



Regulating Beyond the Grid: Harnessing Big Data Analytics for Sustainable and Inclusive Off-Grid Energy Systems

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Abstract

Pay-as-you-go (PAYG) solar firms generate high-frequency operations data, yet regulators rarely use these streams to underpin oversight. This paper analyses twelve months of transaction data from two PAYG portfolios in Uganda and Rwanda (over 115,000 customer accounts; 2019) to propose regulator-ready indicators for off-grid electrification. The two firms' datasets were cleaned, harmonised, and analysed in Microsoft Excel and Python to generate insights for regulatory decisions. GPS cluster client coverage maps at the village level show where access is concentrated. Time series of account and product status show sharp contractions, e.g., the 12.6% contraction in Rwanda and the 36.6% contraction in Uganda. Meanwhile, product-segmented balances reveal concentration in a small number of product lines and lumpy repayments. The Portfolio-at-risk (PAR) analyses quite obviously show the arrears migration: one portfolio shows a PAR90+ increase in the face of overall portfolio contraction, and the other migrates towards shorter-dated arrears alongside contracting active service. The analysis is intentionally non-comparative; each portfolio is read as a singular case to bring both visibility and opacity in existing data to the fore. Critically, the truncated datasets omit payment completions in Rwanda and reconnections in Uganda, limiting differentiation between maturations and write-offs. We argue that indicators such as spatial coverage, account updates, product balances, and PAR trends can support proportionate, real-time regulation and scale to mini-grids, commercial, and grid-tied systems wherever sensor-based monitoring is feasible.

Key words: Off-grid electrification, PAYG solar, big data, regulation, real-time oversight

1. Introduction

1.1. Contextual setting of off-grid access

Access to modern energy remains one of the starkest development divides: more than 500 million people in Sub-Saharan Africa still live without electricity (IEA et al., 2020). While grids will remain the backbone of national electricity systems, their expansion is capital-intensive and slow, particularly in sparsely populated or topographically challenging regions. Over the past decade, decentralised photovoltaic (PV) technologies have offered an alternative pathway, and no innovation has spread faster than the pay-as-you-go (PAYG) solar model. By pairing IoT-enabled remote lock-unlock firmware

with ubiquitous mobile-money platforms, PAYG firms have installed millions of small systems at minimal upfront cost to households (GOGLA, 2020c).

Yet this success story masks a regulatory blind spot. Oversight frameworks in most African countries were drafted for vertically integrated utilities that submit quarterly tariff filings and annual technical reports (ERA, 2019; Government of Rwanda, 2011). PAYG operators, by contrast, generate millions of timestamped transactions each month, such as payment receipts, usage hours, and battery-health logs, none of which are routinely shared with regulators. The result is an information asymmetry: investors are concerned with portfolio quality while consumer-protection agencies often learn of device failures or abusive repossessions only after harm is done (Lighting Global et al., 2022). Therefore, academic literature and industry white papers call for a data-first approach to supervision, yet examples of regulators ingesting and acting on high-frequency PAYG streams remain scarce (Bhattacharyya, 2013; Stritzke et al., 2021).

Uganda and Rwanda provide a compelling laboratory for testing such an approach. Both countries feature vibrant PAYG markets and robust mobile-money payment infrastructure. However, their regulatory frameworks differ. While Rwanda licenses solar-home-system distributors and requires quarterly activity reports, Uganda treats most systems as unregulated appliance sales, although draft mini-grid guidelines are emerging (Government of Rwanda, 2022; United Nations Economic Commission for Africa, 2021). Crucially, regulators in both nations have publicly expressed interest in “live” market dashboards but lack a workable template.

The study, therefore, set out to build a case for integrating high-frequency, privacy-preserving big data into regulatory functions for off-grid electrification. Grounded in PAYG datasets from Uganda and Rwanda, the paper demonstrates how a minimal indicator set, spatial coverage, account-status flows, product-segmented balances, and PAR ladders support routine oversight without exposing customers. The approach is designed to generalise to mini-grids, commercial and industrial systems, and grid-tied electrification wherever sensor-monitored KPIs are available.

1.2. Objectives

The objective is to build a practical case for integrating high-frequency big data into regulatory functions for off-grid electrification. Using PAYG datasets from Uganda and Rwanda to illustrate the workflow, the paper shows how a small set of regulator-ready indicators and routines can support oversight of access, product performance, and portfolio health; and how the same approach generalises to mini-grids, commercial and industrial systems, and grid-tied electrification wherever sensor-monitored KPIs are available.

1.3. Global Momentum for Decentralised Solar

Over the past decade, decentralised photovoltaic (PV) systems have progressed from a niche technology for remote cabins to a cornerstone of universal-energy-access strategies. The fall in PV module prices, the proliferation of mobile-money platforms, and the rise of Internet-of-Things (IoT) monitoring have collectively enabled solar PV penetration markets that national grids still find prohibitively costly to reach (International Renewable Energy Agency, 2019). International agencies now treat off-grid solar not as a mainstream complement to central-grid infrastructure. These systems are capable of meeting Tier 1-3 service levels under the Multi-Tier Framework (Kenning, 2019; World Bank, 2019). However, the pace of adoption has exposed a regulatory lag: many jurisdictions still apply utility-era rules that assume monthly meter reads and paper invoices, leaving PAYG transactions beyond the perimeter of real-time oversight (Bhattacharyya, 2013).

There is a growing demand for adopting operational data in decision-making processing to enable decentralised-energy scale-up with consumer protection and financial stability (Andoni et al., 2019; Charbonnier et al., 2022). In utility contexts, smart meters (such as the Advanced Metering Infrastructure (AMI), pre-paid meters, bi-directional meters, multi-function meters, etc.) and sensors at distribution locations or substations enable utilities to monitor peak-demand events in real time (Wambaugh, 2013; Ye et al., 2023; Zhou et al., 2016). A parallel approach for off-grid solar could shift

supervision from reactive periodic filings (if implemented) towards adaptive, data-centric governance (Njoka et al., 2023). However, industry stakeholders seem to highlight three unresolved challenges: (i) heterogeneous data schemas across vendors (Charbonnier et al., 2022; Panahazari et al., 2023), (ii) privacy concerns when household-level consumption is transmitted to third parties (Westrich, 2025; Zhou et al., 2016), and (iii) a paucity of analytical capacity inside most energy-sector agencies (World Bank, 2020). These bottlenecks are most acute in lower-income regions, with the greatest need for decentralised solutions.

1.4. Continental patterns in Africa

Africa accounts for over half of global solar-home-system sales by volume and almost two-thirds of all PAYG deployments (GOGLA, 2020c, 2020b). The continent’s rapid uptake is driven by an overlap of unmet demand and leap-frogging digital finance: 300 million Africans use mobile money, giving providers a ready-made micro-payments rail (Global System for Mobile Communications Association, 2014; Nique & Smertnik, 2015). Yet, adoption remains geographically uneven. Kenya, Rwanda, and Uganda capture a disproportionate share of investment, while markets such as Burundi lag because of limited policy support, shallow distributor networks, and fragile supply chains (Nsabimana, 2020; USAID, 2020).

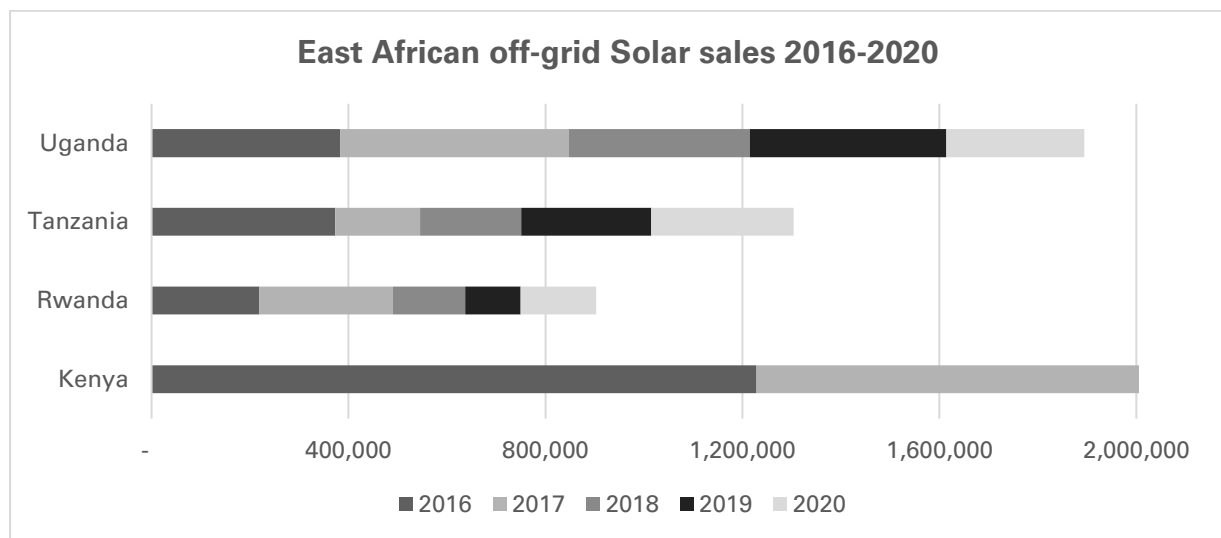


Fig. 1: Off-grid solar sales based on GOGLA reports between 2016 and 2020

Across the continent, three structural risks recur: early-stage consumer enthusiasm, which can sour when poor-quality devices fail or after-sales service is absent (Feron, 2016). Secondly, ballooning credit portfolios expose firms to macro-shocks, as seen in rising arrears during COVID-19 restrictions (GOGLA, 2020a, 2021). In addition, tariff opacity – hidden interest, unbundled activation fees – undermines trust, particularly where financial literacy levels are low (Chowdhury & Mourshed, 2016). Because most regulatory regimes evolved for vertically-integrated utilities, they rarely require PAYG operators to submit key performance indicators such as portfolio-at-risk or mean-time-to-repair (Lighting Global et al., 2022). Scholars therefore call for “data-first” supervisory models tailored to decentralised asset classes (Stritzke et al., 2021).

1.5. East Africa: the world’s test-bed for PAYG

East Africa is frequently highlighted as the global epicentre of PAYG innovation. Kenya’s early combination of M-Pesa, strong last-mile distribution, and an enabling mini-grid clause in the 2019 Energy Act catalysed a wave of venture capital and concessional debt (Carr-Wilson & Pai, 2018). Rwanda followed with the Renewable Energy Fund, which channels subsidised credit to private distributors; electrified households tripled between 2010 and 2016 (Hakizimana, Diego, et al., 2019). In the case of Tanzania, the setting up of a regulatory sandbox for mini-grids spurred experimentation.

That notwithstanding, studies still show that by 2030, half the population will continue to rely on off-grid technologies (Edsand & Bångens, 2024; Ferrall et al., 2021). Ethiopia's NEP 2.0 targets six million off-grid beneficiaries by 2025 but continues to wrestle with logistics and foreign-exchange constraints (Pappis et al., 2021).

In cases of Uganda and Rwanda, contrasting but complementary landscapes are shown from the literature. For instance, Uganda's Rural Electrification Strategy and the Electricity Regulatory Authority's draft mini-grid guidelines have enabled sizeable solar-home-system penetration (Bongomin & Nziu, 2022; MEMD, 2023), yet formal PAYG rules remain sparse, and many devices are sold outside the purview of technical and commercial (i.e. price) regulation. On the other hand, Rwanda licences for solar PV home systems' distributors require quarterly progress reports (GOGLA, 2019). However, there is no clear indication as to whether the reporting requirements include mandatory sharing of solar PV kit performance, including granular credit-risk metrics, in their compliance requirements. Importantly, both regulators acknowledge that near-real-time data could transform their ability to detect distress through mass disconnection waves or sub-standard kit strains on rural consumers' budgets.

1.6. Historically, energy surveys classified households simply as connected or unconnected, while later enhancements introduced the multi-tier framework of energy access (World Bank, 2015). PAYG business models and the promise of big-data streams

The PAYG model couples IoT-enabled lock–unlock firmware with mobile-money instalments: when a customer's balance falls below a threshold, the device is remotely disabled until payment. This architecture generates rich telemetry of energy use, operational interruptions, payments, reconnections and disconnections that cumulatively deliver energy, disconnection events, and battery voltages (Mandelli et al., 2016). PAYG datasets reveal nuanced usage patterns such as partial lighting only at night, load-shedding during school-fee season, or appliance sharing among neighbours. Early studies show that default risks correlate with agricultural cycles (Narayan et al., 2020) and that predictive maintenance can be scheduled days before voltage drop triggers complaints (International Renewable Energy Agency, 2019). However, most analyses remain proprietary, limiting regulator insight and oversight.

1.7. Regulatory architecture: inherited utilities, emerging gaps

Utility statutes across Sub-Saharan Africa were drafted for grid monopolies. Uganda's 2003 Quality-of-Service Code prescribes voltage tolerances but is silent on battery durability; Rwanda's 2012 technical guidelines cover panel installation but not pre-paid remote-lockout firmware (ERA, 2003; Government of Rwanda, 2012). While there is praise for the “light-handed” oversight for allowing rapid diffusion (Stritzke et al., 2021), advocacy groups highlight hidden fees and premature device failure (Chowdhury & Mourshed, 2016). Telecom and fintech precedents show that automated dashboards can give supervisors daily visibility into market health (Andoni et al., 2019); applying similar pipelines to PAYG solar could cut information asymmetry and unlock finance (Bazilian et al., 2010).

1.8. Evidence Pathways to Equitable, Sustainable Electrification

Globally decentralised solar is central to SDG 7; in Africa, PAYG is scaling fastest where mobile money and supportive policy align. Uganda and Rwanda exemplify promise and risks, dynamic firms, extensive kit roll-out, and patchy real-time oversight. Literature recommends anonymised monthly data feeds, early-warning dashboards, tier-linked performance standards, and regulator capacity-building. Grounded in these insights, this study demonstrates a practical workflow (e.g. from Excel and Python cleaning through geo-analytics and Power BI dashboards) that regulators can adapt with modest resources. Big-data-driven governance offers a bridge between entrepreneurial energy markets and the public mandate for safe, affordable, and reliable electricity access across East Africa.

The analysis draws on 858,575 individual payment and device-telemetry events supplied by PAYG companies – 41,727 transactions from Uganda and 816,848 from Rwanda. After harmonisation, these

granular logs are collapsed into a customer-month panel that underpins every result and recommendation in the paper.

2. Methodology

A structured literature review anchored the design. The review synthesised evidence on how operational data can strengthen off-grid oversight and highlighted the current information asymmetry between PAYG firms and regulators, alongside utility analogues for real-time supervision (e.g., smart-meter and sensor-based monitoring). These insights informed our choice of indicators and definitions for analysis.

Building on that framework, the analysis used twelve consecutive monthly datasets (January–December 2019) from one PAYG company in Uganda ($\approx 41,700$ accounts) and one in Rwanda ($\approx 78,900$ accounts). Because each record represents a customer–product pair, the study is a census of operational records rather than a statistical sample. The workflow cleaned and harmonised fields, linked customer GPS clusters to village boundaries to generate country maps, and assembled the indicator panels (spatial coverage, account-status flows, product-segmented balances, and PAR composition) used in the Results. Each portfolio was treated as a separate case and interpreted on its own terms; no cross-country ranking was attempted.

2.1. Study Design and Data Overview

The research follows a parallel-case approach: twelve consecutive monthly datasets (January–December 2019) from one PAYG company in Uganda ($\approx 41,700$ accounts) and one in Rwanda ($\approx 78,900$ accounts) were analysed independently under an identical workflow. Because each file captures a customer-kit pair, the study is based on a census of transactions, not a statistical sample, so findings describe operational realities rather than infer population parameters. Insights are drawn without ranking one country over the other.

2.2. Data characteristics

- **Operational logs** – Monthly CSV extracts from each provider’s business-intelligence system contained hashed customer IDs, kit SKUs and tiers, contractual instalments, cumulative payments, balances outstanding, disconnection counts, cumulative usage hours, GPS cluster centroids, and timestamps.
- **Spatial layers** – District-level GeoJSON boundary files for Uganda and Rwanda were downloaded from the GADM v4 repository.

All source files were stored in an encrypted SharePoint folder accessible only to the study team and deleted upon completion.

2.3. Initial Cleaning and Schema Harmonisation

Excel Power Query removed duplicate rows (customer ID \times kit ID \times month), enforced ISO 8601 date formats, and trimmed text fields. A cross-walk table reconciled company-specific SKUs to eight anonymised electricity supply packages (also called kits) types with two attributes required later: Multi-Tier Framework (MTF) service tier and appliance bundle (lighting only; lighting + radio; lighting + TV).

2.4. Python data-engineering pipeline

A reproducible Jupyter notebook automated the transformation steps:

- Outlier screening set winsorisation limits at the 1st and 99th percentiles; they were removed from the dataset in the subsequent analyses.
- Customers missing early-period rows (e.g., new connections in April) were forward-filled with zero payments for preceding months to maintain balanced cohorts.
- Portfolio-at-risk (PAR) classes (≤ 30 days, 31–90 days, > 90 days) were assigned to every inactive record based on date of last connection.

The final master table comprised 858,575 rows of transaction data from two off-grid solar PAYG providers in Uganda and Rwanda.

2.5. Geospatial processing

Using GeoPandas, customer GPS clusters were spatially joined to district polygons; less than two per cent of observations lacking coordinates inherited their provider branch location to preserve spatial coverage without compromising privacy. Based on the provided data, the maps (Figs. 2 and 3) visualise connection densities across the two countries.

2.6. Interactive dashboard construction (Power BI) and map generation using Python code.

The cleansed file fed four regulatory dashboards:

- A. Geospatial map visualisation – drill-down map from national to district view, filterable by any slicer.
- B. Accounts and product statuses: showing the variability of customers' accounts over the year. The analyses show data split into products that are enabled and those that are disconnected remotely. Enabled products are those where the customer is paid up for the service up to the data capture time. Some of these, in the case of Uganda, are products that have completed payments and are hence permanently enabled. Active and inactive products are further categorised into new, connected, reconnected, disconnected accounts.
- C. Affordability and kit mix – balances outstanding by kit tier; matrix of average daily usage hours.
- D. Portfolio health for PAR 30, PAR 31–90, PAR 90+; a line chart of monthly disconnections.

2.7. Ethical considerations

Customer IDs were anonymised; no names, phone numbers, or precise household coordinates were shared. Results are disclosed only in aggregate or masked. Geospatial analysis generated maps that were clipped to the community level to reduce traceability to an individual household.

2.8. Limitations

Because datasets were volunteered, selection bias may persist. Additionally, the monthly snapshots cannot capture intra-month dynamics of the portfolio; more frequent data insights would be required in order to deliver more representative analyses. Finally, the differences in the volumes of data provided may affect the comparison of findings.

3. Results

3.1. Analytical findings

This chapter presents a comparative analysis of PAYG off-grid datasets from Rwanda and Uganda. Each sub-section highlights distinctive trends in monthly connectivity, product segmentation and status, credit risk analysis, and customer energy access patterns. These analyses aim to showcase how PAYG data analytical outcomes can inform more adaptable regulatory frameworks across East Africa. Table 1 provides the differences in product characteristics between the two contexts.

Table 1: categories of solar products in the two companies' PAYG datasets from Rwanda and Uganda

Solar product	Tier rating	Nr of lights	Battery (Ah)	Lighting Hours	Total output (lumens)	Phone charging?	Radio included	Tv support
Kit A	2	3	3.4	4.9	370	Yes	Yes	No
Kit B	3	4	6	5	1,000	Yes	Yes	Yes
Kit C	2	3	3	5	360	Yes	Yes	No
Kit D	2	3	5.9	5.6	305	Yes	No	No
Kit E	3	3	12	5.1	590	Yes	Yes	No
Kit F	3	5	12.5	8	1,200	Yes	Yes	Yes
Kit G	1	1	3.3	6.6	170	Yes	No	No
Kit H	1	1	2.5	5.7	230	Yes	No	No

Source: Based on test results from Verasol (2022) regarding the products distributed by the two energy companies included in this study.

Importantly, the Rwanda dataset was significantly larger, offering a more granular view of monthly changes in customer status, product segmentation, and repayment behaviour. This scale advantage allows for more robust trend analysis, especially in tracking credit risk and usage patterns across diverse customer segments.

One of the noted differences between the two datasets lies in the structure and diversity of the product portfolios, in that the Rwandan and Ugandan datasets have only two product kits (D and E) in common. In Rwanda, Kit A was the most widely adopted basic product. On the other hand, Kit B was the most advanced product offered, including appliances such as radios and small televisions. Uganda's product offering included kits D to H, with Kit F emerging as the most technically advanced, featuring five lights, a 12.5Ah battery and TV options. By comparison, Kit E, available in both countries, offered more limited appliance support and energy capacity than Kit F.

These distinctions in product design and market targeting influence both payment performance and consumer experience. Uganda's larger-capacity kits suggest a higher-income, appliance-heavy target segment; Rwanda's smaller kits prioritised basic access. That split shapes cross-country patterns in credit risk, usage, and disconnections.

3.2. Monthly Customer Trends

i. Rwanda

The analysis was carried out on the 2019 data accessed from one of the companies in Rwanda representing 78,939 unique customers out of the 1.7 million off-grid connections (Bisaga et al., 2021). On average, there are 68,000 monthly transactions each valued at RWF 44,583. The portfolio represents an annual transaction volume of over RWF 36.42 billion - a substantial financial activity underpinning the increasing role of off-grid solutions in Rwanda's energy sector (Hakizimana, Sandoval, et al., 2019).

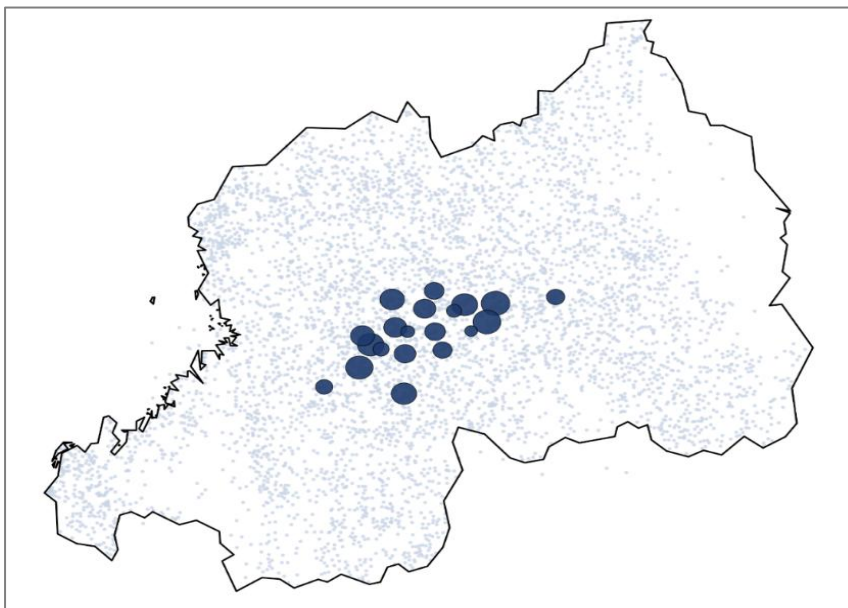


Fig. 2: Spread of PAYG customers across Rwanda.

Figure 2 highlights the spatial distribution of the provider's PAYG customer clusters across Rwanda, with darker shading indicating higher concentrations. The spread of the customers across the country is shown in the map (Fig. 2), showing a near nationwide distribution of customers, emphasising the potential of off-grid solar solutions to contribute significantly to the country's sustainable development goals (Asemota, 2021). The villages with the highest adoption are indicated with the darkest shading. The highest number of customers was in Kabeza village, with 947 accounts. Customer GPS cluster centroids were spatially joined to district polygons and then privacy-protected by district-level

aggregation; <2% of records lacking coordinates inherited the provider's branch location. Heatmaps are clipped at district level to prevent village-scale tracing.

ii. Uganda

Uganda's dataset accessed comprised 41,726 unique accounts served by one company and shows financial transactions, connections, disconnections, and locations of the customers recorded in 2019. 37,625 unique transactions were carried out during this period, with an average of one transaction per user. The average number of transactions per month was 3,135, while the total value of transactions was UGX 10.3 billion, averaging UGX 272,300 per transaction. The spread of accounts from the dataset is shown in the map (Fig. 3).

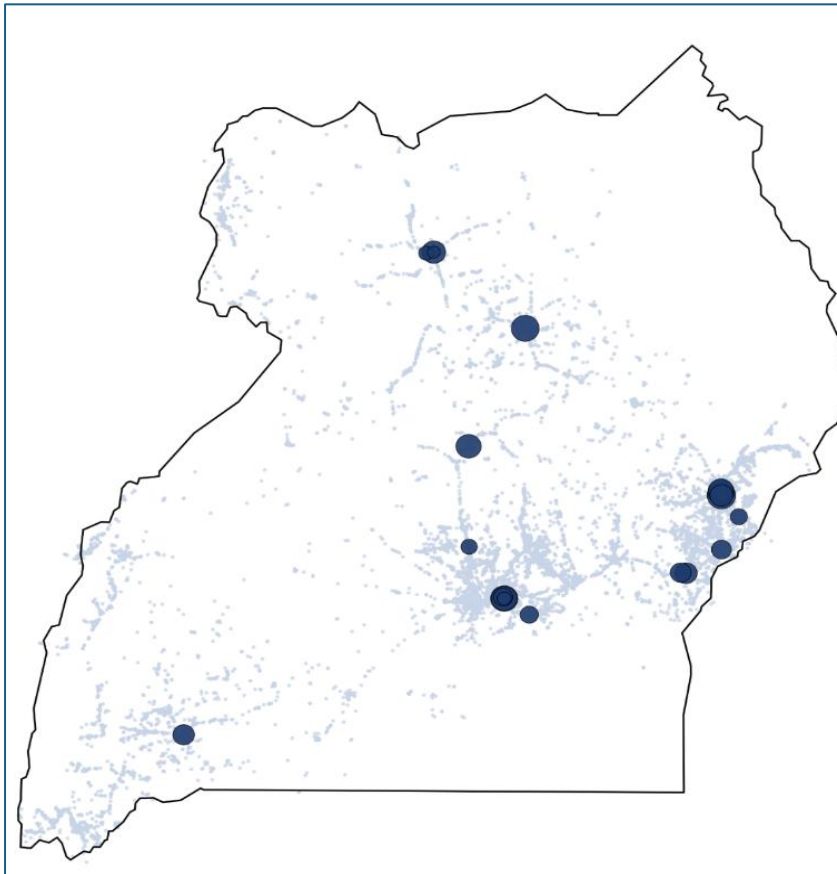


Fig. 3: Map of Uganda showing the coverage of PAYG solutions from the company.

Figure 3 shows the provider's PAYG customer coverage across Uganda, highlighting several concentrated clusters around selected districts and wider areas of lighter density. The map layer was created by joining customer GPS cluster centroids to district polygons and aggregating to the district level for privacy. The pattern is consistent with an established footprint reaching multiple administrative areas while leaving some less observed presence that may warrant agent-network checks or targeted marketing. As with Fig. 2, this is a spatial view that only shows the customers' locations across the country based on the limited datasets provided.

3.3. Rwanda Customer Trends

Figure 4 presents the corresponding data for Rwanda. A slight drop in connectivity also occurs in mid-year; the overall magnitude of disconnections appears less dramatic than in Uganda. Interviews with the Rwanda-based team point to more diversified income sources, such as small-scale trade and community-based financing groups, which help households weather seasonal income fluctuations.

Although newly enrolled customers also plateau around the same period, reconnections tend to happen faster, suggesting that short-term financial relief or partial-payment schemes may be more accessible.

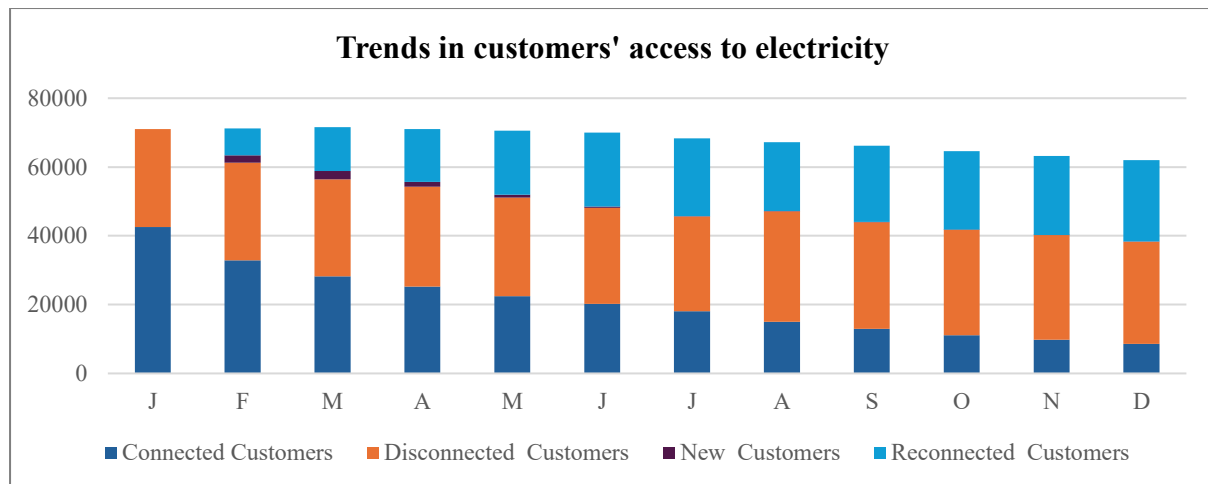


Fig. 4: Changes in account statuses

Figure 4 tracks month-by-month shifts in customer account status within the provider’s Rwanda portfolio. Active accounts peak around March and then trend down to year-end, with no distinct rebound later in the year. Together with the portfolio totals reported alongside the figures ($\approx 71,600$ accounts at the March high vs. $\approx 62,000$ by December), the series points to net attrition across the period—i.e., exits and/or sustained inactive accounts outweighing new activations and reconnections. The chart is therefore evidence of a steady contraction in the active base through the second to fourth quarters; diagnosing *why* requires the decomposition you already propose elsewhere (new sales, reconnections, permanent exits). The monthly status series shows a steady contraction of the active base through 2019, with no late-year rebound. Final portfolio attrition (January to December) is 12.6%, the total customer count across kits falls from 70,980 to 62,010, a delta of 8,970. Within the same period, the snapshot of connected customers declines from 42,577 to 8,606, underscoring that exits and/or sustained inactive accounts outweighed new activations and reconnections over multiple months.

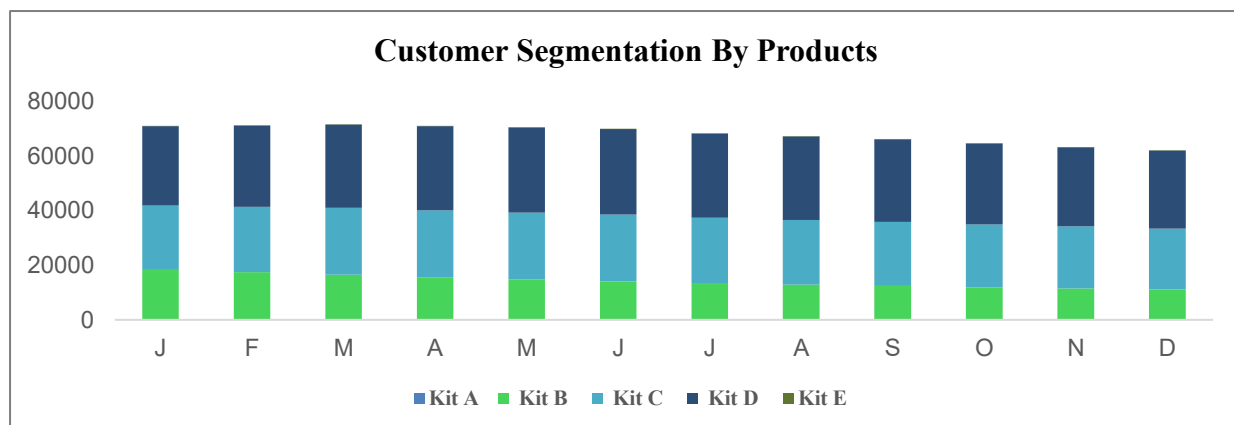


Fig. 51: Monthly trends in customer numbers for each product category

Figure 5 disaggregates the same monthly totals by kit type. Three mid-tier kits dominate the portfolio (B, C, and D), with Kit D consistently the largest segment ($\approx 28,500$ – $31,300$ customers over the year). Across the observation window, the product mix thins, and Kit B shows the steepest contraction (approximately 40% decline from January to December). By contrast, fringe kits (A and E) remain small in absolute terms throughout. Operationally, the overall portfolio decline is concentrated in the large, mainstream segments rather than at the fringes, so any retention or after-sales effort would need to focus on these three kit lines to affect the aggregate materially. Kit B records the largest drop-off in

both absolute and relative terms: 18,085 to 10,941, a 39.5% decrease. Kits C and D decline more modestly: 23,548 to 22,330 (-5.2%) and 29,062 to 28,494 (-2.0%), respectively. In net terms, the overall -8,970 reduction across the year is concentrated in Kit B; stabilising that segment would have the greatest effect on portfolio totals.

3.4. Uganda Customer Trends

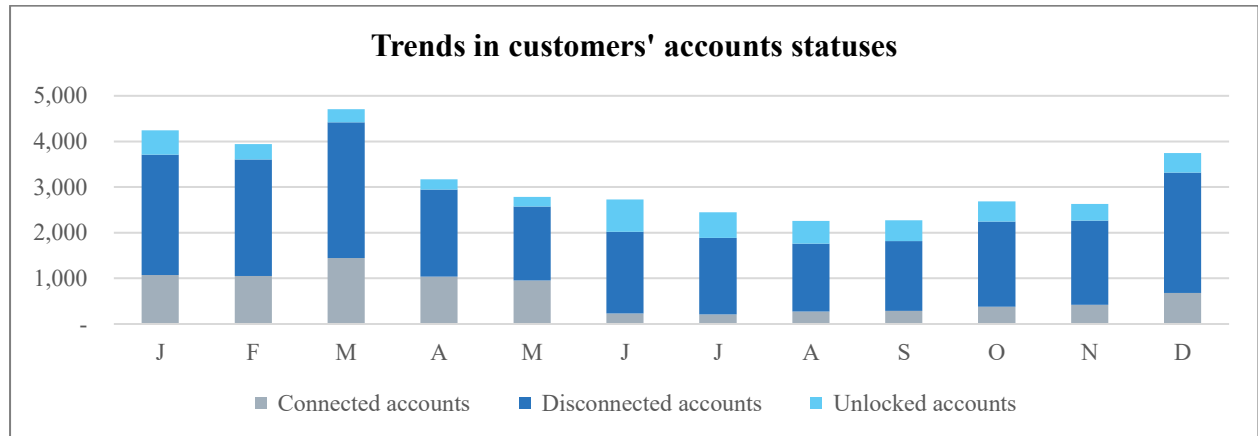


Fig. 62: changes in customer account statuses

Figure 6 shows trends in customer accounts from the Uganda dataset. The connected series shows an early-year rise, a pronounced mid-year trough, and only a partial rebuild by December. This points to a portfolio that experiences frequent service interruptions and does not fully recover active headcount after the mid-year low. Disconnected accounts remain elevated throughout the year, with monthly volumes ranging roughly from 1,491 to 2,975. That persistent high level of disconnected, even in months when connected accounts edge up, suggests ongoing short-term payment strain and active credit-control enforcement. Unlocked accounts (customers who have completed repayments and retain free access) increase visibly through the middle of the year, indicating that cohorts are maturing despite the broader volatility; the unlocked layer also cushions service continuity because these customers no longer face inactive products tied to instalment arrears. Taken together, the chart depicts a system with high churn: many customers cycle between connected and disconnected states while a growing, fully-repaid cohort accumulates in the background. Attrition on a connected-headcount basis is clear: connected accounts fall from 1,072 in January to 680 in December, a decline of 36.6%.

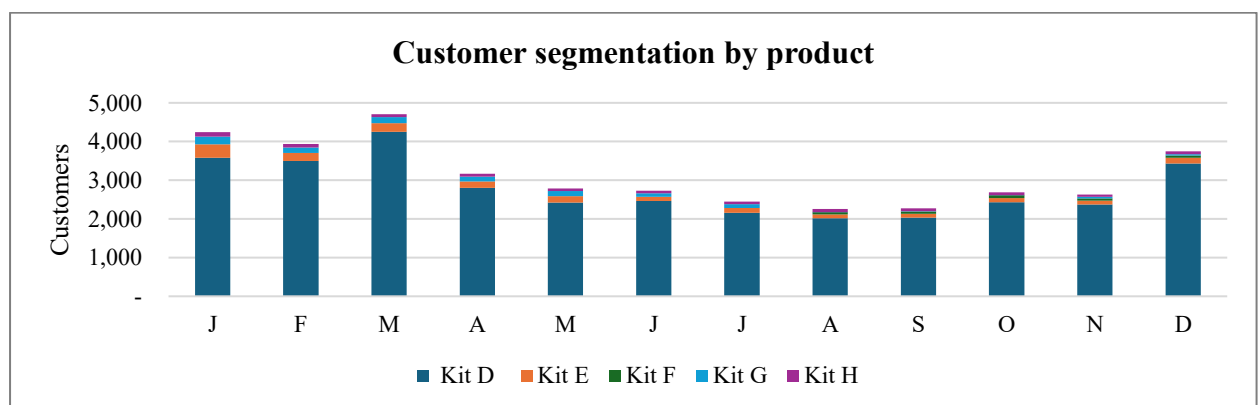


Fig 7: Monthly trends in customer numbers for each product category

Customers in this portfolio mainly use Kit D, accounting for as high as 93% of the portfolio throughout the year. The remaining kits contract sharply: Kit E drops from 348 to 144 (-58.6%), Kit G from 196 to 34 (-82.7%), and Kit H from 122 to 73 (-40.2%). Kit F appears late in the year and grows to 61 by December, consistent with a limited, recent introduction rather than broad adoption. Attrition on a

product-portfolio basis is 11.7%, with totals across kits moving from 4,246 in January to 3,748 in December.

3.5. Product Segmentation and Financial Analysis

3.5.1. Rwanda Product Repayment Trends

Figure 8 shows that outstanding balances decline across the year, with the reductions concentrated in a few high-volume kits. Kit B (Tier 3) records the steepest fall both proportionally and in absolute terms, dropping about 63% over the year (from roughly RWF 1.034 billion to RWF 0.636 billion).

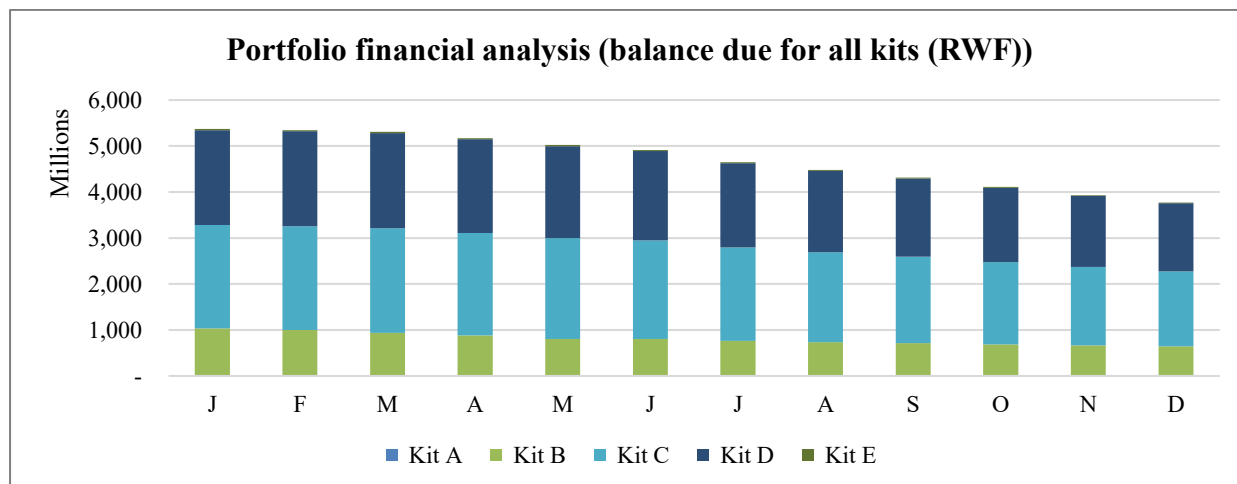


Fig. 8: Product financial analysis (outstanding amount)

Though small in numbers, Kit E (Tier 3) also contracts sharply (about 57%). In absolute terms, the bulk of the portfolio's improvement is carried by Kits B, C, and D together, with a combined reduction of roughly RWF 1.6 billion. This pattern indicates that repayment and collections gains occur where most credit exposure sits. However, it also highlights concentration risk: a relatively small number of premium or appliance-rich bundles still account for a sizeable share of end-year balances despite the decline. The figure suggests two concurrent dynamics within this portfolio: a broad run-off of balances as cohorts mature and repay, and a narrowing of exposure toward a few kit lines that continue to carry the residual debt stock by December.

3.5.2. Uganda Product Repayment Trends

Figure 9 shows that outstanding amounts are dominated by a single product line throughout the year, with Kit D carrying the overwhelming share of the portfolio's credit exposure. Movements in the long-tail kits are comparatively small in value terms but directionally consistent with the general trends: Kits E and G run down over the year as their customer bases shrink, while Kit H also declines from a low base. Kit F appears late in the year with a modest outstanding balance, consistent with a late introduction rather than broad uptake during the period observed. The concentration in Kit D means portfolio-level balances and month-to-month swings are primarily a function of that segment's behaviour; declines or improvements in the other kit numbers make only marginal contributions to the aggregate. Overall, the figure depicts a portfolio that remains highly concentrated by product

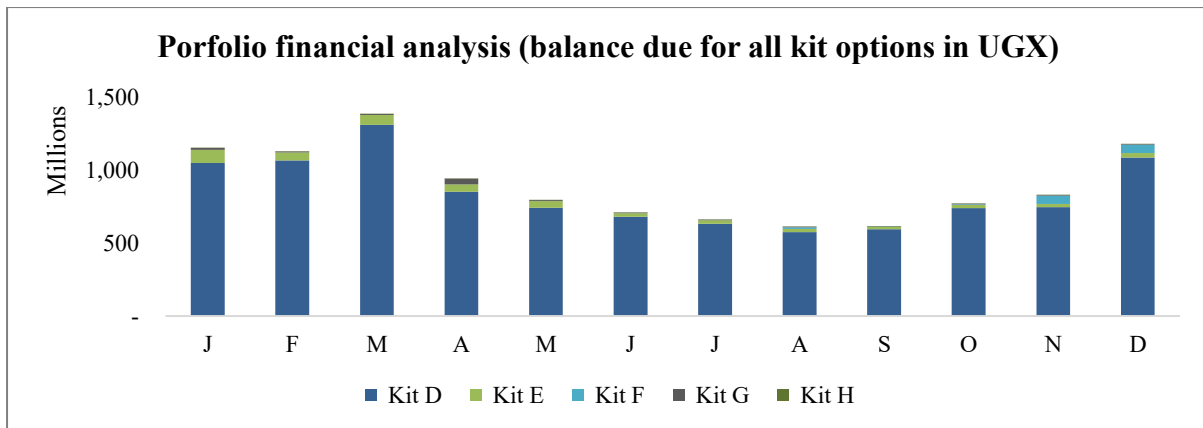


Fig. 9: Product analysis (amounts outstanding)

3.6. Portfolio at Risk (PAR) and default patterns

Active refers to accounts that are paid up; hence, the product provides electricity. On the other hand, defaulting customers are categorised as described below

- PAR30 refers to the portfolio of customers in default up to 30 days
- PAR-31-90 refers to the portfolio in default for between 31 and 90 days
- PAR90+ refers to the portfolio in default for more than 90 days

3.6.1. Rwanda PAR trends

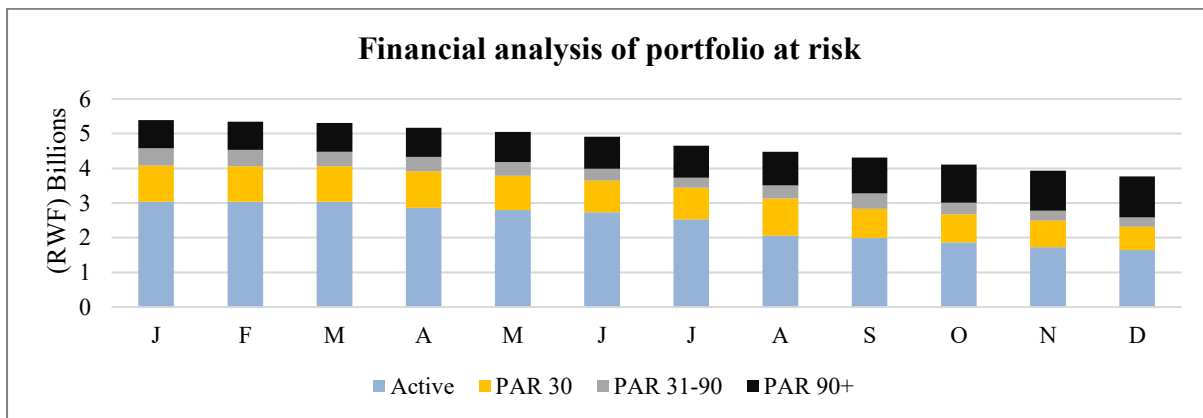


Fig. 30: Portfolio at risk analysis and trends

Figure 10 tracks monthly balances across four status classes: Active, PAR 30, PAR 31–90, and PAR 90+. Over the year, the portfolio total reduces by about 30% (from RWF 5.39 billion in January to RWF 3.77 billion in December). Within that decline, Active balances fall by 46.0% (from RWF 3.04 billion to RWF 1.64 billion), PAR 30 drops by 35.2 % (RWF 1.04 billion to RWF 0.68 billion), and PAR 31–90 drops by 46.5% (RWF 0.50 billion to RWF 0.27 billion). While PAR 90+ rises by 46.9% (RWF 0.81 billion to RWF 1.18 billion). The composition therefore shifts over the year: the share in PAR 90+ nearly doubles, from about 15.0% in January to 31.4% in December, while Active’s share declines from roughly 56.4% to 43.6%. Read together, the chart indicates that although short- and mid-range arrears were reduced alongside a shrinking active book, a growing fraction of the remaining balances aged into long-term default by year-end, signalling potential write-offs.

3.6.2. Uganda PAR trends

Figure 11 shows monthly balances in the same four classes. Unlike Rwanda, the portfolio total increases by about 2.2% over the year (UGX 1.153 billion in January to UGX 1.179 billion in December). The internal mix changes markedly: Active balances decrease by 17.5% (UGX177.8 million to UGX 146.7 million), PAR 30 increases by 50.8% (UGX 247.9 million to UGX373.7 million), PAR 31–90 increases

by 58.5% (UGX 113.3 million to UGX179.5 million), while PAR 90+ declines by 22.0% (UGX 614.6 million to UGX 479.1 million). In share terms, PAR 90+ remains the largest single category but falls from about 53.3% in January to 40.6% in December, while PAR 30 and PAR 31–90 rise to 31.7% and 15.2%, respectively, by year-end. The chart therefore depicts a rebalancing of delinquency from very long-aged arrears toward shorter-dated buckets, alongside a modest reduction in the active balance.

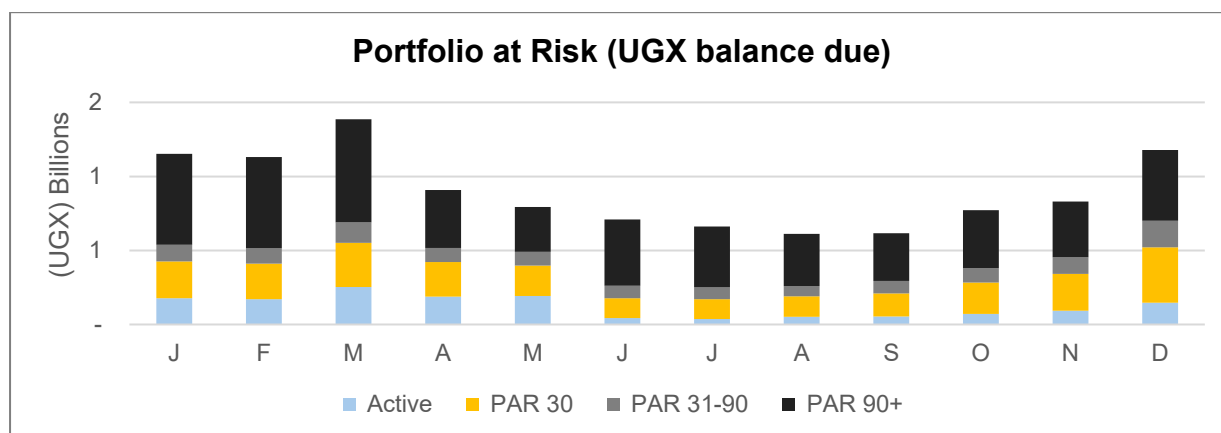


Fig. 114: Portfolio at risk analysis and trends

3.7. Comparative Product Characteristics

Beyond monthly trends and risk metrics, Table 2 offers a country-level comparison of key product characteristics—such as average kit prices, typical instalment durations, and add-on appliances. These differences contextualise why Ugandan consumers might experience steeper payment challenges for premium kits, while in Rwanda, certain socio-financial practices offset high upfront costs.

Table 2: Comparison of off-grid business models based on the two datasets (source: analysis of GOGLA data for specified kits)

Characteristic	Rwanda	Uganda
Kit a price for typical kit (USD)	60-80	50-70
Instalment duration	6-12 months	12-18 months
Included add-on appliance	Television (Kit D)	Radio (Kit B)
Default rate on premium	~15–20% (Kit C/D)	~25–30% (Kit C/D)
Payment channels	Mobile money	Mobile money

Table 3 records different entry-level price bands and instalment tenors: Rwanda’s typical kit prices are USD 60-80 with 6-12-month instalments, while Uganda’s average cost is USD 50-70 with 12-18-month instalments. Interpreted at face value, this means shorter collection windows in Rwanda and longer repayment horizons in Uganda, without implying anything about customer movement between products. Premium-kit default rates are approximately 15–20% in Rwanda and 25–30% in Uganda; it also lists the recorded payment rails (mobile money with local co-signers in Rwanda; primarily mobile money in Uganda) and the stated role of community finance (frequent group saving and credit in Rwanda; limited or informal in Uganda). These are portfolio attributes, not evidence of customers upgrading or switching kits, and they support a straightforward operational takeaway: premium bundles carry higher repayment risk than entry-level kits and merit kit-level monitoring under each country’s prevailing payment and community-finance arrangements.

4. Discussion

This chapter interprets the findings from the two PAYG datasets, drawing lessons on how real-time operational data can support regulatory interventions and market oversight. As noted earlier, the Rwanda dataset was both larger and more detailed than the Uganda dataset. This provided a richer basis for identifying performance trends, especially at the product level, and allowed for closer examination

of repayment patterns across a wider set of consumer segments. Although more limited in scale, the Uganda dataset still offered relevant insights, particularly in understanding how a leaner product portfolio interacts with disconnection trends and usage behaviour over time.

A. Regulatory insights from the spatial distribution of off-grid interventions

While the maps presented are a snapshot of the off-grid progression by the two companies for specified dates in 2019, they provide insight into what could be with more automated data streams from off-grid operators to regulatory bodies. With automated, privacy-preserving data streams (e.g., daily updates that include counts of connected, disconnected, reconnected, and unlocked accounts; fault codes; repair tickets; and anonymised kit/supplier identifiers), regulators can follow regular field performance, attribute reliability issues to specific product lines or suppliers, and verify that account-status improvements are reaching the same places shown on the maps.

Aggregation can move below the village or parish level where policy requires finer targeting, and standard suppression rules are applied at low cell sizes. This keeps customer-level privacy intact while enabling regulators to pinpoint pockets with persistently low access progress, high disable rates, or frequent device faults, and to trace those patterns back to kit categories or suppliers using the anonymised product keys already in the dataset.

Once these spatial layers and automated feeds are in place, regulators can set location-weighted coverage targets that reward expansion into underserved areas. Secondly, the data becomes useful in publishing sub-regional/district/village dashboards that track the shares of connected, reconnected, disconnected, and unlocked accounts alongside failure and warranty-action rates by product tier or type. Thirdly, data would trigger targeted measures, such as supplier-led corrective actions, agent-network strengthening, or consumer-knowledge campaigns, where maps repeatedly show high fault rates or low reliability despite nominal product quality. This turns the maps into actionable supervision tools guiding incentives for coverage where it is thin and enforcing accountability for service quality where reliability lags.

B. Customer-account statuses and product mix

In Rwanda, total customers fall by 12.6% between January and December (70,980 to 62,010), with the steepest headcount losses in Kit B and milder drifts in Kits C and D. This contraction is a regulatory signal in its own right: a shrinking customer base can reflect permanent exits and write-offs as much as contract completions, but the figures do not disclose how much of the decline is due to each pathway. Because the Rwanda series does not separately show a “completed payment/unlocked” accounts, regulators are left blind to how many customers genuinely reached end-of-contract versus were written off or repossessed during the year; that uncertainty matters for consumer-protection and market-stability assessments.

Uganda’s connected accounts declined by 36.6% (1,072 to 680) against a product mix dominated by a single kit line. Concentration raises systemic exposure to any product-specific shock. However, an additional visibility gap was material here: the data did not provide explicit reconnection counts, so we couldn’t tell whether mid-year improvements in connected numbers reflect genuine new connections and sustained reconnections or short-lived cycling that quickly reverts to disconnections. In both portfolios, the regulatory implication is the same: attrition and product concentration are observable, but the lack of transparent status-flow disaggregated data (new activations, reconnections, write-offs, completions) limits the ability to distinguish healthy maturation from distress.

C. Repayment Trends

Rwanda’s outstanding balances declined over the year, driven in absolute terms by Kits B, C, and D, yet residual exposure remains concentrated by December. For regulators, this pattern implies that repayment performance is uneven across product lines and that end-year exposure is clustered in a few kits; without matched fields that tag restructures, extensions, or settlement types, supervisors cannot tell whether reductions stem from healthy amortisation, accelerated settlements, inventory swaps, or silent write-offs.

Balances, in Uganda, were dominated by one kit throughout, so the portfolio's financial trajectory was largely the behaviour of that line; again, without visibility into restructures versus pay-downs, regulators cannot separate genuine affordability from portfolio management choices that keep balances flat while deferring risk.

Both datasets imply that product-segmented balances were informative but incomplete: they showed where exposure sits, not whether observed improvements were durable or merely accounting movement.

D. Portfolio at Risk

Rwanda's composition shifted as the portfolio shrank: Active, PAR30 and PAR31–90 fell, while PAR90+ increased and took a larger share by year-end. The implication was a long-tail arrears problem; near-term delinquencies were being worked down, but a portion was ageing into persistent default. That ageing tail also connected back to the attrition signal: drops in customer numbers over the year could indicate write-offs rather than completions, and prolonged disablement could be masked by headline portfolio reduction if interventions and write-offs are not separately disclosed.

In Uganda, the total portfolio was broadly flat to slightly higher, while delinquency rebalances from long-aged arrears toward "PAR30" and "PAR31–90" and "Active" declines. Interpreted for regulation, default was being slowed, but active service was still being eroded; without a visible reconnection series, it was impossible to confirm whether growth reflected genuine remedial interventions.

Across both portfolios, the implication is that the PAR steps highlighted risk migration but do not disclose remedial interventions, account settlement practices, or the scale and timing of write-offs; indeed, the blind spots that drive uncertainty in market health and consumer outcomes.

Collectively, the maps, status/product mix series, repayments and PAR analyses justified the need for a data-driven continuous regulatory model with privacy-preserving data-streams, operational KPIs, and targeted remedies where low coverage or defaults persist. These steps align oversight with how off-grid business models operate and create clear incentives for sustainable access expansion and accountable service quality.

4.1. Implications for consumer protection

The delicate balance between customers' default risk and product affordability is where regulatory oversight can play a critical role in ensuring consumer protection. Households purchasing premium kits could face significantly higher monthly instalments, and without clarity on the over all cost of the kits, customers may enter into unfavorable contracts that end could up as recurring disconnections. Mandating clear disclosures and setting minimum quality standards would safeguard consumers from unreliable products and services.

Transparent data reporting also helps weed out substandard equipment, in that, if providers must submit periodic usage and maintenance logs, regulators can intervene wherever equipment failures happen at an unusually high rate. Over time, these measures can foster trust in off-grid solutions where consumers can expect durable products and consistent service.

4.2. Towards a data-driven regulatory framework

Results presented in this study confirm the value of integrating operational datasets into off-grid policy. Real-time indicators of arrears and usage patterns can enable adaptive tariff structures, early-warning interventions for delinquency, data-driven performance benchmarks, and tailored subsidies or credit guarantees for vulnerable populations. Developing this potential, hinges on both technical and institutional capacity. Regulators need secure data-sharing protocols, analytics tools, and legal frameworks or licensing conditions that mandate monthly reporting and protect consumers.

The findings presented highlight the potential of PAYG operational data to enrich our understanding of off-grid electricity access and inform more responsive regulatory oversight. Through analyses of PAYG datasets from Rwanda and Uganda, this paper has illustrated how real-time data streams reveal nuanced trends in disconnections, product segmentation, repayment behaviour, and household energy use.

The analysis highlighted differences in portfolio scale and kit configurations, showing how such factors influence credit risk and consumer experience. It also demonstrated that early signals, such as usage decline or shifting PAR indicators, can serve as actionable points of intervention before disconnections become widespread or irreversible.

While the datasets examined reflect the operations of only two providers, they offer clear evidence that regulatory models integrating such granular data can move beyond retrospective reporting to real-time responsiveness. These insights pave the way for a regulatory approach more attuned to consumer affordability and provider sustainability, setting the foundation for the recommendations discussed in the next chapter.

5. Conclusions

This study achieved its objective by demonstrating that converting high-frequency operations data, using PAYG datasets from Uganda and Rwanda, can deliver off-grid regulatory support through providing a set of actionable indicators for routine oversight while preserving privacy. The pipeline and maps establish how access can be monitored at district level with anonymised aggregation, enabling visibility of customer spread and clusters, and proportionate supervision of market footprints. From the results, regulators can act on concrete risk signals mitigating further attrition while informing policy and financing mechanism and technology options that offer long term sustainable access. Because the indicators rely only on aggregated, sensor-based KPIs, the same approach generalises to mini-grids, C&I systems, and grid-tied contexts, providing a practical template for data-driven regulation beyond PAYG.

The study shows that routinely collected PAYG operational data, when cleaned, spatially aggregated, and organised into a small set of standard indicators, can support continuous oversight of off-grid markets. The district-level maps established where access was clustered and where gaps persisted, but they were snapshots; pairing them with automated status and reliability feeds is essential if regulators are to see progress of access and service quality over time. The customer-status and product-mix series revealed material attrition within each portfolio (including a 12.6% fall in Rwanda's total customers over the year and a 36.6% drop in Uganda's connected headcount). However, the available data did not disaggregate exits into completed payments, reconnections, write-offs, or repossessions. That missing visibility is a regulatory concern: shrinking customer numbers can reflect maturations, distress, or both, and supervisors cannot tell which without explicit flow fields.

Repayment panels and product-segmented balances indicated that exposure was concentrated in a few product lines in each portfolio; improvements were not uniform across products, and end-year balances remained clustered. Portfolio-at-risk ladders clarified how arrears migrated across buckets. In one portfolio, the share of PAR90+ grew even as the total book shrank, signalling a long-tail arrears problem likely to translate into write-offs without targeted remediation. In the other, arrears shifted toward shorter-dated buckets while active service eroded, suggesting earlier engagement but uncertain outcomes in the absence of reconnection and cure-rate fields. Taken together, the figures demonstrate both the feasibility and the limits of data-driven supervision with today's provider datasets: regulators can already see where customers are, which products anchor exposure, and how arrears age, but cannot yet verify which exits are completed repayments versus losses, or which short-bucket improvements are durable. Closing these gaps is pivotal to protect consumers, maintain portfolio health, and sustain equitable expansion of access.

In practical terms, the evidence points to a small, standard data feed that regulators can require and use: regular geo-aggregated counts (district, and where feasible village/parish), status-flow updates (new activations, reconnections, completed/unlocked, write-offs, repossessions), anonymised product and supplier identifiers, basic reliability fields (fault codes and warranty actions), balances by product, and a PAR ladder by product and geography. Simple timestamps—such as median reconnection latency and intervention rates by PAR band—and, where telemetry exists, a usage-drop alert used only as an early-warning signal, make this feed actionable without being onerous.

The maps and status panels also imply how oversight can track fairness and service quality, not just coverage. Publishing periodic coverage snapshots with the shares of connected, disconnected, reconnected, and unlocked accounts by area allows regulators to identify under-served places and recurrent reliability issues. Linking public support to measured expansion in these under-served cells and to demonstrated improvements in reliability turns the same indicators into transparent accountability tools.

Given the concentration of exposure in a few products, reporting and supervision should remain product-segmented. Where a product carries a large share of balances or shows outsized attrition, minimum disclosures, documented issue-resolution steps before permanent disablement or repossession, and baseline after-sales standards (service-point reach, repair turnaround, spares availability) are warranted. Where a single product dominates exposure, proportional internal limits and evidence that staffing and parts provisioning match that concentration help contain risk.

Finally, PAR governance benefits from a shared taxonomy and a visible “ladder” by product and geography. Two simple checks follow from the findings: timely outreach when PAR30 rises or a usage-drop alert is triggered, and a long-tail remediation plan when the PAR90+ share rises over consecutive reports in a district or product (with clear criteria for restructures, settlements, write-offs, and consumer safeguards). A small analytics function within the regulator can ingest these feeds, compute core indicators, and publish concise dashboards; where fault clusters or repeated inactivity concentrate, providers can be asked for time-bound corrective action plans.

Off-grid energy grows when service is visible and accountable. With simple, regular data (village-level maps, customer-status updates, balances by product, and PAR trends) regulators can see what works, where help is needed, and who is responsible. Closing the gaps noted could turn a page on visibility of off-grid operations triggering faster decisions, fairer support, and a more straightforward path to reliable energy for the households these systems are meant to serve.

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