Title: Productive Use of Energy Demand Role in Integrated Energy Planning, Yuezi Wu

Stakeholder: Winch Energy

Theory of Change: If one can understand the upfront and recurrent costs of a transition from diesel-operated productive uses to electric machines powered by solar, this understanding can in turn clean energy (either grid, mini-grid or off-grid) allow governments to create suitable policy and private sector to create suitable business models for a large-scale shift away from expensive fossil fuels.

Winch installed electric grinding mills in their mini-grids, an example of a diesel to electric conversion of a productive use of energy (PUE). By February 2024, Winch provided a full year of load data. In general, these PUEs in minigrids not only boost overall demand but also alter the load profile, enhancing solar and battery utilization and improving the economic viability of minigrids.

After cleaning the data, we analyzed electricity consumption for 2124 domestic customers and 21 PUE customers, across 25 minigrids. There is a strong contrast in electricity demand between these two groups. Domestic customers typically have relatively low electricity usage, with average and median monthly consumptions of 7.0 kWh and 3.2 kWh respectively. In comparison, the PUE customers have much higher usage, with average and median monthly consumptions of 353.4 kWh and 298.4 kWh, respectively. The figure below shows the average monthly consumption by minigrid for both groups, illustrating that the demand from just a few PUE customers is comparable to the combined demand of domestic users.

Moreover, subplot (b) shows the average daily load profiles for aggregated domestic customers by minigrid and for each PUE. From the load timing perspective, both domestic and PUE load peaks occur in the late afternoon to evening. Comparing the 16 minigrids with PUE customers, we observed that the daytime load ratio (the ratio of daytime load from 9am to 5pm to the total load) increased from 22% to 34% after incorporating the PUEs. With more daytime load, more electricity is used directly from solar sources, lowering the need to shift electricity usage to night hours using battery storage.

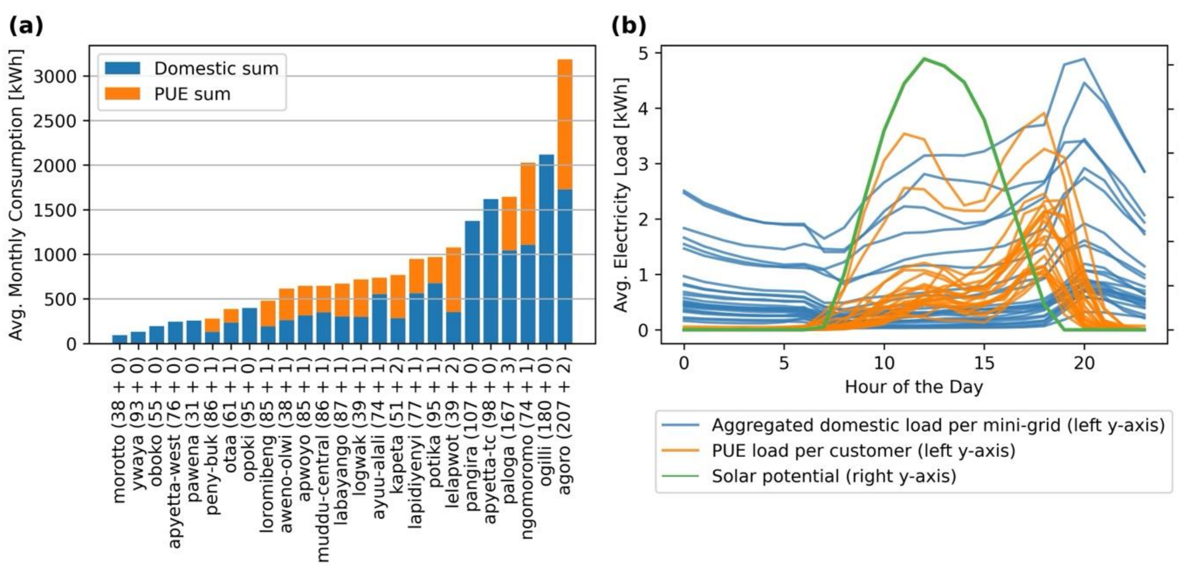

Figure – (a) Average monthly electricity consumption by aggregated domestic customers and aggregated Productive Use of Energy (PUE) customers across villages. The village name with domestic and PUE customer numbers are presented on x axis. **(b)** Hourly average of diurnal load patterns for per minigrid domestic customers aggregated and per PUE customer (left-side y-axis), compared with the pattern of solar generation potential (right-side y-axis).

We have found that the peak-to-average daily load ratio is crucial for minigrid economics. Higher ratios require increased solar and battery capacity to supply peak demands but lead to lower utilization on typical days. Incorporating PUEs has been shown to reduce this ratio. One reason is that PUEs generally maintain a more constant load day-to-day. Another reason is that PUEs increase the average demand. Our findings suggest that minigrids with smaller demand can be affected by occasional high-demand events from domestic customers. A higher average daily demand ensures that equal consumption spikes have a lesser overall impact.

Lastly, our project installed 35 three-phase grinding machines in these minigrids. However, 14 of them lack complete annual data, so the current analysis focuses only on the remaining 21 machines.

Title: Electric Cooking Demand in Rural Minigrid

Stakeholder: Winch Energy, MEMD

Electric cooking not only fosters cleaner cooking practices but also could increase electricity demand. This study started a pilot project to study the adoption of e-cooking appliances and demand changes in mini-grids developed by Winch Energy in the Lamwo district of Uganda. This project selected 189 customers and distribute electric kettles in February 2024.

We obtained 15-minute resolution load records of each customer, treating any consumption of 0.05 kWh or more during 15-minute interval as an event likely indicating water boiling. This assumption is based on two facts: 1. Most customers do not have appliances that consume more than 0.05 kWh in 15 minutes. 2. Boiling a full 1.7-liter kettle consumes about 0.17 kWh, with less water requiring less energy. Consequently, additional events observed after distributing kettles are used as proxies for boiling water. The load records of the 189 customers, revealed that 34 customers never recorded events, suggesting they may not have used their kettles. 18 customers showed a high number of events before receiving their kettles, suggesting they likely possess other high-power appliances, making it difficult to determine if the events are from water boiling. The remaining 137 customers, who are the primary focus, demonstrate findings below.

The figure shows that among the 137 customers, there is an increase of 52 events per day, suggesting potential kettle usage. Each customer uses their kettle an average of 11 times per month, leading to an additional 107 kWh per month on top of their previous monthly consumption of 1281 kWh. However, usage varies significantly among 137 households: six customers use their kettles more than twice daily, and another 12 use them more than once a day, and less frequent use by others.

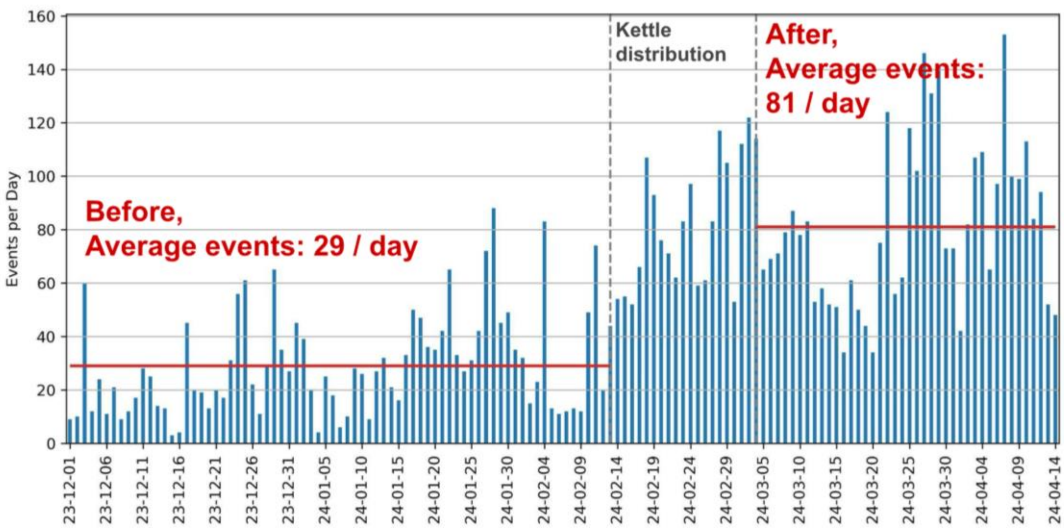

Figure - This figure shows an increase of 52 events per day among a group of 137 customers after receiving electric kettles, suggesting a rise in water boiling activities. An event, serving as a proxy for estimating water boiling, is defined as the use of 0.05 kWh or more within a 15-minute period as recorded by customer meters. The x-axis represents daily data from December 1, 2023, to April 14, 2024.

Based on preliminary results, two additional findings were observed: First, while customers use their kettles throughout the day, notable peaks in usage occur before noon (7-11 AM) and after dinner (7-10 PM). Second, an observation of the maximum load in mini-grids with more than 10 kettles distributed shows that the peak load has not increased and remains within the safe operating limits of the current systems. (These minigrid systems have either 40 kW or 80 kW solar with 144 kWh battery systems)

These preliminary results are based on only two months of data after the distribution of kettles. Continuing data collection over a longer period will help solidify the findings. One investigation is to determine whether existing electricity consumption features can indicate potential electric kettle usage after getting the kettle. Moreover, two additional initiatives will be implemented: 1. For customers who received kettles, Winch Energy has set up a time-of-use tariff that offers a 50% discount during off-peak hours (9 AM-3 PM) to encourage increased usage, with the current rate set at 0.28 USD/kWh. 2. The potential for other appliances, such as induction cookers, is being explored; and efforts are underway to replicate the study in areas connected to the national grid where the lifeline tariff is significantly lower at 0.066 USD/kWh.

Title: Two level network design model and its application in electrification

Simone Fobi and Ayse Selin Kocaman, under the supervision of Professor Vijay Modi, developed the two-level network design algorithm. This algorithm inputs household locations and optimizes the total connection costs, to determine transformer placements and low-voltage (LV) and medium-voltage (MV) networks connecting all households. In the preprocessing phase to identify households locations in rural areas, a merging process is implemented to address the issue of multiple structures per household, where structures are often identified from satellite data. This process aims to align merged households with actual household counts from the district-level census.

The figure from the paper illustrates a computed network for a section of a ward in Kenya, effectively demonstrating the model's capabilities. It highlights varying settlement patterns within the ward, where some transformers connect to more households (upper left transformers in (b)) while others serve fewer (transformers on the right edge in (b)). This variation significantly impacts electrification costs and levels, particularly in rural areas. Nucleated settlements are more likely to have transformers compared to spread-out ones due to shorter required electric lines and fewer transformers, even if these two regions have the same population density.

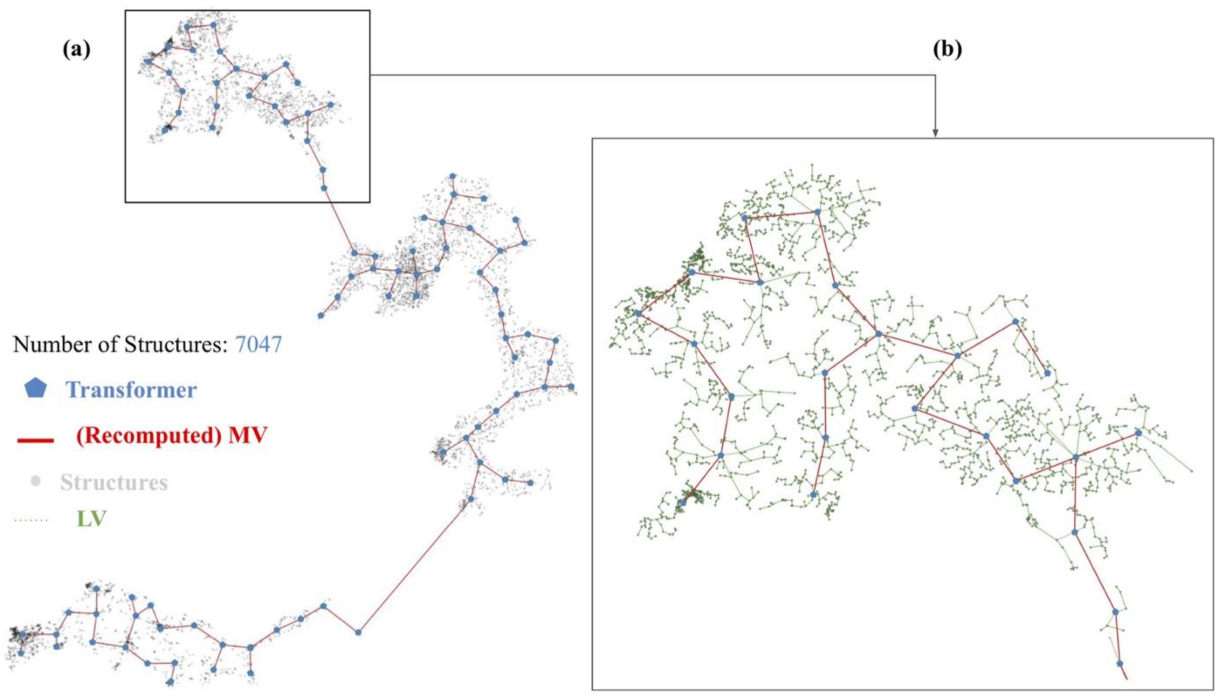

Fig. 8. Complete network for a sample ward with 7047 structures. Figure (a) shows transformer placement and the MV network connecting the transformers. Figure (b) includes the LV network for a small section of the ward, showing connections between structures and transformers. (This paper is from the paper: https://doi.org/10.1016/j.esd.2020.12.005.)

Consequently, one application of this algorithm is to provide a metric that represents settlement patterns, derived from transformer locations and associated metadata, including the number of connected households, average LV length per household, distance to the farthest connected structure, and proximity to adjacent transformers. This allows for clustering of households based on electricity grid network considerations, effectively indicating different settlement patterns.

The two-level network design is applicable not only to regional grid connections but also to mini-grid network designs. It calculates the average distribution costs per household, assessing the economic viability of establishing mini-grid connections based on geographic locations. Further decisions can be added, such as excluding distant customers where the connection is not economical and opting instead for standalone systems.

Overall, this study develops network design algorithm and showcases how different areas might benefit from different electrification strategies, whether through grid extensions, mini-grids, or stand-alone systems. Find the published paper at https://doi.org/10.1016/j.esd.2020.12.005.