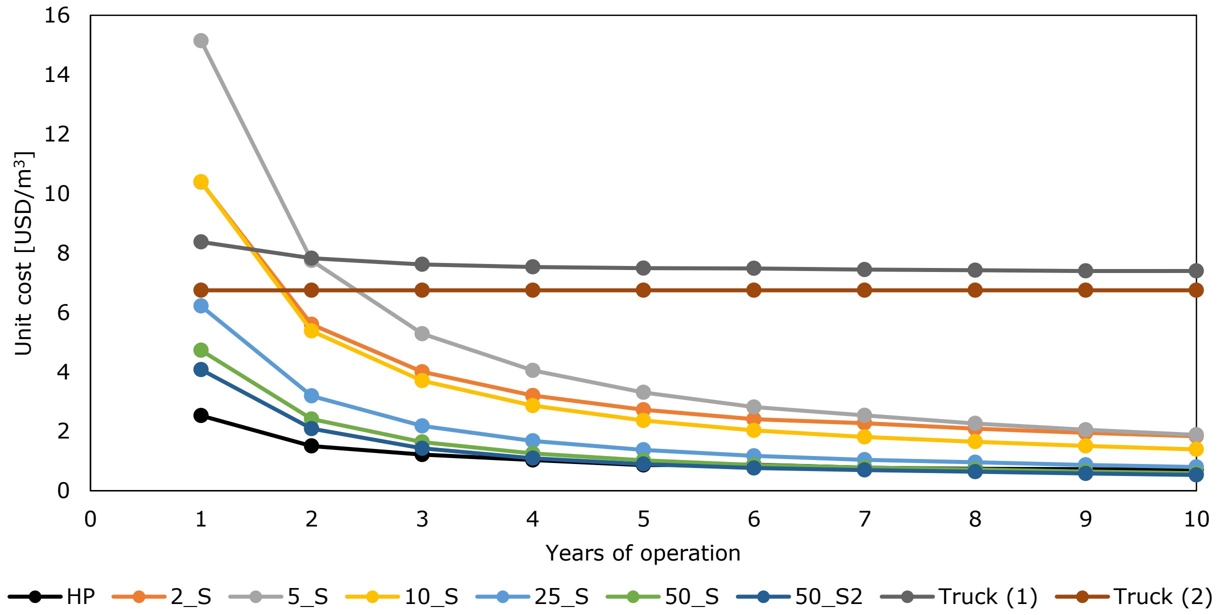


Figure 20: Costs in USD / m³ for all the alternatives with a solar powered system (running for 7 hours), hand pump and water trucking

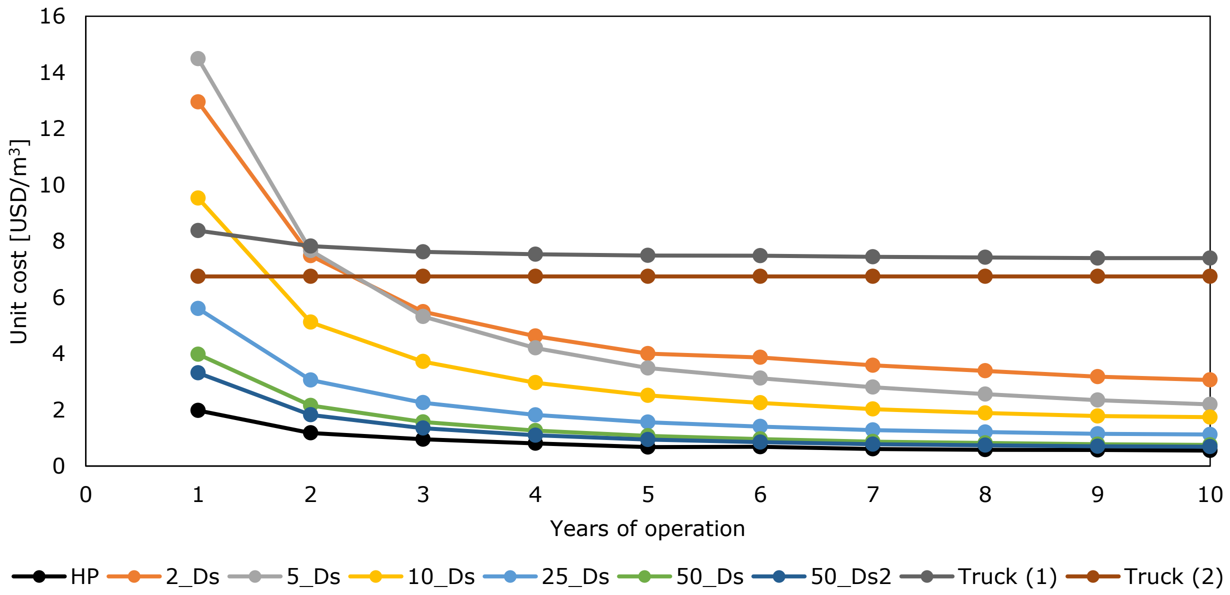


Figure 21: Costs in USD / m³ for all the alternatives with a diesel-powered system running for 7 hours, hand pump and water trucking

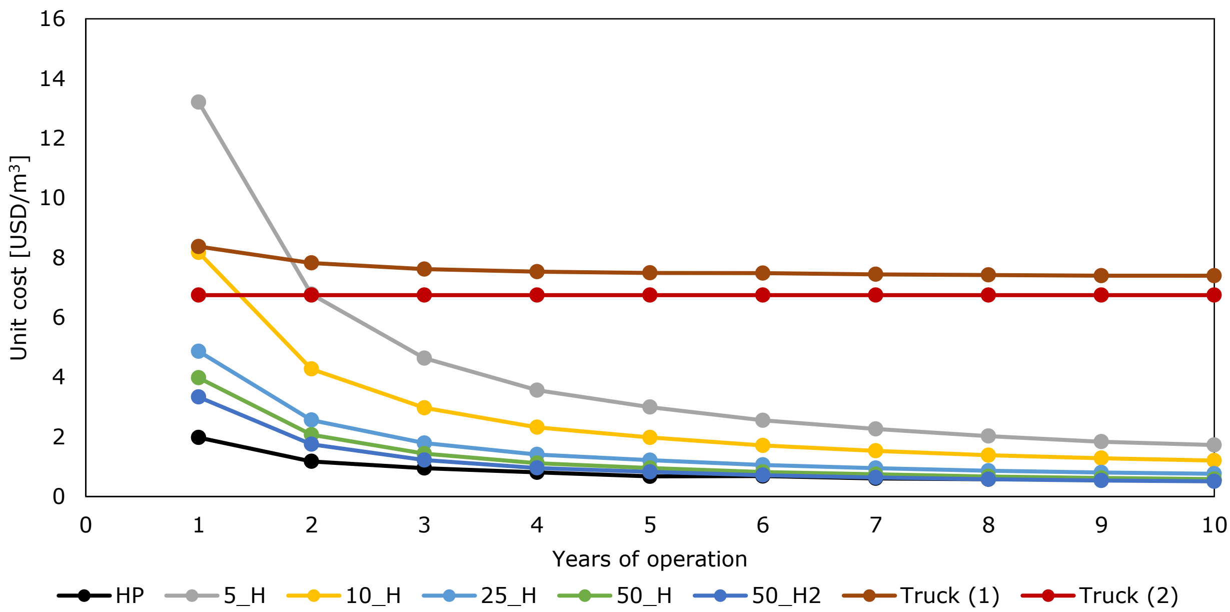


Figure 22: Costs in USD / m^3 for all the alternatives with a hybrid-powered system (solar + diesel) running for 10 hours (2 and 5 m^3/h) and 12 hours (for the other), hand pump and water trucking

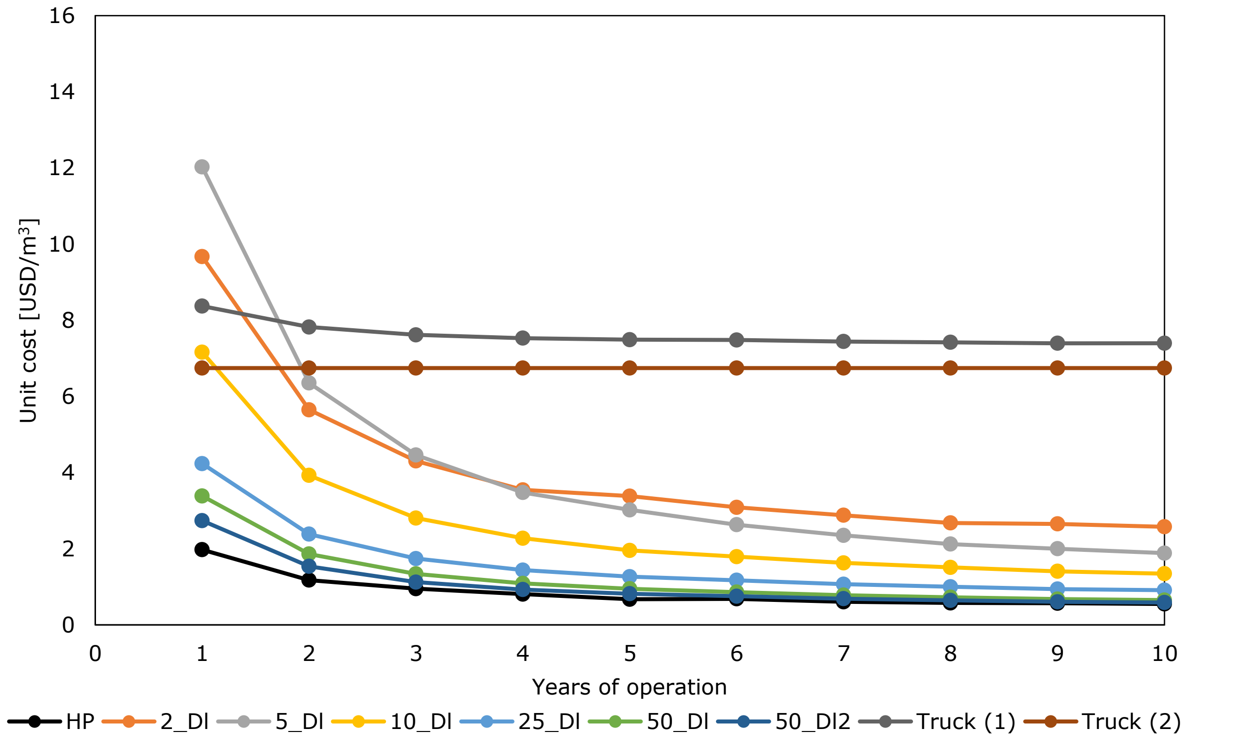


Figure 23: Costs in USD / m^3 for all the alternatives with a diesel-powered system running for 10 hours (2 and 5 m^3/h) and 12 hours (for the other), hand pump and water trucking

SM A.17 Results of the LCC: O&M unit costs [USD/m^3]

Table 19, Table 20 and Table 21 illustrate the Operation and maintenance costs (O&M) per m^3 of water delivered in all the systems with a discount rate of 0%, 6% and 10%, respectively. It can be seen that the solar-powered system is almost always the cheaper option, followed by the hybrid systems, the diesel-powered system running for 10/12 hours per day and lastly the diesel-powered system running for only 7 hours per day.

To be noted that these are cumulative unit cost: at the year 3 the values indicate how much each m^3 of water produced in the 3 years should cost to have full cost recovery of all the O&M (operation expenditures) happened in the first 3 years; at the year 10 the values indicate how much each m^3 of water produced in 10 years should cost to obtain full cost recovery of all the O&M happening in the 10 years.

Table 19: O&M costs in USD/m^3 of water for all the alternatives calculated with a discount rate of 0%. The colours show which one of the power systems (solar, short-running diesel, hybrid and long-running diesel) is cheaper fixed the pumping yield and the timeframe. Green is the cheapest and yellow the most expensive.

	HP	2_S	2_Ds	2_Dl	5_S	5_Ds	5_H	5_Dl	10_S	10_Ds	10_H	10_Dl	25_S	25_Ds	25_H	25_Dl	50_S	50_Ds	50_H	50_Dl	50_S2	50_Ds 2	50_H2	50_Dl 2
1	0.18	0.81	1.50	1.27	0.35	0.63	0.34	0.53	0.35	0.71	0.37	0.57	0.16	0.52	0.25	0.46	0.09	0.33	0.16	0.30	0.10	0.33	0.16	0.30
2	0.33	0.81	1.76	1.44	0.35	0.73	0.34	0.60	0.35	0.71	0.37	0.63	0.16	0.52	0.25	0.49	0.09	0.33	0.16	0.32	0.10	0.33	0.16	0.32
3	0.43	0.81	1.67	1.50	0.35	0.70	0.34	0.63	0.35	0.77	0.37	0.61	0.16	0.56	0.25	0.48	0.09	0.35	0.16	0.31	0.10	0.35	0.16	0.31
4	0.45	0.81	1.76	1.44	0.35	0.73	0.34	0.60	0.35	0.76	0.37	0.63	0.16	0.55	0.25	0.49	0.09	0.35	0.16	0.32	0.10	0.35	0.16	0.32
5	0.39	0.81	1.71	1.70	0.35	0.71	0.42	0.72	0.35	0.75	0.42	0.64	0.16	0.54	0.29	0.51	0.09	0.34	0.19	0.33	0.10	0.34	0.19	0.33
6	0.48	0.81	1.96	1.69	0.35	0.81	0.41	0.71	0.35	0.77	0.41	0.69	0.16	0.56	0.29	0.54	0.09	0.35	0.19	0.35	0.10	0.35	0.19	0.35
7	0.44	0.91	1.95	1.68	0.42	0.82	0.42	0.71	0.37	0.76	0.41	0.69	0.18	0.55	0.29	0.53	0.12	0.35	0.20	0.34	0.13	0.35	0.18	0.34
8	0.45	0.89	1.95	1.63	0.41	0.82	0.41	0.69	0.39	0.78	0.41	0.69	0.20	0.57	0.29	0.53	0.14	0.37	0.19	0.34	0.14	0.37	0.18	0.34
9	0.47	0.88	1.90	1.72	0.41	0.80	0.41	0.72	0.39	0.80	0.42	0.67	0.20	0.58	0.29	0.52	0.13	0.37	0.20	0.33	0.14	0.37	0.18	0.33
10	0.47	0.88	1.92	1.73	0.40	0.81	0.44	0.74	0.39	0.86	0.42	0.69	0.19	0.61	0.30	0.53	0.13	0.39	0.20	0.34	0.13	0.39	0.19	0.34

Table 20: O&M costs in USD/m³ of water for all the alternatives calculated with a discount rate of 6%. The colours show which one of the power systems (solar, short-running diesel, hybrid and long-running diesel) is cheaper fixed the pumping yield and the timeframe. Green is the cheapest and yellow the most expensive.

	HP	2_S	2_Ds	2_Dl	5_S	5_Ds	5_H	5_Dl	10_S	10_Ds	10_H	10_Dl	25_S	25_Ds	25_H	25_Dl	50_S	50_Ds	50_H	50_Dl	50_S2	50_Ds 2	50_H2	50_Dl2
1	0.18	0.81	1.50	1.27	0.35	0.63	0.34	0.53	0.35	0.71	0.37	0.57	0.16	0.52	0.25	0.46	0.09	0.33	0.16	0.30	0.10	0.33	0.16	0.30
2	0.33	0.81	1.75	1.44	0.35	0.73	0.34	0.60	0.35	0.71	0.37	0.63	0.16	0.52	0.25	0.49	0.09	0.33	0.16	0.32	0.10	0.33	0.16	0.32
3	0.42	0.81	1.67	1.50	0.35	0.70	0.34	0.62	0.35	0.77	0.37	0.61	0.16	0.55	0.25	0.48	0.09	0.35	0.16	0.31	0.10	0.35	0.16	0.31
4	0.44	0.81	1.75	1.44	0.35	0.73	0.34	0.60	0.35	0.76	0.37	0.63	0.16	0.55	0.25	0.49	0.09	0.35	0.16	0.32	0.10	0.35	0.16	0.32
5	0.39	0.81	1.71	1.67	0.35	0.71	0.41	0.71	0.35	0.75	0.41	0.63	0.16	0.54	0.29	0.51	0.09	0.34	0.19	0.33	0.10	0.34	0.19	0.33
6	0.47	0.81	1.92	1.66	0.35	0.80	0.40	0.70	0.35	0.77	0.40	0.68	0.16	0.55	0.28	0.53	0.09	0.35	0.18	0.34	0.10	0.35	0.18	0.34
7	0.44	0.89	1.92	1.66	0.41	0.81	0.42	0.70	0.37	0.76	0.41	0.68	0.17	0.55	0.29	0.53	0.12	0.35	0.20	0.34	0.12	0.35	0.18	0.34
8	0.44	0.88	1.93	1.62	0.40	0.81	0.41	0.68	0.39	0.78	0.40	0.68	0.19	0.57	0.28	0.53	0.13	0.36	0.19	0.34	0.13	0.36	0.18	0.34
9	0.46	0.87	1.89	1.69	0.40	0.80	0.40	0.71	0.38	0.79	0.41	0.67	0.19	0.57	0.29	0.52	0.13	0.37	0.19	0.33	0.13	0.37	0.18	0.33
10	0.46	0.87	1.90	1.71	0.40	0.80	0.43	0.72	0.38	0.83	0.42	0.68	0.19	0.60	0.30	0.53	0.12	0.38	0.20	0.34	0.13	0.38	0.19	0.34

Table 21: O&M costs in USD/m³ of water for all the alternatives calculated with a discount rate of 12%. The colours show which one of the power systems (solar, short-running diesel, hybrid and long-running diesel) is cheaper fixed the pumping yield and the timeframe. Green is the cheapest and yellow the most expensive.

	HP	2_S	2_Ds	2_Dl	5_S	5_Ds	5_H	5_Dl	10_S	10_Ds	10_H	10_Dl	25_S	25_Ds	25_H	25_Dl	50_S	50_Ds	50_H	50_Dl	50_S2	50_Ds 2	50_H 2	50_Dl 2
1	0.18	0.81	1.50	1.27	0.35	0.63	0.34	0.53	0.35	0.71	0.37	0.57	0.16	0.52	0.25	0.46	0.09	0.33	0.16	0.30	0.10	0.33	0.16	0.30
2	0.32	0.81	1.74	1.43	0.35	0.73	0.34	0.60	0.35	0.71	0.37	0.62	0.16	0.52	0.25	0.49	0.09	0.33	0.16	0.32	0.10	0.33	0.16	0.32
3	0.42	0.81	1.67	1.49	0.35	0.70	0.34	0.62	0.35	0.77	0.37	0.61	0.16	0.55	0.25	0.48	0.09	0.35	0.16	0.31	0.10	0.35	0.16	0.31
4	0.43	0.81	1.74	1.44	0.35	0.73	0.34	0.60	0.35	0.75	0.37	0.62	0.16	0.55	0.25	0.49	0.09	0.35	0.16	0.32	0.10	0.35	0.16	0.32
5	0.39	0.81	1.71	1.64	0.35	0.71	0.40	0.69	0.35	0.75	0.41	0.63	0.16	0.54	0.29	0.51	0.09	0.34	0.19	0.33	0.10	0.34	0.19	0.33
6	0.46	0.81	1.89	1.64	0.35	0.79	0.40	0.69	0.35	0.77	0.40	0.67	0.16	0.55	0.28	0.53	0.09	0.35	0.18	0.34	0.10	0.35	0.18	0.34
7	0.43	0.88	1.89	1.64	0.40	0.80	0.41	0.69	0.37	0.76	0.41	0.67	0.17	0.55	0.28	0.52	0.11	0.35	0.19	0.33	0.12	0.35	0.18	0.33
8	0.43	0.87	1.90	1.61	0.40	0.80	0.40	0.68	0.38	0.77	0.40	0.67	0.19	0.56	0.28	0.52	0.12	0.36	0.19	0.33	0.13	0.36	0.18	0.33
9	0.45	0.87	1.87	1.67	0.39	0.79	0.40	0.70	0.38	0.78	0.41	0.67	0.19	0.57	0.29	0.52	0.12	0.36	0.19	0.33	0.13	0.36	0.18	0.33
10	0.45	0.86	1.88	1.68	0.39	0.79	0.42	0.71	0.38	0.82	0.41	0.67	0.19	0.59	0.29	0.53	0.12	0.37	0.19	0.34	0.13	0.37	0.19	0.34

SM A.18 Results of the LCC: O&M unit costs [USD/m^3] vs. local water fees

Figure 24 - Figure 29 show the comparison between local water fee and the O&M unit cost [USD/m^3] for the 2m^3/h (Figure 24), 5 m^3/h (Figure 25), 10 m^3/h (Figure 26), 25 m^3/h (Figure 27) and 50 m^3/h (Figure 28 and Figure 29) with a discount rate of 0%. The local water fees found in the West Nile region in the host communities and were between 1,000 UGX (0.28 USD) per household per month (equal to 444 UGX per m^3 assuming 5 persons/household and 15 litres/day/person) and 3,000 UGX/m^3 (0.83 USD).

To be noted that these are cumulative unit cost: at the year 3 the values indicate how much each m^3 of water produced in the 3 years should cost to have full cost recovery of all the O&M (operation expenditures) happened in the first 3 years; at the year 10 the values indicate how much each m^3 of water produced in 10 years should cost to obtain full cost recovery of all the O&M happening in the 10 years.

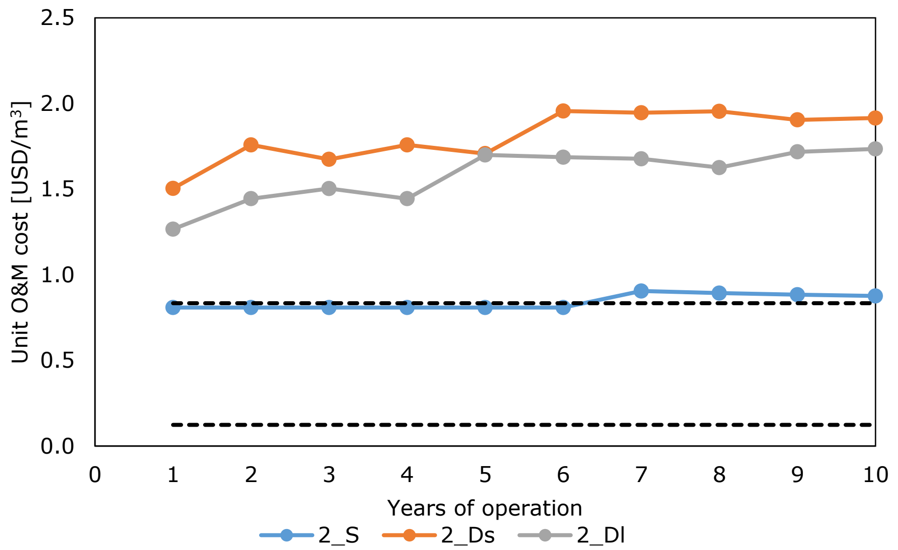


Figure 24: Comparison between the O&M costs [USD/m^3] of the motorised systems with a pumping yield of 2 m^3/h and the local water fee found in the West Nile region in the host communities. The water fees are 0.1236 USD/m^3 (444 UGX/m^3) and 0.83 USD/m^3 (3,000 UGX/m^3)

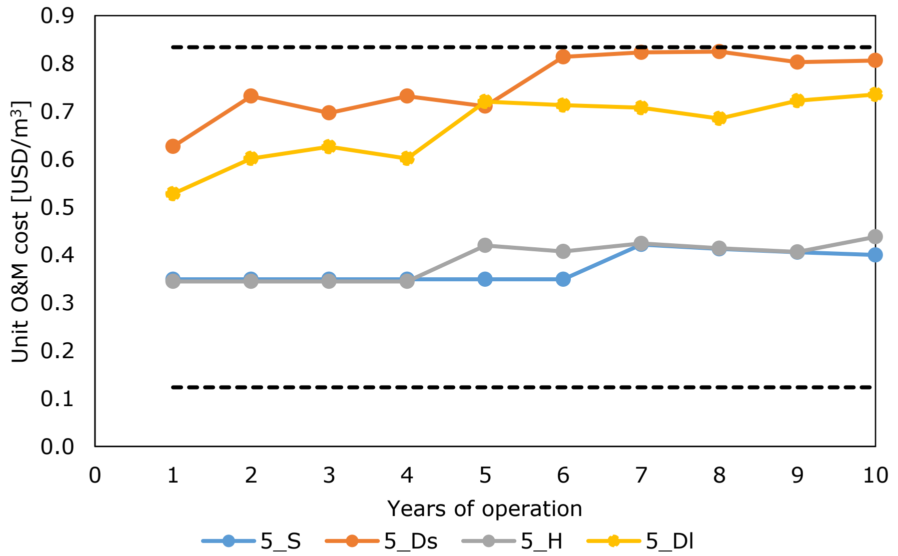


Figure 25: Comparison between the O&M costs [USD/m^3] of the motorised systems with a pumping yield of 5 m^3/h and the local water fee found in the West Nile region in the host communities. The water fees are 0.1236 USD/m^3 (444 UGX/m^3) and 0.83 USD/m^3 (3,000 UGX/m^3)

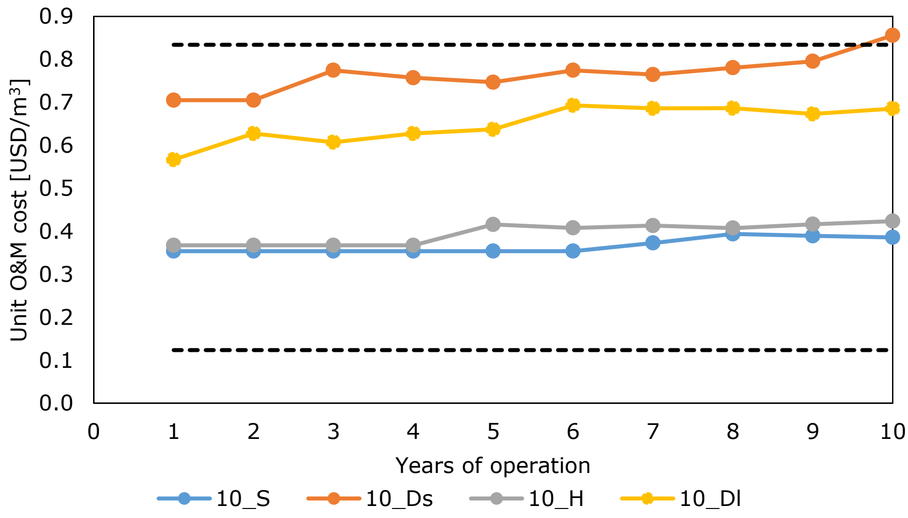


Figure 26: Comparison between the O&M costs [USD/m³] of the motorised systems with a pumping yield of 10 m³/h and the local water fee found in the West Nile region in the host communities. The water fees are 0.1236 USD/m³ (444 UGX/m³) and 0.83 USD/m³ (3,000 UGX/m³)

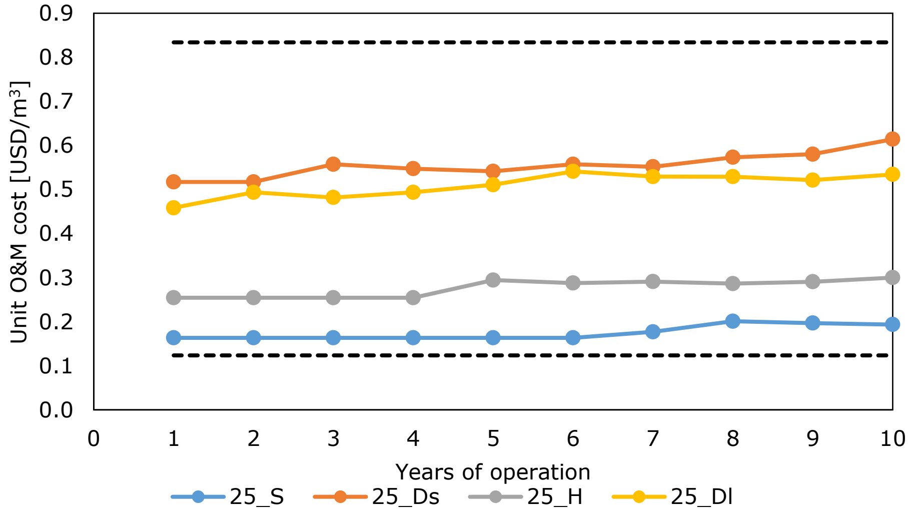


Figure 27: Comparison between the O&M costs [USD/m³] of the motorised systems with a pumping yield of 25 m³/h and the local water fee found in the West Nile region in the host communities. The water fees are 0.1236 USD/m³ (444 UGX/m³) and 0.83 USD/m³ (3,000 UGX/m³)

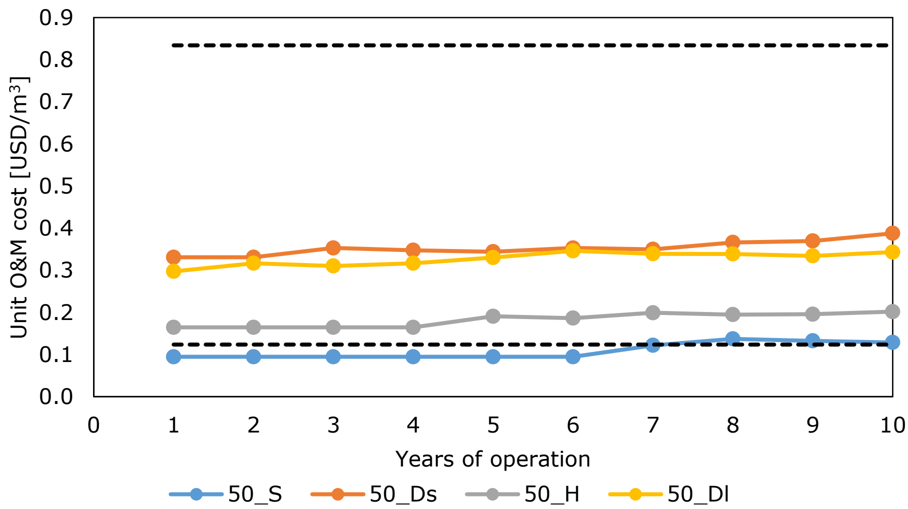


Figure 28: Comparison between the O&M costs [USD/m³] of the motorised systems with a pumping yield of 50 m³/h (1) and the local water fee found in the West Nile region in the host communities. The water fees are 0.1236 USD/m³ (444 UGX/m³) and 0.83 USD/m³ (3,000 UGX/m³)

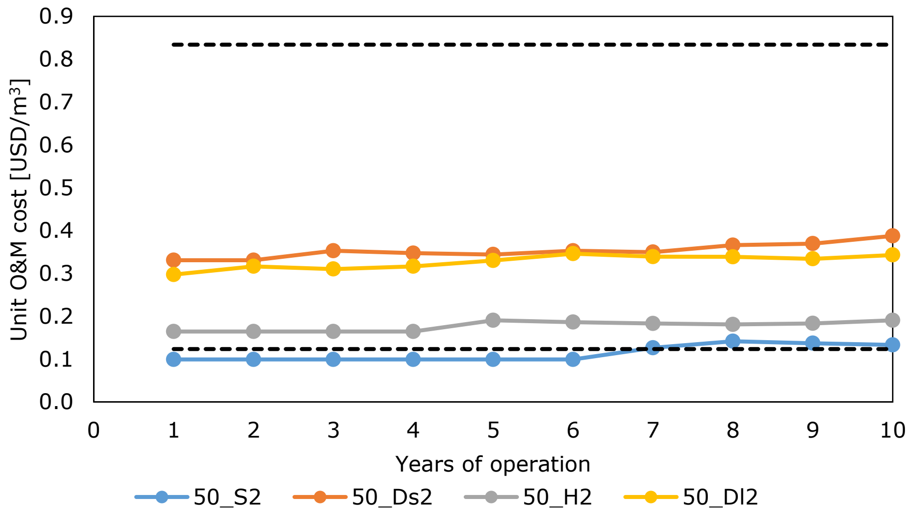


Figure 29: Comparison between the O&M costs [USD/m³] of the motorised systems with a pumping yield of 50 m³/h (2) and the local water fee found in the West Nile region in the host communities. The water fees are 0.1236 USD/m³ (444 UGX/m³) and 0.83 USD/m³ (3,000 UGX/m³)

SM A.19 Results of the LCC: O&M unit costs [USD/m^3], economy of scale

The local water fees were compared with the O&M unit cost [USD/m^3] for the solar-powered systems (Figure 30), short running diesel powered systems (Figure 31), hybrid systems (Figure 32) and long-running diesel powered systems (Figure 33). The local water fees found in the West Nile region in the host communities and were between 1,000 UGX (0.28 USD) per household per month (equal to 444 UGX per m^3 assuming 5 persons/household and 15 litres/day/person) and 3,000 UGX/m^3 (0.83 USD).

To be remembered that these are cumulative unit cost: at the year 3 the values indicate how much each m^3 of water produced in the 3 years should cost to have full cost recovery of all the O&M (operation expenditures) happened in the first 3 years; at the year 10 the values indicate how much each m^3 of water produced in 10 years should cost to obtain full cost recovery of all the O&M happening in the 10 years.

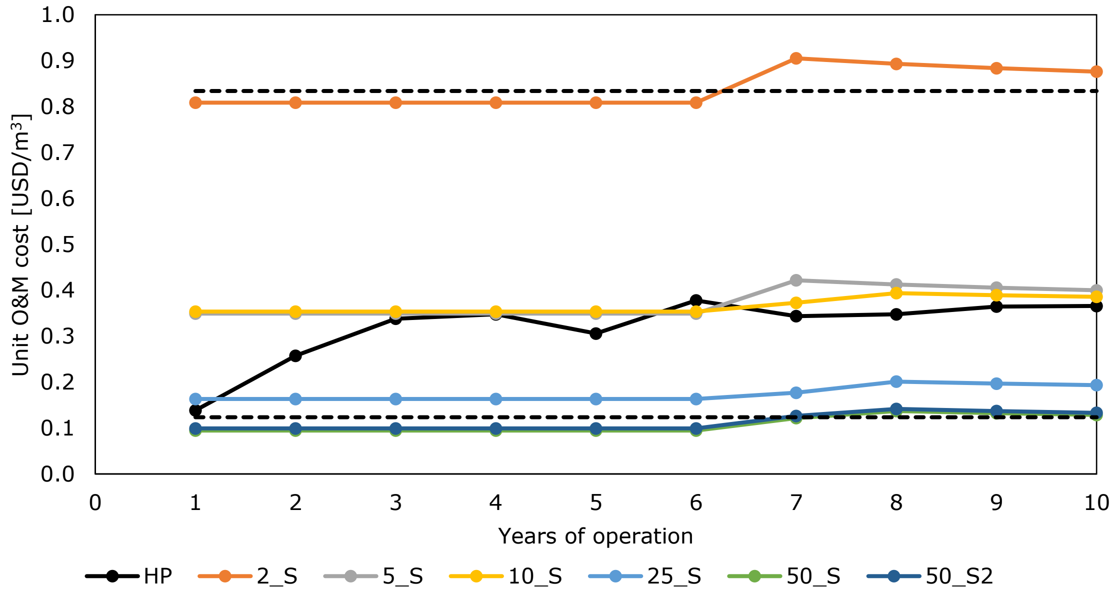


Figure 30: Comparison between the O&M costs [USD/m^3] of a hand pump and all the solar-powered systems (2, 5, 10, 25 and 50 m^3/h) and the local water fee found in the West Nile region in the host communities. The two-dotted lines indicate the cost of water in the host communities in similar conditions: 0.1236 USD/m^3 (444 UGX/m^3) and 0.83 USD/m^3 (3,000 UGX/m^3).

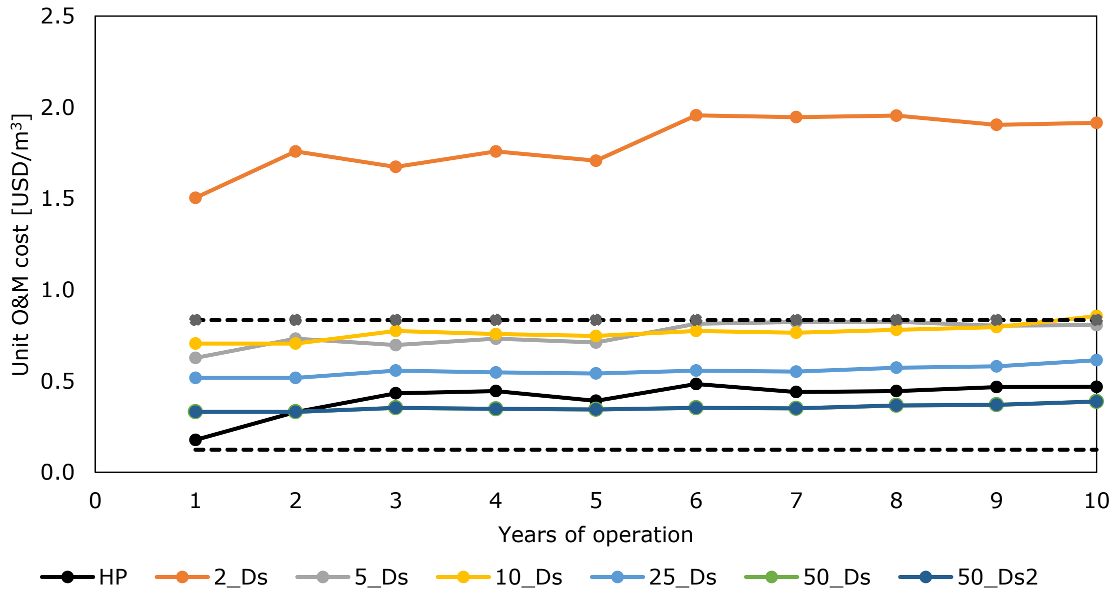


Figure 31: Comparison between the O&M costs [USD/m^3] of a hand pump and all the short running diesel-powered (7 hours per day) systems (2, 5, 10, 25 and 50 m^3/h) and the local water fee found in the West Nile region in the host

communities. The two-dotted lines indicate the cost of water in the host communities in similar conditions: 0.1236 USD/m³ (444 UGX/m³) and 0.83 USD/m³ (3,000 UGX/m³).

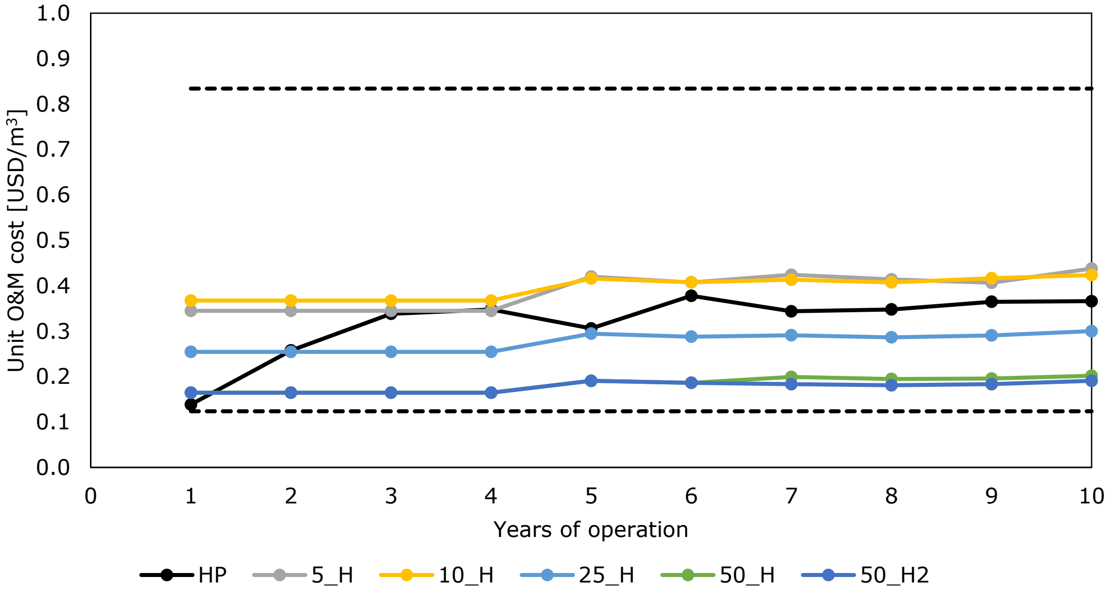


Figure 32: Comparison between the O&M costs [USD/m³] of a hand pump and all the hybrid (solar + diesel) systems (2, 5, 10, 25 and 50 m³/h) and the local water fee found in the West Nile region in the host communities. The two-dotted lines indicate the cost of water in the host communities in similar conditions: 0.1236 USD/m³ (444 UGX/m³) and 0.83 USD/m³ (3,000 UGX/m³).

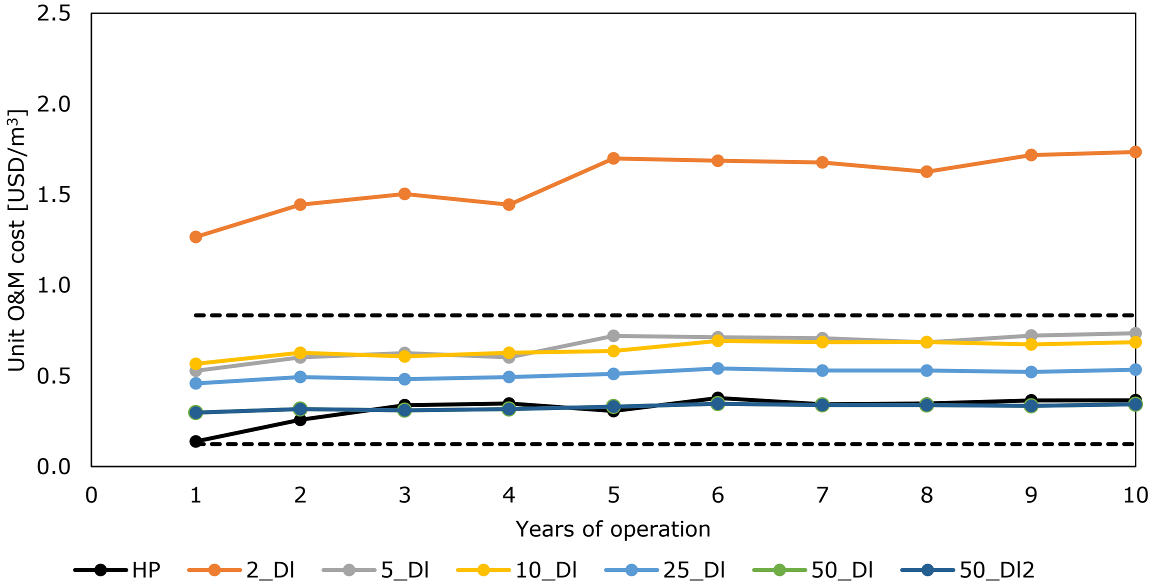


Figure 33: Comparison between the O&M costs [USD/m³] of a hand pump and all the long-running diesel-powered (10/12 hours per day) systems (2, 5, 10, 25 and 50 m³/h) and the local water fee found in the West Nile region in the host communities. The two-dotted lines indicate the cost of water in the host communities in similar conditions: 0.1236 USD/m³ (444 UGX/m³) and 0.83 USD/m³ (3,000 UGX/m³).

SM A.20 Results of the LCC: O&M costs, contribution analysis

The O&M costs were further analysed by dividing them in four classes: salary, fuel, minor maintenance, and major maintenance (Table 22).

To be remembered that these are cumulative O&M cost: at the year 3 the values indicate the contribution analysis of the sum of all the O&M costs encountered during the first 3 years of operations; at the year 10 the values indicate the contribution analysis of the sum of all the O&M costs encountered during the first 10 years of operations.

Table 22: contribution analysis of the cumulative O&M costs for all the timeframes (1-10 years) and all the alternatives modelled in the paper

	Year	Salary	Fuel	Minor maint.	Major maint.	TOT
HP	**1**	36%	0%	64%	0%	100%
	2	19%	0%	35%	46%	100%
	3	15%	0%	26%	59%	100%
	4	14%	0%	26%	60%	100%
	5	16%	0%	29%	55%	100%
	6	13%	0%	24%	63%	100%
	7	14%	0%	26%	60%	100%
	8	14%	0%	26%	60%	100%
	9	13%	0%	24%	62%	100%
	10	13%	0%	24%	62%	100%
2_S	**1**	80%	0%	20%	0%	100%
	2	80%	0%	20%	0%	100%
	3	80%	0%	20%	0%	100%
	4	80%	0%	20%	0%	100%
	5	80%	0%	20%	0%	100%
	6	80%	0%	20%	0%	100%
	7	71%	0%	18%	11%	100%
	8	72%	0%	18%	9%	100%
	9	73%	0%	18%	8%	100%
	10	74%	0%	19%	8%	100%
2_Ds	**1**	43%	39%	18%	0%	100%
	2	37%	33%	16%	14%	100%
	3	39%	35%	16%	10%	100%
	4	37%	33%	16%	14%	100%
	5	38%	34%	16%	12%	100%
	6	33%	30%	14%	23%	100%
	7	33%	30%	14%	23%	100%
	8	33%	30%	14%	23%	100%
	9	34%	31%	14%	21%	100%
	10	34%	30%	14%	21%	100%
2_Dl	**1**	36%	46%	18%	0%	100%
	2	31%	40%	16%	12%	100%
	3	30%	39%	15%	16%	100%
	4	31%	40%	16%	12%	100%
	5	27%	34%	14%	25%	100%
	6	27%	35%	14%	25%	100%
	7	27%	35%	14%	25%	100%
	8	28%	36%	14%	22%	100%
	9	26%	34%	13%	26%	100%
	10	26%	34%	13%	27%	100%
5_S	**1**	75%	0%	25%	0%	100%
	2	75%	0%	25%	0%	100%
	3	75%	0%	25%	0%	100%
	4	75%	0%	25%	0%	100%
	5	75%	0%	25%	0%	100%
	6	75%	0%	25%	0%	100%
	7	62%	0%	21%	17%	100%
	8	64%	0%	21%	15%	100%
	9	65%	0%	21%	14%	100%
	10	66%	0%	22%	13%	100%
5_Ds	**1**	42%	37%	21%	0%	100%
	2	36%	32%	18%	14%	100%

	3	38%	34%	19%	10%	100%
	4	36%	32%	18%	14%	100%
	5	37%	33%	18%	12%	100%
	6	32%	29%	16%	23%	100%
	7	32%	28%	16%	24%	100%
	8	32%	28%	16%	24%	100%
	9	33%	29%	16%	22%	100%
	10	33%	29%	16%	22%	100%
5_H	**1**	53%	20%	26%	0%	100%
	2	53%	20%	26%	0%	100%
	3	53%	20%	26%	0%	100%
	4	53%	20%	26%	0%	100%
	5	44%	17%	22%	18%	100%
	6	45%	17%	22%	15%	100%
	7	43%	17%	21%	19%	100%
	8	44%	17%	22%	17%	100%
	9	45%	17%	22%	15%	100%
	10	42%	16%	21%	21%	100%
5_Dl	**1**	35%	44%	21%	0%	100%
	2	31%	39%	18%	12%	100%
	3	29%	37%	18%	16%	100%
	4	31%	39%	18%	12%	100%
	5	25%	32%	15%	27%	100%
	6	26%	33%	16%	26%	100%
	7	26%	33%	16%	25%	100%
	8	27%	34%	16%	23%	100%
	9	25%	32%	15%	27%	100%
	10	25%	32%	15%	28%	100%
10_S	**1**	83%	0%	17%	0%	100%
	2	83%	0%	17%	0%	100%
	3	83%	0%	17%	0%	100%
	4	83%	0%	17%	0%	100%
	5	83%	0%	17%	0%	100%
	6	83%	0%	17%	0%	100%
	7	79%	0%	16%	5%	100%
	8	74%	0%	15%	10%	100%
	9	75%	0%	16%	9%	100%
	10	76%	0%	16%	8%	100%
10_Ds	**1**	42%	47%	11%	0%	100%
	2	42%	47%	11%	0%	100%
	3	38%	43%	10%	9%	100%
	4	39%	44%	10%	7%	100%
	5	39%	45%	10%	6%	100%
	6	38%	43%	10%	9%	100%
	7	38%	44%	10%	8%	100%
	8	38%	43%	10%	10%	100%
	9	37%	42%	10%	11%	100%
	10	34%	39%	9%	18%	100%
10_H	**1**	47%	38%	16%	0%	100%
	2	47%	38%	16%	0%	100%
	3	47%	38%	16%	0%	100%
	4	47%	38%	16%	0%	100%
	5	41%	33%	14%	12%	100%
	6	42%	34%	14%	10%	100%
	7	41%	34%	14%	11%	100%
	8	42%	34%	14%	10%	100%
	9	41%	33%	14%	12%	100%
	10	40%	33%	14%	13%	100%
10_Dl	**1**	30%	59%	11%	0%	100%
	2	27%	53%	10%	10%	100%
	3	28%	55%	10%	7%	100%
	4	27%	53%	10%	10%	100%
	5	27%	52%	10%	11%	100%
	6	25%	48%	9%	18%	100%
	7	25%	49%	9%	17%	100%
	8	25%	49%	9%	17%	100%
	9	25%	50%	9%	16%	100%
	10	25%	49%	9%	17%	100%

25_S	1	74%	0%	26%	0%	100%
	2	74%	0%	26%	0%	100%
	3	74%	0%	26%	0%	100%
	4	74%	0%	26%	0%	100%
	5	74%	0%	26%	0%	100%
	6	74%	0%	26%	0%	100%
	7	68%	0%	24%	8%	100%
	8	60%	0%	21%	19%	100%
	9	62%	0%	21%	17%	100%
	10	63%	0%	22%	16%	100%
25_Ds	1	23%	67%	9%	0%	100%
	2	23%	67%	9%	0%	100%
	3	22%	62%	9%	7%	100%
	4	22%	63%	9%	6%	100%
	5	22%	64%	9%	4%	100%
	6	22%	62%	9%	7%	100%
	7	22%	63%	9%	6%	100%
	8	21%	61%	9%	10%	100%
	9	21%	60%	8%	11%	100%
	10	20%	56%	8%	16%	100%
25_H	1	28%	57%	15%	0%	100%
	2	28%	57%	15%	0%	100%
	3	28%	57%	15%	0%	100%
	4	28%	57%	15%	0%	100%
	5	24%	49%	13%	14%	100%
	6	25%	50%	14%	12%	100%
	7	24%	50%	13%	13%	100%
	8	25%	50%	14%	11%	100%
	9	24%	50%	13%	12%	100%
	10	24%	48%	13%	15%	100%
25_Dl	1	15%	76%	9%	0%	100%
	2	14%	70%	8%	7%	100%
	3	15%	72%	8%	5%	100%
	4	14%	70%	8%	7%	100%
	5	14%	68%	8%	10%	100%
	6	13%	64%	8%	15%	100%
	7	13%	66%	8%	13%	100%
	8	13%	66%	8%	13%	100%
	9	14%	67%	8%	12%	100%
	10	13%	65%	8%	14%	100%
50_S	1	64%	0%	36%	0%	100%
	2	64%	0%	36%	0%	100%
	3	64%	0%	36%	0%	100%
	4	64%	0%	36%	0%	100%
	5	64%	0%	36%	0%	100%
	6	64%	0%	36%	0%	100%
	7	50%	0%	28%	22%	100%
	8	44%	0%	25%	31%	100%
	9	46%	0%	26%	29%	100%
	10	47%	0%	26%	26%	100%
50_Ds	1	19%	71%	10%	0%	100%
	2	19%	71%	10%	0%	100%
	3	18%	66%	9%	6%	100%
	4	19%	67%	9%	5%	100%
	5	19%	68%	10%	4%	100%
	6	18%	66%	9%	6%	100%
	7	18%	67%	9%	5%	100%
	8	18%	64%	9%	10%	100%
	9	17%	63%	9%	10%	100%
	10	17%	60%	8%	15%	100%
50_H	1	23%	59%	18%	0%	100%
	2	23%	59%	18%	0%	100%
	3	23%	59%	18%	0%	100%
	4	23%	59%	18%	0%	100%
	5	20%	51%	16%	14%	100%
	6	20%	52%	16%	12%	100%
	7	19%	49%	15%	17%	100%
	8	19%	50%	15%	16%	100%
	9	19%	50%	15%	16%	100%

	10	19%	48%	15%	18%	100%
50_Dl	**1**	13%	79%	9%	0%	100%
	2	12%	74%	8%	6%	100%
	3	12%	75%	8%	4%	100%
	4	12%	74%	8%	6%	100%
	5	11%	71%	8%	10%	100%
	6	11%	67%	8%	14%	100%
	7	11%	69%	8%	12%	100%
	8	11%	69%	8%	12%	100%
	9	11%	70%	8%	11%	100%
	10	11%	68%	8%	13%	100%
50_S2	**1**	61%	0%	39%	0%	100%
	2	61%	0%	39%	0%	100%
	3	61%	0%	39%	0%	100%
	4	61%	0%	39%	0%	100%
	5	61%	0%	39%	0%	100%
	6	61%	0%	39%	0%	100%
	7	48%	0%	31%	21%	100%
	8	43%	0%	27%	30%	100%
	9	44%	0%	28%	28%	100%
	10	45%	0%	29%	25%	100%
50_Ds2	**1**	19%	71%	10%	0%	100%
	2	19%	71%	10%	0%	100%
	3	18%	66%	9%	6%	100%
	4	19%	67%	9%	5%	100%
	5	19%	68%	10%	4%	100%
	6	18%	66%	9%	6%	100%
	7	18%	67%	9%	5%	100%
	8	18%	64%	9%	10%	100%
	9	17%	63%	9%	10%	100%
	10	17%	60%	8%	15%	100%
50_H2	**1**	23%	59%	18%	0%	100%
	2	23%	59%	18%	0%	100%
	3	23%	59%	18%	0%	100%
	4	23%	59%	18%	0%	100%
	5	20%	51%	16%	14%	100%
	6	20%	52%	16%	12%	100%
	7	21%	53%	16%	10%	100%
	8	21%	54%	16%	9%	100%
	9	21%	53%	16%	10%	100%
	10	20%	51%	16%	14%	100%
50_Dl2	**1**	13%	79%	9%	0%	100%
	2	12%	74%	8%	6%	100%
	3	12%	75%	8%	4%	100%
	4	12%	74%	8%	6%	100%
	5	11%	71%	8%	10%	100%
	6	11%	67%	8%	14%	100%
	7	11%	69%	8%	12%	100%
	8	11%	69%	8%	12%	100%
	9	11%	70%	8%	11%	100%
	10	11%	68%	8%	13%	100%

SM A.21 Results of the LCC: scenario analysis

We tested our baseline results (with a discount rate of 0%) by varying the following parameters:

- Lifetime of the pump, 1 year shorter
- Lifetime of the pump, 1 year longer
- Lifetime of the inverter, 1 year shorter (6 instead than 7)
- Lifetime of the inverter, 1 year longer (8 instead than 7)
- Lifetime of the generator, 10,000 hours
- Lifetime of the generator, 35,000 hours
- Time needed before a generator overhaul, 3,500 hours (for 2 and 5 m^3/h) and 5,000 hours (for 10, 15 and 50 m^3/h)
- Time needed before a generator overhaul, 10,000 hours
- Cost of panels, 20% lower
- Cost of panels, 20% higher
- Cost of fuel – 4,000 UGX (instead than 3,000 UGX)
- Diesel consumption, 50% more

The scenario analysis quantified the impact of these choices on the unit cost per m^3 of water delivered and on the breakeven years.

*Table 23: Differences in the breakeven years. -x indicates that the breakeven year is x years earlier than in the baseline (in green), +x indicates that the breakeven years is x years later than in the baseline (in red). *the breakeven is not seen when fixing the maximum timeframe as 10 years, while it is observed during the scenario analysis*

Breakeven year													
		Pump lifetime		**Inverter lifetime**		**Generator lifetime**		**Generator overhaul**		**Cost of panels**		**Cost fuel**	**Diesel consumption**
Alternatives comparison	**Baseline**	**-1year**	**+1year**	**6 years**	**8 years**	**10,000h**	**35,000h**	**3,500h or 5,000**	**10,000**	**-20%**	**+20%**	**4,000 UGX**	**+50%**
2_S & 2_Ds	1st	0	0	0	0	0	0	0	0	0	0	0	0
2_S & 2_Dl	2rd	0	0	0	0	0	0	0	+1	0	0	0	0
5_S & 5_Ds	3rd	0	0	0	0	0	0	0	+1	0	+1	0	0
5_H & 5_Dl	5th	0	+1	0	0	-1	+1	0	0	0	0	0	0
5_S & 5_Dl	10th	0	-	0	0	0	-	0	-	0	+1	-1	-1
10_H & 10_Dl	3th	0	0	0	0	0	0	0	4th	0	+2	0	0
10_H & 10_Dl	6th	0	0	0	0	-2	0	-1	-1	-1	0	-2	0
10_S & 10_Dl	-	-	-	-	-	8th	-	-	-	-	0	8th	-
25_H & 25_Dl	3th	0	0	0	0	0	0	0	0	0	0	0	0
25_H & 25_Dl	4th	0	0	0	0	-1	0	0	0	0	0	-1	0
25_S & 25_Dl	7th	+1	0	0	0	-1	0	-1	0	-1	0	-2	-1

Supporting information

50_S & 50_Ds	4th	0	0	0	0	0	0	0	0	0	+1	-1	0
50_H & 50_Dl	6th	0	0	0	0	-1	0	-1	-1	-1	0	-2	-1
50_S & 50_Dl	8th	0	0	0	-1	-2	0	-2	0	-2	+1	-3	-2
50_S2 & 50_Ds2	5th	0	0	0	0	-1	0	0	0	-1	0	-1	-1
50_H2 & 50_Dl2	6th	0	0	0	0	-2	0	-1	-1	-1	0	-2	-1
50_S2 & 50_Dl2	8th	0	0	0	-1	-2	0	-2	0	-2	+1	-3	-2

SM A.22 Results of the carbon footprint: total kg CO_2-eq

We calculated the cumulative kg CO_2-eq for each timeframe for each alternative. The cumulative kg CO_2-eq indicates the cumulative carbon footprint given a certain timeframe:

$$Cumulative\ (kg\ CO_2 - eq)_{year\ i} = \sum_{i=1}^{n} (kg\ CO_2 - eq)_i\ ,where\ i\ is\ the\ year\ of\ reference$$

For example, the cumulative kg CO_2-eq at the timeframe 1 indicates the CO_2-eq due to the construction of the system and of the operation and maintenance activities encountered in the first year. The cumulative kg CO_2-eq at timeframe 2 indicates the sum of the kg CO_2-eq due to the construction of the system + the operation and maintenance activities done in the first and in the second year.

Figure 34 shows the total kg CO_2-eq in the first year due to both the construction of the systems and the operation and maintenance activities encountered in the 1st year.

Table 24 Table 25 and Table 26 show the total kg CO_2-eq for all the timeframes (1 to 10 years9 and all the alternatives).

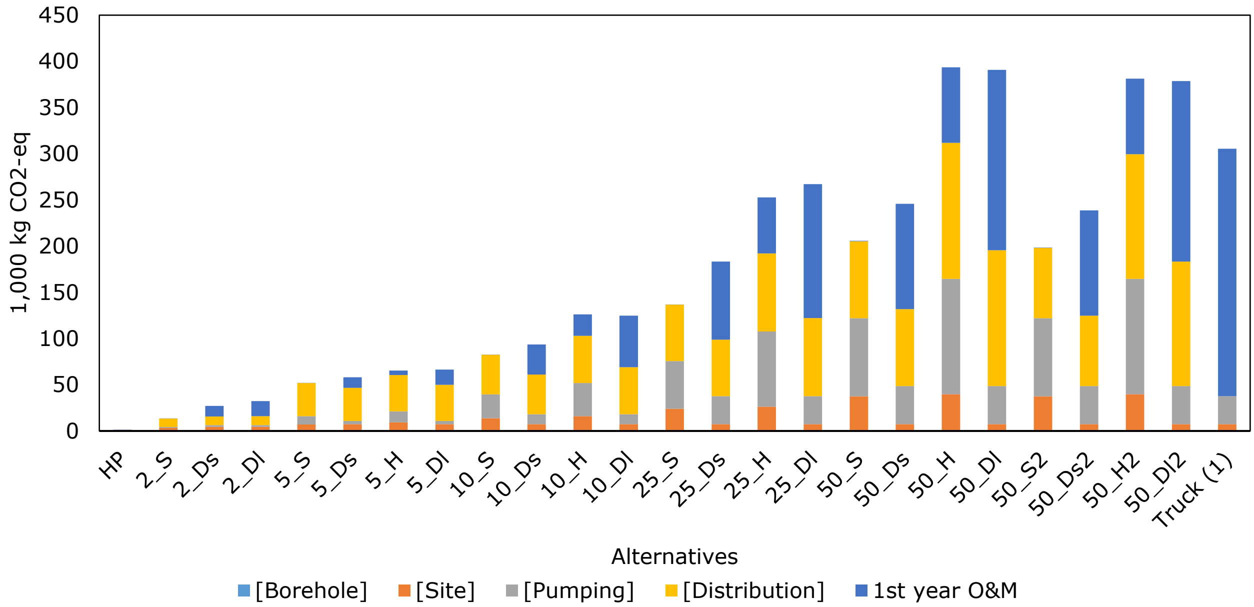


Figure 34: total kg CO_2-eq emitted in the first year (due to capital and operational activities encountered in the 1st year) for all the alternatives

Table 24: total kg CO_2-eq (due to capital and operational activities) for all the timeframes (1 to 10 years) for the hand pump and the motorised systems with a pumping yield of 1,5 and 10 m^3/h

	HP	2_S	2_Ds	2_DI	5_S	5_Ds	5_H	5_DI	10_S	10_Ds	10_H	10_DI
1	1,342	13,457	27,098	32,300	51,968	58,108	65,431	66,392	82,616	93,645	126,209	124,850
2	1,405	13,472	39,121	49,232	52,006	70,477	70,352	83,681	82,693	126,205	149,544	183,709
3	1,484	13,488	50,577	66,164	52,045	81,957	75,273	100,970	82,770	161,807	172,878	239,527
4	1,547	13,503	62,600	82,531	52,083	94,326	80,195	117,370	82,847	194,367	196,212	298,386
5	1,610	13,518	74,056	100,832	52,122	105,805	86,371	137,100	82,924	226,928	223,042	354,657
6	1,689	13,534	87,400	117,765	52,160	120,251	91,292	154,389	83,001	262,530	246,376	420,614
7	1,753	13,850	98,904	134,697	53,145	132,095	96,760	171,678	84,171	295,090	270,803	476,431
8	1,816	13,865	110,927	151,063	53,184	144,465	101,681	188,077	84,744	328,104	294,137	535,290
9	1,895	13,881	122,383	169,317	53,222	155,944	106,602	207,443	84,821	363,706	320,513	591,108
10	1,958	13,896	134,405	186,297	53,261	168,313	112,779	225,097	84,898	406,404	344,301	650,421

Table 25: total kg CO_2-eq (due to capital and operational activities) for all the timeframes (1 to 10 years) for the motorised systems with a pumping yield of 25 and 50 m^3/h

	25_S	25_Ds	25_H	25_DI	50_S	50_Ds	50_H	50_DI	50_S2	50_Ds2	50_H2	50_DI2
1	136,965	183,367	252,669	267,161	205,757	245,825	393,481	390,853	198,606	238,674	381,222	378,594
2	137,158	267,950	313,278	421,058	206,142	359,736	475,230	598,262	198,991	352,585	462,971	586,003
3	137,350	361,430	373,886	566,056	206,526	485,780	556,979	793,536	199,375	478,629	544,720	781,278
4	137,542	446,013	434,494	719,953	206,911	599,690	638,728	1,000,945	199,760	592,539	626,469	988,686
5	137,735	530,595	504,542	865,492	207,296	713,600	733,248	1,196,857	200,145	706,449	720,990	1,184,598
6	137,927	624,076	565,150	1,040,151	207,680	839,645	814,998	1,432,578	200,529	832,494	802,739	1,420,320
7	141,098	708,658	628,737	1,185,149	211,739	953,555	900,420	1,627,853	204,588	946,404	888,162	1,615,594
8	141,882	793,781	689,345	1,339,046	212,821	1,068,102	982,169	1,835,262	205,670	1,060,951	969,911	1,823,003
9	142,074	887,262	758,852	1,484,044	213,205	1,194,146	1,076,053	2,030,537	206,054	1,186,995	1,063,794	2,018,278
10	638,750	638,750	1,095,000	1,095,000	1,277,500	1,277,500	2,190,000	2,190,000	1,277,500	1,277,500	2,190,000	2,190,000

Table 26: total kg CO_2-eq (due to capital and operational activities) for all the timeframes (1 to 10 years) for the water trucking (1) and (2)

	Truck (1)	Truck (2)
1	305,475	122,833
2	276,730	122,833
3	267,831	122,833
4	276,730	122,833
5	268,372	122,833
6	297,493	122,833
7	267,831	122,833
8	276,730	122,833
9	267,831	122,833
10	277,270	122,833

SM A.23 Results of the carbon footprint: kg CO_2-eq / m^3 of water delivered

Table 27 and Table 28 show the kg CO_2-eq / m^3 for each year for each alternative. The cumulative kg CO_2-eq indicates the cumulative carbon footprint given a certain timeframe:

$$Cumulative\ \left(\frac{kg\ CO2-eq}{m^3}\right)_{year\ i} = \frac{\sum_{i=1}^{n} kg\ CO2-eq_i}{\sum_{i=1}^{n}(water\ delivered)_i}, where\ i\ is\ the\ year\ of\ reference$$

For example, the cumulative kg CO_2-eq at year 2 indicates the sum of the kg CO_2-eq due to the construction of the system + the O&M activities done in the first and in the second year divided the amount of water produced the first and the second year. To be noted that these are cumulative unit cost: at the year 3 the values indicate the kg CO_2-eq associated to each m^3 of water produced in the 3 years including all the activities happening in the first 3 years.

Table 27: results of the carbon footprint: kg CO_2-eq / m^3 for the hand pump and the motorised systems with a pumping yield of 2, 5 and 10 m^3/h for all the timeframes (1 to 10 years). The colours show which one of the power systems (solar, short-running diesel, hybrid and long-running diesel) is cleanest fixed the pumping yield and the timeframe. Green is the cleanest and yellow the dirtiest.

	HP	2_S	2_Ds	2_Dl	5_S	5_Ds	5_H	5_Dl	10_S	10_Ds	10_H	10_Dl
1	0.49	2.63	5.30	4.42	4.07	4.55	3.59	3.64	3.23	3.67	2.88	2.85
2	0.26	1.32	3.83	3.37	2.04	2.76	1.93	2.29	1.62	2.47	1.71	2.10
3	0.18	0.88	3.30	3.02	1.36	2.14	1.37	1.84	1.08	2.11	1.32	1.82
4	0.14	0.66	3.06	2.83	1.02	1.85	1.10	1.61	0.81	1.90	1.12	1.70
5	0.12	0.53	2.90	2.76	0.82	1.66	0.95	1.50	0.65	1.78	1.02	1.62
6	0.10	0.44	2.85	2.69	0.68	1.57	0.83	1.41	0.54	1.71	0.94	1.60
7	0.09	0.39	2.76	2.64	0.59	1.48	0.76	1.34	0.47	1.65	0.88	1.55
8	0.08	0.34	2.71	2.59	0.52	1.41	0.70	1.29	0.41	1.61	0.84	1.53
9	0.08	0.30	2.66	2.58	0.46	1.36	0.65	1.26	0.37	1.58	0.81	1.50
10	0.07	0.27	2.63	2.55	0.42	1.32	0.62	1.23	0.33	1.59	0.79	1.48

Table 28: results of the carbon footprint: kg CO_2 -eq / m^3 for the motorised systems with a pumping yield of 25 and 50 m^3/h and the water trucking (1) and (2) for all the timeframes (1 to 10 years). The colours show which one of the power systems (solar, short-running diesel, hybrid and long-running diesel) is the cleanest fixed the pumping yield and the timeframe. Green is the cleanest and yellow the dirtiest.

	25_S	25_Ds	25_H	25_Dl	50_S	50_Ds	50_H	50_Dl	50_S2	50_Ds2	50_H2	50_Dl2	Truck (1)	Truck (2)
1	2.14	2.87	2.31	2.44	1.61	1.92	1.80	1.78	1.55	1.87	1.74	1.73	2.79	1.12
2	1.07	2.10	1.43	1.92	0.81	1.41	1.08	1.37	0.78	1.38	1.06	1.34	2.66	1.12
3	0.72	1.89	1.14	1.72	0.54	1.27	0.85	1.21	0.52	1.25	0.83	1.19	2.59	1.12
4	0.54	1.75	0.99	1.64	0.40	1.17	0.73	1.14	0.39	1.16	0.72	1.13	2.57	1.12
5	0.43	1.66	0.92	1.58	0.32	1.12	0.67	1.09	0.31	1.11	0.66	1.08	2.55	1.12
6	0.36	1.63	0.86	1.58	0.27	1.10	0.62	1.09	0.26	1.09	0.61	1.08	2.58	1.12
7	0.32	1.58	0.82	1.55	0.24	1.07	0.59	1.06	0.23	1.06	0.58	1.05	2.56	1.12
8	0.28	1.55	0.79	1.53	0.21	1.05	0.56	1.05	0.20	1.04	0.55	1.04	2.55	1.12
9	0.25	1.54	0.77	1.51	0.19	1.04	0.55	1.03	0.18	1.03	0.54	1.02	2.54	1.12

10	0.22	1.57	0.75	1.50	0.17	1.06	0.53	1.02	0.16	1.05	0.52	1.02	2.54	1.12

SM A.24 Water availability

Comparison of the Bidibidi and Imvepi settlements and results from the report called "GIS for Good - Optimal Site Selection for Refugee Camps in Uganda (Figure 35 and Figure 36): A GIS Based Methodology" for safe water coverage and crop suitability [20]. The crop suitability and water availability are just two of many parameters investigated in the report that investigate many environmental factors (distance to water, flood risk, drought risk, interannual water variability, safe water coverage, elevation, slope, land use and soil type-food suitability) and social factors (population density, poverty density, distance from borders, distance to roads, distance to health centres, distance to education facilities and distance to towns).

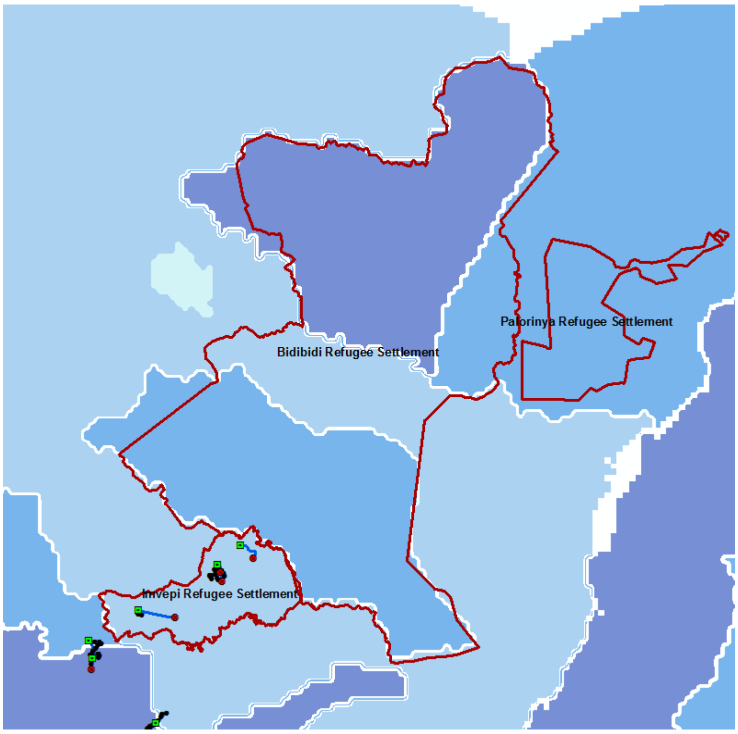


Figure 35: "Safe water coverage" of Bidibidi and Imvepi settlements based on Mong et al. (2014)*. Dark colours mean higher water coverage.*

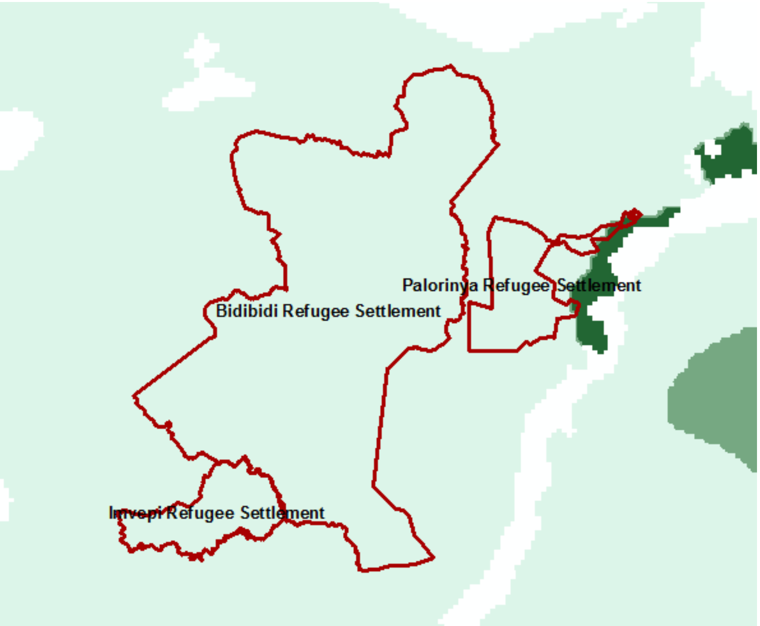
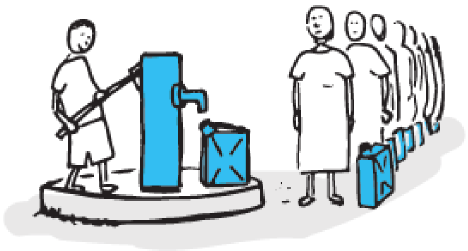


Figure 36: "Crop suitability" of the Bidibidi and Imvepi settlements based on Mong et al. (2014)*. Dark colours mean better crop suitability.*

SM A.25 Hazard Analysis and Critical Control Points (HACCPs)

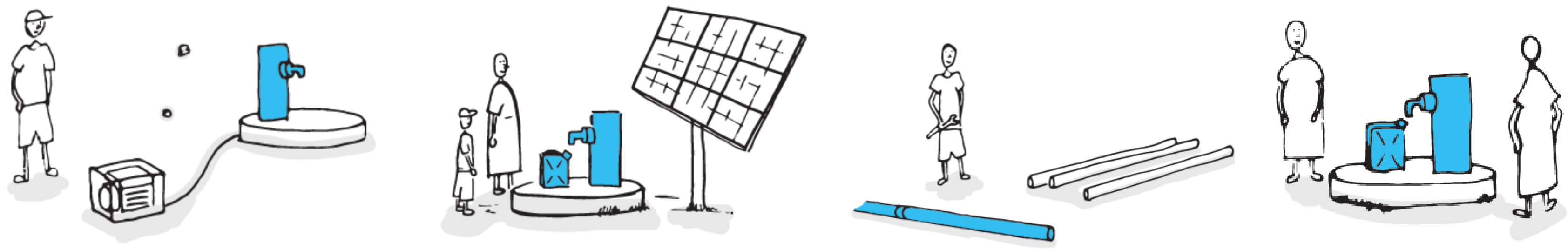
Hand pump



Drawing made by Iskandar Tange

	Borehole & site	Pump	Distribution & storage
Hazard assessment			
Design & finance	N/A	N/A	N/A
Construction			
O&M	• Infiltration of contaminated water into the aquifer • Microbial attachment in the well casing • Infiltration of contaminated water into the aquifer (from animal grazing, washing kids, latrines leaking)	• Microbial attachment to surface inside the pump (using dirty hands) • Contamination of water used for the priming of the pump	• Contamination of the water from the jerrycans
Disposal	N/A	N/A	N/A
Questions and answers			
Design & finance	N/A	N/A	N/A
Construction			
O&M	• Can animals and people access it? How far are the latrines? Usually there is no protection of the handpumps; in some host communities, a simple divider made of branches was found. • How well is the aquifer protected from surface? It depends on how the borehole was built • Do you add a concrete casing? NGOs should. • Do you do "shock chlorination" in the well to disinfect the well? No.	• People don't use specific attention when pumping the water • No problems regarding using contaminated water for the priming of the pump was observed.	• Do people wash the jerrycans? NGOs run awareness campaigns about how to use properly the jerrycans. This study did not quantitatively assess the results of these awareness campaigns. • Do people use the lids of the jerrycans to collect and store water? Very often lids were not found when collecting water at the tap stands
Disposal	N/A	N/A	N/A

Motorised systems (Diesel and solar powered pumping systems with gravity distribution (pipes)

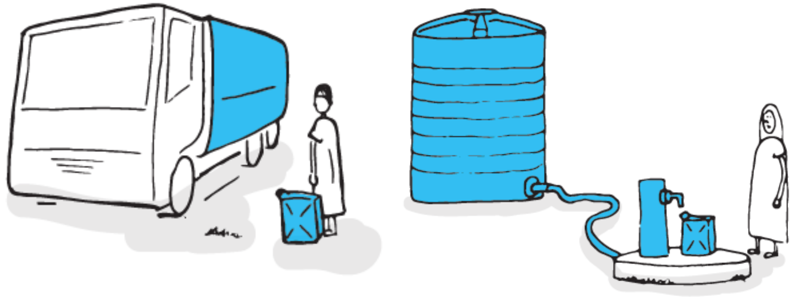


Drawings made by Iskandar Tange

	Borehole & site	**Pump**	**Distribution & storage**
		Hazard assessment	
Design & finance	N/A	N/A	N/A
Construction			
O&M	• Infiltration of contaminated water into the aquifer • Microbial attachment in the well casing • Infiltration of contaminated water into the aquifer (from animal grazing, washing kids, latrines leaking)	• Contamination of water used for the priming of the pump • Contamination of the environment due to the diesel or oil leakage	<u>Jerrycans</u> • Contamination of the water from the jerrycans <u>Distribution systems and storage tanks</u> • Contamination of pumped water if people add their own pipes • Contamination of the water in the pipes if not continuously under pressure and in case of leakage from the single pit latrines. • Contamination of the water in the storage tanks if people add their own pipes
Disposal	N/A	• Contamination of the environment by an unsound disposal of the solar panels or of the diesel generator.	N/A
		Hazard assessment	
Design & finance	N/A	N/A	N/A
Construction			<u>Distribution systems and storage tanks</u> • How deep in the ground, are the pipes built? Usually pipes are installed 1 meter deep in the ground. There were cases the pipes were less than a meter. No specific issues

			• Material of the distribution pipes? HDPE. The lifetime of the pipes was assumed to be 10 years if the construction was proper. • Are the pipes close to sewage pipes or latrines? There were some considerations regarding the distance between the borehole and the latrines but very often latrines were built by the refugees just closed to their home.
O&M	• Can animals and people access it? How far are the latrines? Motorised boreholes are protected with some a fence. • How well is the aquifer protected from surface? It depends on how the borehole was built but it seems NGOs put more attention on drilling boreholes for motorised pumps. • Do you add a concrete casing? NGOs should. • Do you do "shock chlorination" in the well to disinfect the well? No.	• Do people fetch the water at the pumping site? No, the boreholes are more isolated since the water is pumped into the storage tanks but people don't fetch directly at the borehole site. •	[Jerrycans, same as above] Distribution systems and storage tanks • Do people add their own pipes? No, because pipes were always under the ground. • At which control point do they add chlorine? Always at the pumping site • Do they add a constant amount of chlorine or does it vary (depending on what?) They add always the same amount of chlorine depending on the amount of residual chlorine. End users can complain in case the chlorine is too high. • No O&M activities for the pipes were planned. If there was a leakage, NGOs would assume the community would contact them seeing the water coming out from the pipe. End users tap stands • How do they check if chlorination is working? The NGOs check the residual chlorine always at the tap stand • Do they measure residual chlorine? How often? Yes, the responsible NGOs (or the water committees) was measuring residual chlorine every day. In case of cholera outbreak, E. coli count was done every day until the end of the emergency. • Do people add their own water hose to the tap? Not seen during the field trip.
Disposal	N/A	N/A	N/A

Water trucking



Drawings made by Iskandar Tange

Control point	Note	What to do
Borehole and site		
1. Water source	If centralised water treatment plant, outside the scope of the project If high yield pump, as before	• % water trucked • What is the source of water trucking? • How many km/hours of driving each time?
Pump		
Distribution and storage		
2. Water truck	Considered as a water storage – same as water tank	See before

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