WASH Results R/5/2024

Financial and Environmental Impact of Solar-Powered Water Systems in Ethiopia

SUMMARY

In Ethiopia, one of the major challenges to ensuring universal access to water is the distance of motorized water systems from the electric grid and the reliability of the power provided by the grid for water systems. To tackle these issues, UNICEF has been promoting and investing in solar photovoltaic (PV) systems as a cost-effective solution for providing equitable and reliable water services to off-grid systems between 2021 and mid-2023. As a result, 1.17 million people including over 287,000 forcibly displaced people have benefited from 59 solarized water supply schemes. 38 of these systems were dependent on diesel fuel power. It is expected that for these 38 partly or fully solarized systems alone, over 15 years, US$ 101.8 million will be saved on investment, operation, or maintenance costs corresponding to a return on investment of US$ 25.8 per dollar invested; and 40.6 kilo metric ton of avoided carbon dioxide (CO^2) emissions.

Introduction

Water situation in Ethiopia

Ethiopia, a nation endowed with significant water resources, faces a paradoxical situation marked by both water abundance and scarcity. Despite its rivers, lakes, and underground aquifers, the country grapples with water shortages that deeply affect the health, education, and livelihoods of its people. The complexity of Ethiopia's water crisis stems from a combination of factors including recurrent droughts, insufficient infrastructure, and a burgeoning population that strains existing water systems. According to the Joint Monitoring Programme (JMP) data of 2022, only 38% of the population has access to basic drinking water services (29% of the rural population), which means they can get water from an improved source within 30 minutes[1]. The rest of the population relies on unprotected resources, such as rivers, ponds, or wells, which expose them to various health risks. Waterborne illnesses like cholera and diarrhea are the primary cause of death among children under five in the country. Women and children are usually responsible for fetching water, which can take

[1] UNICEF-WHO Joint Monitoring Programme for Water Supply, Sanitation and Hygiene (https://washdata.org/, accessed Oct 2023)

hours and limit their opportunities for education and income generation compromising their safety.[2]

Climate Change and Water Scarcity

Climate change is altering the patterns and variability of rainfall, temperature, and evaporation in the country, which have direct and indirect impacts on the availability and quality of water resources. Ethiopia is at high risk of flooding as well as drought and the increased frequency and intensity of drought and flood occurrences directly impact water service delivery. Drought is the single most destructive climate-related natural hazard in Ethiopia, likely impacting negatively on water supply, biodiversity, and hydropower generation.[3]

Non-climate stressors and infrastructure challenges [4,5,6,7]

Ethiopia's vulnerability to climate change is exacerbated by non-climatic stressors such as inadequate infrastructure to handle the increasing population, limited access to electricity, and water system dependency on fuel or fuel imports. A World Bank study indicated that while only 33% of the country's population is connected to the electric grid, 80% of surveyed companies in Ethiopia experienced frequent power outages (eight times per month, for six hours on average during each outage). In certain parts of Ethiopia, water pumping systems are vulnerable to power fluctuations in the grid, which, without adequate surge protection equipment, can cause electromechanical equipment such as pumps to burn. Ethiopian water service providers face additional challenges such as the lack of easy access to foreign currency to purchase spare parts for maintaining or upgrading water systems, insecurity affecting isolated water systems regarding access to fuel or moving parts for maintenance increasing their vulnerability to climate change.

Solar-Based Water Solutions

While the upfront investment in solar-based water supply schemes is higher than generator-driven-riven or water trucking systems, the financial costs on a life cycle basis are favorable due to the much lower running costs, related to the quasi-free supply of energy, improved reliability of photovoltaic (PV) systems with less moving parts to be maintained.[8] The financial advantage, along with decreased reliance on unreliable grid power or fuel and less need for imported spare parts, are anticipated to greatly enhance water systems' resilience by contributing to water production cost reduction and supporting the provision of dependable and fair water services. The shift to solar technology is even more relevant in Ethiopia as it addresses challenges related to grid power failures or power fluctuations and helps to reduce fuel dependency for "off-grid" water systems or areas affected by access restrictions due to insecurity, thereby increasing the water coverage in the country.[9] In 2023, following the wing installation of solar equipment by UNICEF in Ethiopia, several water service providers reported that they preferred going completely off-grid to avoid losing pumps due to power surges in the power grid.

The potential reductions in carbon dioxide (CO^2) emissions which result from shifting to solar-powered water systems are equally significant.

UNICEF's Solar Initiatives and Impact

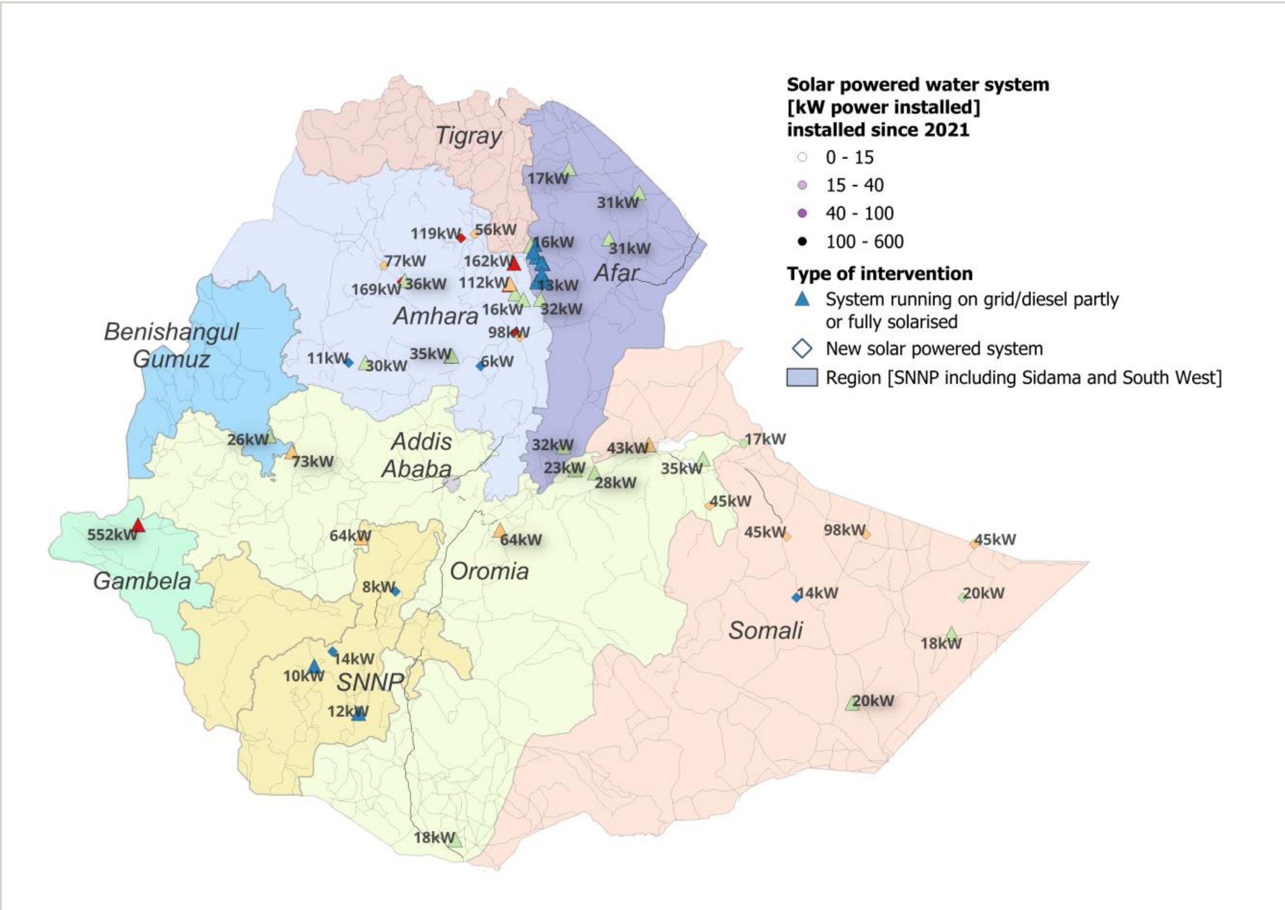
Since 2021, UNICEF has been installing solar PV equipment to power 59 water supply systems

[2] UNICEF, WHO, July 2023. Women and girls bear brunt of water and sanitation crisis. (https://www.unicef.org/wca/press-releases/women-and-girls-bear-brunt-water-and-sanitation-crisis-new-unicef-who-report, accessed Oct 2023))
[3] The World Bank Group, 2021. Climate Risk Country Profile: Ethiopia.
[4] Ibid
[5] About 56% of the total population have no access to any form of electricity. Source: Yalew, 2022. The Ethiopian energy sector and its implications for the SDGs and modeling, Renewable and Sustainable Energy Transition, Volume 2. https://doi.org/10.1016/j.rset.2022.100018
[6] Government of Ethiopia, Ministry of Water, Irrigation and Electricity, 2019. National Electrification Program 2.0
[7] The World Bank. Enterprise Surveys (http://www.enterprisesurveys.org, accessed Oct 2023)
[8] Federal Democratic Republic of Ethiopia. 2018. One WASH National Programme Phase 2 – A multi-sectoral SWAp Programme Document. Ministry of Water and Energy.
[9] Water systems which are not connected to the National electricity network.

across Ethiopia. Of these, 38 systems were fully or partially powered by diesel before installing the solar equipment, while 21 systems were newly installed (Figure 1 and Annex 1). Solar equipment has been installed especially to power water systems that are off-grid water systems or connected to an unreliable grid power to save the fuel and fuel transportation expenses which have been increasing significantly over the past years[10].

The initiative has had a significant impact, providing cleaner and more reliable water sources to approximately 1.17 million people, including over 230,000 refugees, thereby showcasing the positive financial and environmental impacts of shifting from fuel to solar power for water systems.

Figure 1: Water systems that have benefited from solar power investments with UNICEF support across different administrative regions in Ethiopia between mid-2021 and mid-2023



[10] The retail diesel price has increased with over 90 per cent in US dollar terms against the official exchange rate between May 2022 and May 2023 and with over 300 per cent since 2002 (https://ethiopianmonitor.com/; https://data.worldbank.org/, accessed Aug 2023)

Methodology

The study's methodology entailed an in-depth assessment of the financial and environmental impacts of transitioning from diesel to solar-powered water systems in Ethiopia. Extensive analysis was carried out on the system upgrade of the 38 systems that were initially fully or partially powered by diesel generators, before the installation of solar equipment. This was to evaluate the financial and environmental impact of solar power components of water systems. Lifecycle cost data was collected, encompassing capital installation and upgrade costs, anticipated capital maintenance, current and projected operational expenses, as well as reductions in CO_2 emissions. Financial analyses were conducted to compare 15-year projections of expenditures for continuing to operate water systems fully or partly powered by diesel generators as opposed to switching to solar power, factoring in an annual inflation rate of 15%[11]. For the environmental component, the avoided CO_2 emissions by transitioning to solar energy were calculated using established formulas that account for diesel consumption and the carbon content of the fuel. Assumptions were made related to the expected lifespan of the electromechanical and solar installations and the stability of solar energy output, with the recognition that technological advancements and economic shifts could influence future conditions. This approach provided a structured framework for synthesizing data to inform our findings on the viability and sustainability of solar-powered water systems.

The 38 water system solarization projects analyzed exhibit a high degree of diversity. Initially, 12 systems (32% of the total), which were entirely powered by diesel generators, were completely transitioned to solar power, while the remaining systems underwent partial solarization. Nine systems (24%) that were connected to the national electricity grid continue to receive partial power from the grid. The water systems vary significantly in size, serving a range of just over 1,000 to more than 260,000 beneficiaries (with a median of 5,854 beneficiaries), and the installed solar capacity ranges from 6.6kW to 891kW (median: 26.75). The system upgrades were implemented through various contractual arrangements: direct service contracts with UNICEF (13 systems), UNICEF partnership agreements with NGOs (20 systems), or directly by local government authorities with financial support from UNICEF (five systems). The government contributed financially to the upgrade of six systems (16% of all systems), with contributions averaging 15% of the total capital expenditure (CAPEX) for these systems.

Given the significant diversity among the solarization projects analyzed, efforts were made to collect as much data as possible on actual site-level expenditures. This includes capital expenditures and costs for diesel fuel and electricity, which were gathered for each site[12]. For other projected expenses related to operation, maintenance, and capital maintenance, calculations were performed based on equipment lifecycle analysis, the size of the system and number of beneficiaries, and average local unit costs for elements like equipment, staffing, and transport.

To assess the financial and environmental impact of the investments in solarization on the consumption, the fuel consumption before and after the upgrade was assessed. For the 18 solar systems not yet fully operational or handed over at the time of writing this paper, the expected fuel consumption and electricity bills after the investment were estimated with inputs from the water system service providers and local authorities.

[11] 15 per cent corresponds to the average annual inflation of consumer prices in Ethiopia between 2001 and 2023; source: The World Bank Data, Inflation, consumer prices (annual %) – Ethiopia (https://data.worldbank.org/, accessed July 2023)

[12] Fuel consumption can be considered as the proportionally most significant component impacting power expenses.

Calculation of the Cost Impact

This assessment compared the cumulative expenditure of operating 38 water systems over a specified period, focusing on systems that transitioned fully or partially from diesel to solar power. We analyzed *two scenarios:* The first assumes the continued use of diesel generators or hybrid diesel-grid systems (if an electricity grid is available) for water pumping over 15- years without adopting solar technology. The second scenario considers the costs of partial or complete solarization and operating solar or hybrid power water pumping systems for the same duration. In this scenario, for the systems still partially reliant on generator power post-upgrade, we factored in the average generator operation time post-upgrade compared to pre-upgrade. Capital investment expenditures (CAPEX), operational and minor maintenance expenditures (OPEX), and capital maintenance expenditures (CAPMANEX) were projected based on specific assumptions for each scenario.

CAPEX: The capital expenditure in this study refers to the initial investment cost for procuring and installing equipment to solarize the power system of the water supply system. The water pumping systems that were solarized included a wide range of pumps, both surface and submersible, with power configurations tailored to each site's needs. Some systems are exclusively solar-powered, while others are hybrid and utilize multiple energy sources including solar, diesel, or grid power. Typical capital investments for system upgrades included photovoltaic arrays with cabling, variable-speed pumps[13] (replacing single-speed pumps), security fencing, facilities like guard houses, drainage facilities, inverters, switchboards, surge protection devices, and other accessories. None of the upgraded systems incorporated a backup battery power.

OPEX: Operational and minor maintenance expenditures (OPEX) cover recurrent, regular, and routine maintenance necessary to maintain design performance, excluding major repairs or renewals. Operational costs typically involve human resources and energy costs (diesel or electricity), while minor maintenance costs are mainly material-related. OPEX, a relatively stable and ongoing expense, differs from the bulkier and irregular capital maintenance expenditure.[14] We employed a simplified model based on field data to calculate operating and maintenance costs, considering the size of the service delivery system and number of users. This analysis included average fuel consumption and electricity purchase costs before and after system solarization, gathered for each site. As of December 2023, the diesel price was set at 79.75 Birr per liter.

The calculation of operation and maintenance costs (OPEX), both for solar or fuel powered system, utilized current market data to evaluate unit costs associated with staffing for operators and guards, maintenance (including necessary fast-moving parts for system upkeep, and lubricants), and grid power, diesel, and diesel transportation where applicable. A simplified model, based on field data, was employed to compute operating costs and service and maintenance costs, taking into account the size of the service delivery system (determined by the number of users). To ensure an accurate representation of operational costs, average fuel consumption and costs for purchasing electricity from the grid, both before and after system solarization were gathered for each site and incorporated into the cost analysis. of this study, the diesel price was set at 79.75 Birr per liter, reflecting the retail diesel price in December 2023.

CAPMANEX: Capital maintenance expenditure (CAPMANEX) both for solar and fuel powered systems, relates to costs incurred in renewing assets (including replacing, rehabilitating,

[13] A variable speed pump is equipped with a pump motor that can run at variable speed with varying flow output depending on sun radiation availability allowing to take advantage more effectively from the limited hours sunshine time per day and do not require, as opposed to single speed pumps, extra power for starting the pumps, also known as surge power or peak power.

[14] Fonseca et al, March 2013. Financing capital maintenance of rural water supply systems: current practices and future options. IRC International Water and Sanitation Centre.

refurbishing, or restoring) to maintain the initial level of service. Renewing these assets, often after some years of operation, ensures the same level of service that users received when the asset was first installed.[14] In this analysis, only the capital maintenance costs related to the power systems were considered, which include the periodic overhaul of diesel generators and the replacement of inverters, switchboards and generators. The cost estimation was based on the size of the evaluated systems' pump capacity and solar capacity.

To account for future price escalations and budgeting, an annual inflation rate of 15% per[11] was applied to CAPEX, OPEX, and CAPMANEX projections. Annex 2 provides assumptions and rationale behind cost calculations of the system operation, maintenance, and lifecycle costing.

Calculation of Environmental Impact

In assessing the environmental impact, this study has exclusively focused on the CO_2 emissions from diesel-powered systems throughout their daily operation over their lifetime. Other significant potential impacts that have not been considered include environmental hazards related to over abstraction due to extended pumping hours, other forms of emissions, and the emissions linked to the manufacturing or transportation of electromechanical or solar equipment.

The solarization of water pumping systems significantly contributes to the reduction of CO_2 emissions, a key factor in mitigating global climate change. Over 15 years, the reduced CO_2 emissions were calculated to assess the environmental benefits stemming from decreased diesel fuel consumption. The CO_2 emissions were calculated using the following formula, assuming combustion of diesel fuel:

CO_2 emissions (kg) = amount of diesel (l) x diesel density (kg/l) x diesel carbon content (kg C/kg fuel) x CO_2 to carbon ratio (44/12). Diesel has a density of about 0.832 kg/l and a carbon content of about 0.85 kg C/kg fuel. The CO_2 to carbon ratio is 44/12 because the molecular weight of CO_2 is 44 and the molecular weight of carbon is 12. [15]

Results: Expected Financial and Environmental Impact

The total capital investments for upgrading the 38 systems amounted to 4.96 million US dollars, inclusive of a 120 thousand US dollar contribution from local regional governments. It is important to note that the capital investments for the diesel generators, serving as backup or complementary power sources, are not included in this assessment, as these generators were pre-existing.

An overview of the expected financial and environmental impacts following investments to shift the power of 38 motorized water systems from fuel power (diesel generators) to solar PV power is provided. The calculations were based on data related to capital, capital maintenance, operational and maintenance expenditures, estimated CO_2 emission, and other related factors for 38 water supply systems. The analysis covers multiple regions, including Gambella, SNNP, Amhara, Oromia, and Afar. The impact calculations assume proper operation, maintenance, and capital maintenance over 15 years.

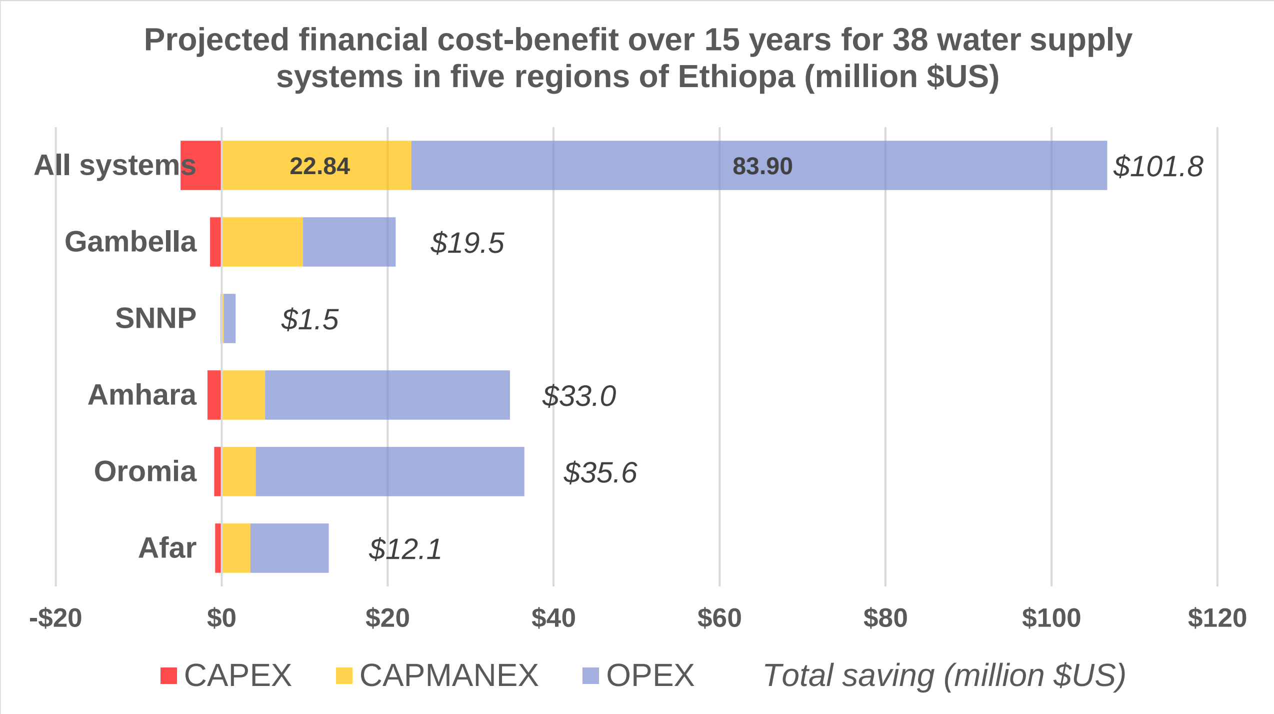
Financial Impact

Over 15 years, substantial savings are projected from the switch from fuel generators to solar systems, as illustrated in Figure 2. This figure displays the estimated savings in millions of US dollars, highlighting the impact of investment in solarization. The graph shows the negative CAPEX, associated with the investment, along with

[15] United States Environmental Protection Agency. Greenhouse Gases Equivalencies Calculator - Calculations and References. (https://www.epa.gov/energy/greenhouse-gases-equivalencies-calculator-calculations-and-references, accessed July 2023)

the cumulative savings in terms of CAPMANEX and OPEX across various Ethiopian regions.

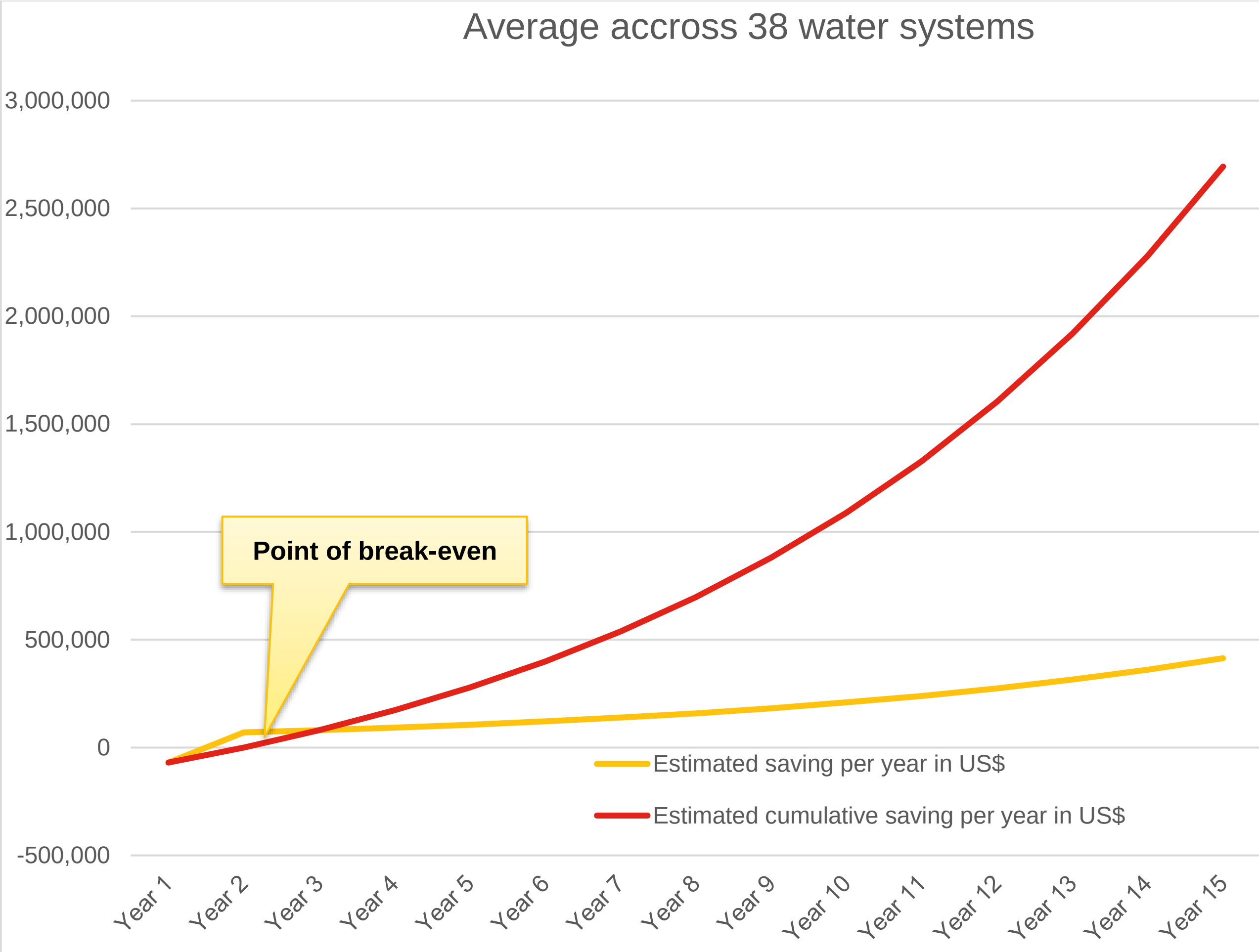
Figure 2: Projected cost-benefit over 15 years in million US$ as a result of shifting existing diesel-powered systems to solar power of 38 water supply systems in five regions of Ethiopia



It is clear from the graph above that OPEX, mainly influenced by factors such as high fuel costs, contributes most significantly to the savings, exceeding CAPMANEX and CAPEX contributions. Overall, it is estimated that 101.8 million US dollars will be saved over 15 years, mainly due to avoided expenditures related to system operations and routine maintenance, including investment costs needed to ensure wear and tear of the solar systems (83.9 million) and to a lesser extent to avoided replacement or reinvestment costs (22.8 milion).[16] This demonstrates that solar systems contribute to sustainable water service provision increasing accessibility for beneficiaries through reduced water system lifecycle and water production costs. Notably, the return on investment (ROI) is typically achieved before the third year of operation (see Figure below).

[16] It must be noted that b none of the upgraded systems incorporated a backup battery power.

Figure 3: Estimated saving in US$ by solarizing a water system as compared to keeping it running on diesel-fueled power over 15 years (lifecycle costs of the system without solarization investments minus life cycle costs when shifting to solar energy, including CAPEX, CAPMANEX, and OPEX) - average per system across 38 systems.



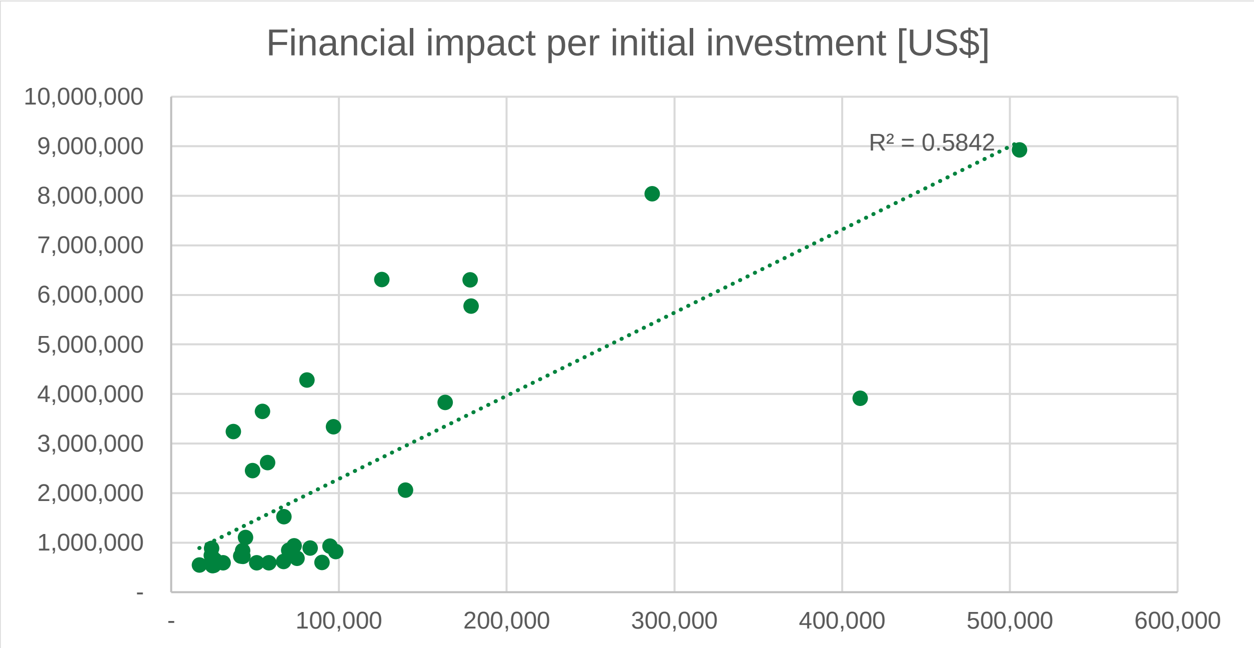
On average, for every US dollar invested, a saving of 25.8 US dollars is expected over 15 years in avoided expenditures on operation, maintenance and capital maintenance costs on diesel powered systems by shifting power to solar. The financial impact and the ROI vary significantly across various regions. Due to the considerable diversity among the solarization projects and the limited number of sites analyzed (see Methodology chapter), it is challenging to pinpoint the factors causing these regional variations.

Investment efficiency

Figure 4 presents a scatter plot that displays the relationship between the total investment in solar power projects (CAPEX) on the x-axis and the resultant financial impact on the y-axis. This plot shows a positive correlation between the initial investment and anticipated savings, with a correlation value (R^2 value) of 58%. This means that 58% of the variation in the expected savings can be explained by the initial investment in solar power projects. It's important to note that while this indicates a strong relationship, it doesn't imply causation, and other factors could also be influencing the expected savings. The correlation analysis was conducted for 37 out of the 38 sites;

one site, where the initial investment was tenfold the average of the other 37 sites, was excluded from this plot to prevent distortion of the analysis.

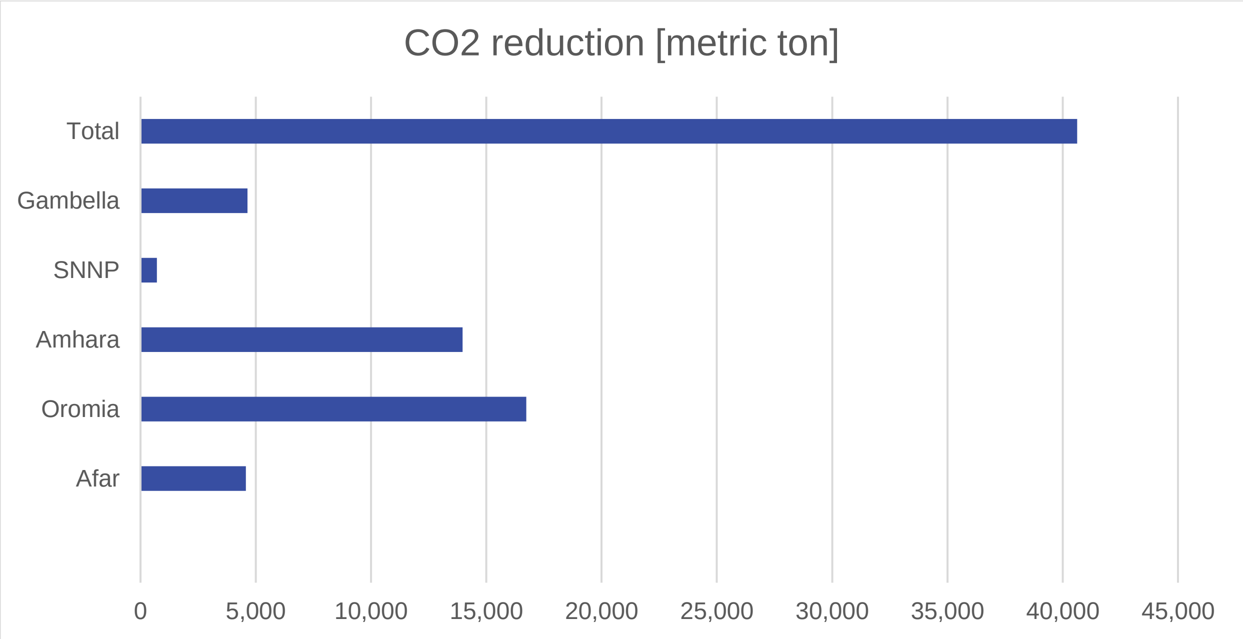
Figure 4: Return on investment (Y-axis) per initial capital investment (X-axis) over a 15-year period



Environmental Impact

Figure 5 below shows the avoided CO_2 emissions in metric tons (mt) for different regions in Ethiopia a over 15-year period following the replacement of fuel generators with solar power systems. It is projected that the shift in 38 project sites across Ethiopia will result in a reduction of 40,634 mt of CO_2, marking a substantial environmental impact; 40,000 mt corresponds to the emissions of 20,000 gasoline run passenger cars driving one year The main reason for this significant CO_2 reduction is the decrease in diesel fuel usage for operating generators over 15 years. However, it should be noted that some factors limit CO_2 emissions reduction, such as the use of eco-friendly on-grid power before the solar system installation and the continued use of fuel generators even after the solar power. Some sites may continue to use their diesel generators alongside the new solar systems if the solar panels cannot produce enough power on their own to meet the community's needs, particularly during periods of insufficient solar energy generation. Despite these considerations, the overall forecast, incorporating both financial and environmental aspects, highlights the cost-effectiveness, and sustainability of adopting solar systems, as previously detailed in the figure analysis of financial savings. The average avoided carbon dioxide emissions correspond to 11 metric per 1,000 US $ invested over 15 years.

Figure 5: Avoided CO2 emissions over a 15 year period



It's important to highlight that the calculated reduction in carbon dioxide emissions is likely an underestimation. The capacity and efficiency of the generators installed at the assessed water systems is not known. Due to limited availability of generators on the market, the generators installed for water pumping are frequently inadequately sized and for that matter oversized. This is because operators often struggle to find a generator that fits their needs perfectly at the time of installation and rather install generators with higher capacity than required. An oversized generator often runs at a fraction of its capacity, which can lead to lower efficiency and higher fuel consumption per unit of electricity produced. This increased fuel consumption can lead to higher carbon dioxide emissions. The efficiency of diesel generator is inversely proportional to its rated power, fuel consumption rate and carbon dioxide emissions. Therefore, the rated power of selected diesel generator should be close to the required load demand. The increment of a single kW rated power diesel generator at a constant emission factor was found to increase 1.1 to 1.2 times carbon footprint emissions.[17]

KEY POINTS

- *Return on investment, on average of assessed systems per US $ invested is US$25.8 over a 15 years' period*
- *An average of 11 tons of carbon dioxide emissions are avoided per 1,000 US$ invested over 15 years, equivalent to driving a gasoline-powered car for 2.4 years*[18]

Discussion

Focus on two solarization projects: the Itang water supply system in Gambella region and the Hariro water supply system in East Haraghe, Oromia region

[17] Jakhrani and all, 2012. Estimation of carbon footprints from diesel generator emissions, Proceedings International Conference Green Ubiquitous Technology, pp. 78-81, July 2012. (DOI: 10.1109/GUT.2012.6344193)

[18] United States Environmental Protection Agency. Greenhouse Gases Equivalencies Calculator - Calculations and References. (https://www.epa.gov/energy/greenhouse-gases-equivalencies-calculator-calculations-and-references, accessed July 2023)

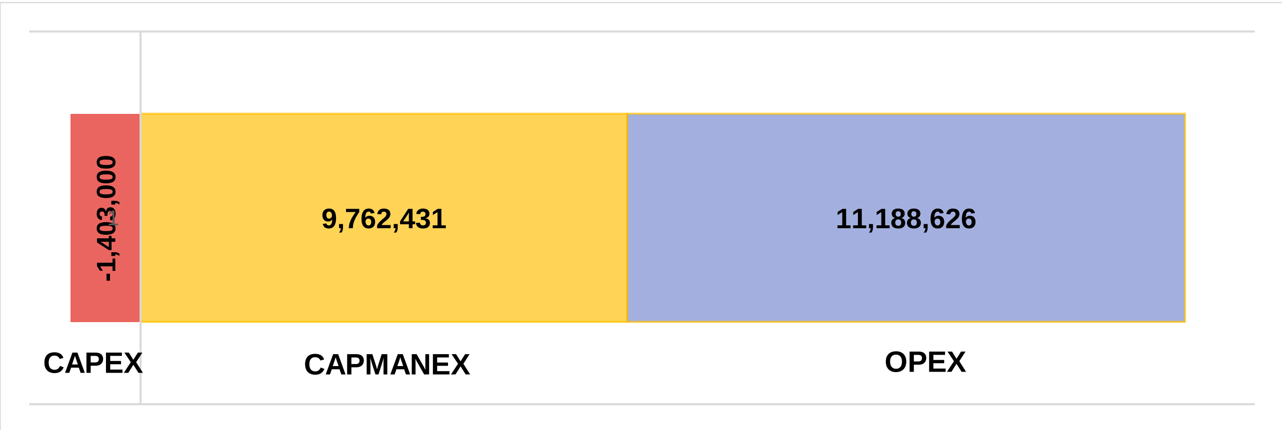
Case of Itang water supply system

Gambella region is hosting over 380,000 South Sudanese refugees and the numbers seeking refuge have increased steadily since 2014 as a result of civil war (2013-2020) with over 237,000 refugees (including 148,763 children) now living in the three camps of Kule, Tierkidi and Nguenyiel located close to the town of Itang.[19] Itang lies near the Baro river, a major White Nile tributary. With UNICEF support and significant financial support from UKAid and the German BMZ / KfW bank, a water supply system was constructed to provide water to over 265,000 people, including the three camps and two host communities, Itang and Turpham. The system is operated by the Itang Town Water Utility. As part of the ongoing efforts to improve sustainability, water provision reliability and to reduce the cost of water production solar systems have been installed at the collection chamber (333 KW PV capacity) and booster station (371 KW PV capacity) in 2023. The system provides power to five solar surface pumps with varying levels of 203 KW of total power. Three pumps are setup at the collection chamber and two pumps at the booster station.

The system is powered by solar, grid and generators (which used when there is cloud cover and no electricity). The average diesel consumption per day prior to solarization was close to 800 liter per day, with peaks of over 2,000 liter per day when grid power not available.

The introduction of the solar system is expected to have a significant impact on costs related to powering the water supply system due to the reduction in the grid and diesel fuel requirement, but also the savings on maintenance and capital maintenance. The investment of around $ 1.4 million in the solarization of part of the system, is expected to reduce the generator power generation with 41 percent. Over a 15-year period the solar system should lead to savings on capital maintenance costs (for renewing assets to maintain the initial level of service) of over 9.7 million US$ and on day-to-day operation (mainly due to diesel fuel costs) and routine maintenance of over 11 million US$ (see figure below).

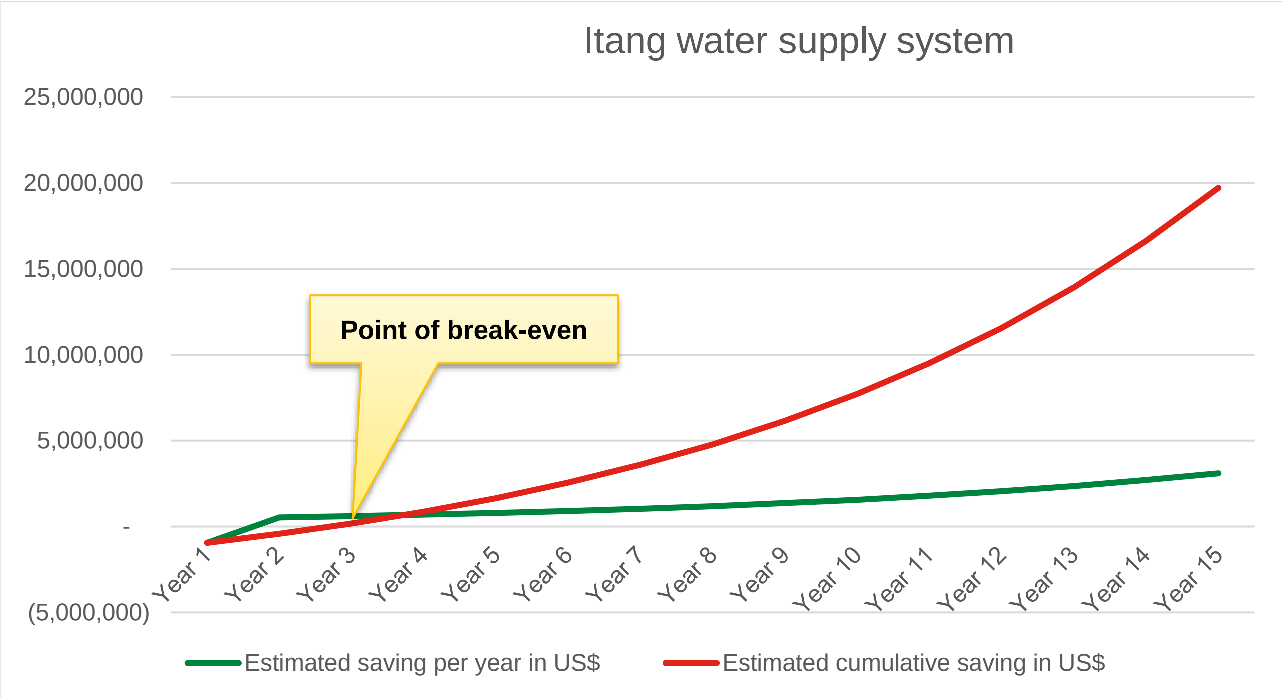
Figure 6: CAPEX, CAPMANEX and OPEX Contributions to the predicted financial impact over 15 years for the Itang water supply system.



[19] UNHCR, 2023. UNHCR sub office Gambella, Ethiopia, Operational overview as of 31 August 2023. (https://data.unhcr.org, accessed Dec 2023)

The return on investment (ROI) of $13.9 saved for each dollar invested is relatively low compared to the average ROI of the 38 systems analyzed. This could be due to the substantial initial investment needed for solarizing the system, which involved considerable leveling and drainage work, as well as measures to secure the equipment, like building security walls. Furthermore, the unstable security conditions and access limitations led to multiple pauses in the implementation, escalating the service costs of contractors and suppliers engaged for equipment installation.

Figure 7: Estimated saving in US$ by solarizing the booster station and collection chamber of the Itang water supply system as compared to doing no intervention over 15 years (lifecycle costs of the system without solarization investments minus life cycle costs when shifting to solar energy, including CAPEX, CAPMANEX, and OPEX).



Over a period of 15 years, this investment will have avoided the emission of 4,645 metric tons of carbon dioxide.

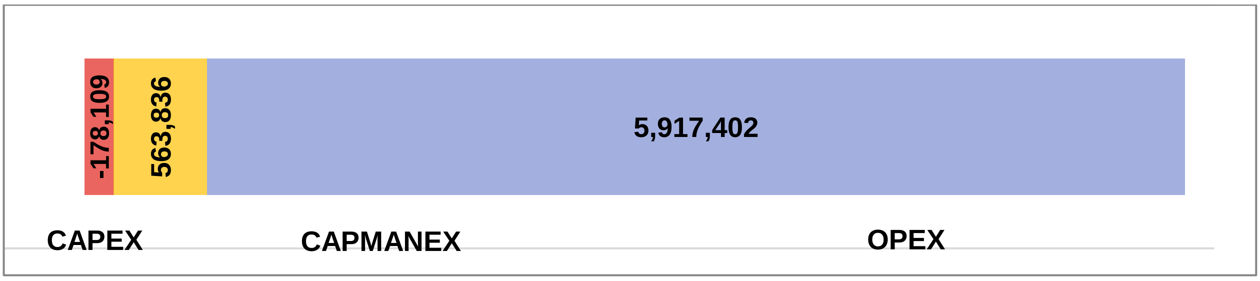
Case of the Hariro water supply system in East Hararghe, Oromia region

The Hariro community is situated in East Hararghe zone, Oromia Region, where the 2023 drought has taken a devastating toll on children, their families and livestock. The Hariro water system is an off-grid remote system, which operates on a single borehole and serves over 41,000 people. The system was solarized as part of the UNICEF response to the drought. The borehole with pump of 45kW was replaced with a variable speed pump adapted to solar power supply and solar equipment with solar PV panels with a capacity of 64kW was installed.

Figure 8: Solar array constituted of 162 solar PV panels powering the Hariro water supply system. (@UNICEF Ethiopia/2023)

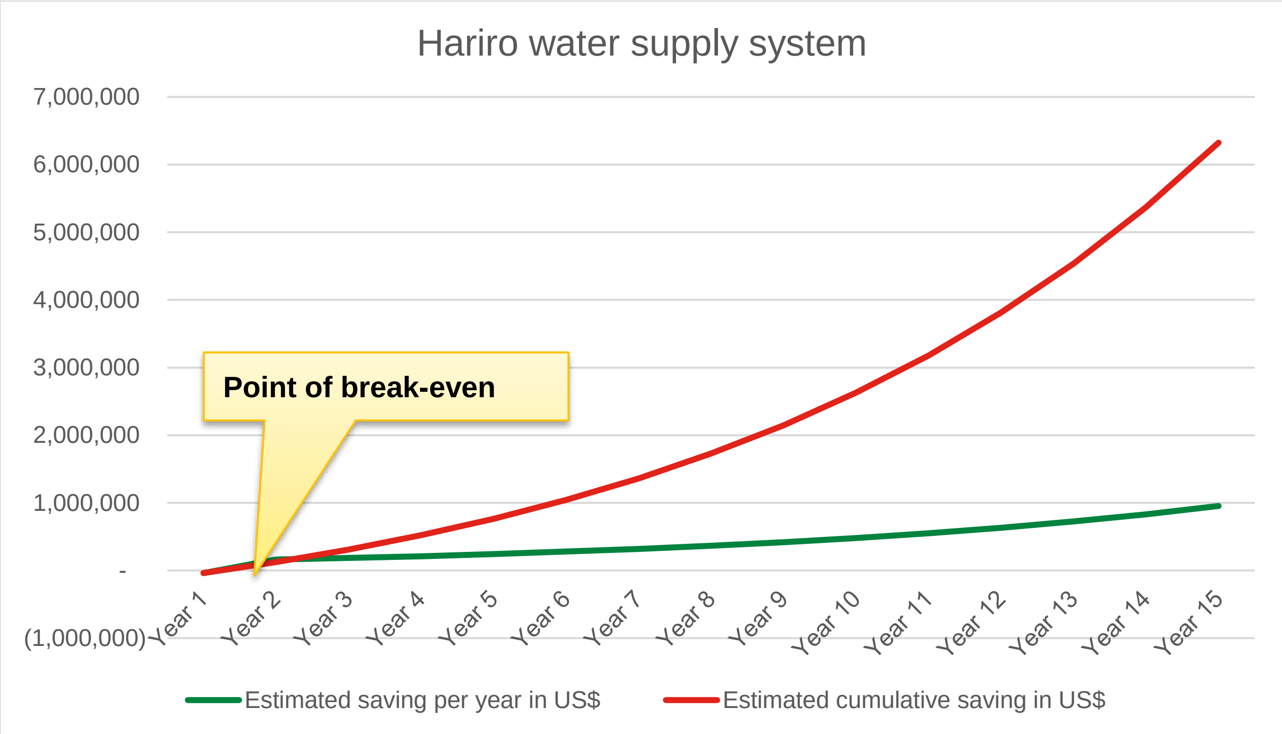
While the community required an average of 220 liter diesel per day prior to the solarization, the diesel requirements have been reduced to zero. The generator is still in place as a backup power option, in case the solar system is failing. The initial investment of about US$ 178,000 is expected to lead to savings on capital maintenance costs (for renewing assets to maintain the initial level of service) of over US$ 563,000 and on OPEX, which constitutes of the day-to-day operation (mainly fuel costs) and routine maintenance of over 5.9 million US$ (see figure below). The lower CAPMANEX contribution (9 per cent) than OPEX contribution (91 per cent) towards the savings (reduced expected expenditures for OPEX and CAPMANEX) can be explained by the fact that the CAPEX of the equipment which was in place prior to system solarization, constituted of one pump pumping water into one overhead tank from where the water is distributed to the nearby community, was relatively small to start off with, resulting in a higher percentage of savings being attributed to OPEX rather than CAPMANEX.

Figure 9: CAPEX, CAPMANEX and OPEX Contributions to the predicted financial impact over 15 years for the Hariro water supply system.



The ROI for this system is already achieved after two years and is expected to reach after 15 years of operation 22.6 dollar per dollar initially invested

Figure 10: Estimated saving in US$ by solarizing the Hariro water supply system as compared to keep it running on diesel over 15 years (lifecycle costs of the system without solarization investments minus life cycle costs when shifting to solar energy, including CAPEX, CAPMANEX, and OPEX).



Over a period of 15 years, this investment will have avoided the emission of over 3,123 metric tons of carbon dioxide.

Multiple benefits

Lowering the cost of water production can have multiple benefits. It not only makes the water system more sustainable and resilient in the long term, but it also allows the water utility to provide more equitable access to water services. This is particularly important in contexts where affordability can be a barrier to access. Moreover, in fragile environments, where refugees and host communities co-exist, lower water production costs can contribute to social cohesion. By reducing the financial burden of water access, it can help alleviate potential sources of conflict and promote harmony between different communities.

This approach aligns with the principles of social sustainability, which emphasize the importance of creating inclusive and equitable societies. Solarizing systems also reduces the dependency on diesel which proves to be regularly challenging in both sites due to local market conditions, supply or interrupted access to the sites as a result of local security incidents.

Government contribution towards capital investments

Certain Regional Water Bureaus and water utilities had the financial capacity and opportunity to contribute monetarily or in-kind to the solarization of water systems. In the case of joint capital investments, the local authorities invest typically in the site preparation and establishment of security fences and guard houses while UNICEF provides the equipment which is purchased from overseas. This co-financing arrangement is mutually beneficial. UNICEF, unlike local authorities, has easy access to foreign currency and can take advantage of Value Added Tax (VAT) exemptions on all electromechanical equipment. On the other hand, local authorities have made contributions to the investments by making use of local labor and equipment, including bulldozers or compactors, for tasks such as site preparation and setting up security installations.. The shared capital costs for system upgrades are anticipated to enhance the long-term sustainability of the systems due to increased ownership of the improved systems.

Access to foreign currency

Local entities such as authorities, communities, or utilities and importers face challenges in accessing foreign currency, which is essential for procuring electromechanical and solar equipment. Converting local currency into US dollars necessitates an official request to the National Bank, a process that has been found to be quite time-consuming. These hurdles have led to a limited supply of certain items like pumps, generators, or solar PV systems on the local market. When these items are available, they often come with a higher price tag compared to the international market. Although UNICEF has assisted in procuring electromechanical equipment for system upgrades, these challenges need to be taken into account for the sustainable operation of these systems, especially when considering maintenance and reinvestment needs in the future.

Post construction operation and maintenance capacity

For the best use of investments and to ensure sustainable delivery of water services, it's crucial that water operators and their support structures, such as local authorities or private service providers, receive adequate attention. The capabilities of water service providers and utilities are generally weak and need to be continually enhanced with assistance from the private sector, government, implementation partners, and donors in areas like commercial and financial system management, non-revenue water management, business planning, water quality management and management of assets and spare parts. This also applies to the water operator governance systems, their regulation, and the market development for spare parts and equipment. Grouping water systems and their management structures geographically or institutionally can be an effective strategy to leverage economies of scale for system servicing and repairs, especially in areas where parts and technicians are in short supply.

Humanitarian, Development, and Peace Nexus

Solarization of water systems can play a significant role in supporting the Humanitarian-Development-Peace (HDP) nexus by providing a reliable source of clean and affordable water. In many situations, andspecifically in Ethiopia, water insecurity is viewed as a catalyst for conflict. Addressing this insecurity involves measures to mitigate climate risks. The solarization of water systems enhances the resilience and viability of water service providers, thereby preventing conflicts related to water and laying a foundation for strengthening social cohesion among communities, particularly in communities that are fragile, hosting forcibly displaced people or affected by drought.[20][21] A resilient and solarized water system can better respond to the needs of users in diverse contexts, such as in emergencies (e.g. providing services to additional displaced people) but also long-term development contexts.

[20] Tillett et all. 2020. Applying WASH systems approaches in fragile contexts: A discussion paper (https://washagendaforchange.org/wp-content/uploads/2020/10/WASH-Syst.-Str_Fragile-Contexts_Final.pdf, accessed August 2023)

[21] UNICEF (2019): Water Under Fire – Volume 1; https://www.unicef.org/media/58121/file/Water-under-fire-volume-1-2019.pdf

Limitations of the analysis

The analysis is based on several assumptions described in Annex 2. Factors such as the future cost of diesel per liter or the inflation rates are heavily influenced by the macroeconomic environment and national policy.

This study, in its evaluation of environmental impact, has strictly concentrated on the CO_2 emissions from diesel-powered systems during their regular operation throughout their lifespan. To consider other environmental hazards linked to the over extraction of groundwater due to prolonged pumping hours, as well as to discuss other types of emissions, additional analysis, data gathering, or long-term monitoring would be necessary.

The study relies on the data collected from the local authorities or service providers for each site related to fuel costs for the generators before and after the system upgrades, which are estimates as they fluctuate over time.

The high diversity of technical characteristics across the discussed water pumping systems in this paper does not provide a lot of room to compare specific types of systems (such as small versus large water systems) in terms of financial impact, as the factors influencing the cost are multiple. Technical information related to the system design such as system water storage capacity, pumping head, water losses, or correct generator sizing versus pump sizes were not available or considered, while these factors are expected to influence the OPEX or CAPMANEX.

Assumption of long-term system operation

The installation of solar systems is crucial strategy for maintaining a long-term steady water supply. However, this paper examines the financial implications and CO_2 reduction, presuming uninterrupted operation for a span of 15 years. It is consequently essential to elucidate the elements that could potentially hinder this continuous operation.

Pump capacity: Despite the increased strength of solar power, if the pump capacity remains unchanged, it is not possible to pump enough water during the day. As a result, fuel generators might still be needed for nighttime operations.

Access to spare parts and equipment for reinvestment: The high cost and potential delays in importing solar power materials can pose challenges. Thus, keeping fuel generators and fuel on standby as a backup is often necessary in case of solar system failures.

Post-construction operation and maintenance of the water systems: Effective Operation and maintenance of solar power equipment require new expertise from service providers or from local authorities. This includes the skills to fix solar systems and systems in place to monitor the operation and perform the maintenance and repair. Inadequate maintenance can lead to decreased system efficiency over time, diminishing the ROI.

It must also be noted that conflict sensitivity (through identification, monitoring, and mitigation of conflict risks and interactions) while developing and operating these water systems, can strengthen their resilience, and the strengthening of social cohesion around the system can protect it from conflict impacts. These aspects have not been measured or taken into account in this assessment.

The capacity and efficiency of the generators and pumps installed

Only limited information was available on the capacity and efficiency of the generators and pumps installed for each of the systems. As the generators are, due to limited availability of this type of equipment on the market, often oversized, it is likely that the calculated reduction in dioxide emissions following system solarization is under-estimated.

Conclusion

These initiatives highlight the potential of solar power in enhancing the efficiency and sustainability of water systems, particularly in regions where access to the national electricity grid, fuel, or clean water is a challenge. They also stress the importance of continued investment and innovation in this area. Transitioning from diesel-powered to solar-powered water systems in Ethiopia can yield substantial savings and environmental benefits over the long term for the water sector and for UNICEF in particular. Based on the data gathered across 38 project sites, the cumulative 15-year savings from reduced expenditures on diesel fuel and generator maintenance are projected at approximately US$ 101.8 million. The environmental impact is also significant, with an estimated 40.6 thousand metric tons of carbon dioxide emissions avoided due to decreased diesel consumption.

Reducing the cost of water production through solarization has numerous benefits. It enhances the sustainability and resilience of water systems, promotes equitable access to water services, and fosters social cohesion in fragile environments. Joint capital investments by local authorities and UNICEF in solarization projects enhance the long-term sustainability of these systems due to increased ownership.

However, challenges exist, such as local entities' limited access to foreign currency for procuring essential equipment, leading to a limited supply and higher local market prices. Despite UNICEF's assistance in procuring equipment, these challenges need consideration for the sustainable operation of these systems, particularly for future maintenance and reinvestment needs.

Post-construction operation and maintenance capacity is crucial for sustainable water service delivery. Water service providers and utilities often have weak capabilities that need continuous enhancement with support from various stakeholders. This includes areas like commercial and financial system management, non-revenue water management, business planning, water quality management, and asset and spare parts management. Effective strategies such as geographic or institutional grouping of water systems can leverage economies of scale for system servicing and repairs, especially in areas where parts and equipment are scarce. Transitioning the power of water systems to solar energy which strengthens the climate resilience of water provision is a key entry point for conflict risk mitigation and peacebuilding.

Further analysis is required to better unpack the specific factors influencing financial and environmental impact that can be expected to solarize systems.

KEY POINTS

- *Solar system installation is an effective way to have a positive impact both on finance and CO2 reduction for the sustainable water supply.*
- *To optimize the effect of solar system installation, it is mandatory to take care of utility systems for continuous operation.*

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Annex 1. Overview of water systems that benefited from investments in solar power

Region		Afar	Oromia	Amhara	SNNP[22]	Gambella	Somali	BG[23]	Total
Project numbers	Newly installed[24]	0	0	8	2	0	9	2	21
	ReplacementError! Bookmark not defined.	17	9	9	2	1	0	0	38
Beneficiary numbers (x1,000)	Host Community	56	135	577	8	29	73	3	882
	Refugees	0	0	0	0	237	0	0	237
	IDPs[25]	0	16	25	0.7	0	13	0	1,174

Figure 11: Number and beneficiaries of solar projects installed with UNICEF support across different administrative regions in Ethiopia between mid-2021 and mid-2023

Annex 2. Assumptions and rationale behind cost calculations of the system operation and maintenance and lifecycle costing

The operation and maintenance of systems, along with lifecycle costing, are evaluated using concepts like capital expenditures (CAPEX), capital maintenance cost (CAPMANEX), and operation and maintenance cost (OPEX). These concepts are crucial in determining the financial and environmental consequences of shifting from diesel-based to solar-powered water systems. The assumptions and parameters used in this evaluation for calculating CAPEX, CAPMANEX, and OPEX are elaborated further.

Capital expenditures (CAPEX)

The capital expenditure (CAPEX) represents the initial financial investment for the installation or conversion to solar systems. These expenditures were converted to US dollars using the exchange rates applicable at the time of installation. The CAPEX takes into account contributions from local authorities, if applicable. A significant portion of the CAPEX consists of electromechanical and solar equipment purchased from abroad, which is not subject to VAT. The CAPEX covers costs related to the acquisition, transport, and installation of equipment, along with the training of service providers for equipment operation and maintenance.

[22] SNNP: Southern Nations and Nationalities Region
[23] BG: Benishangul Gumuz
[24] Newly installed photovoltaic (PV) solar powered stations are differentiated from the systems which were upgraded from diesel to solar powered system (referred to as “Replacement”).
[25] The beneficiaries of the water supply systems include communities or hosts and in certain cases forcibly displaced people such as refugees or internally displaced people (IDPs)

Capital maintenance cost (CAPMANEX)

Capital maintenance expenditure (CAPMANEX) refers to the expenses incurred in renewing assets to ensure that services continue at a similar level of performance as was initially provided[26]. For the calculations of the CAPMANEX, the following assumptions were made:

- Generator overhaul was costed at 30% of a new generator, done every 10,000 hours of its operation (assuming an average of 12 hours of generator operation per day).

- Generator replacement was costed at 100% of a new generator, done every 40,000 hours of its operation (assuming an average of 12 hours of generator operation per day).

- The cost of a generator is based on the average prices of generator systems with capacity ranging between 15 and 650 kVA between 2021 and 2023 procured by UNICEF in Ethiopia. For calculations, the generators were sized at 250% of the pump capacity to accommodate the surge power needed for pump start-up. This cost encompasses expenses for offshore procurement, transportation, and installation. The equation used to estimate the cost of the generator used for CAPMANEX calculations was empirically derived from a "Power Trendline" correlating generator cost to pump capacity: ***generator cost [US$] = 3797.9 x pump capacity (kVA) ^ 0.6901***

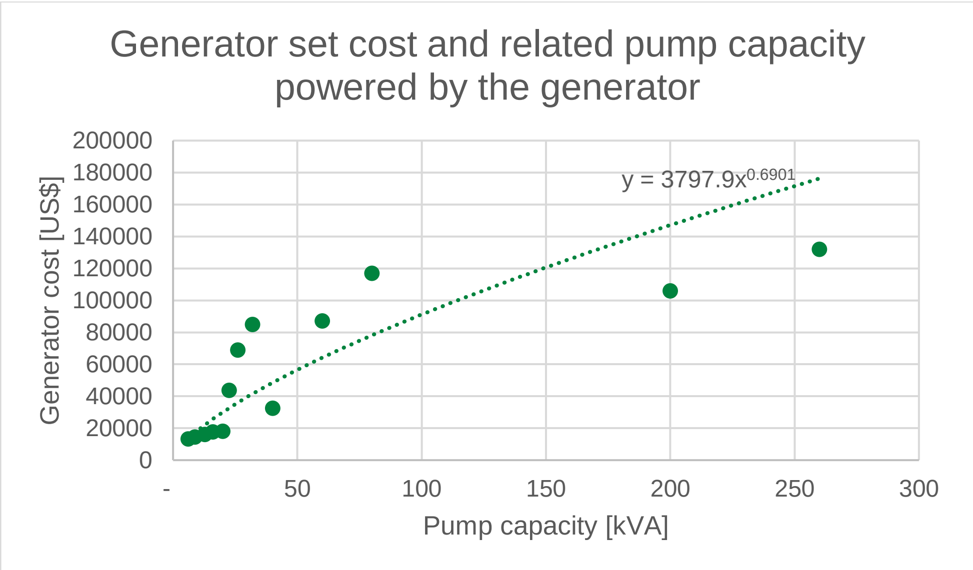

Figure 12. The cost of generator sets in Ethiopia in function of the pump capacity these can power (UNICEF data; prices are without tax).

- Inverter replacement was costed at 12% cost of overall capital expenditure for a solarization site.[27]

[26] Fonseca et all. 2013. Financing capital maintenance of rural water supply systems: current practices and future options. Working Paper, IRC

[27] 12 per cent corresponds to the average of the proportion of the inverter cost compared to total capital investment cost for system upgrade of seven solarization contracts signed in 2023 by UNICEF in Ethiopia.

Operation and maintenance cost (OPEX)

The operational and minor maintenance expenditures (OPEX) refer to recurrent, regular ongoing, and routine maintenance expenditures needed to keep systems running at design performance.

- Labor and office expenses were calculated in function of several f beneficiaries served by the water supply system based on experiences and data from the field, as shown below:

Labor and office costs [ETB]	Salary/benefits/year	Beneficiary number <5000	<8000	8000-30000	30000-100000	>100000
Guard	48,500	2	3	4	10	20
Operator	140,500	2	3	5	30	40
Director / higher level staff	191,000		1	2	4	5
Labor costs		378,000	758,000	1,278,500	5,464,000	7,545,000
Diverse office costs (20% of labor)		75,600	151,600	255,700	1,092,800	1,509,000
Total labor and office costs		**453,600**	**909,600**	**1,534,200**	**6,556,800**	**9,054,000**

Figure 13. Labor and office-related costs for professional water service providers and water utilities for water systems serving a range of beneficiaries.

- Power expenses:
  - Fuel costs for the generators before and after the system upgrades were based on data collected from the local authorities or service providers for each site. It is assumed that the use of backup diesel generators, when no sun is available, is included in this cost estimate.
  - Fuel transportation costs were calculated at 10% of fuel cost.
  - Grid electricity costs before and after system upgrades were based on data collected from the local authorities or service providers for each site.
- Maintenance expenses[28]
  - Generator minor maintenance was costed at 20 US dollars per 40kVA pump capacity, done every 250 hours of its operation (assuming an average of 12 hours of generator operation per day).
  - Generator major maintenance was costed at 180 US dollars per 40kVA pump capacity, done every 1,000 hours of its operation (assuming an average of 12 hours of generator operation per day).
  - Maintenance of solar PV panels was costed at 10 US Dollars per kW installed per year

[28] Maintenance expenses are based on several sources including: (i) Franceys, Pezon, 2010. Services are forever: the importance of capital maintenance (CapManEx) in ensuring sustainable WASH services. Briefing note. IRC (https://www.ircwash.org/resources/services-are-forever-importance-capital-maintenance-capmanex-ensuring-sustainable-wash); (ii) Asante et al. 2019. Capital Maintenance Study, the Case of Water Supply Systems in Selected Small Towns. WEDC, Loughborough University. https://hdl.handle.net/2134/30873

General considerations

- An inflation rate of 15 percent per annum was applied to CAPEX, OPEX, and CAPMANEX projections, corresponding to the average annual inflation of consumer prices in Ethiopia over the past 20 years (World Bank Data, July 2023)

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UNICEF's water, sanitation and hygiene (WASH) country teams work inclusively with governments, civil society partners and donors, to improve WASH services for children and adolescents, and the families and caregivers who support them. UNICEF works in over 100 countries worldwide to improve water and sanitation services, as well as basic hygiene practices. This publication is part of the UNICEF WASH Learning Series, designed to contribute to knowledge of good practice across UNICEF's WASH programming. In this series:

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