Supporting Rural Electrification in Developing Countries

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Case Study: Solar minigrids in Rwanda

Introduction

Current minigrids for rural electrification in Rwanda rely almost entirely on solar power as their main generation source. The full potential of wind is largely unstudied and while hydropower has been used for domestic generation, its high installation and maintenance costs make it unattractive for private micro-utility companies working in rural electrification. Owing to high levels of poverty in Rwanda, the power demand of those of the rural population with access to electricity is low and focused only mainly on lighting and phone charging, and has experienced little growth. At present, the challenge of meeting electricity needs with solar power lies in the difference between the times of generation and demand.

Minigrid development in Rwanda is led by the private sector and in order to be financially effective the capital cost of installation must be low. The possibility of future system expansion as more households gain a connection is therefore extremely important. This is where CLOVER's process of continuous optimisation throughout the lifetime of a minigrid can be effective. Here we first use CLOVER to assess an underperforming minigrid and suggest how the system can be improved. Secondly, we demonstrate how CLOVER can be used to plan system expansion as the electrification rate of the community grows, as intended by the Government of Rwanda's 'Vision 2020'.

In this case study, we consider an example based on a minigrid installed in the Mayange sector of Bugesera district, East Province of Rwanda, south of the capital Kigali. The community consists of around 100 households of which 45 are currently connected to the solar minigrid. The minigrid is formed of 1 kWp of solar and 4.8 kWh of lead acid batteries. We assume an average household has access to 2.5 lights (8 W each, restricted to three hours per light per day), owns one phone which requires charging 1.5 times per week (7.5 Wh per charge) with ten per cent of households owning a radio (5 W). Currently no productive use operations are connected to the minigrid and we here assume no load growth over the timeframe simulated.

Analysis of present solar minigrid system

CLOVER was used to analyse the system over a ten-year period and an assessment of the usage of generated power is shown in Figure 1 (below). The reliability of the system was assessed to be 70%, or more than seven hours of power unavailability per day. This low reliability occurs as a result of an undersized battery system. The usable battery capacity, around 50% of the nameplate capacity for lead acid batteries, is expended before midnight meaning that the demand due to lighting in the early hours of the morning goes unmet.

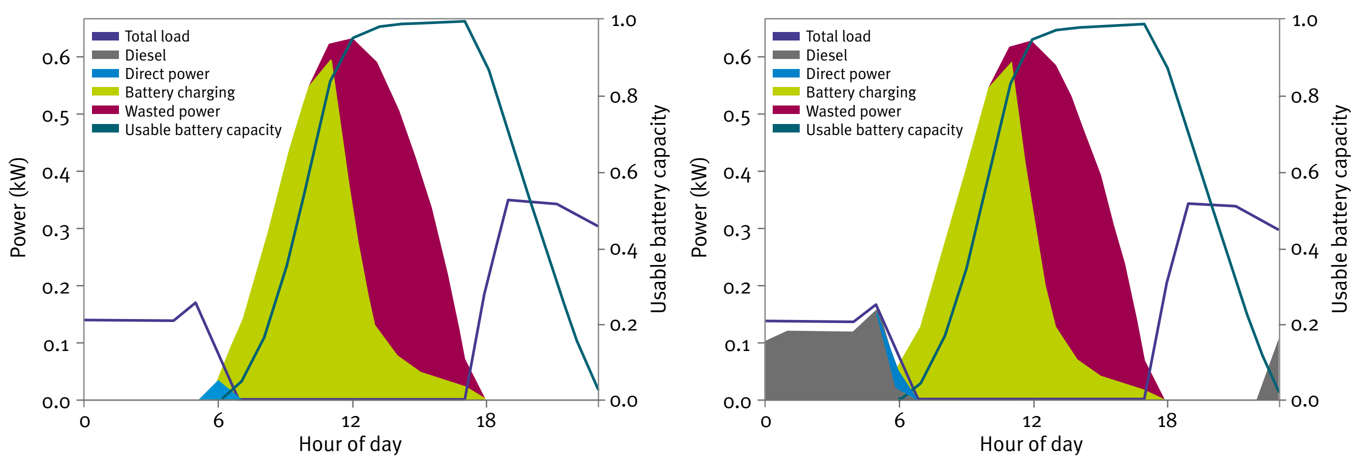

Figure 1: Average generated power usage by hour of the day. **Left:** Basic solar and battery system with 70% reliability. **Right:** The same solar and battery system with an additional diesel backup to achieve > 95% reliability.

The undersized battery capacity also means a large proportion of the generated solar power is dumped, leading to a load factor of 59% for the system. Using CLOVER to determine the correct system size, showed that doubling the battery capacity to 9.6 kWh would provide >95 % reliability, reducing the amount of wasted solar power and increasing the load factor to 85%.

CLOVER was also used to investigate how a diesel generator can be used, instead of increasing the battery capacity, to cover the unmet demand of the current basic solar and battery system, and yield a reliability over 95%. The results are shown in Figure 1 with the diesel generator turning on in the early hours of the morning to meet the previously unmet demand. This configuration does not improve the load factor of the renewable system, but could give the possibility of introducing daytime productive uses to make use of the unused solar generation. The disadvantages of using a diesel backup hybrid system is higher levelised cost of used electricity (LCUE) and total greenhouse gas emissions. The diesel system has an estimated LCUE 30% higher than an optimised solar and battery only system of the same reliability, with total greenhouse gas emissions being 68% greater. However, the emissions from both of these alternatives are significantly less than the basic undersized system due to the reduction in kerosene usage coming from the increased power supply reliability.

Meeting 'Vision 2020'

One of the most encouraging policies in Rwanda is the ambitious plan to increase rural electrification rate from 18% in 2016 to 100% by 2020, as set out in Rwanda's Rural Electrification Strategy and long-term 'Vision 2020' plan to become a middle-income country. In communities where minigrids are seen as the most viable option, the number of connected households will be expected to increase rapidly, and with it will come an increase in total community demand.

To demonstrate how CLOVER can be used to plan such demand growth we consider the earlier community where household connections to the minigrid increase from 25, seen as a lower limit to make minigrid installation viable, to the entire community of 100 households within five years. Figure 2 shows a comparison between two system design approaches: on the left is a static system designed to provide power at least 95% of the time for the final community size in a one-off installation, on the right a modular system which is reassessed and resized every year to meet the growing demand.

The system which has only been sized to meet the final demand of the community is oversized in early years meaning much of the generated electricity is dumped, represented by the large area of red in Figure 2. This leads to a low initial yearly load factor of 41%. In comparison, the load factor of the modular system (which installed only 0.75 kWp of PV and 4.8 kWh of battery in the first year, compared to 2 kWp and 16.8 kWh for the oversized system) remains high throughout, which can be seen in figure 2 right, as the wasted power is significantly reduced, averaging 81% over the 5-year period. This modular approach also reduces the initial capital cost spreading it over the lifetime of the system, as well as reducing the higher maintenance costs associated with an oversized system. The result is a lower LCUE year-on-year for the modular system.

CLOVER has been used to evaluate the most appropriate minigrid solutions for rural electrification of off-grid communities in Rwanda. With private micro-utility companies operating minigrids where community wealth is low and initial capital hard to raise, being able to use basic weather and power demand profiles to design systems that can grow over time will be especially useful.

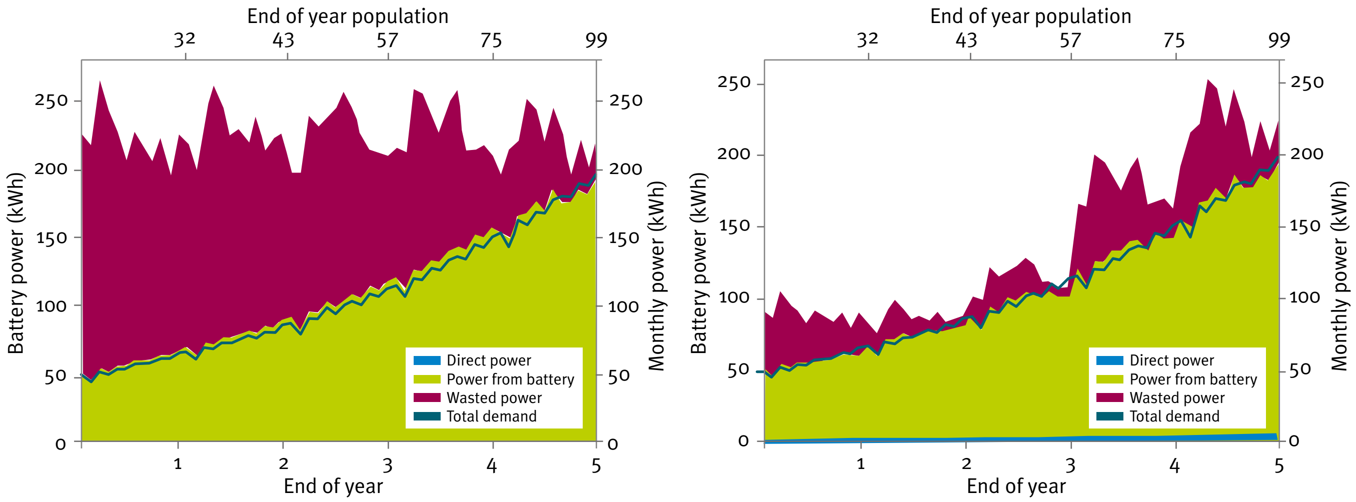

Figure 2: Monthly energy usage profiles for minigrid systems with connections increasing from 25 to 100 households over a five-year period. Both systems provide a minimum 95% reliability. **Left:** A static system designed to meet the demand of the final community size. **Right:** A modular system which is reassessed and resized if necessary every year to meet the growing demand.