Uganda, Data Brief

Productive Uses of Energy (PUEs) Business Survey

A Columbia World Projects Initiative carried out by
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Diesel-Powered PUE in Uganda

Executive Summary:

In 2019, Columbia World Projects (CWP) launched the initiative 'Using Data to Catalyze Energy Investments' to support energy planning and electrification efforts in rural Uganda. Led by Professor Vijay Modi's lab at Columbia University, the initiative emphasized large-scale field data collection on productive uses of energy (PUEs), such as agro-processing, cold storage, and irrigation, to guide energy investments that support livelihood and income growth. The project's focus on PUEs addresses a critical, yet often overlooked, segment of rural energy planning where machinery, such as grinding mills, threshers, and oil presses, consume 50 to 100 times more energy than typical households. The project's collaboration with Uganda's Ministry of Energy and Mineral Development (MEMD) was essential in the planning and design of the project. The project focused on productive uses of energy (PUEs) that directly support livelihood and income growth in rural Uganda, aligning with national priorities such as Uganda's Parish Development Model (PDM).

The detailed data from this survey is available on our Data Dashboard, which includes all the information discussed in this brief. For further exploration, please visit the dashboard.

This Brief condenses key insights from the CWP 2022 survey of small businesses focused on PUEs throughout rural Uganda Among the key highlights are as follows:

- The survey conducted interviews at approximately 20,000 operating PUE businesses across rural Uganda. These businesses provided energy intensive services such as agro-processing (grinding mills, threshers, presses) and cold storage. These businesses were found in nearly all inhabited rural areas, except for national parks, wildlife reserves, and the most sparsely populated portions of Karamoja.
- Since some PUE businesses operate more than one machine, these ~20,000 business interviews comprised a total of about 27,000 individual machines. Grinding mills were the most prevalent PUE machines, accounting for approximately 65% (~17,350 machines) of the total. Threshers/dehuskers comprised 25% (~6,800 machines), followed by oil presses at 5% (~1,300 machines), and cold storage equipment at 2% (~640 machines). Miscellaneous machines for tasks like grating, drying, and sorting collectively represented less than 1% each.
- Among all surveyed PUE businesses, approximately 75% relied on diesel-powered equipment, while 25% utilized electric-powered machines connected to the national electricity grid. A "typical" diesel-powered grinding mill business had only one machine, of 16-24 HP capacity, operating, on average, between about 30 minutes and two hours per day, and consuming around 200-600 liters of fuel per year. The "typical" electric milling business had 2-3 machines, of 20-40 kW capacity, and consumed, on average, around 5,600

kWh per machine per year. For comparison, a “typical” diesel mill using 400 liters of fuel per year converts to an approximate equivalent of 660 kWh/yr. Clearly there are other factors at play which may explain why electric machines are used more heavily than diesel.

- The key geographic patterns are seen in differences between the northern and more arid parts of the country vs. the southern areas around Lake Victoria which have more rainfall and higher population density. PUE businesses throughout the northern areas tend to have smaller machines which are more likely to be diesel-powered, while the areas around Lake Victoria tend to have larger machines with a higher frequency of electric-powered machines (reflecting the greater penetration of the electric grid network in these areas).
- Proximity to the electricity grid strongly influenced energy choice. Around 97% of businesses within 500 meters of the grid were electric-powered, while only 2-3% beyond this range relied on electricity. Higher population density areas, such as those near Lake Victoria, were more likely to feature larger, grid-connected mills serving 250-500 households, compared to the 150-250 households served by diesel mills in less densely populated regions.

Survey goals and approach

Survey program goals/objectives:

Among the most important objectives of the national survey effort is to assess productive use businesses throughout rural Uganda, the most common being larger agro-processing machinery like grinding mills, threshers and oil presses. These PUEs often use 50 to 100 times more energy than a typical rural household, yet are frequently overlooked in energy planning. The survey gathered data for the location, size, energy consumption and use patterns for specific PUE machines, among other details.

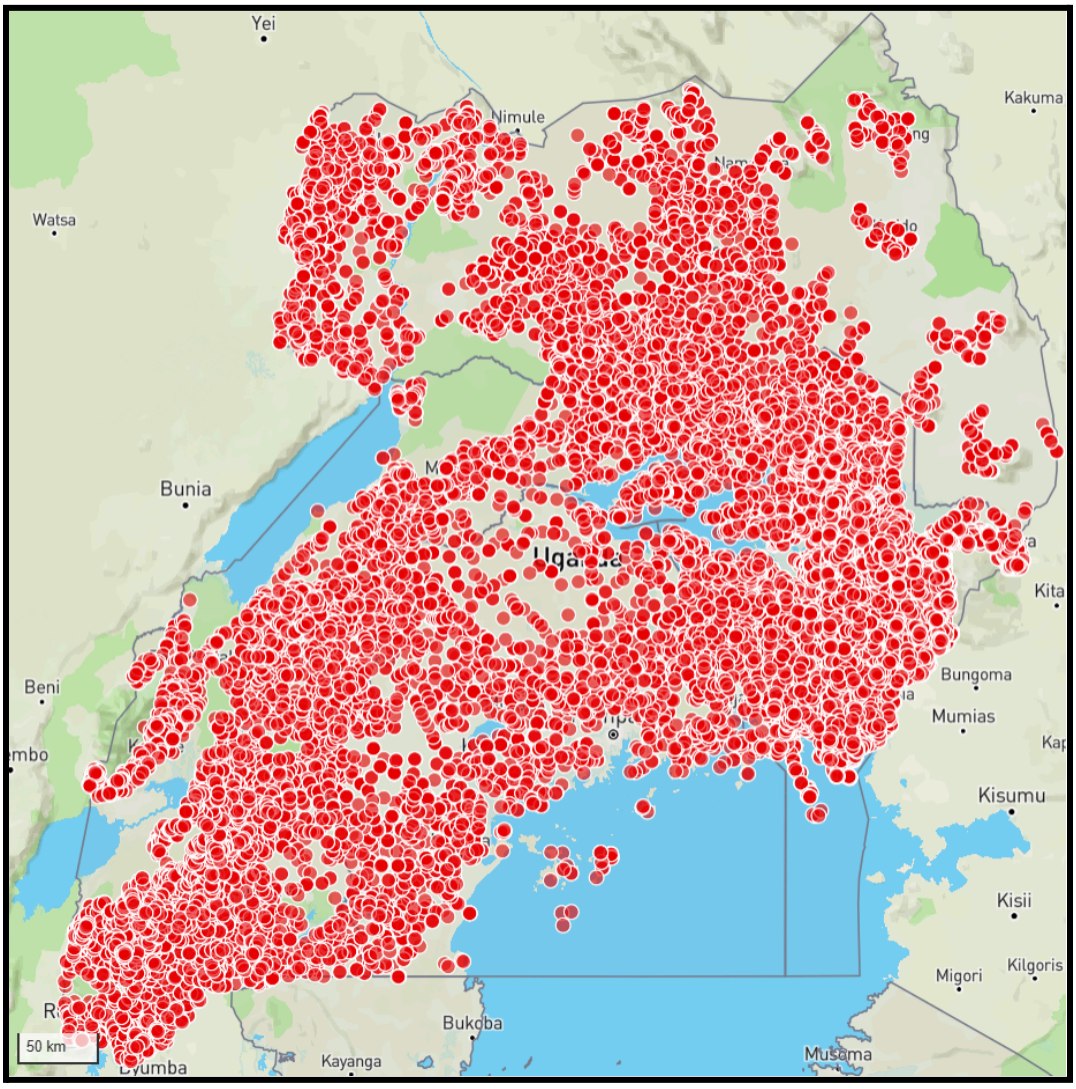
How PUEs were surveyed:

The field survey work took place in Uganda in phases throughout 2022-2023, with the most intensive phase of national surveying occurring in early 2023. A team of more than 90 local enumerators speaking 7 different languages traveled through rural communities and markets seeking out small “productive use” businesses, most of which focused on agricultural processing like grain grinding and seed processing. The surveying program covered all areas of rural Uganda that showed evidence of human habitation, such as household structures or cropland. Cities, major towns, and large rural agribusiness areas (such as large sugarcane plantations) were not surveyed, mainly because they already have modern energy services, such as the electricity grid.

Enumerators sought out all PUE businesses throughout rural Uganda, whether they may be located in small villages, rural markets, or, more rarely, in isolated areas, distant from towns or concentrations of buildings. The field teams used a combination of tools and strategies in this work, including following rural road networks and building density maps, and inquiries with locally knowledgeable people including local leaders, villagers encountered in rural markets, and local motorcycle taxi drivers.

At each business, enumerators interviewed equipment operators or business owners about all aspects of the business's daily and seasonal operations. Equipment operators tended to be young men skilled in processing local agricultural products, such as grinding maize, sorghum and millet into flour, or pressing sunflower seeds to extract oil. Interviews typically lasted 30-45 minutes, and included questions on the types of machinery used, daily hours of operation, and seasonality of the business, specifically which months typically saw heavy use of equipment versus lighter use. Some of the most important questions related to how equipment was powered (fossil fuels, electricity or, rarely, manual human labor); the size of machinery, and, for diesel-powered equipment, the consumption of fuel per week in heavy and light use periods.

PUE Businesses and machine types:



PUE businesses surveyed, all types: Grinding mills, threshers / dehuskers, oil presses, etc. (20,594 businesses surveyed, Source: QSEL dashboard)

About 20,000 PUE businesses were surveyed nationwide. These businesses were found throughout nearly all parts of rural Uganda, with the main exceptions being national parks and wildlife reserves, as well as the more sparsely populated portions of the roughly 7 districts in the northeastern sub-region of Karamoja.

PUE Type	# of Individual Machines	Percent (of all machines)
Grinding	17,348	65%
Dehusking	6,779	25%
Cold Storage	638	~2%
Pressing	1,323	5%
Other (washing, drying, sorting, etc.)	681	~3% total (<1% ea. type)
Total All PUE Types	**26,769**	**100%**

Individual PUE machines of different types encountered across Uganda

These businesses housed a total of about 27,000 individual machines. Nearly two-thirds of these (~17,350 or 65%) were grinding mills, also called “hammer mills”, used mostly for processing maize into flour, were most common. The second most common – around 6,800 machines, or about 25% – were machines for removing the outer coating or “bran” from maize, also called “threshers”, “dehuskers” or “decorticators”. Oil presses, most commonly used for extracting oil from sunflower seeds, were less common - 1,300 machines, or about 5% of the total. Cold storage equipment, used for collection and storage of locally produced animal products like milk, were found in small numbers, numbered around 640, about 2% of the businesses surveyed. The remaining equipment included machines for tasks like grating, drying, sorting and washing, and preparation of animal feed, and these occurred in small numbers, generally less than 1 % each.

Typical PUE businesses (diesel-powered grinding mill) in Lamwo, Uganda

Detailed Survey findings

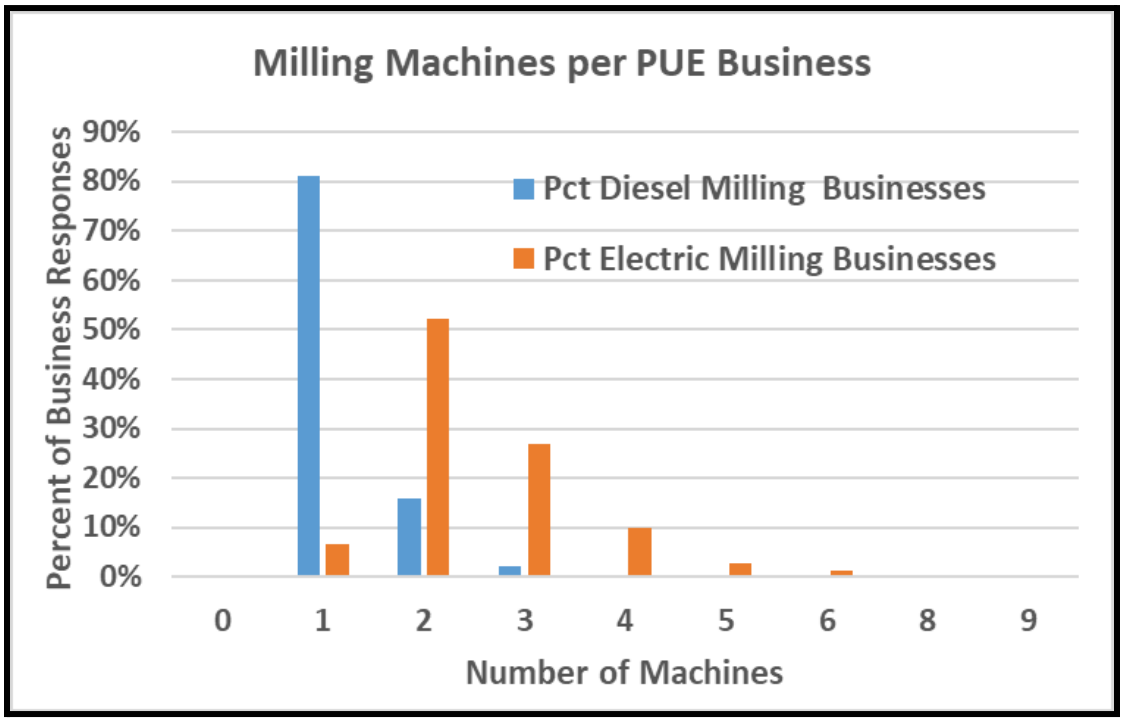
Throughout this report, it is critical to emphasize that all reported values and patterns for electric powered machines and businesses refer to electricity sourced from the grid. While a very small number of surveys focused on solar PV powered PUEs, this was a very small fraction of the total. This distinction between electricity sourced from the national grid verses other technologies (such as stand-alone solar systems, or solar mini-grids) is important to keep in mind due to key factors, including the unit cost of electricity as well as reliability / availability at different times of the day.

Number of Machines at Milling Businesses[1]

There is a key difference between the number of machines found at diesel-powered milling businesses compared with electric-powered (grid-connected[2]) milling businesses. The most common PUE business in rural Uganda is a maize mill with one or two machines, while grid-connected milling businesses tend to operate two or more machines.

- **Diesel-powered milling businesses:** the overwhelming majority of diesel-powered milling businesses had only one machine (~80%) while a relatively small fraction had two machines (~15%), and very few had three or more.
- **Electric (grid-powered) milling businesses:** In contrast, only a small fraction (~5%) of electric-powered milling businesses had one machine, while more than half (~52%) had two machines, and a significant fraction (25%) had three machines, while another 10% had 4 machines.

Based on these data, it is assumed that a "typical" diesel-powered milling business has only one machine, and a "typical" electric-powered PUE business has 2-3 machines.



Number of Machines in PUE (Milling) Businesses Powered by Diesel vs. Electricity

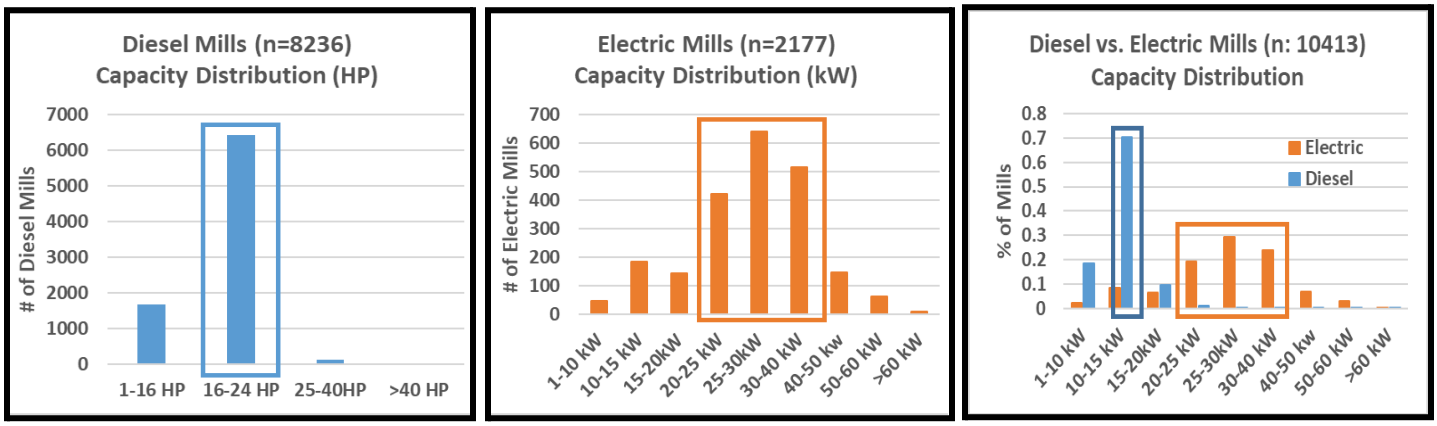
[1] A business is defined as a "milling business" if the primary machine is reported to be a mill. The second machine can also be another mill but may be a different machine such as a "dehusker" (for removing maize bran).

[2] All data for electric-powered mills refer to businesses connected to the grid. Solar-powered electric mills were extremely rare, making the number of instances and data quality too limited.

Size Distribution of Diesel and Electric Mills

The distribution of sizes (or capacities[3], generally reported in HP for diesel mills and kW for electric mills) is presented in this section, highlighting the most frequently seen, or "typical" capacities. Note that the capacity of mills tends to differ depending on the power source.

- **Diesel mills:** About 75% of mills identified in this survey were diesel-powered, and the "typical" diesel mill had a capacity of 16-24 horsepower. See figure below, which shows that ~¾ (78%) fell into this capacity range (6,420 of 8,236 total diesel mills for which capacity data was available).
- **Electric (grid-powered) mills:** The remaining roughly 25% were electric mills of about double the size. The "typical" electric mill had a capacity of 20-40 kW. See figure below, which shows that ~¾ (73%) fell into this capacity range (1,580 of 2,177 total electric mills for which capacity data was available).
- **Comparison:** The third figure below compares the size (capacity) of machines by type, using common units of kW. The electric mills are typically around 2 - 2.5 times larger than diesel mills: diesel mills were 12.8 kW mean / 13.5 kW median and electric mills were 28.6 kW mean / 30 kW median.



Mill capacities and "typical" sizes (boxes) for Diesel (HP); Electric (kW) & Both (kW)

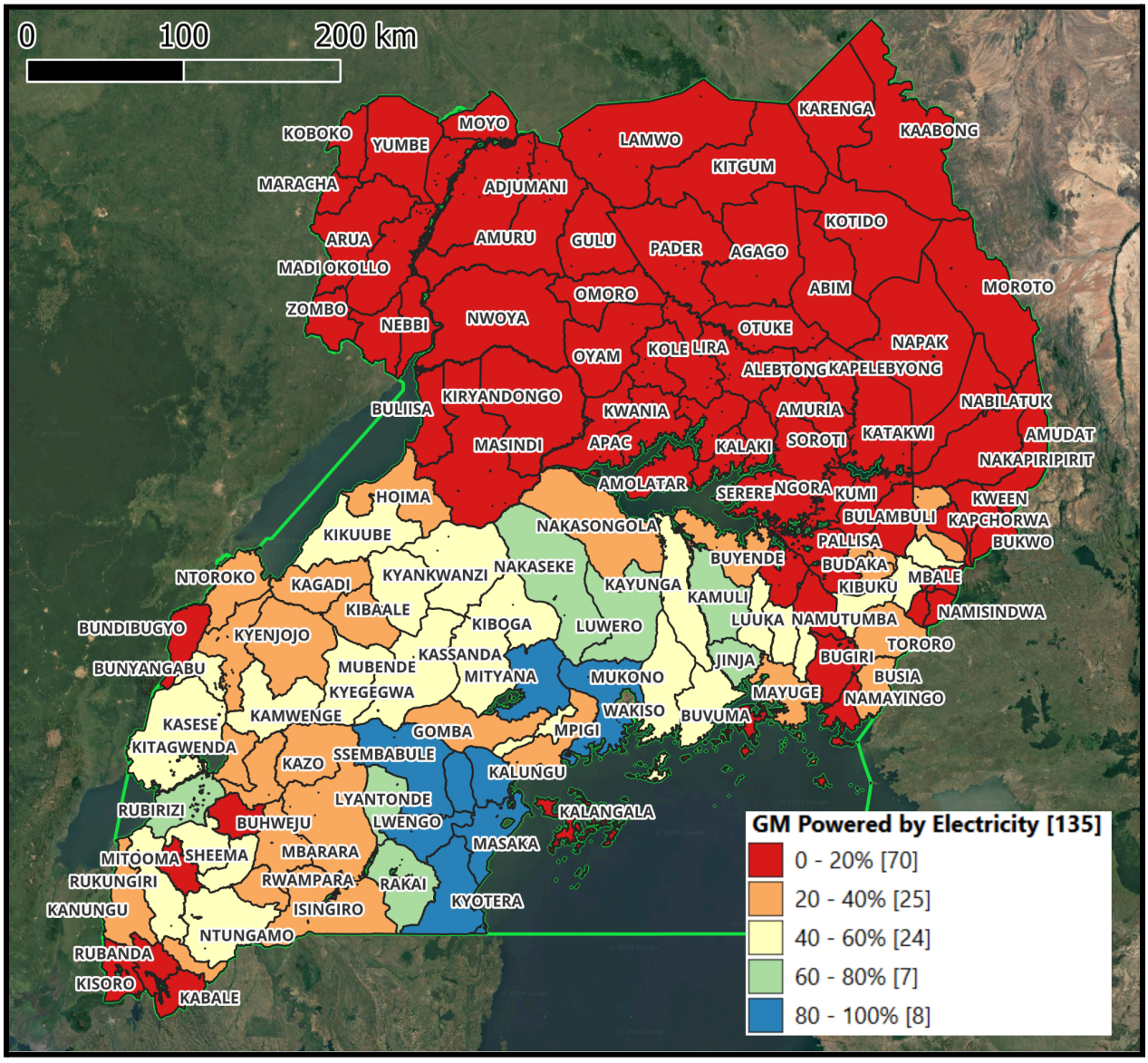
Note: The n values in these figures are for only those machines for which capacity information was available (10,413) compared with total mills encountered (17,348).

[3] Capacity data was unavailable for many individual PUE machines. For the 17,348 mills encountered during surveying, capacity data was available for 8,236 diesel mills and 2,177 electric mills, for a total 10,413 (or 60% of all mills). This was for a variety of reasons, including missing or unreadable nameplates, and milling businesses were sometimes closed, permitting interviews with operators but preventing access to machines.

Geographic Patterns in Mill Power Source and Households Served

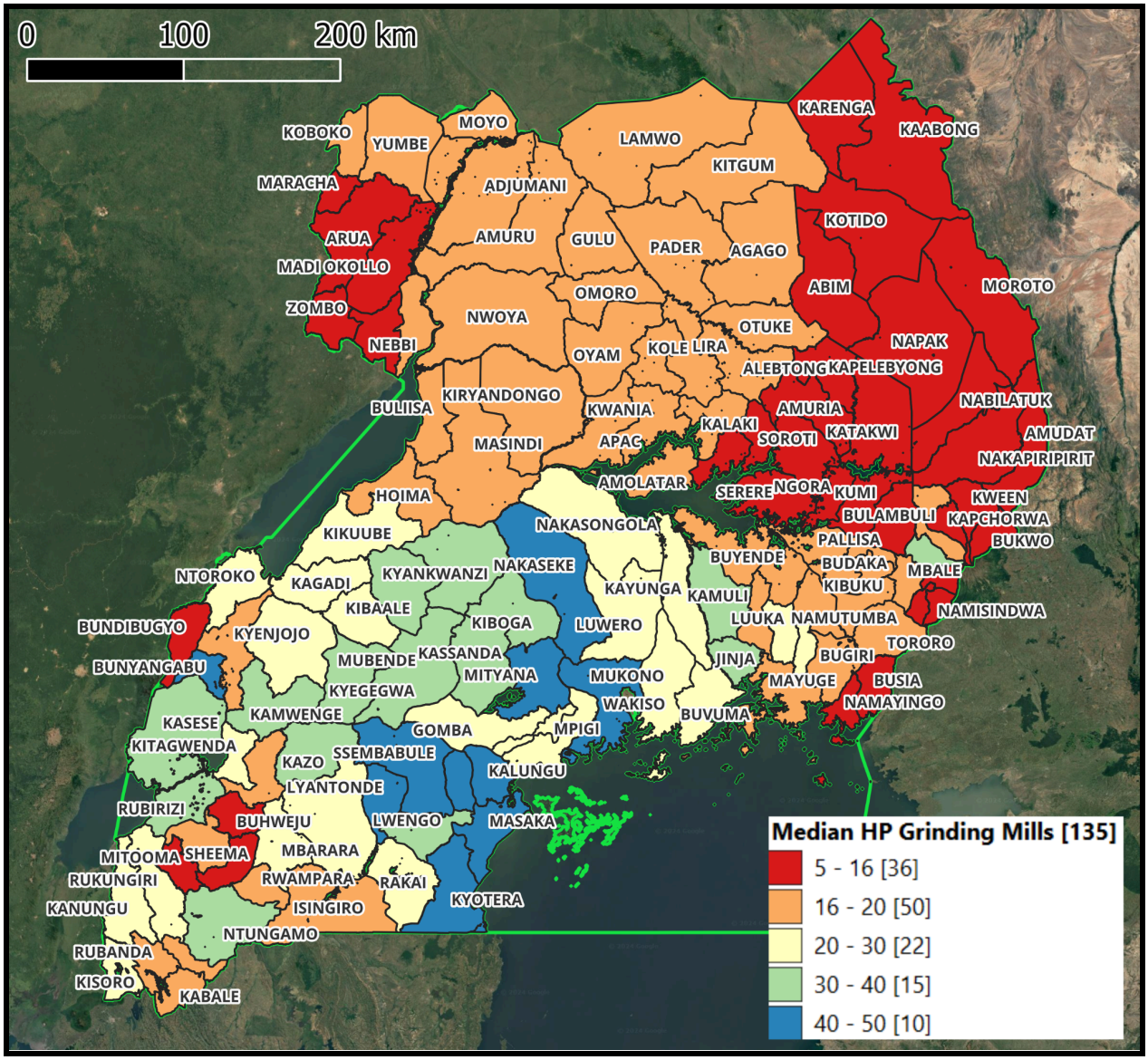
There were also important **geographic patterns**, largely related to population density and proximity to the national electricity grid. These patterns generally reflect that the Lake Victoria area tends to have both higher grid penetration and higher population density than northern parts of the country.

- The overwhelming majority (97%) of businesses very close to the grid (within 500 m) were electric powered, while extremely few (2-3%) beyond that distance were electric powered. This is shown in far higher prevalence of grid-connected mills in the Lake Victoria area vs. the North.



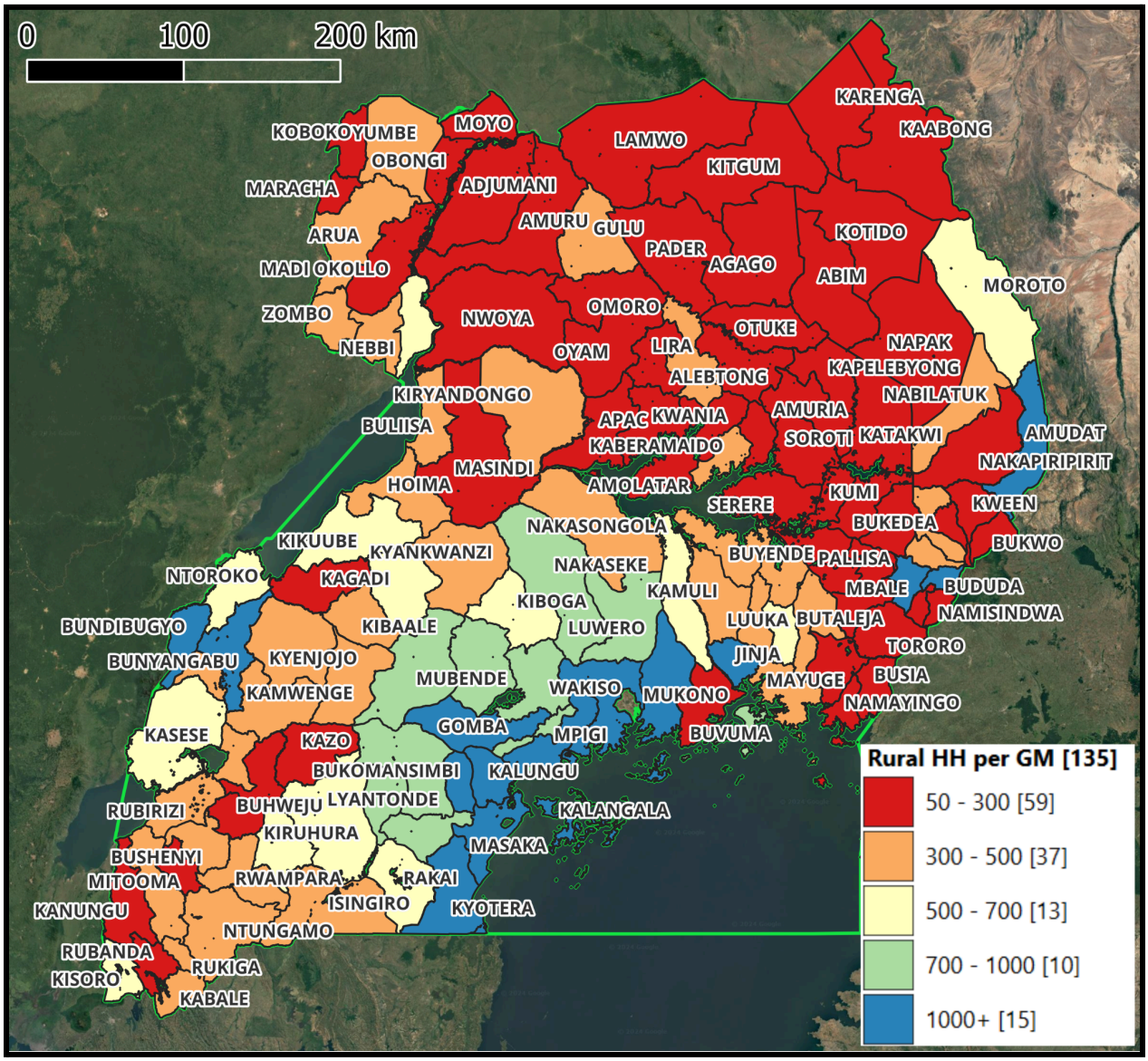
Percentage of Grinding Mills connected to the electricity grid, by District

- Areas with low population density and less electric grid coverage, particularly the northern and north-eastern parts of the country, also tended to be smaller in size (20 HP or less).



Median capacity (in HP) for all Grinding Mills (diesel & electric), by District (National median: 20 HP)
Note: all capacities are reported in HP; any capacities reported in kVA or kW have been converted.

- In more densely-populated areas surrounding Lake Victoria, mills tended to serve more households (250-500 households per PUE business) versus in the north, mills tended to serve fewer households (typically between 150-250 households per PUE business)[4].



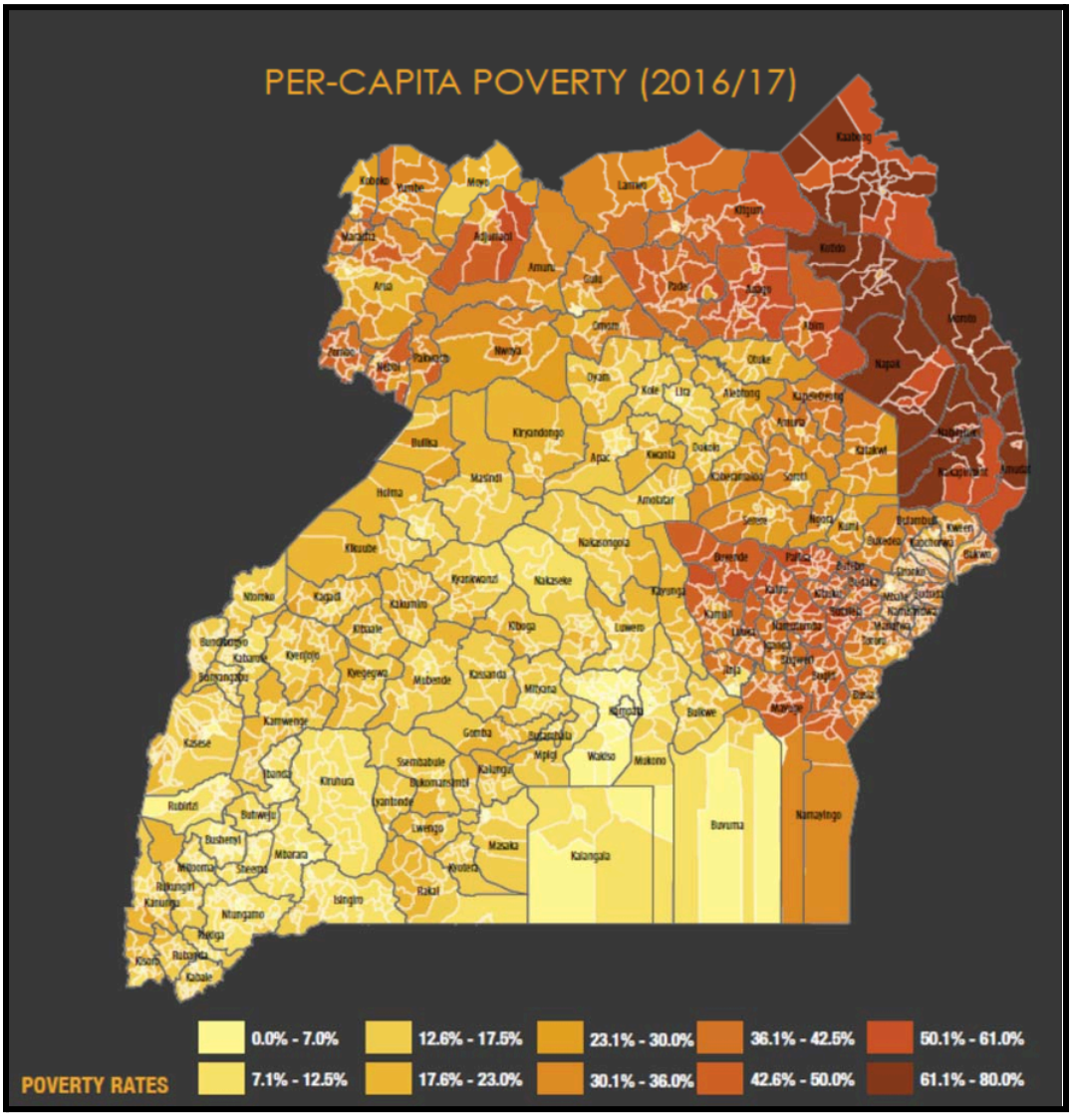
Estimated number of households likely served by a grinding mill, by district (National median: ~330 HHs per mill; National mean: ~520 HHs per mill)

[4] A count of rural households for each district was determined by using publicly available data for structures visible in satellite imagery which were merged to approximate the number of rural households across Uganda. This count of rural households was then divided by the number of grinding mills in each district to estimate rural households per grinding mill.

Taken together, these data show a broad pattern: In more densely-populated areas surrounding Lake Victoria, the typically larger, electric (grid-connected) machines tended to serve more households versus in the north, smaller, diesel machines tended to serve fewer households.

Geographic Patterns and Poverty

The geographic patterns described above track poverty patterns nationwide, as can be seen in this figure from a recent UBOS report. Comparing geographic patterns from the survey to the UBOS results, areas with higher per capita poverty rates generally have less access to electric machines, and are served primarily by smaller diesel machines.



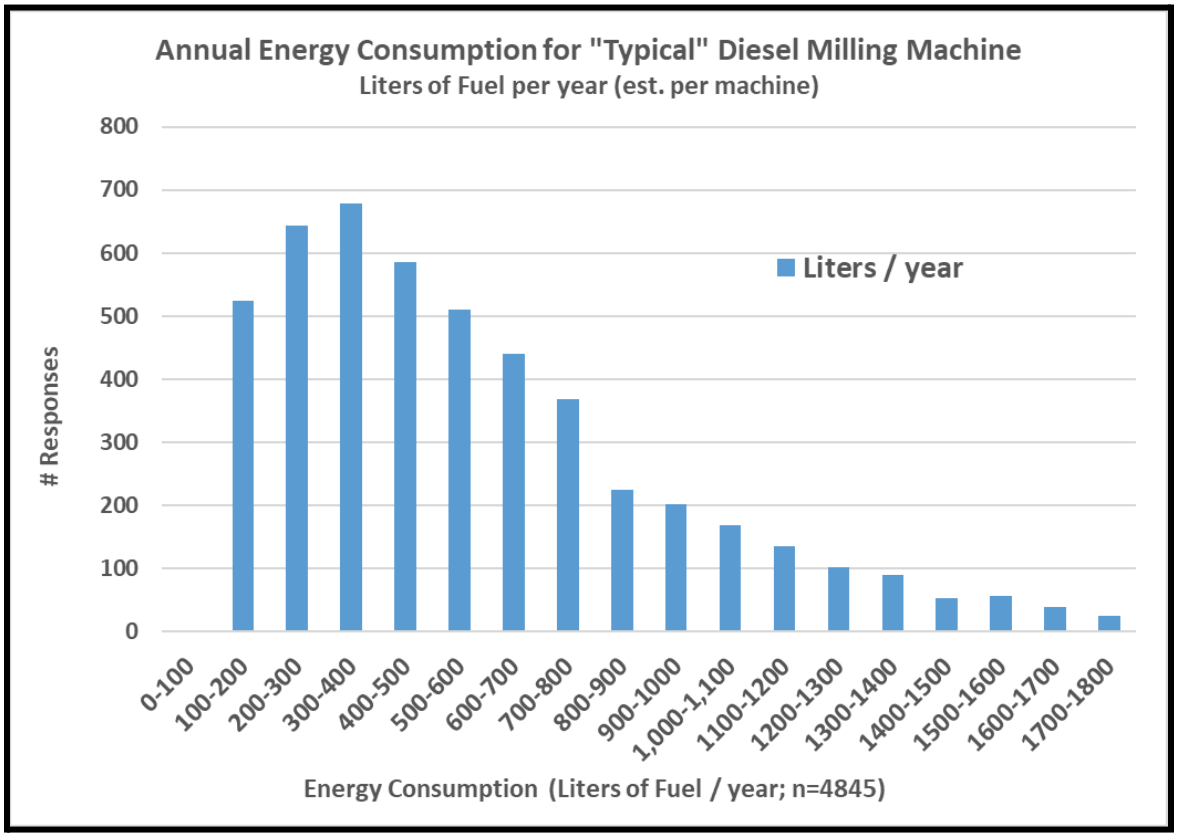
Per Capita Poverty 2016 / 2017 (UBOS, 2020[5]).

[5] https://www.ubos.org/wp-content/uploads/publications/02_2020Poverty_Map_for_Uganda.pdf

Use Patterns and Energy Consumption

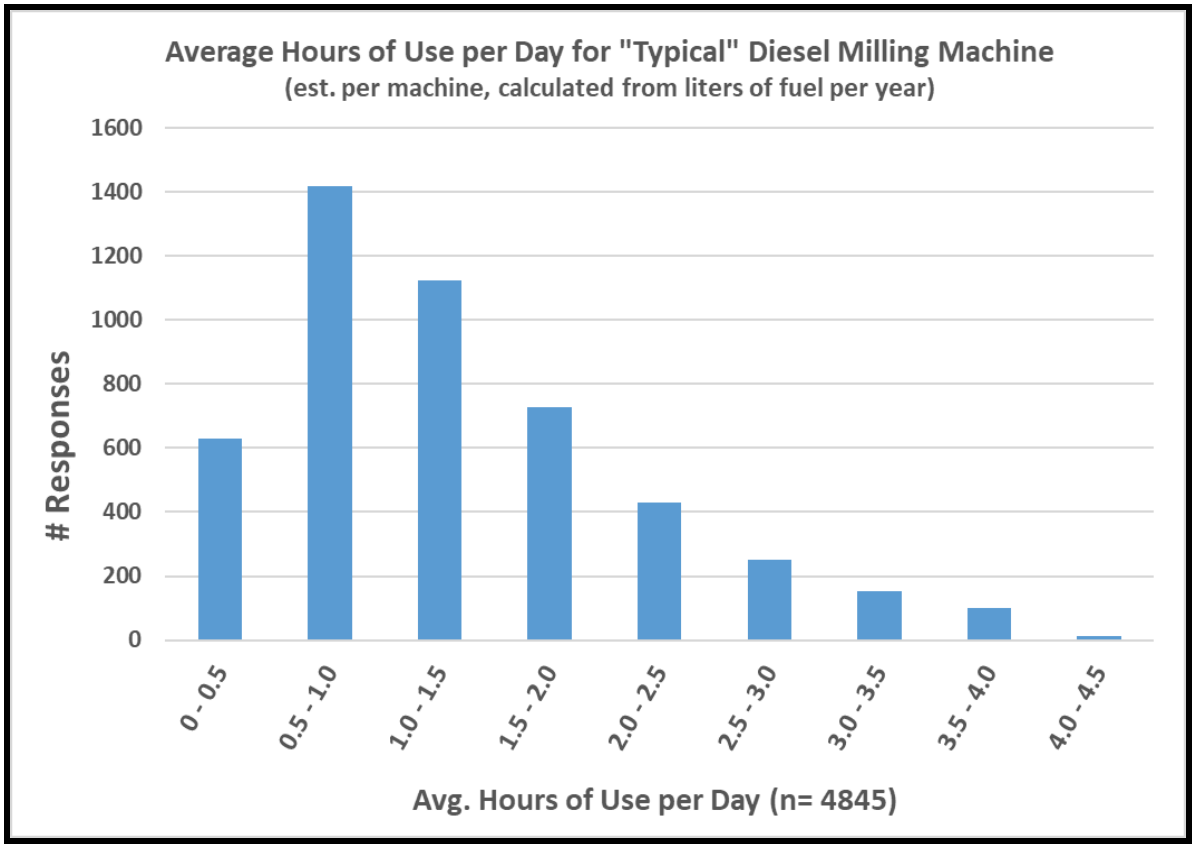
Total Annual Energy Consumption for "Typical" Diesel Grinding Mills

The most widespread ("typical") PUE business found in rural Uganda is a diesel-powered grinding mill, with only one milling machine of 16-24 horsepower. A simple measure of utilization across the year of such machines is the annual energy consumption, obtained here as the liters of diesel fuel consumed per year, per machine. The histogram below shows the distribution of surveys responses converted to annual liters of fuel used for these typical diesel machines[6]. Note that this fuel consumption rate is much lower than what a fully loaded 20 hp diesel machine would consume suggesting that the machines are currently being operated at part load.



Liters of fuel consumed per year for 16-24 hp Diesel-powered Milling Machines (n=4845).
Here, n reflects the number of responses with reliable consumption data, after removing the highest and lowest 5% as potential outliers.

[6] For milling businesses with more than one machine, total annual liters consumed by the business were divided by the number of milling machines.



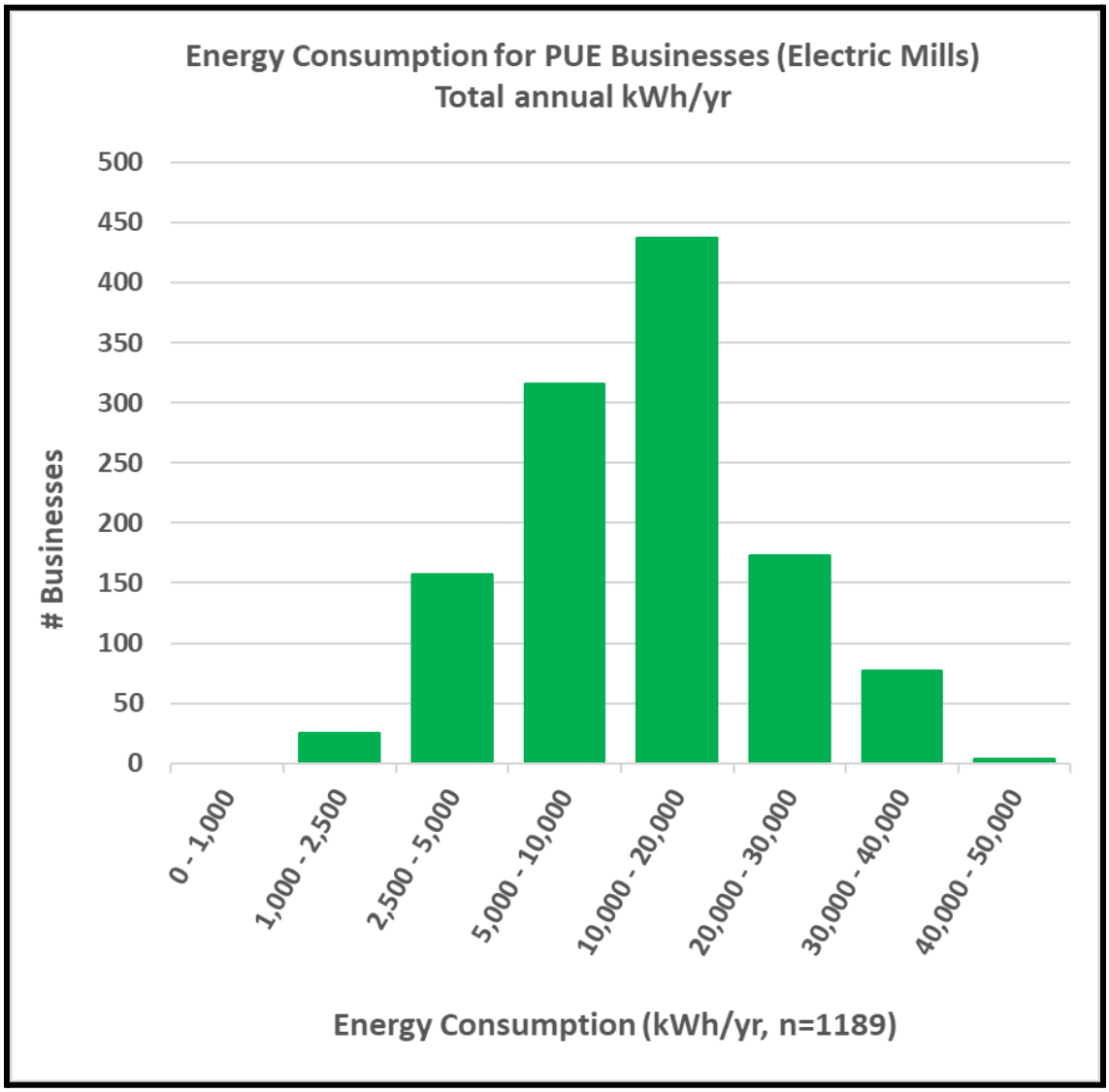
Average Hours of Use per Day for "Typical" Diesel Milling Machines

Here, n reflects the number of responses with reliable consumption data, after removing the highest and lowest 5% as potential outliers.

To assist in interpreting this utilization metric, we carried out a separate small exercise using vibration-based hour meters to link fuel use to actual hours of operation. This exercise showed us that a typical machine consumed 1.5 liters of fuel per hour of operation. Applying the learning from this exercise to the fuel consumption responses provides us with the distribution of hours or machine operation as shown below. A range of 200-400 liters/yr per machine as commonly seen earlier, would imply 0.5 to 1 hours of actual operation per day. From the charts above, 40% use less than 1 hour a day, 40% use between 1 hour and 2 hours a day, and 20% use between 2 hours and 4.5 hours a day. This suggests that the existing machines are generally underutilized and could potentially be replaced by lower kW electric machines.

Total Annual Energy Consumption for "Typical" Electric Grinding Mills

Data for energy consumption *at the level of the PUE business* shows that electric-powered PUE businesses with typically sized mills (20-40 kW) had annual consumption across a broad range from ~5,000 - 40,000 kWh (calculated from reported electricity expenditure[7]).

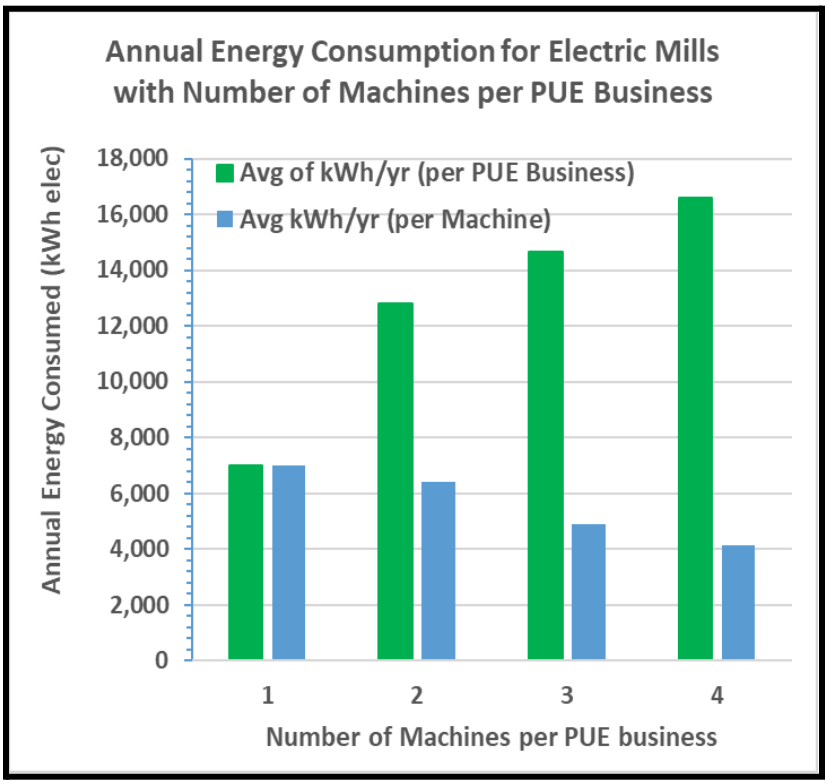


Annual Energy Consumption in kWh for a 20-40 kW Electric Mill

Here, n reflects the number of responses with reliable consumption data, after removing the highest and lowest 5% as potential outliers.

[7] The formula for calculating energy consumption for electric machines: Energy Usage (kWh/year) = (Electricity Expenditure in Heavy Months * # of Heavy Months + Electricity Expenditure in Light Months * # of Light Months) / 825UGX/kWh

Electric-powered PUE businesses with more machines consume more power in a roughly linear trend. Dividing total electricity consumption across all machines identified in a single business yields an average of ~5,600 kWh per machine.



Machines per PUE Business	Electric PUE Businesses in this Category	Avg of kWh/yr (elec)	Avg kWh/yr (elec) per Machine
1	65	7,003	7,000
2	609	12,815	6,410
3	334	14,643	4,880
4	126	16,614	4,150
Total:	**1,134**	**Avg:**	**5,610**

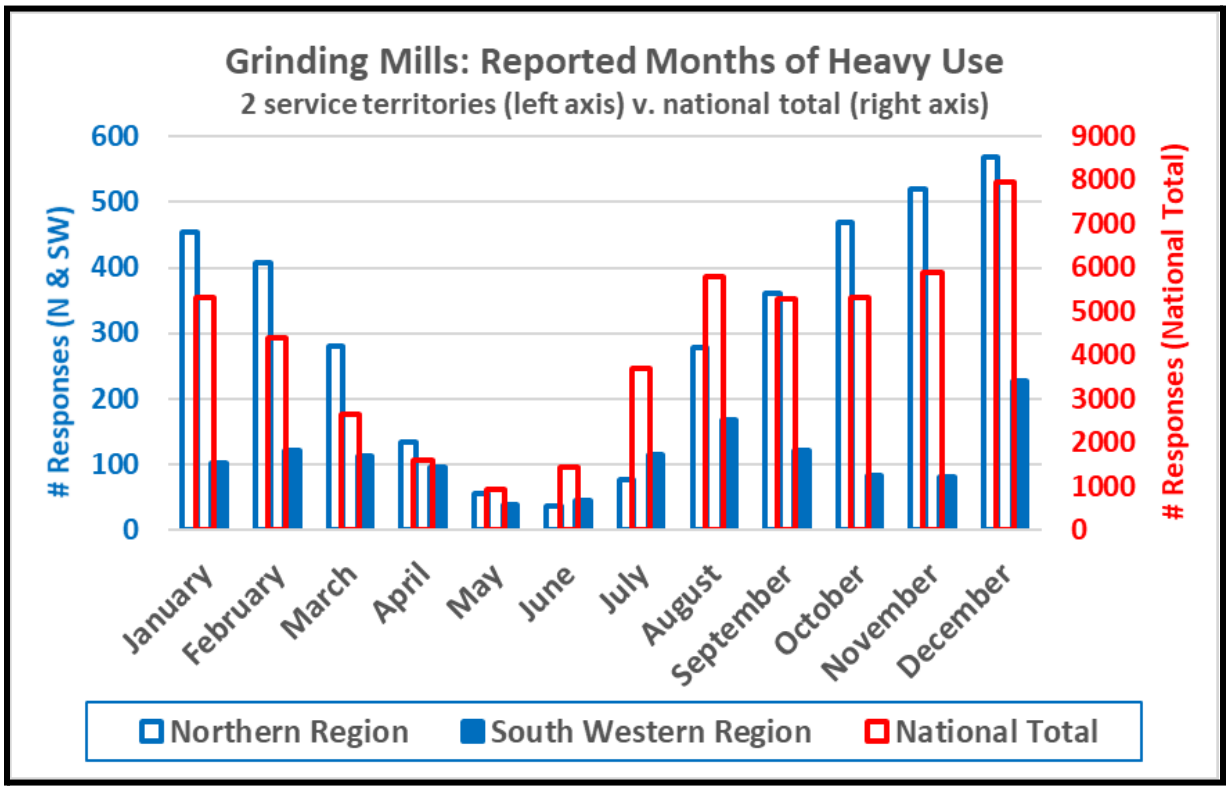
Annual Energy Consumption in kWh for "Typical" Electric Businesses and Individual Milling Machines

Seasonal Use of PUEs

There were also **seasonal patterns**, with important differences between months of "heavy" vs. "light" use:

- Throughout the country, the months of highest use spanned from August through December, the period including and following the "short rains". The months with the lightest use spanned from March to July, the period generally known as the "long rains".
- The difference in fuel consumption in heavy versus light use was substantial, with a decrease in diesel use somewhere in the range of 40-80% for most PUE businesses.

These seasonal use patterns for rural PUE businesses broadly follow rainfall patterns, though both rainfall and PUE use data vary somewhat by region, with the Northern portions of the country tending to have only one rainy season.[8]

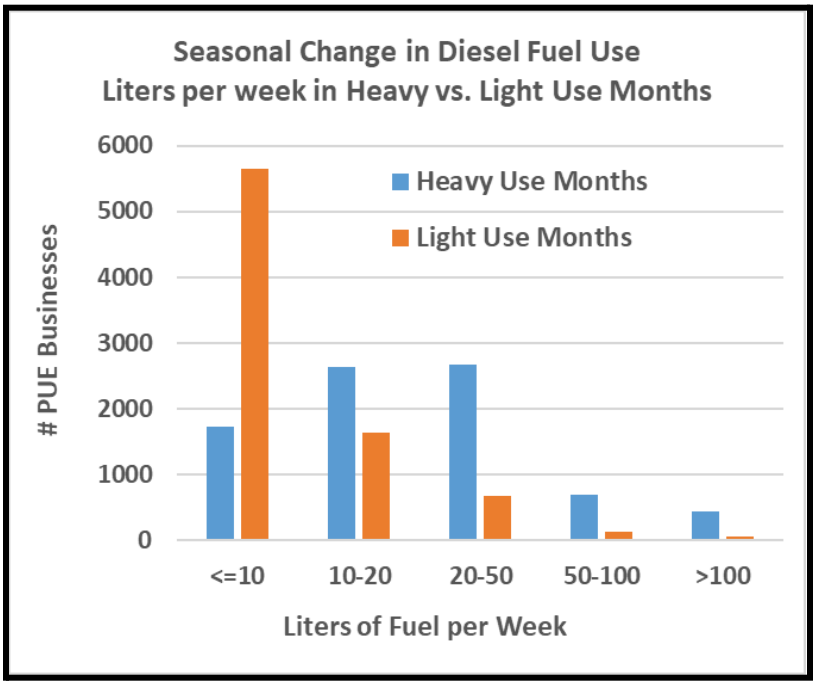


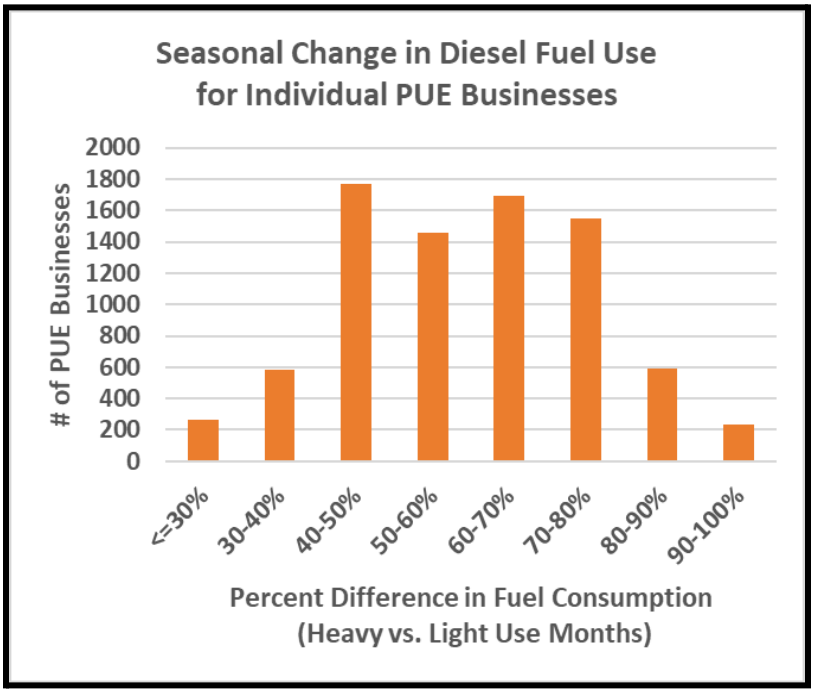
National vs. Regional Patterns in Reported Months of Heavy Use:
Northern and South Western Service Territories (left axis) vs. National Total (right axis)

[8] https://climateknowledgeportal.worldbank.org/country/uganda/climate-data-historical

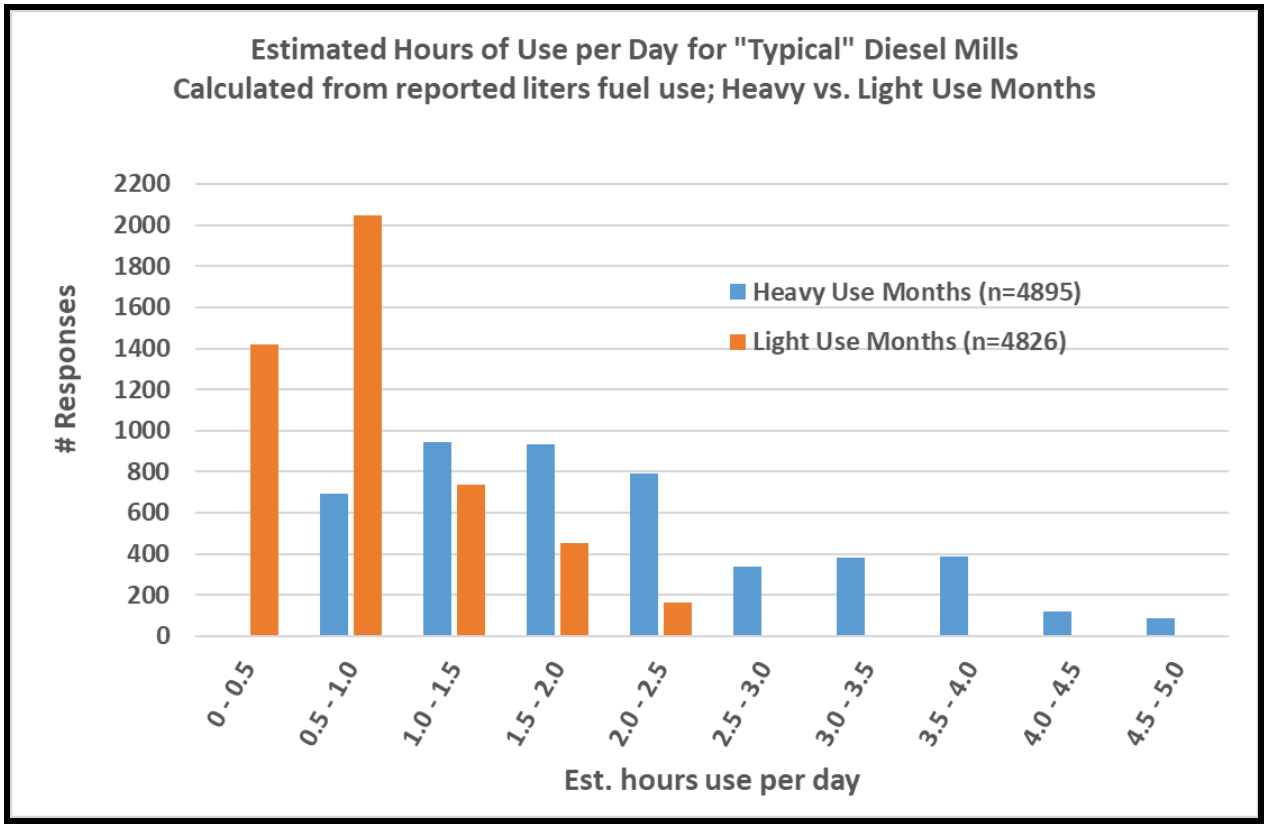
Liters of fuel used per week (Heavy & Light Seasons)

The charts below show the seasonal change in liters of fuel use as both the total liters consumed in heavy and light use months, as well as the percentage change for individual PUE businesses between heavy and light use months.





Seasonality of Weekly Energy Consumption, Diesel Mills (Liters/wk in Heavy vs. Light Use months)

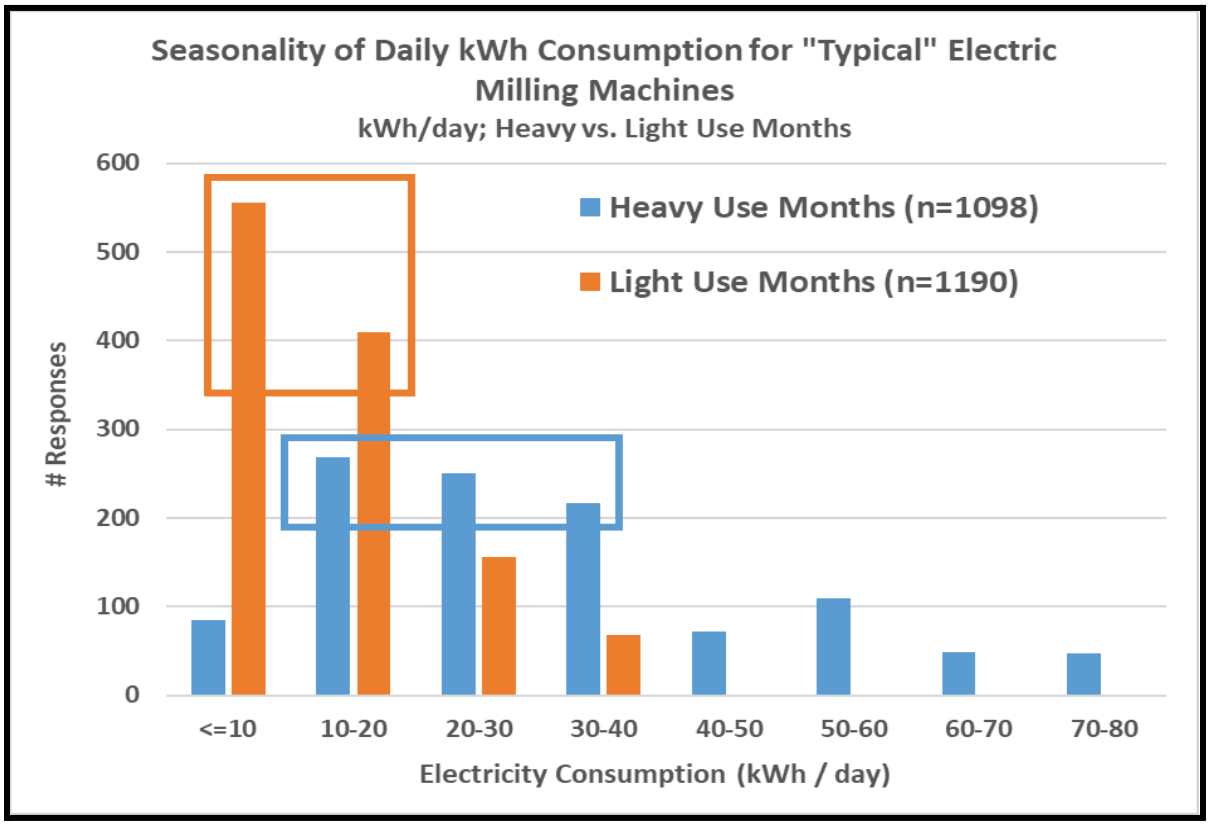


Hours of use per day (Heavy and Light Seasons)

(n values reflect responses with hours of use data after removing the highest and lowest 5% as potential outliers. 207 Responses for Heavy use months greater than 5 hours per day are not shown)

Note that hours of use per day are not provided for electric machines, as a measurement for a relationship between the consumption of electricity at a business and hours a machine was operated was not conducted. If we consider the average kWh consumption of a single machine located in a business with two machines[9] to be a "typical" 30kW machine loaded at 50% of the capacity, then we would expect this single machine to be used 1.5 hours per day. When considering this "typical" electric machine, with a capacity between 20 and 40 kW, and using expenditures on grid power as the indicator of electricity consumption, the typical electric machine uses around 20-40 kWh per day in months of heavy use, with a median value of 25 kWh and mean of 30 kWh, and about 10-20 kWh per day in months of light use, with a median value of 10 kWh and mean of 12 kWh.

[9] As with the diesel consumption, electricity consumption calculations assume that electricity purchased by the business is divided equally among the electric machines identified at the business. The typical diesel-powered milling PUE business has only one machine, while the typical electric powered milling PUE business has between 2-4 machines and sometimes more. Therefore, the assumption that electricity is consumed equally among all machines at a grid-connected business is likely to be somewhat less accurate. This is still the best assumption possible from the available data, given that there is no feasible way to disaggregate electricity purchases for a PUE business for specific machines.



Seasonality of Daily Energy Consumption for Electric Mills (kWh/d in Heavy v. Light Use months)

Conclusion

The findings from this national survey effort provide critical insights into the energy demands and characteristics of productive uses of energy (PUE) businesses across rural Uganda. The survey, covering nearly 20,000 PUE businesses, highlighted the significant role that energy plays in driving rural economic activities, particularly in agro-processing. The data underscores the stark contrast between energy sources, with a predominant reliance on diesel-powered machinery in areas with limited access to the national electricity grid, while electric-powered mills were more common in densely populated regions closer to the grid. This geographic variation in energy usage patterns reflects both the infrastructure challenges and the potential for expansion of electricity access through grid extension or alternative solutions such as solar mini-grids.

The survey's insights are instrumental for guiding future energy investments, helping policymakers and stakeholders make informed decisions that align with Uganda's national priorities including the Parish Development Model (PDM). By focusing on the energy needs of PUE businesses, the data offers a roadmap for enhancing energy access that directly supports livelihoods and income generation in rural communities.

Acknowledgments

Focal Points Within the Government of Uganda

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Participants in Working Groups or other supplementary discussions

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- Uganda Ministry of Agriculture, Animal Industry and Fisheries (MAAIF)
- Uganda National Meteorological Authority (UNMA)
- Uganda Ministry of Water and Environment (MWE)
- Uganda Ministry of Local Government (MOLG)
- Uganda Electricity Distribution Company Limited (UEDCL)
- UMEME (https://www.umeme.co.ug/)
- Uganda Energy Credit Capitalisation Company (UECCC)

Other Key Stakeholders

World Bank:

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Entities Consulted and Invited:

African Forum for Utility Regulators, Agsol, Air Water Earth (AWE) Engineers, Clean Cooking Alliance, GOGLA, Digital Green Investment Agency, FAO Uganda, GEAPP, GIZ, International Solar Alliance (ISA), Kilimo Trust, Open Capital/UOMA, Power Africa, Power For All, Rockefeller Foundation, Second Stream, SEforALL, SELCO, The Policy Practice, Uganda Association of Impact Assessment, UNREEA, USAID, WRI

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