# Planning for Productive Uses: Remote Monitoring & Evaluation for Off-Grid Power Projects in Rwanda

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***Abstract*— We examine the opportunities for remote monitoring systems in responding to distinct needs in increasing energy access. We present 'real-time' and historical technical monitoring data from three distinct remote monitoring configurations across technically identical off-grid deployments in Rwanda, along with time-lapse satellite imagery of sites and baseline HOMER Pro system integration modeling. We examine and position the identified challenges within gaps in the empirical literature on rural and urban power projects, and identify areas for future analysis to inform the design of 'productive use' models of electricity delivery.**

***Index Terms*--appropriate technology; off-grid infrastructure; productive uses of electricity; remote monitoring; monitoring and evaluation**

## I. Introduction

Technological innovations and falling costs of off-grid solutions have powered much of the progress towards universal electrification, with most of the worldwide adoption of energy access from off-grid solutions largely driven by sub-Saharan Africa [1]. Practitioners and scholars have developed a substantive body of insights into the challenges and opportunities for off-grid deployments in emerging markets alongside this rapid proliferation, seeking in particular to address technical and financial sustainability challenges.

Innovations in remote monitoring (RM) represent one such avenue. RM enables real or near real-time visibility into a variety of system measurements, from array and battery voltage to energy consumption. These data enable community and remote partners to track the technical performance of hard-to-access systems, and can thus help operators detect and diagnose technical failure from afar, or address under- or over-utilization scenarios [2]. Use-cases for RM data have, to date, largely focused on reducing operations and maintenance costs [3], and to a lesser extent monitoring and evaluation for social impact [4] and strategic expansion planning.

In parallel, interventions that support appropriate, productive uses of electricity grounded in community needs have been shown to increase consumption levels, lower the levelized cost of electricity, and spur local economic growth [1]; a 'cornerstone' of the long-term sustainability of off-grid systems.

Although both RM and productive uses of electricity have been identified as ways to foster the technical and financial sustainability of electricity access solutions, there has been less work exploring their intersection. In this paper, we broach this intersection by positioning RM data against other analytical methods that can inform the design of productive uses — satellite imagery, anonymized cell phone data, and energy modeling simulation tools — to examine how the insights generated can inform planning for productive use applications. We undertake this exercise in the context of OffGridBox (OGB) systems in Rwanda.

## II. Overview of OffGridBox

OffGridBox is a social enterprise whose Africa operations are based in Kigali. Its principal offering is a 'containerized' off-grid infrastructure solution. Each unit — a roughly 2x2x2 meter "Box" — is shipped with technology assets inside that, when installed, is capable of (a) generating, storing, and distributing photovoltaic (PV) electricity, (b) purifying local water, and (c) providing local data and connectivity services through cellular networks. There are to date over 75 OGBs deployed in 12 countries around the world.

OGB operates in a liminal space between commercial providers of standalone home/single-structure energy solution vendors like Mobisol or Fenix, and operators of more traditionally understood mini-grid operators like PowerGen or Equatorial Power that act as 'micro-utilities.' This novel positioning, along with exceptional comparability across its technically identical deployments, provides a unique research perspective into the 'thickening' continuum of electricity access solutions. The benefits which standardization, transportability, and modularity such containerized solutions can bring to the mini-grid scalability imperative in particular have seen a proliferation of pilot and commercial ventures in recent years [5], but little has as of yet been comprehensively written on the topic in the scholarly literature.

OGB actively manages 20 systems across its Rwanda portfolio through local commercial ventures — principally, sales of purified water and a portable power bank charging lease/distribution model. These activities are supported by

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co-financing schemes from international development stakeholders and strategic investors in the energy access domain. Utilization rates remain low; however, this motivates the opportunity for improved unit-economics through the development of further "productive" — alternatively known as "income-generating" — uses of electricity. The usage of RM data in the planning and design of OGB's anticipated roll-out of productive uses of electricity business models provides a concrete yet under-explored use-case at the intersection of two critical fields of research and innovation in off-grid systems' technical, social, and economic sustainability.

## III. Methods of Contextualizing RM & Results

We use a mixed-methods approach to analyze the role of remote monitoring in planning for the design of productive use models within a Box's technical and operational constraints. We focus on results from time-lapse satellite imagery, GSMA population data, HOMER mini grid models, and remote monitoring data from installed systems.

### *A. Satellite Imagery & GSMA Population Data*

To better understand the economic character of site communities and given the impossibility of ground-visits due to the COVID-19 pandemic, we draw from historical time-lapse satellite imagery of sites to contextualize simple categorizations of "rural," "urban," or "peri-urban." Historical imagery is accessed from time-lapse features of Google Earth Pro between 2005-2020 for each site based on available quality.

Several sites have become completely urbanized metropolises over the period and exhibit rapid unplanned sprawl; others are predominantly agricultural and dispersed, yet still exhibit significant densification. Others are entirely new urban formations that did not exist a decade ago. Two sites serve refugee communities with visibly planned growth patterns, and six serve rural clinics.

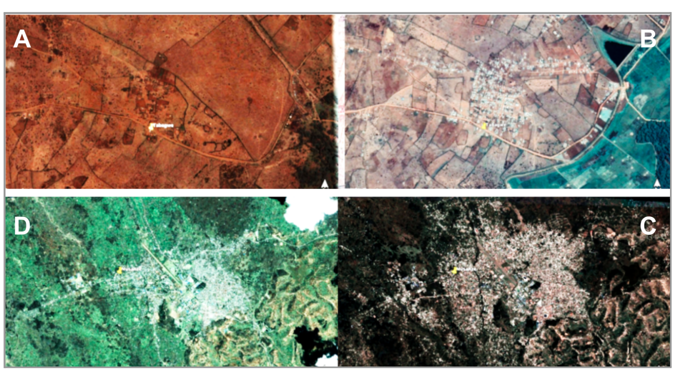


Figure 1. Clockwise, from top-left: (a) Tabagwe 2006, (b) Tabagwe 2020, (c) Musanze 2020 (d) Musanze 2006. Time-lapse imagery of 20 sites illustrate (i) radical variability in level of urban development across installed sites; and (ii) generalized yet variegated increase in urban expansion and densification visible over time across all sites.

We employ a publically available geospatial data extraction tool developed by GSMA using anonymized cell phone data to estimate population density within 1km, 3km, and 10km radii from each Box's exact GPS coordinate. Fig. 1 above highlights two sites with radically different scales of urbanization: Tabagwe, a new urban formation of less than 2,000 inhabitants, and Musanze, a major metropolis in the north of the country.

### *B. HOMER Pro Models of the mini-grid systems*

Next, we characterize baseline comparability across boxes and sites using HOMER Pro, an industry-standard techno-economic microgrid modeling tool. We simulate demand load across Boxes for a single hour of welding based on a real-world trial of a locally available welding machine with OGB staff. After parameterizing the technical and locational components, we use HOMER Pro to simulate energy output in hourly time steps over one year.

We calibrate these models by comparing the baseline energy consumption and production of deployed Boxes to the HOMER Pro simulations based on technical specifications of current OGB system components (PV capacity, battery type, battery capacity, inverter limits).

| Community Name | Solar Capacity (kW) | Battery usable nominal capacity (kWh) | PV - Annual Production (kWh/Year) | Net Present Cost ($) | Levelized Cost of Energy (LCOE, $) | Operating Cost ($/Year) |
|---|---|---|---|---|---|---|
| Buyaga | 3.12 | 3.46 | 2,933 | $5,395 | $0.46 | $107.90 |
| Gatungo | 3.12 | 3.46 | 4,131 | $5,395 | $0.46 | $107.90 |
| Huye | 3.12 | 3.46 | 2,992 | $4,992 | $0.42 | $99.92 |
| Karongi | 3.12 | 3.46 | 2,991 | $4,992 | $0.42 | $99.92 |
| Kayonza | 3.12 | 3.46 | 2,844 | $4,997 | $0.42 | $100.27 |
| Kigeme | 3.12 | 3.46 | 4,071 | $5,395 | $0.46 | $107.90 |
| Kirehe | 3.12 | 3.46 | 2,860 | $4,994 | $0.42 | $100.80 |
| Matimba | 3.12 | 3.46 | 4,202 | $5,395 | $0.46 | $107.90 |
| Muhanga | 3.12 | 3.46 | 2,933 | $4,992 | $0.42 | $99.92 |
| Muhumuro | 3.12 | 3.46 | 2,953 | $4,992 | $0.42 | $99.92 |
| Musanze | 3.12 | 3.46 | 2,969 | $4,992 | $0.42 | $99.92 |
| Mwogo | 3.12 | 3.46 | 2,970 | $4,992 | $0.42 | $99.92 |
| Nyanza | 3.12 | 3.46 | 3,004 | $4,992 | $0.42 | $99.92 |
| Rubavu | 3.12 | 3.46 | 2,854 | $5,205 | $0.44 | $101.30 |
| Ruhango | 3.12 | 3.46 | 2,992 | $4,992 | $0.42 | $99.92 |
| Rusizi | 3.12 | 3.46 | 2,913 | $4,992 | $0.42 | $99.92 |
| Ruyaga | 3.12 | 3.46 | 4,048 | $5,395 | $0.46 | $107.90 |
| Tabagwe | 3.12 | 3.46 | 4,171 | $5,395 | $0.46 | $107.90 |

Table I. Each Box's PV, battery, charge controller, inverter and GPS coordinates were inputted into HOMER. Despite slight variations in hardware models installed and sites' insolation, OGB units are shown to be effectively technically identical.

Calibrated models are presented in Table I above to illustrate technical standardization of units at "full output." The model results reveal that despite moderate differences in insolation due to geography, the expected performance of each Box from components' rated specifications track closely to one another with respect to estimated annual energy production, net present cost, levelized costs of energy, and operating costs/year.

### *C. Remote Monitoring Systems - Overview and Live Data*

Though the Boxes consist of technically interchangeable components with respect to electricity production, three distinct RM configurations are installed. All Boxes use a Morningstar Tristar TS-MPPT-60 Charge Controller; three Boxes include additional dedicated web monitoring units connected to the Tristar. These are Sirus Solar (1 Box) and Efergy (2 Boxes, both serving clinics). All Box live monitoring and historical data can be accessed remotely via a secured IP address, serviced by a local Rwandan host provider. Fig. 2 below presents the dashboard view when accessing these three configurations' live monitoring IP addresses.

Figure 2. (From left to right) Morningstar, Sirus Solar, and Efergy RM web platform each provide different visibility on system state of operation.

### *D. Remote Monitoring - Aggregate, Comparative, Historical*

For selected systems, we extracted the Box's daily battery recharge data in kWh/day. Daily data logs are hosted for approximately 90 days via the IP-accessible platform; we present an aggregated historical view for five Boxes for which RM systems were active and available over our extraction period in Fig. 3 below.

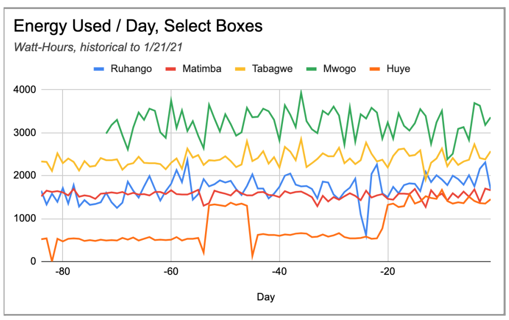


Figure 3. Daily kwh/day usage for select Boxes over 90 days. Manually extracting and aggregating these data provide novel insight into site-specific Box utilization dynamics.

Many of the RM systems were being installed and configured during our extraction process. Coordination challenges with IP host company, incorrect settings that prevented communication between the controller and router, faulty hardware and out-of-date software, and poor cellular network reception at certain sites limited the RM data availability across all systems. While we do not present them here, we also access RM data of water sensor flows, quantitative and qualitative data from OGB sales, and local market surveys, which will inform future analyses.

## IV. Discussion

We observe significant implementation challenges in the operationalization of RM data within business operations. While Tristar 'baseline' RM data provided useful insights into the relative technical performance of a Box for the basic purpose of status-checking and troubleshooting, the interface is failure-prone and inconsistently available. The dedicated web monitoring Sirus Solar interface significantly improves responsiveness, as well as provides a wider array of data points for analysis, but no significant improvement in data resolution. The Efergy add-on, however, automatically tracks power output at 18 second intervals, which significantly increases opportunities to pilot and rapidly iterate on productive use models through analysis of daily load profiles. Eliminating the need for manually processing and packaging data for historical, comparative analysis is hypothesized to be the most valuable data asset for planning and iterating on productive use models.

We do not observe that levels of urbanization correlate directly with either technical performance of remote monitoring, nor with power consumption or water sales. Operator feedback suggests that satellite imagery and geospatial population estimators can be usefully paired with RM data to calibrate market size for products, services, and needs which a Box can serve. These results suggest further demographic segmentation of Box sites from such data streams is needed to synthesize RM results into actionable strategic planning at a given Box/community.

We find that custom-built RM systems can be tailored to organizational needs but are labor and time-intensive to develop and learn from, representing a significant risk that technical knowledge is lost through staff turnover. We note in particular the challenge of identifying and selecting among nascent technology solution providers which are high in both "local usability" (for e.g., integrate easily with local cloud hosting providers) as well as globally "best-in-class."

## V. Conclusion

The analytics described above will be used to explore predicted and observed productive use loads to develop and analyze context-specific productive use scenarios. In particular, we will explore separate optimization opportunities for specific income-generating appliances within a time-of-day analysis, as well as consider implications such as power factor correction for inductive power loads. Multiple data streams are needed to evaluate the scope, boundaries, and use-cases of each remote system within our scenario development. With robust remote monitoring, we expect to evaluate OGB's unique degrees of freedom: strategic relocation, matching productive use models with local 'energy budgets,' and "stacking" for modular mini-grid expansion.

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