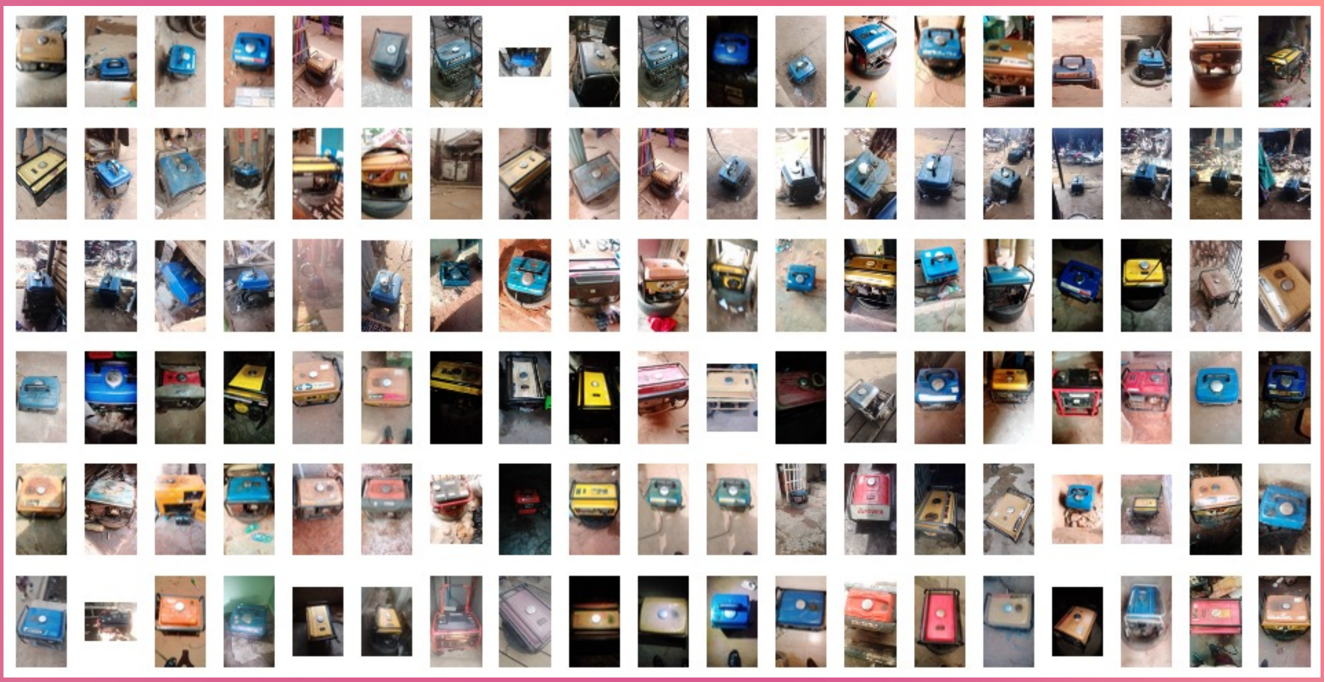
ZE-Gen

A2E ACCESS TO ENERGY INSTITUTE

FOSSIL FUEL GENERATOR INSIGHTS FOR NIGERIA

Real-time data-based analysis of generator usage across different customer categories



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ACCESS TO ENERGY INSTITUTE | ZE-GEN | DECEMBER 2025

This report was prepared by

ZE-Gen. A2E ACCESS TO ENERGY INSTITUTE I

ZE-Gen funding reference

This project has been brought to life with funding from ZE-Gen with support by UK Aid via the Transforming Energy Access (TEA) platform.

ZE-Gen programme description

Launched at COP27, ZE-Gen is the leading international initiative working to improve the lives of people across Africa, South Asia and the Pacific Islands by driving the use of renewable energy in place of polluting fossil fuel generators. ZE-Gen does this through enabling new R&D, innovating financing, developing skills and growing local market appetite. The programme is supported by the IKEA Foundation and UK Aid via the Transforming Energy Access (TEA) platform, and delivered by the Carbon Trust and Innovate UK.

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ACRONYMS

FFG - Fossil Fuel Generator
PV - Photovoltaic
SM - Smart Meter

1 INTRODUCTION

Globally, approximately 840 million people lack reliable access to electricity, forcing many to depend on fossil fuel backup generators. While common, these generators pose significant issues: they are expensive to operate, generate disruptive noise pollution in neighbourhoods and cities, and emit harmful exhaust that negatively impacts public health and the environment.[1]

In Nigeria, about 22 million gasoline-powered generators used by households and small businesses result in over 1,500 deaths annually from exposure to toxic fumes and carbon monoxide. Additionally, the cost of fuel in Nigeria has seen a significant surge in recent months. In early 2024, the price of petrol stood at ₦617 per litre, but by September of the same year, it had soared to around ₦897 per litre. The situation worsened further, with prices reaching as high as ₦1,060 per litre in some areas by October 2024. This dramatic increase in fuel prices has placed a heavy financial burden on users of fossil fuel generators.[2]

Recent advances now position solar-powered generators as a viable, sustainable alternative, offering dependable performance, significant cost savings, and environmental benefits.[3] Until recently, diesel generators have been the primary option available for people and businesses lacking reliable or any grid access.

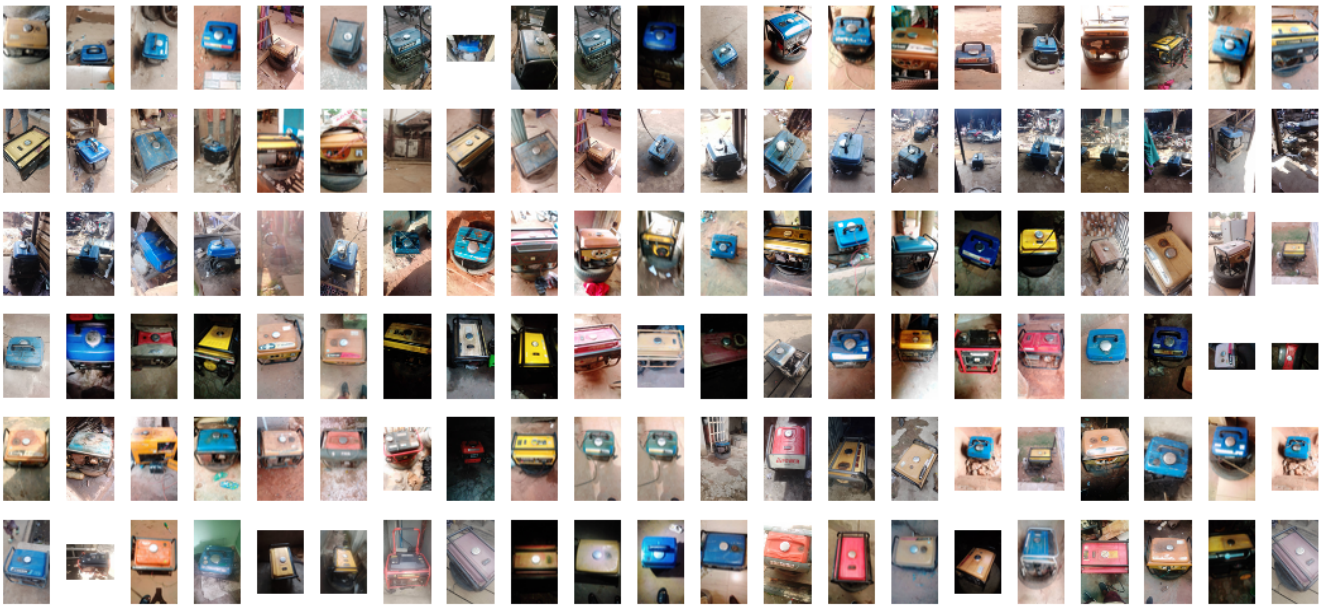

Figure 1: observed fossil fuel generators

1 "The Dirty Footprint of the Broken Grid", IFC, 2019

2 https://insidesuccessnigeria.com/petrol-price-in-nigeria-the-powerful-impact-on-daily-life/

3 "Putting an End to Nigeria's Generator Crisis: The Path Forward", A2EI, 2019

Solar generators (large standalone off grid solar systems) are emerging as a viable and sustainable replacement for traditional fossil fuel-based backup power solutions. Unlike fuel generators, which rely on a constant supply of diesel or gasoline and produce noise and toxic emissions, solar generators operate silently, require no fuel input, and emit zero pollutants. These systems are particularly well-suited for deployment in regions with unreliable grid access, such as many parts of Nigeria, where power outages are frequent and prolonged. The modular and scalable design of solar generators allows them to be customised to meet the specific energy demands of different user types. Businesses typically consume electricity during the day, aligned with solar generation hours, while households often use more energy in the evening. Knowing how different users consume power helps tailor solar system sizes that work reliably without wasting capacity or driving up costs.

The detailed usage of fossil fuel generators across different sectors is a crucial consideration for this project. A typical solar generator setup consists of 2 to 4 photovoltaic panels mounted on rooftops, connected to an inverter with a capacity ranging from 0.5KVA to 3KVA, and coupled with battery storage of approximately 2kWh. This configuration can support a range of loads, from basic household needs like lighting, phone charging, and small appliances, to commercial operations involving fans, refrigeration, and point-of-sale devices.

One of the most critical advantages of solar generators is their ability to provide uninterrupted power. When grid electricity fails, the system seamlessly switches to stored solar energy without any manual intervention, unlike fuel generators which require startup delays and manual oversight. This uninterrupted transition is especially valuable for services that rely on continuous electricity, such as clinics, schools, and hospitality businesses. Installations can be completed in under a day, minimizing disruption to end users and allowing for rapid deployment at scale.

From a financial perspective, solar generators offer compelling long-term benefits. While the upfront capital cost may be higher than that of a small fuel generator, the absence of fuel and significantly reduced maintenance costs lead to much lower monthly operating expenses. These savings accumulate, resulting in a typical payback period of seven to eight years.[1] Beyond that point, the system continues to generate free electricity for the remainder of its 10- to 20-year lifespan, depending on component quality and usage conditions.

Figure 2: solar generators have emerged as a viable alternative to fossil fuel generators in Nigeria

1 "Putting an End to Nigeria's Generator Crisis: The Path Forward", A2EI, 2019

A small number of companies (including Biolite and Sunking) are offering solar gensets as replacements for fuel generators. However, the sector still faces significant barriers, such as poor market data, high upfront costs, limited access to financing, insufficient product testing, and unsupportive policies and regulations, which continue to hinder its growth.

To address these challenges and better understand fossil fuel generator (FFG) usage in Nigeria, the Access to Energy Institute (A2EI), on behalf of the Carbon Trust, deployed 500 Smart Meters across various clusters to capture real-world generator usage data. By analysing this data, A2EI is uncovering valuable insights into usage patterns, identifying suitable solar alternatives, and highlighting market opportunities for clean energy solutions. This data-driven approach is key to informing a practical, scalable transition away from fossil fuel-based backup power. The findings presented in this report aim to support that transition by providing a clearer picture of how, where, and for whom solar generators can serve as a viable replacement.

Figure 3: fossil fuel generators are onmipresent at Nigerian markets

2 APPROACH

To support the transition from fossil fuel generators (FFGs) to cleaner, solar-based alternatives, this project focused on gathering and analysing real-world data on generator usage across various customer segments in Nigeria. FFGs remain a widespread backup power solution, filling the gap left by unreliable grid access and enabling homes and businesses to maintain essential services. However, their high operating costs and negative environmental and health impacts make them unsustainable in the long term. The Zero Emission Generator Initiative (ZE-Gen) seeks to replace these systems with solar generators which comprise of photovoltaic panels, batteries, and inverters that can deliver reliable and cost-effective energy with zero emissions.

Designing appropriate solar replacements requires a deep understanding of how FFGs are currently used: how often they run, how much power they draw, and under what conditions. To generate this insight, 500 Smart Meters were deployed across diverse customer types – including *households, schools, markets, health centres, and hotels*. These meters record data every five minutes, capturing detailed time-series information on generator performance, including power, voltage, current, frequency, and power factor.

Alongside the meter deployments, a comprehensive survey was conducted to capture contextual information about generator owners. The survey collected data on user demographics, generator specifications, fuel and maintenance costs, and openness to adopting clean energy alternatives. This helped link observed usage patterns with the lived realities and preferences of users, providing a complete view of the FFG landscape.

This report presents the results of both the smart meter data analysis and the survey. It begins by outlining the methodology – how customer segments were selected, how meters were installed and monitored, and how data was processed and validated. It then explores insights into the FFG market, including generator brands, efficiency, and lifetime expectations. The focus of this report is to show how different types of users run their generators, how much power they use, how often they use it, and how their energy needs vary to reveal key relationships and informing the design of tailored, effective clean energy solutions. One customer cluster is examined in greater depth, and all clusters are made accessible via the open-source, real-time data analytics platform Prospect[1] introduced here as a tool for further exploration.

The Project commenced in September 2023, with an initial 3-month period dedicated to procuring and repurposing existing Smart Meters (SM) that had previously been used in other projects. Following this procurement and repurposing phase, the installation of the configured Smart Meters took place over the subsequent 9 months, concluding by the end of August.

1 https://prospect.energy/

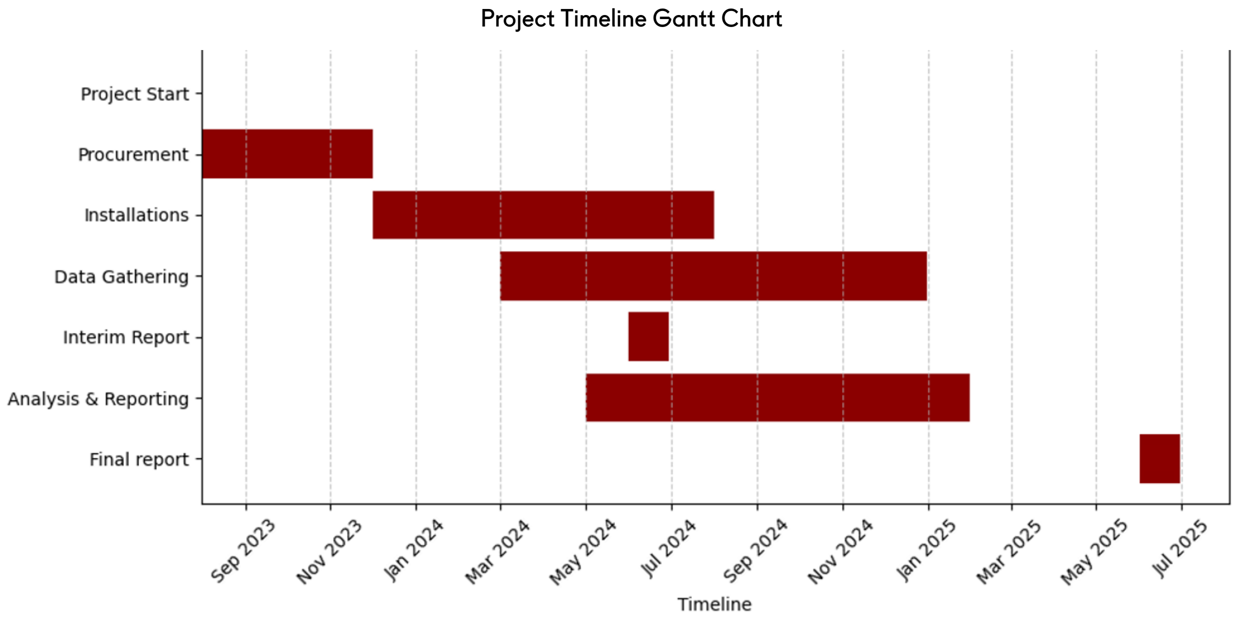

Figure 4: project timetable

As each Smart Meter was installed, the data collection process for the observed FFG began immediately. The initial analysis of the data from small and medium-sized markets commenced in May 2024 and was completed with the delivery of an interim report at the end of June.

Following the ongoing data analysis, this final report has now been prepared and is being submitted at the beginning of July. The comprehensive data gathered through the Smart Meter network has provided valuable insights into the performance and operation of FFGs. (see Figure 4)

The escalating cost of fuel in Nigeria has rendered the continued reliance on fossil fuel generators increasingly unsustainable for households and businesses alike. With petrol prices soaring from ₦617 per litre in early 2024 to approximately ₦897 per litre by September 2024 and reaching as high as ₦1,060 per litre in some areas by October 2024, the financial burden on FFG users has intensified significantly.[1] This surge in fuel prices has led to a substantial increase in the monthly operational costs for generator users. For instance, a business operating a generator for six hours daily could incur fuel expenses ranging from ₦38,000 to ₦114,000 monthly, excluding maintenance costs. When maintenance and other ancillary costs are factored in, the total monthly expenditure can be significantly higher.[2] Collectively, Nigerians are estimated to spend around US$10 billion annually on petrol and generator maintenance, highlighting the economic strain imposed by the country's heavy reliance on fossil fuel generators. This financial pressure is increased by the removal of fuel subsidies, which led to a ripple effect on the economy, increasing the cost of goods and services, and straining household budgets.[3]

1 https://insidesuccessnigeria.com/petrol-price-in-nigeria-the-powerful-impact-on-daily-life/

2 https://nexgennigeria.com/solar-vs-fuel-generators

3 https://businessday.ng/business-economy/article/nigerians-spend-10bn-annually-on-petrol-generator-maintenance-report/

This comprehensive analysis will provide valuable insights into the usage patterns of FFGs in Nigeria, enabling the development of effective strategies to transition towards clean energy solutions and improve the overall reliability and sustainability of the country's electricity supply.

2.1 Customer Segments

The FFG market assessment for Nigeria, conducted by the Carbon Trust, was used as the primary source to identify the observed customer categories in this research. Based on an estimation of the current FFG usage and the desire to transition to solar power, six different use cases were initially identified as the most important to examine.[1]

However, upon further analysis, one of the use cases – installation in universities and government buildings – was deemed not feasible due to the high organizational expenses associated with field installations in these settings. As a result, the remaining five use cases were selected for potential solar installation:

1. Households: This category encompasses individual residential dwellings that currently rely on FFGs for their power needs. Transitioning these households to solar power presents a significant opportunity to reduce fossil fuel consumption and emissions. 104 smart meters have been installed on FFGs to monitor this use case.

2. Small and Medium Markets: Small and medium-sized commercial establishments, such as local markets, shops, and enterprises, were identified as another key customer segment. These businesses often have a high demand for reliable electricity and could benefit from the cost savings and sustainability offered by solar power. 213 smart meters have been installed on FFGs to monitor this use case.

3. Hotels: The hotel industry in Nigeria was recognised as a promising target for solar power adoption. Hotels typically have a consistent and predictable electricity demand, making them well-suited for the integration of solar photovoltaic systems. 75 smart meters have been installed on FFGs to monitor this use case.

4. Healthcare Facilities: Ensuring reliable and uninterrupted power supply is crucial for healthcare facilities, such as hospitals and clinics. The transition to solar power in this sector could enhance the resilience and sustainability of these critical infrastructure assets. 81 smart meters have been installed on FFGs to monitor this use case.

5. Schools: Educational institutions, including primary and secondary schools, were also identified as potential customers for solar power solutions. By transitioning schools to solar, the initiative could not only reduce energy costs but also serve as an educational platform, promoting renewable energy awareness and adoption among the younger generation. 19 smart meters have been installed on FFGs to monitor this use case.

1 "Generator Customer Use Cases - Nigeria", ZE-Gen, 2024

The plan to cover multi-house apartments was explored, but after 8 installations, it became clear that the target number of installations was not achievable due to installation constraints. By focusing on these five customer categories – households, small and medium markets, hotels, healthcare facilities, and schools – the FFG market assessment for Nigeria aims to maximise the impact of the transition to solar power. This targeted approach ensures that the available resources and interventions are directed towards the most promising and impactful use cases, ultimately contributing to the goal of reducing fossil fuel dependence and promoting sustainable energy solutions.

2.2 Installation Process

The installation of Smart Meters (SMs) to monitor Fossil Fuel Generators was carried out by Creeds Energy Limited, a trusted local partner in Nigeria. To minimise electronic waste, repurposed Smart Meters has been used from completed projects, with local partners in Tanzania and Abuja handling refurbishment and updates. The majority of Smart Meters, approximately 94%, have been repurposed and supplemented with additional new meters. To manage installation logistics efficiently and reduce fuel-related travel costs, field activities were concentrated in central Nigeria. The installation process was carefully coordinated by field experts, who selected a diverse range of customers to ensure the sample of monitored FFGs is representative across key sectors.

Installations began in December 2023 and concluded by September 2024. Figure 5 presents the weekly installation progress: the bar chart displays the number of meters installed each week, while the line graph shows the cumulative total installed over time. The rollout began with a focus on small and medium-sized markets, followed by a staggered expansion across other customer categories.

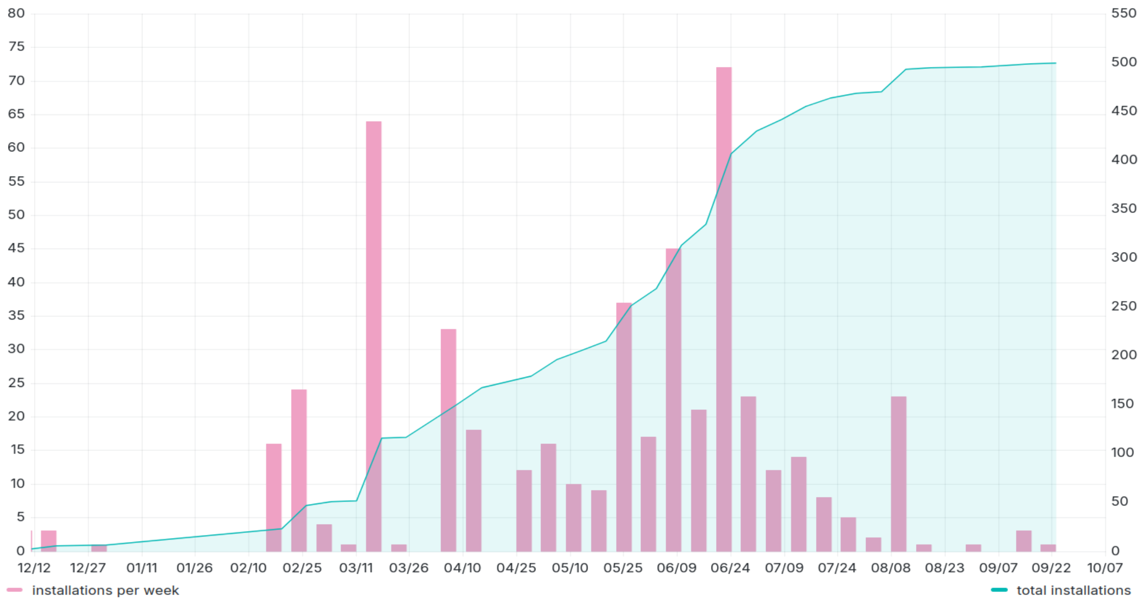

Figure 5: time of installations

During the installation, the technicians ensured that each smart meter was fully functional and capable of transmitting the necessary data. Additionally, a comprehensive survey was conducted to help categorise the different customers (e.g., by customer type, on-grid or off-grid status) and gain a deeper understanding of their perspectives on the use of FFGs.

2.3 Data Collection

This section delves into the details of the data collection process, encompassing both the survey findings and the time-series data gathered from the smart meters (SMs).

2.3.1 Survey

During installation, the installation partner conducted a comprehensive quantitative survey using the Impact Survey Bot (ISB)[1] – a fully digital survey and customer engagement tool developed by A2EI, leveraging WhatsApp for remote data collection and direct, interactive communication with users – to gather contextual information about Nigerian users of FFG. The survey encompassed four main areas:

MAIN AREAS	SPECIFIC INFORMATION GATHERED
1. General data	• contact information • installation date • location • customer category • grid connectivity status • appliance usage
2. Generator specifications	• brand • nominal power • fuel type • installation location • maintenance requirements • expected lifespan
3. Financial parameters	• purchase time and costs • maintenance frequency • monthly fuel costs • monthly repair expenses
4. Attitudes toward clean energy alternatives	• willingness to transition • motivating factors • possibility of installing solar panel

This contextual data provides an essential framework for interpreting the monitoring data and categorising the findings, with detailed analysis to follow.

1 https://a2ei.org/resources/uploads/2021/06/A2EI_Impact_Survey_Bot.pdf

2.3.2 Smart Meter Data

The Smart Meters collect data points at five-minute intervals, enabling detailed analysis of FFG usage patterns. Key metrics collected include power output, average and maximum power consumption, and day/night usage patterns. The analysis also tracks generator utilisation rates, measured in hours per day and days per month, providing crucial insights into market opportunities for clean energy alternatives (i.e. solar generators) across Nigeria.

A2EI led the data analysis effort, incorporating input from external partners like Carbon Trust, Open Capital and local partners such as Creeds Limited. The project has collected over 3.3 million data points as of mid-June 2025, representing measurements from 500 generators at five-minute intervals. A crucial aspect of the data collection methodology is that Smart Meters only transmit data when generators are operational. Therefore, periods without data points indicate generator inactivity. However, the analysis focuses on approximately two-thirds of the observed generators, as one-third either never transmitted data or ceased transmission, the primary reason is the high fuel costs (explained in section 3.1.6). To ensure data accuracy, only meters active within the last two months were included in the analysis, operating under the assumption that inactive meters represent discontinued generator use.

The survey data enabled clustering of results by customer category, subcategory (such as market type or number of residents/guests/pupils), and grid connectivity status. All analysis results are accessible through the open-source Prospect platform.

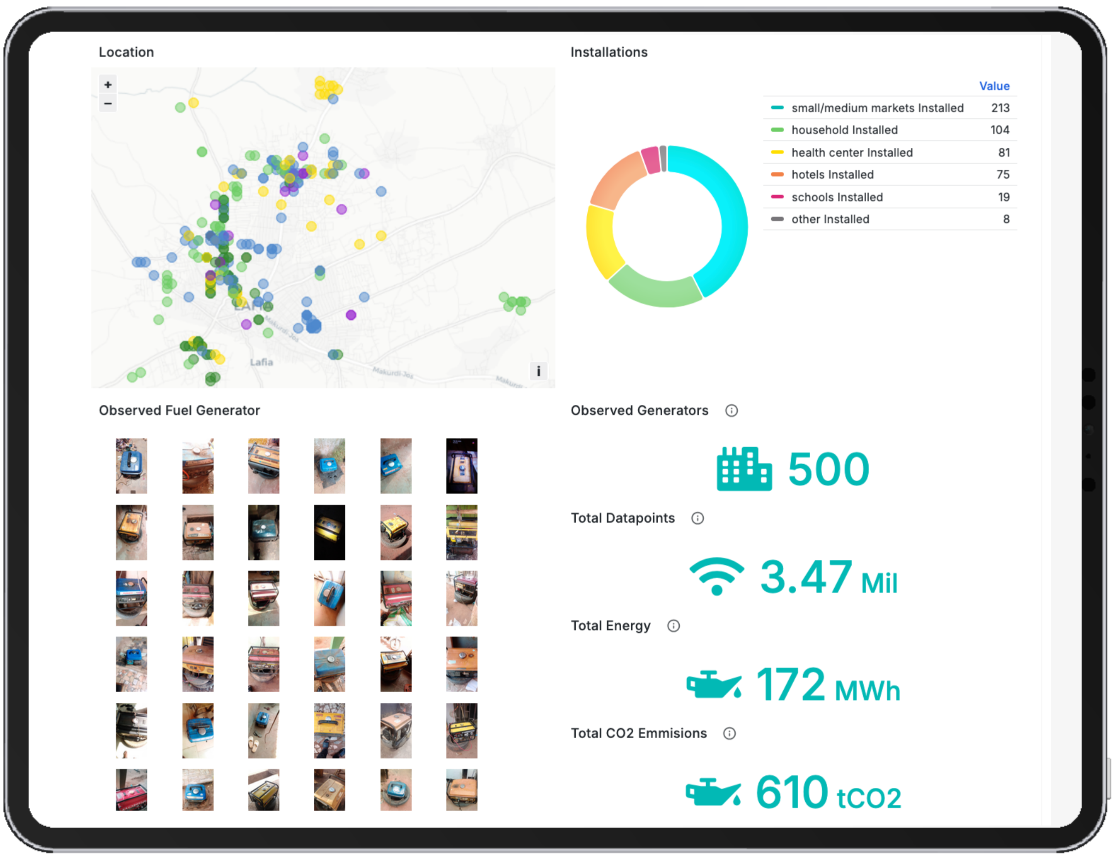

Figure 6: installed Smart Meters have collected over 3.4 million data points

2.4 Data Analysis Methodology

This section provides a detailed explanation of the data analysis methodology.

2.4.1 Data Evaluation

Based on time series data collected between December 2023 and July 2025, a comprehensive set of key factors were established. These indicators are categorized into three primary domains: Power, Usage, and Energy consumption patterns.

The power-related metrics encompass seven key measurements:

1.	Average Power (kW)
2.	Power Standard Deviation (kW)
3.	95th Percentile of Power Usage (kW)
4.	Maximum Power (kW)
5.	Average Power Factor
6.	Average Load Factor (relative to nominal power) Average Power Factor
7.	Load Profile (per Cluster)

These power metrics are instrumental in determining appropriate specifications for replacement systems. The average power and standard deviation provide insights into typical operational ranges and load variability. Maximum power requirements are particularly crucial for sizing replacement systems to ensure optimal efficiency through maintaining favourable load factors.

Three primary metrics characterise usage patterns:

1.	Running Hours per Active Day
2.	Running Days per Month Maximum Power (kW)
3.	Usage Profile (per Cluster)

These metrics offer crucial insights into operational patterns, with running hours per active day specifically focusing on actual usage days to provide more accurate utilisation data.

Energy Consumption Energy metrics include:

1.	Energy per Active Day (kWh)
2.	Monthly Energy Consumption (kWh
3.	Daylight Energy Ratio (%)

These energy metrics are essential for designing alternative power solutions, particularly in sizing battery capacity and photovoltaic systems. The daylight energy ratio is especially valuable for solar implementation planning, indicating the proportion of energy consumed during sunlight hours and thus the potential effectiveness of solar power integration.

This comprehensive set of metrics was calculated individually for each FFG in the study. Subsequently, the FFGs were grouped into clusters based on these characteristics, with the results visualised through various analytical representations.

For the data analysis, it was crucial to ensure the use of only valid data. Observed FFGs with incorrect timestamps were excluded, as were smart meters that provided erroneous data, such as zero or unrealistically high values. The most important criterion was the use of active meters, defined as those that were operational in the last two months and had at least 10 hours of recorded data. As explained in section 3.1.6, not all generators were included in the analysis, as a significant number of people had stopped using their generators due to the lack of availability or high costs of fuel. This decision was made to maintain the integrity and accuracy of the data used for the analysis, ensuring that the results accurately reflect the current state of the energy landscape and consumer behaviour.

By carefully filtering the data and focusing on active and reliable meters, the analysis was able to provide a more accurate and representative picture of the energy consumption patterns and the usage of FFGs in the region. This approach helped to minimise the impact of outliers and anomalies, leading to more robust and reliable findings that can be used to inform future energy planning and decision-making.

2.4.2 Visualisation

The data analysis for this project has been conducted using the open-source platform Prospect, which was developed by the A2EI and GET.invest for the energy access sector. This platform has proven to be highly beneficial for this endeavour, as it automatically gathers and consolidates all the data received from the smart meters (SMs), providing a fully customisable visualisation experience that enables a detailed analysis of different customer clusters.

The Prospect platform features three distinct dashboards designed to facilitate a comprehensive understanding of the data (see Figure 7):

1. Cluster Comparison (First Level): This dashboard allows for a high-level comparison of all the identified customer clusters across various metrics, as explained in the data analysis methodology section.

2. Cluster Deep Dive (Second Level): This dashboard enables a more granular exploration of each customer category, including the ability to delve into subcategories (e.g., type of shop, number of residents/guests/pupils) for a deeper understanding of the nuances within each segment.

3. Survey Analysis: This dashboard focuses on the analysis of the survey data, providing the ability to filter and examine the findings in detail, categorised by each customer segment.

All the analysis and visualisations presented in this report can be accessed and explored in greater detail through the PROSPECT platform.

Please access the FFG public dashboard with some of the most important data findings here: https://app.prospect.energy/public-dashboards/369f3cbbf302470a997e2fd9ec980298

To gain access to the entire FFG platform on Prospect and all corresponding dashboards, please contact the A2EI via info@a2ei.org.

Figure 7: overview of Prospect dashboards

2.5 Limitations

In the realm of data analysis, there are always inherent limitations that must be acknowledged. In the case of the observed FFGs in central Nigeria, one such limitation is the limited differentiation among the observed units. All the meters were installed in the same geographical location, which raises the question of whether the usage patterns of the FFGs might differ in other states or regions. Another significant limitation is the willingness of the people to install smart meters that observe their generators. There was a preconception that the smart meters would somehow affect the operation of the FFGs, which is not the case. However, the fact that people had to be financially incentivised to install the smart meters suggests a potential bias in the data.

The data collection process itself also presents limitations. The meters only record data when they are powered, which occurs only when the FFGs are in use. This means that the data does not capture any information about the times when the generators are turned off. This leads to a level of uncertainty, as it becomes difficult to distinguish between instances where the generator is off and instances where the smart meter is not functioning and failing to transmit data. Despite these limitations, the researchers have made a concerted effort to ensure the reliability of the data. The meters that were not functioning properly have been excluded from the analysis, and the team has worked diligently to maintain the overall functionality of the smart meter network.

One positive aspect to consider is the potential impact of the Hawthorne effect, which describes the phenomenon where people modify their behaviour due to the awareness of being observed. In the case of the FFGs, this effect is estimated to be relatively low, as the usage of these generators is a crucial aspect of the people's access to reliable electricity, and their behaviour is unlikely to be significantly altered by the presence of the smart meters.

An important limitation of the data used in this analysis is that it only reflects the past and does not necessarily represent the future. As the energy landscape continues to evolve, the potential replacement of FFGs with solar generators could have a significant impact on the availability and cost of energy. If solar generators become more widely adopted, increased availability and potentially lower costs of energy may lead to a higher overall energy usage by consumers. This shift in energy consumption patterns could, in turn, necessitate a different design and sizing of solar generator systems to meet the increased demand. The current data, which is based on the historical usage of FFGs, may not accurately capture the potential changes in energy consumption that could occur with the widespread adoption of solar power.

Overall, while the data analysis in this study faces certain limitations, the researchers have made an effort to address these challenges and ensure the validity and reliability of the findings to the extent possible.

3 FOSSIL FUEL GENERATOR MARKET

Before examining the usage patterns of FFGs captured by Smart Meters, the characteristics of the observed generators is analysed based on the survey data. This market overview provides context for understanding the current state of generator deployment and differences of the selected customer categories.

3.1.1 Brands

The analysis of FFG brands reveals significant market concentration among a select few manufacturers. Firman emerges as the dominant player, commanding 43% of the installed base. This substantial market share positions Firman as the clear industry leader, with a commanding presence that significantly exceeds its closest competitors. Following at a considerable distance, Tiger holds the second position with 13% of observed FFG, while Parsun occupies the third spot at 9%. The observed FFGs are notably fragmented, distributed among 36 other manufacturers. This fragmentation suggests a highly competitive landscape beyond the top three brands. The presence of 39 different brands in total indicates a diverse market with multiple options for consumers, though the strong preference for Firman's products suggests either superior market positioning, product quality, competitive pricing, or a combination of these factors.

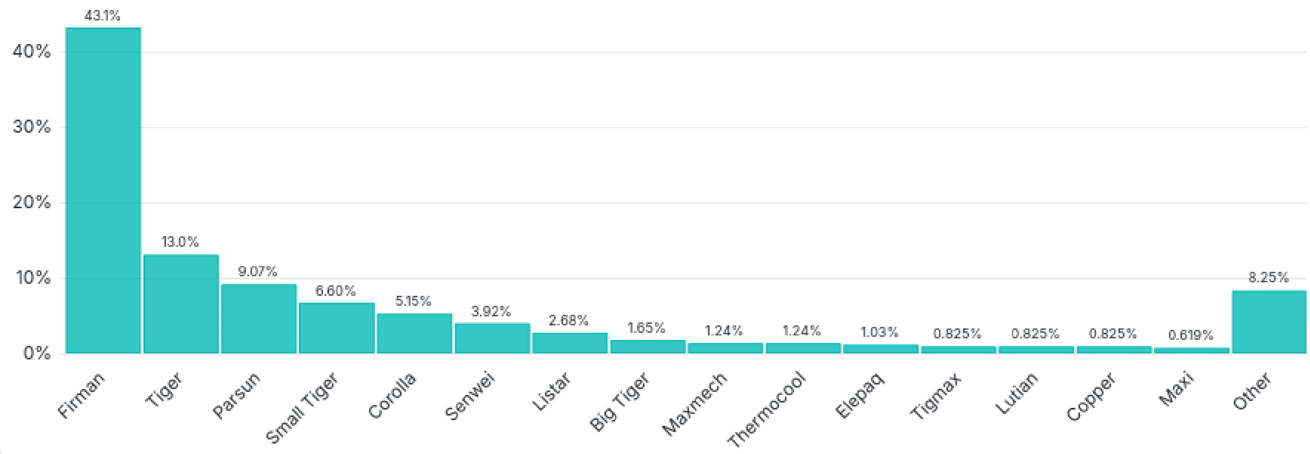

Figure 8: brand of observed generator

By comparing the observed customer categories, it becomes evident that Firman generators are widely adopted in health centres, accounting for 88% of the market share, and are also significantly above the average usage in hotels at 55%. Conversely, Firman's presence is below the average in small and medium-sized markets. This trend could suggest that the perceived reliability of a well-established brand like Firman is a key factor driving its popularity in critical facilities such as health centres and hotels.

Furthermore, the data reveals a higher variance in the selection of generator brands among households and smaller markets, compared to the more consistent usage in health centres, hotels, and schools. This disparity can be attributed to the lower financial resources available to these smaller customers, leading them to prioritise cost-effectiveness over brand loyalty, resulting in a more diverse range of generator models in use.

3.1.2 Nominal Power

The analysis of FFG nominal power reveals a clear concentration in the lower power ranges. A significant majority (83%) of observed FFGs operate below 3KVA, with 1.5KVA and 3KVA being the most prevalent configurations.

3.1.3 Lifetime cycle

The survey data reveals a diverse age distribution within the observed units (Figure 9). Half of the surveyed FFGs (50%) were purchased between 4-10 years ago, while approximately 30% represent more recent acquisitions, obtained within the past three years.

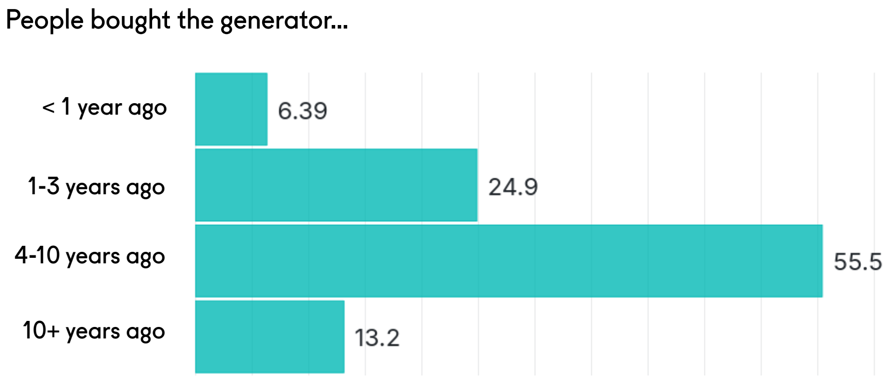

Figure 9: time of generator purchase

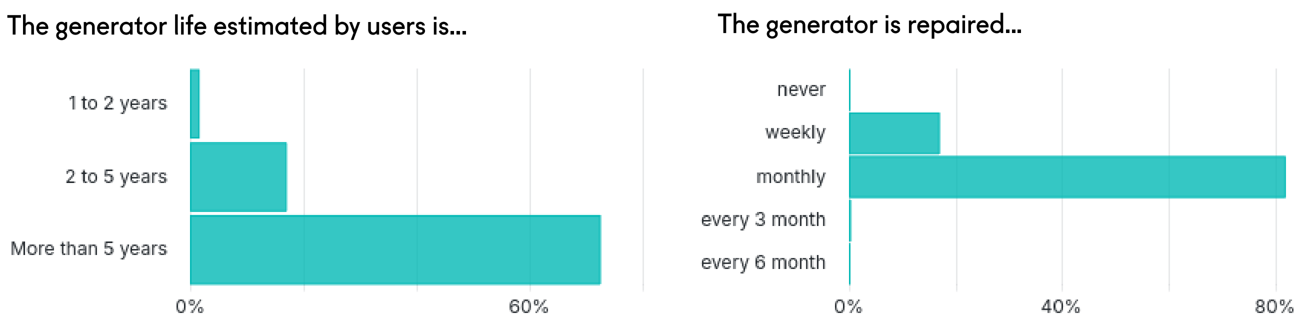

Figure 10: lifetime estimation (l.) and repair frequency (r.) of FFGs

Regarding operational longevity, respondents predominantly anticipate a service life exceeding five years for their units (Figure 10, left). However, this extended operational lifespan is accompanied by significant repair requirements. The user survey indicates that, rather than maintaining their FFGs on a regular schedule, the customers tend to repair them only when necessary. The repair frequency data – based on user estimation – reveals a concerning pattern: 82% of FFGs require monthly repairs, while 18% necessitate weekly maintenance interventions. These high repair requirements translate into two critical operational challenges:

1. Elevated recurring repair costs that impact the total cost of ownership (14% of OPEX, see in section 3.1.4 below)
2. Reduced reliability of power supply due to frequent repair downtime, as skilled workers are required for the repairs

This repair burden significantly affects both the economic viability and operational dependability of these power generation systems.

3.1.4 Monthly Costs

Aside from the actual usage of FFGs, the financial aspect is also a crucial consideration in the transition to cleaner alternatives. During the survey, respondents were asked to provide estimates of various costs associated with their FFG usage. It is important to note that these are merely estimates and should not be treated as definitive figures, but they do provide valuable insights into the cost perceptions of the customers.

Figure 11: repair and fuel costs add up to large costs for FFG users

Figure 12 provides a comprehensive breakdown of the monthly operating costs associated with FFG, presenting the fuel costs on the left and the repair costs on the right. The median monthly fuel costs range from a minimum of ₦10,000 to a maximum of ₦70,000, with an additional notable peak at ₦200,000. The median monthly fuel cost is observed to be ₦30,000, indicating a significant financial burden for users in maintaining the fuel supply for their FFGs.

On the repair cost side, the data reveals that the typical monthly repair expenses are generally below ₦10,000, with two distinct peaks observed at ₦15,000 and ₦20,000. The median monthly repair cost is found to be ₦5,000, suggesting that while repair costs are a factor, they are lower compared to the fuel expenses. Combining the fuel and repair costs, the total monthly operating cost for FFGs is approximately ₦35,000, with the repair expenses accounting for 14% of this total.

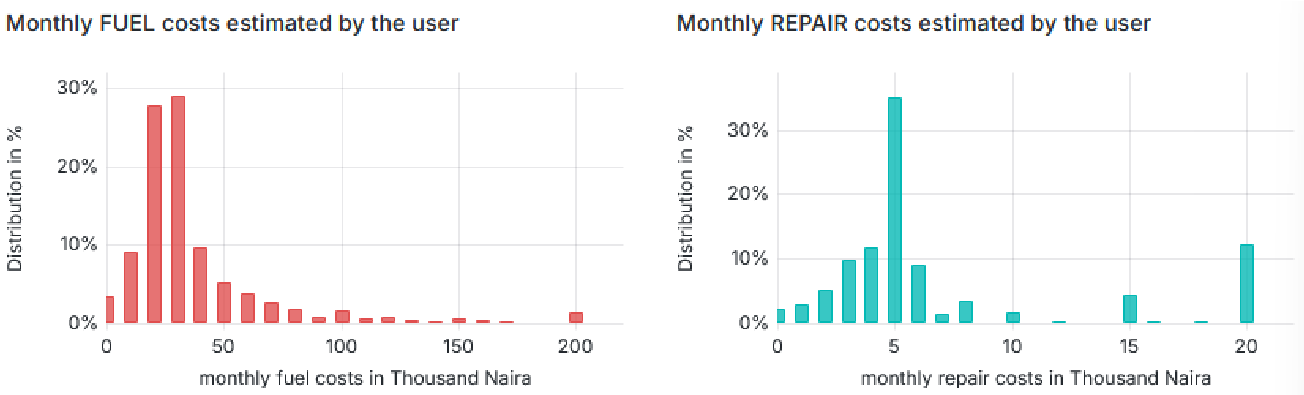

Figure 12: monthly cost of a FFG (left: fuel costs, right: repair costs)

These cost estimates provide a valuable baseline for understanding the financial implications of the current FFG usage and can inform the development of viable clean energy alternatives. They offer insight into the ongoing operational burden and highlight the relative weight of fuel and maintenance expenses. This information is critical for guiding the design and justification of clean energy alternatives, which is essential for evaluating potential cost savings and the long-term economic benefits associated with the transition.

3.1.5 Appliances

Another interesting aspect to consider is the types of appliances the customers typically use. While the exact power consumption at different times will be analysed through the time series data, understanding the general appliance usage can provide valuable insights. This information could be particularly useful for sizing an inverter, as it may reveal the presence of high inductive loads or other factors that could impact the system's design.

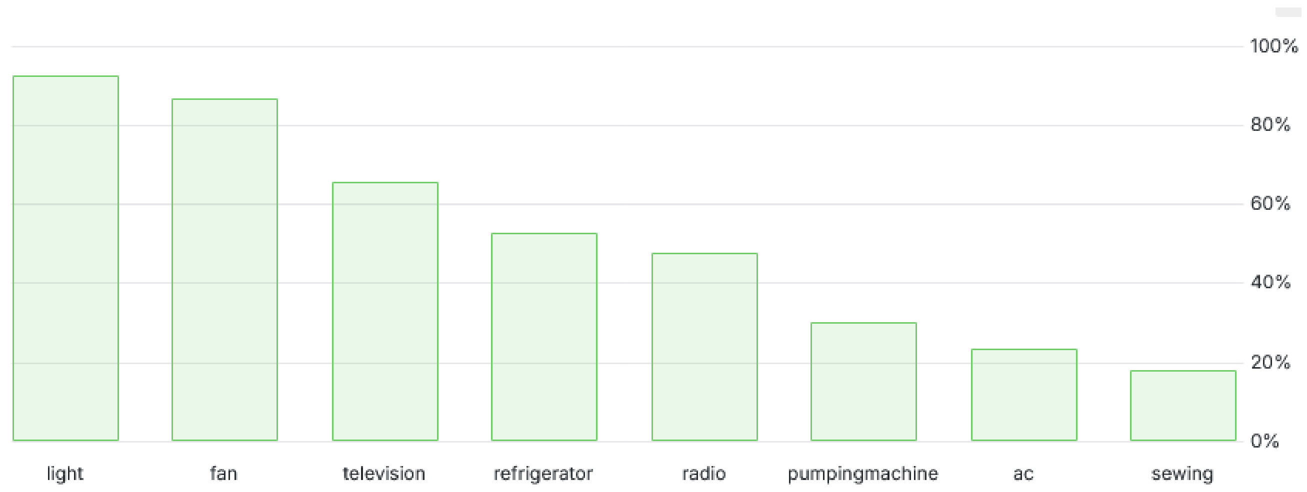

Figure 13: powered appliances

Figure 13 presents the top 8 most used appliances and their respective percentages of usage across all observed generators. It is important to note that the differences between the various customer categories are not displayed here but can be found in Prospect in the dashboard "Survey Analysis". The figure shows that almost all customers, regardless of their cluster, use fans and lights, as these are essential for their daily lives in central Nigeria. Additionally, a significant number of modern electrical devices, such as televisions, radios, and computers, are also being powered. Certain equipment, such as pumping machines (e.g., water pumps) and air conditioning systems, are powered by FFGs for some customers, specifically those representing less than 30% of the total customer base. The differences in usage patterns between customer categories are not particularly pronounced, except for the fact that televisions are less commonly used in small and medium-sized markets, while radios are more prevalent in these segments compared to other clusters.

Furthermore, electronic devices like refrigerators and air conditioners (ACs) are also being utilised, as the hot temperatures in the region necessitate their use. Interestingly, the usage of ACs is more prevalent in healthcare centres, hotels, and households, where people tend to spend more time, as opposed to markets and schools. This information could be valuable in understanding the specific power requirements and load profiles of different customer segments, which can inform the design and sizing of energy solutions.

3.1.6 Generator Usage

One significant issue encountered in the project was the usage of FFGs in general. After a few months following the installation of most smart meters which observe the usage of each FFG, the data revealed that not all smart meters were sending data. As explained in section 2.4.2, this does not necessarily mean that the smart meters were defective in all cases, but rather that the FFGs connected to the smart meters were not in use at all. To better understand the root cause of the non-sending data, the installation team visited 56 customers to investigate the reasons. The results of this investigation were then extrapolated to all 500 installed smart meters and are displayed in Figure 14.

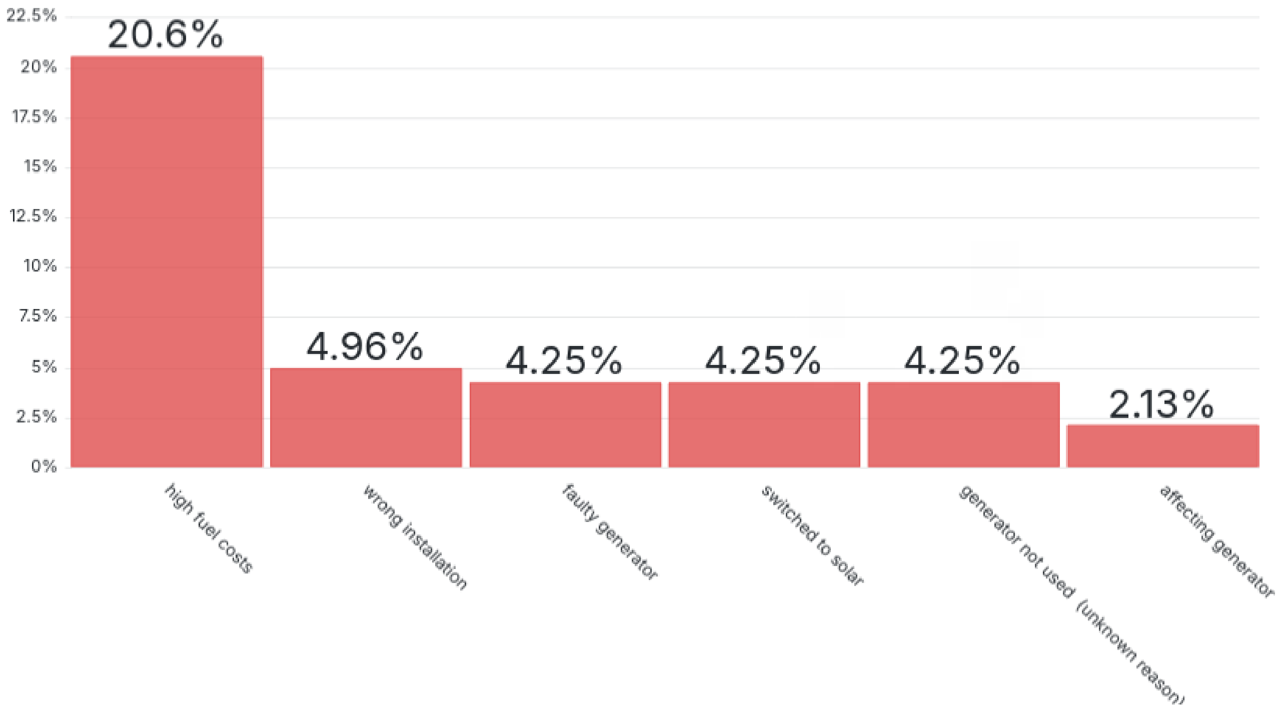

Figure 14: reason and proportion of people who stopped their generator (based on 56 surveys, extrapolated to all FFGs)

A minority of 2.13% of the users believed that the smart meter was affecting their generator's performance. Although the exact issues were not always clear, they requested the removal of the meter. However, their generators remained in use. On a positive note, 4.25% of the people had already fully transitioned to solar energy systems, no longer relying on fuel generators for backup power. This is a notable signal of adoption and growing interest in sustainable alternatives. In another 4.25% of the installations, the generators had broken down or were no longer functional. With limited access to affordable repair services or the high cost of replacing parts, it is likely that many users found repairs economically unviable and chose to stop using their generators altogether. In about 5% of the cases, the smart meters were not correctly installed and did not send data but were subsequently repaired by the installers. However, 20% of the people who had a smart meter installed to observe their FFG stopped using it due to high fuel costs. Petrol prices soared from ₦617 per litre in early 2024 to approximately ₦897 per litre by September 2024 and reaching as high as ₦1,060 per litre in some areas by October 2024.[1] The users explicitly stated that they stopped using their generators because the cost of fuelling them had become unaffordable. This aligns with the broader economic reality in Nigeria, where rising fuel prices continue to strain household and small business budgets.

1 https://insidesuccessnigeria.com/petrol-price-in-nigeria-the-powerful-impact-on-daily-life/

4 SMART METER DATA ANALYSIS

This section provides a comparative analysis of critical performance factors across various customer categories and grid connectivity types. The methodology for calculations and visualizations is documented in the Data Analysis Methodology section. Based on the key factors, insights will be provided on the design considerations and important aspects to acknowledge for a solar generator as a replacement.

In a first step, all key performance factors will be analysed at a high level, grouped by customer category and grid connection (on-grid or off-grid). This approach provides a broad overview of the trends and patterns across the various customer segments and their respective grid connectivity. Following the initial high-level analysis, the report delves deeper into one specific customer category – the small and medium markets. This detailed examination of the small and medium markets serves as an illustrative example, offering a more granular understanding of the performance factors within this customer segment. Detailed analyses of other customer categories are accessible via Prospect.

This comprehensive approach ensures that the overall assessment covers the full spectrum of customer segments, allowing for a thorough and well-rounded understanding of the key performance factors across the entire market.

4.1 Cluster Comparison

Firstly, the different clusters (customer category and grid connectivity) are compared to each other. Table 1 provides a clear breakdown of the observed customer categories, their grid connectivity status (on-grid or off-grid) and the corresponding number of analysed meters for each group.

CUSTOMER CATEGORY	OFF GRID	ON GRID	TOTAL
small and medium markets	68	64	132
hotels	21	25	46
health centre	-	45	45
households	31	30	61
schools	8	-	8

Table 1: Number of observed FFGs

4.1.1 Power Patterns

This section explores the power usage patterns of fossil fuel generators using two key metrics: average power consumption and maximum power demand. These indicators reveal distinct trends across various customer segments and grid connectivity types, offering insight into how power needs differ by user profile.

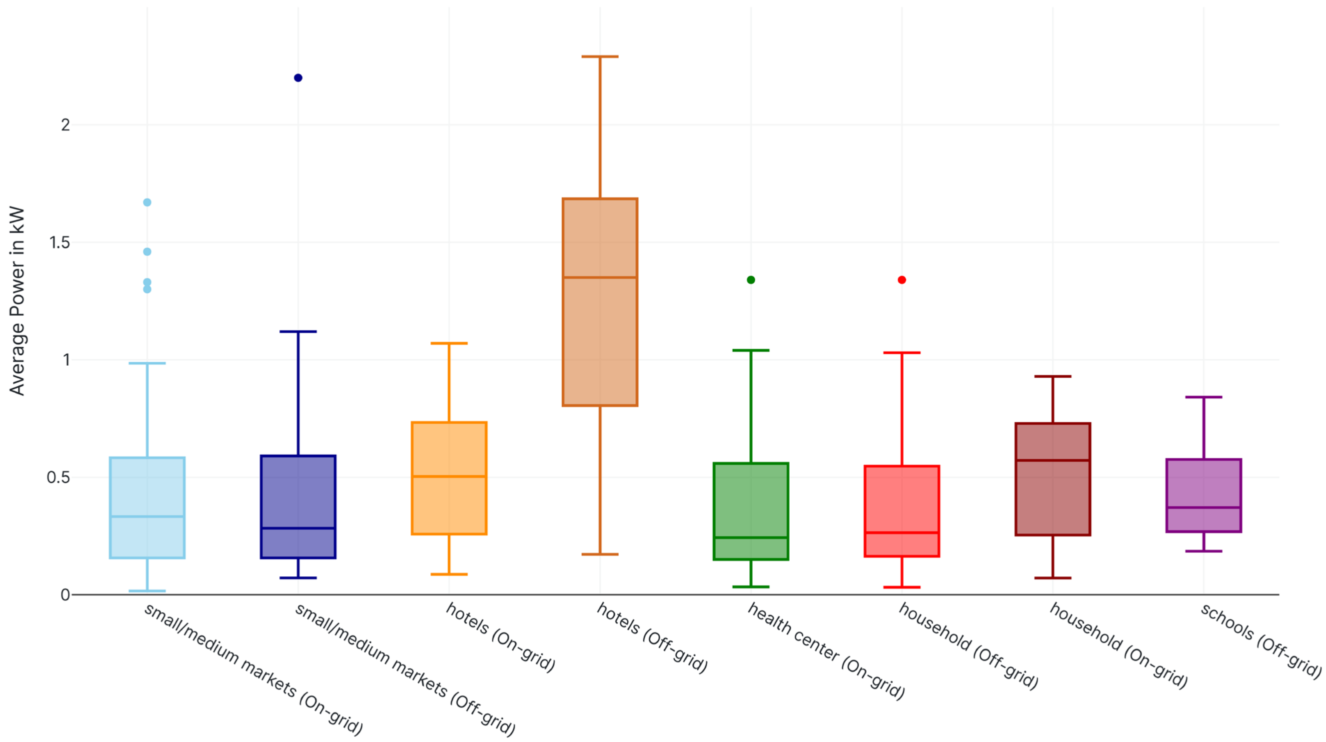

Figure 15: average power distribution across different clusters

A notable disparity exists in average power consumption across segments, with most categories operating below 0.5kW, except for off-grid hotels, which demonstrate substantially higher consumption at 1.35kW. The significant power demand differential between off-grid and on-grid hotels can be attributed to their fundamental differences in electricity sourcing. Off-grid hotels rely exclusively on generators for their entire power supply, necessitating the operation of all electrical equipment through these units. In contrast, on-grid hotels primarily depend on utility power, typically reserving generator usage for essential equipment during grid outages. This selective approach to backup power usage by on-grid hotels results in lower average power consumption during generator operation, as they prioritise only critical electrical loads rather than supporting their full electrical infrastructure.

Small and medium-sized markets show consistency in power consumption regardless of grid connectivity, with off-grid locations averaging 0.28kW compared to 0.33kW for grid-connected establishments. This consistency suggests similar appliance usage patterns independent of grid accessibility. On-grid health centres and off-grid schools exhibit comparable consumption patterns to these markets, likely due to similar basic electrical requirements (lighting, ventilation, and entertainment systems).

Household consumption patterns reveal an interesting inverse relationship: on-grid households demonstrate higher average power consumption (0.57kW) compared to their off-grid counterparts (0.26kW). This disparity might be attributed to on-grid households' established patterns of higher electricity consumption and broader appliance ownership, which persists during grid outages. Conversely, off-grid households typically maintain minimal essential electrical applications, likely due to the economic constraints of FFG-based power generation.

The maximum power distribution analysis reveals a concentrated pattern, with most customers operating within a 2.5kW threshold. Instances of power demand exceeding this level are relatively rare across all customer segments due to the limited power of the observed FFGs.

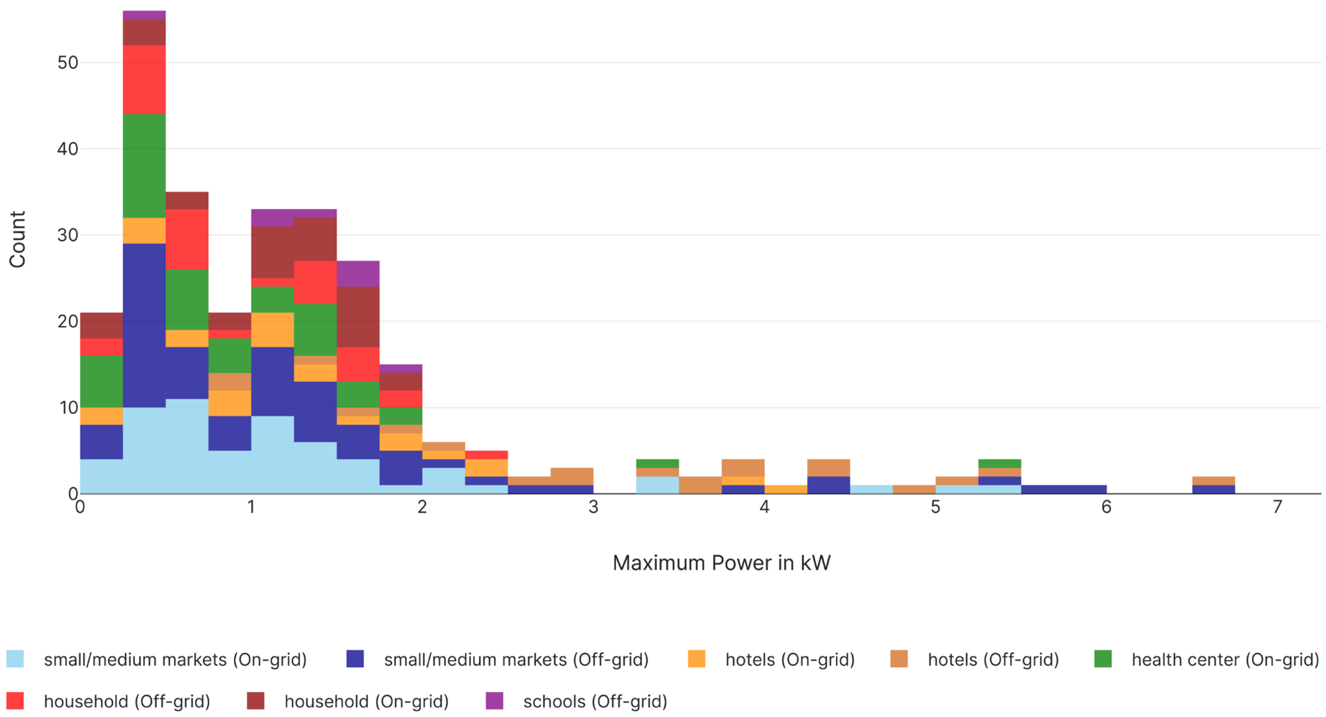

Figure 16: distribution of maximum used power of FFGs

4.1.2 Usage Patterns

This section examines the usage patterns of FFGs through two key metrics:

1. Average Hours of Daily Use: This factor represents the average number of hours the system was used on the days it was actively used. Days when the generator was not used are excluded from this calculation, to focus on understanding the typical daily usage patterns. (Figure 17)
2. Average Active Days per Month: This shows how many days in a month the generator was used, on average. This provides insight into how frequently the system is being utilized monthly. (Figure 18)

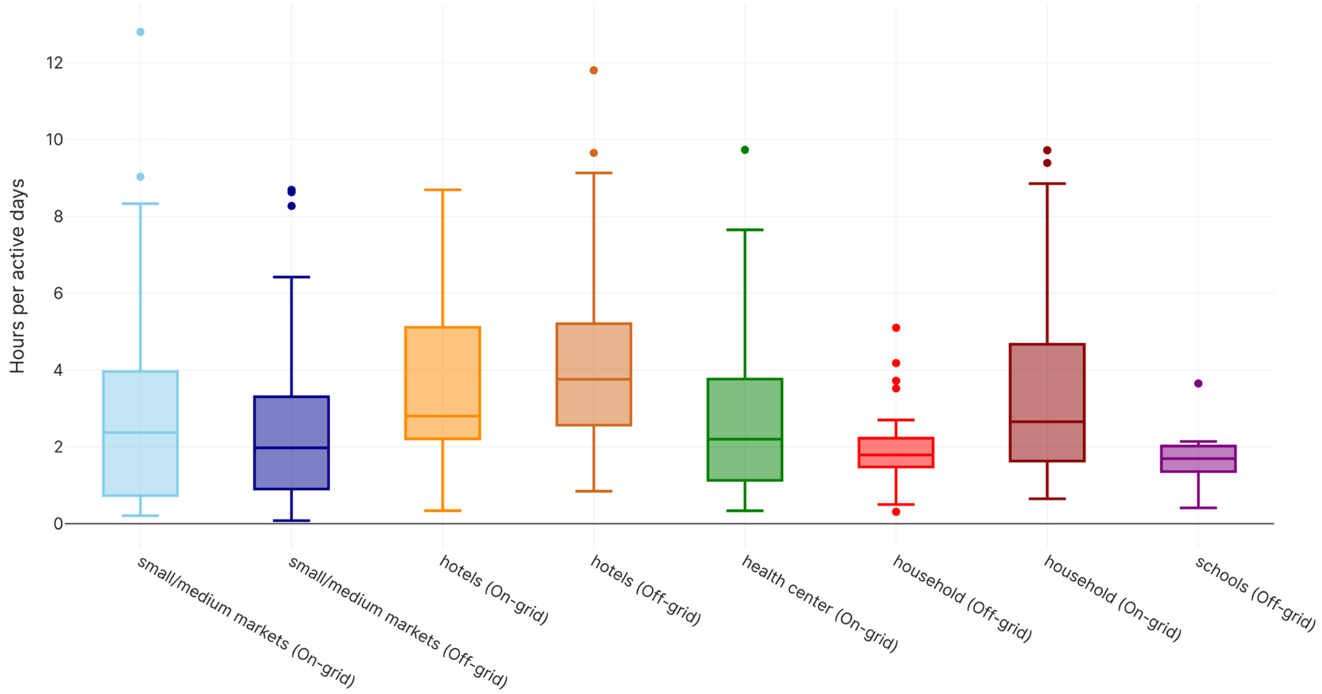

Figure 17: distribution of hours per active day across different clusters

The data of hours per active days reveals that median operational duration across sectors typically ranges between 2 to 4 hours per active day, though with significant variability across categories. In the small/medium market segment, an unexpected pattern appeared: on-grid establishments show longer daily operation (2.4 hours) compared to their off-grid counterparts (2 hours). This counter-intuitive finding might be attributed to different energy consumption behaviours, where grid-connected businesses have developed usage patterns that demand consistent power availability, while off-grid establishments have adapted their operations to more limited power availability.

Health centres with grid access and schools show operational patterns similar to small/medium markets, suggesting comparable energy usage behaviours. However, the hotel sector presents a distinct pattern, with off-grid establishments showing significantly higher daily operation (3.8 hours) compared to on-grid hotels (2.8 hours). This increased usage in off-grid hotels reflects their need to provide consistent power supply for guest comfort, particularly during nighttime hours, while grid-connected hotels can supplement their power needs through utility electricity.

In the residential sector, on-grid households demonstrate longer daily operation (2.7 hours) compared to off-grid households (1.8 hours). Notably, on-grid households exhibit substantially higher variability in usage patterns compared to their off-grid counterparts. This variance suggests that off-grid households have developed more standardised energy consumption patterns, likely driven by necessity and fuel optimisation, while on-grid households display more diverse usage patterns reflecting varied lifestyle preferences and energy consumption habits.

The usage of generators across different sectors and grid connection statuses is further explored by calculating the active days per month that each generator is utilised. This metric is displayed in Figure 18, providing insights into the frequency of generator usage.

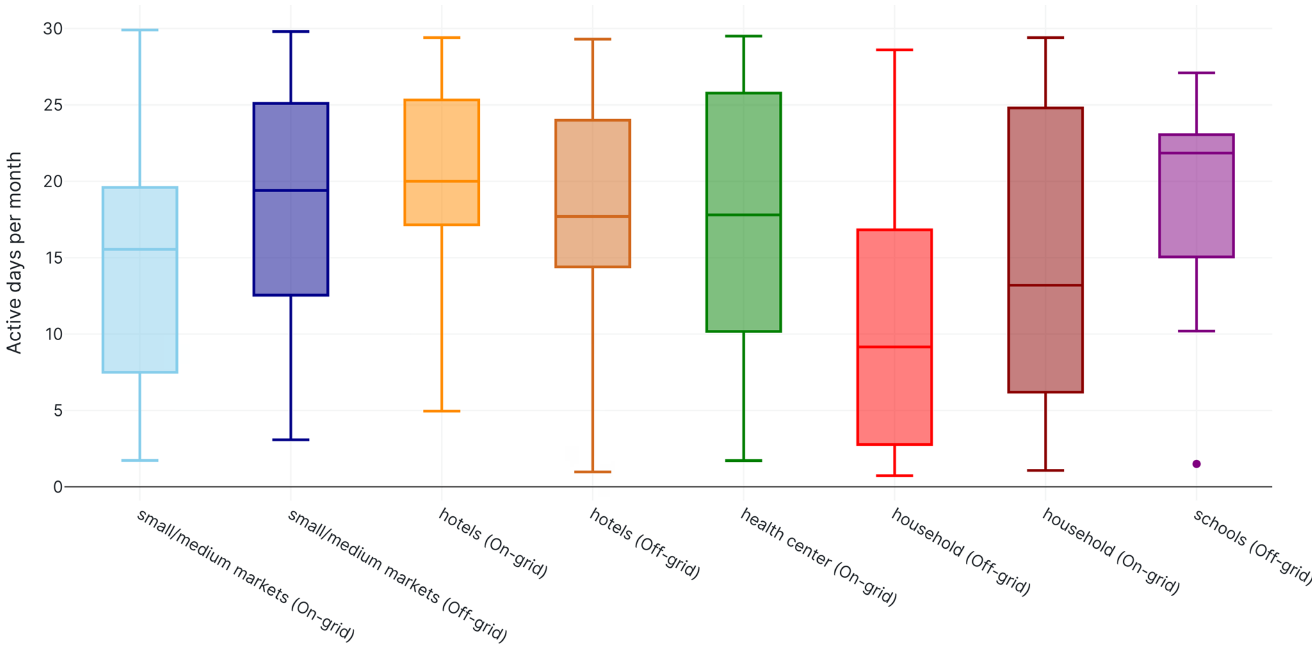

Figure 18: distribution of active days per month across different cluster

The data reveals that most generators, regardless of sector or grid connection, are used across a wide range of 10 to 25 days per month. However, some notable differences emerge between on-grid and off-grid usage patterns. In the markets sector, off-grid generators are used for nearly 20 days per month on average, while on-grid markets use their generators for only around 16 days per month. This suggests that off-grid markets rely more heavily on their generators, as they do not have the option to utilise the grid when it is available. Conversely, the household sector exhibits the opposite trend. On-grid households use their generators for more days per month than off-grid households. This can be attributed to the higher electricity demand and reliance on consistent power supply among on-grid households, who are accustomed to the convenience, and reliability of grid-connected electricity. Additionally grid-connected households tend to be wealthier than off-grid households, enabling them to run generators more frequently. A similar, though less pronounced, pattern is observed in the hotel sector, where on-grid hotels tend to use their generators for slightly more days per month compared to off-grid hotels. In the health centre sector, no clear pattern emerges, indicating that generator usage is more variable and dependent on specific operational requirements and power needs. Schools, on the other hand, show a more consistent usage pattern, with generators being utilised between 15 to 23 days per month. This can be attributed to the regular schedule and non-usage on weekends, which is typical for educational institutions.

The insights gained from analysing the active days per month provide a comprehensive understanding of how frequently generators are used across different sectors and grid connection statuses. This information, combined with the findings from Section 4.1.4 on the interdependency of generator usage, offers a holistic view of generator utilisation patterns and the factors that influence them.

4.1.3 Energy Patterns

This section examines the energy patterns of FFGs through two key metrics:

1. Daily Energy Usage: This metric represents the average amount of energy used per day on the days the system was actively used. This information is helpful when determining the appropriate size for the photovoltaic (PV) panels and the battery capacity needed to power the system. (Figure 19)
2. Daytime Energy Ratio: This metric describes the proportion of total daily energy usage that occurs during daylight hours (between 6am and 6pm). This insight is useful for understanding when the energy is needed, which is crucial for finding the right balance between PV panel size and battery capacity. (Figure 20)

In Figure 19, the distribution of the average used energy per day is presented across different customer clusters. The data reveals that many customers consume less than 1.5 kWh of energy per day on average. However, there are also instances of higher energy consumption patterns observed across all customer categories.

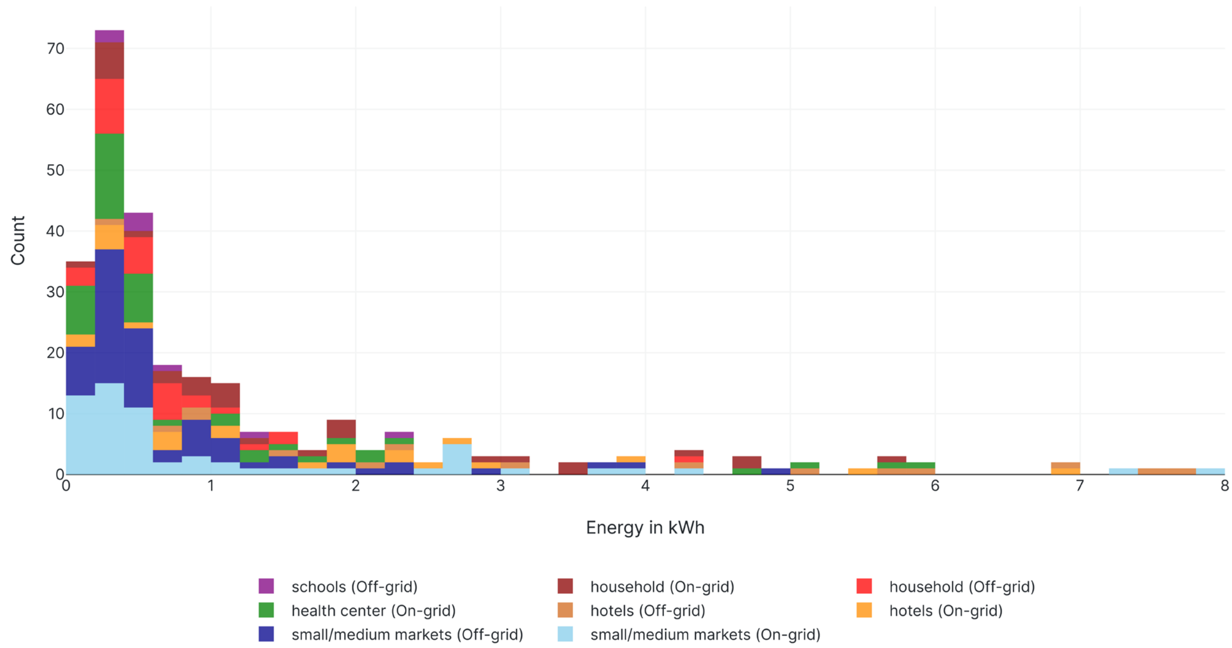

Figure 19: distribution of used energy per day across different clusters

The graph shows that there are even more outliers with energy usage exceeding 6 kWh per day, though these are not displayed in the figure itself. These outliers, while present, are relatively few and can be considered negligible for the purposes of this analysis. Interestingly, the data suggests that there is not a significant difference in energy consumption patterns between most customer clusters, except for on-grid and off-grid hotels.

The analysis indicates that off-grid hotels tend to have a higher average energy consumption compared to their on-grid counterparts. These insights gained from this energy usage analysis are invaluable in guiding the technical design and planning of the PV panel and battery system, ultimately leading to a more tailored and effective renewable energy solution for the customer base.

The ratio of daylight usage is a crucial factor in the sizing of the photovoltaic (PV) panel and the battery size. The more energy that is used during daylight hours, the more it can be utilised directly from the PV panel without the need for storage in a battery. This would lead to a lower battery size, as it would not be as heavily utilised during the night.

The results of this observation can be seen in Figure 20, which presents a boxplot. The boxplot illustrates the ratio of the usage during the daylight hours, which are defined in Nigeria as 6 AM to 6 PM, even though the generated PV energy may not be constant throughout the day.

The data reveals that schools (except for one outlier) use their energy primarily during the day when students are present. The energy usage of small and medium-sized markets is predominantly during the day, with a median of approximately 85%. This suggests that these markets also use energy in the early evening hours to dismantle their shops, necessitating the need for battery sizing.

In contrast, hotels, whether on or off the grid, use less than 50% of their energy during the day, as indicated by the median. This could be attributed to the fact that hotel guests are typically present in the evenings rather than during the day, and this is when most of their energy consumption occurs.

Health centres exhibit a wide range of usage patterns, and the ratio of daylight usage varies among different health centres. However, for households, no clear pattern can be observed, and the usage during the day or night is quite random. Nevertheless, on-grid households tend to use more energy during the day than off-grid households, as indicated by the median.

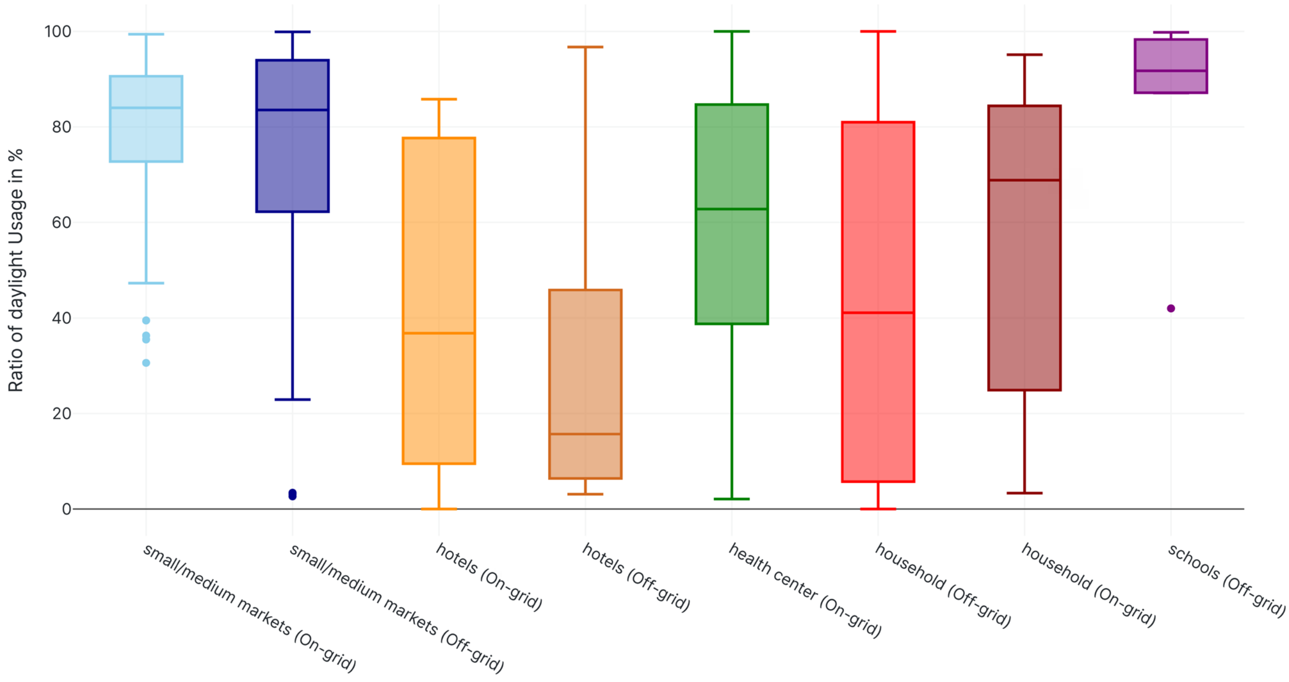

Figure 20: distribution of daylight usage across different clusters

Overall, the analysis of the daylight usage ratio provides valuable insights into the energy consumption patterns of different types of consumers, which can inform the appropriate sizing of PV panels and battery systems to optimize the utilisation of renewable energy resources.

4.1.4 Interdependencies

Besides looking at single key factors, it is also interesting to examine the interdependencies between different key factors. This can provide a deeper understanding of what these factors mean in practice. For example, if a small or medium-sized market uses a high percentage of its energy during the night, but the total energy consumption is very low, the battery size may not need to be as large - even though a significant portion of the energy is used at night.

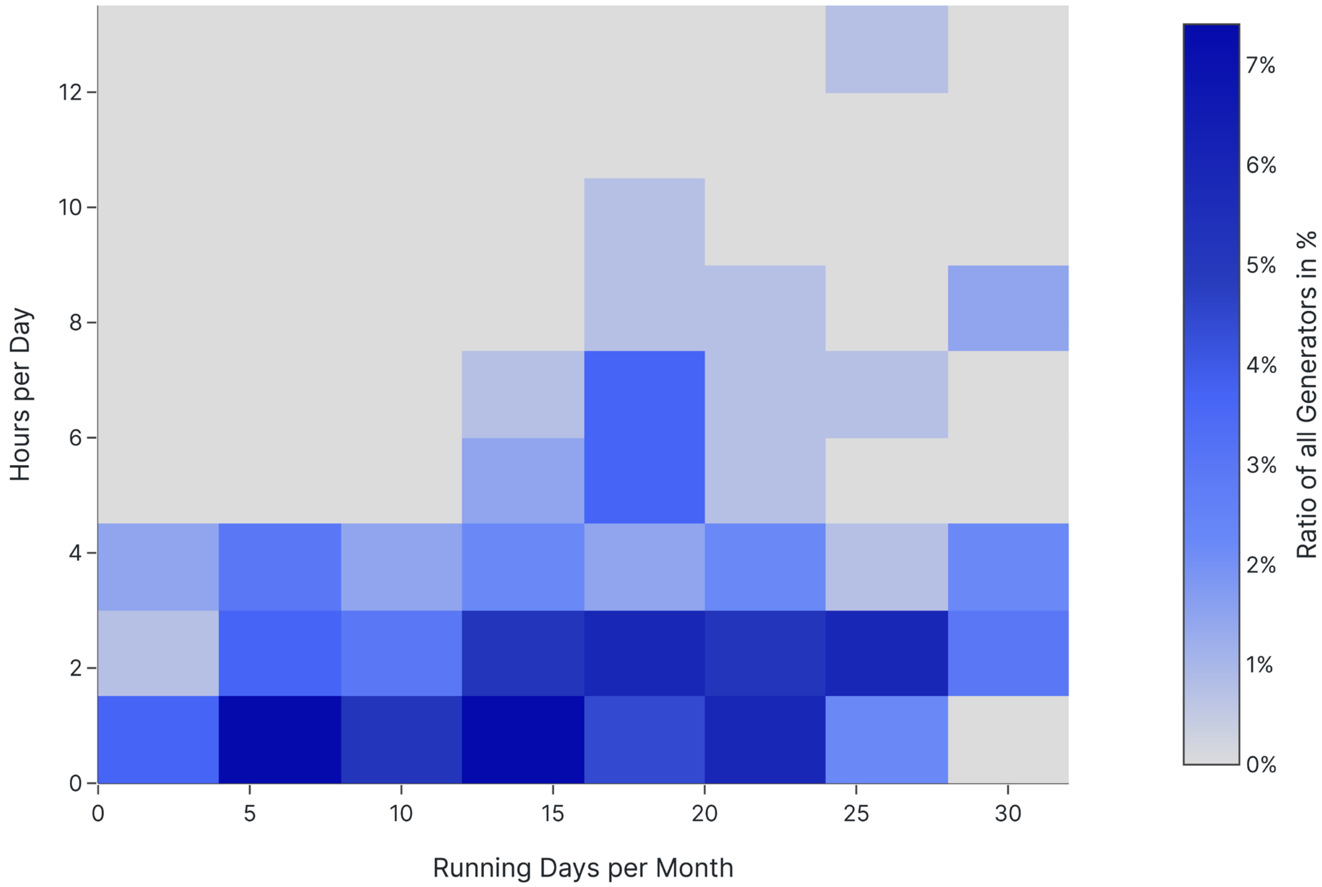

Figure 21: relation between hours per day and running days per month

In Figure 21, the relationship between active hours per day (x-axis) and running days per month (y-axis) is visualised using a heatmap. The colour scale on the right indicates the percentage of all generators that fall into the corresponding group defined by the x and y-axis values – the darker the blue rectangle, the more generators are observed in that group. It is important to note that this chart does not differentiate between different customer categories; those details can be found in the more comprehensive dashboards within Prospect.

This diagram reveals that there is no strong correlation between the active hours per day and the running days per month. In other words, how often the generator is used per month does not necessarily dictate the number of active hours per day. This suggests that the daily usage patterns are largely independent of the monthly usage patterns. However, this does not mean there is no relationship at all. The data shows that the higher the number of active hours per day, the more likely the generator is to be used more frequently during the month. This implies that some generators are used very regularly, while others are only used a few times per month to provide backup power during critical periods.

In the following figures, the interdependence between the energy per active day and the Peak Power (Figure 22) as well as the Daylight Ratio (Figure 23) is presented. All observed FFGs are shown in these charts, differentiated by their clusters. The different customer categories are represented by distinct colours, and the on-grid FFGs are displayed with a circle, while the off-grid FFGs are displayed with a cross.

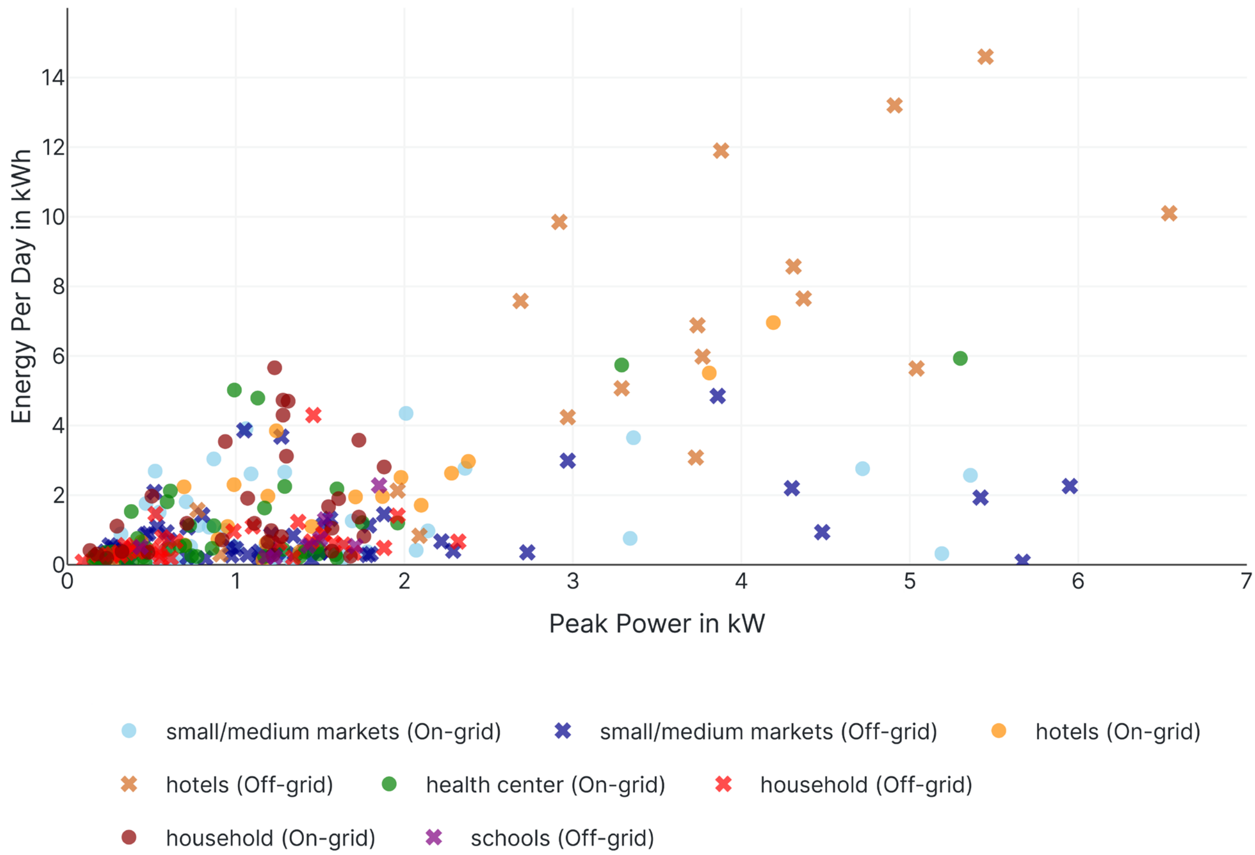

Figure 22: interdependencies between energy per day and peak power

In Figure 22, it can be observed that the Energy per Day has a slight correlation with the Peak Power. This makes sense, as a higher power generally leads to higher energy consumption if it is used frequently. However, there is a significant cluster in the region below 2kWh per day, as observed in the energy patterns in Section 4.1.3. It is noteworthy that off-grid hotels, in particular, exhibit a high energy demand and high peak power. This suggests that for the design of a solar generator, a higher demand for peak power can lead to a higher demand for energy per day, which in turn may require a larger battery capacity or more solar panels.

Figure 23 displays the energy per day over the daylight ratio, and it is evident that there is no significant correlation between these two variables. Regardless of the energy demand, the daylight ratio is distributed across all energy levels. This implies that there is no single combination of solar generator, peak power, battery capacity, and solar panel that can fit all clusters. However, it can be observed that each specific cluster can be supplied by a particular type of solar generator. Additionally, the clusters are not segregated but rather overlap extensively. This is a positive finding, as it suggests that a single solar generator could potentially cater to different clusters.

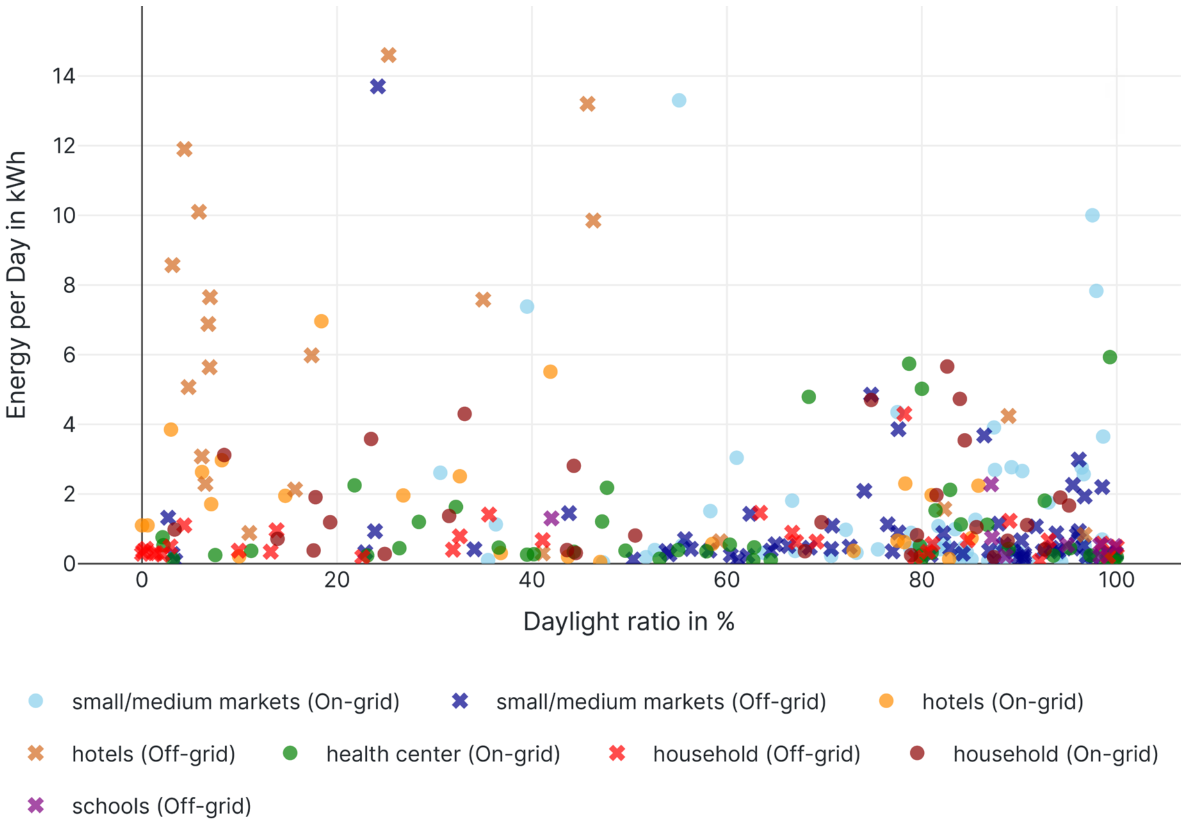

Figure 23: interdependencies between energy per day and daylight usage

In summary, the analysis of the interdependence between energy per active day, Peak Power, and Daylight Ratio provides valuable insights for the design and selection of solar generators. While there are no universal solutions that fit all clusters, the data suggests that tailored solar generator configurations can be developed to meet the specific needs of individual clusters.

4.2 Detailed Cluster

In the previous chapter, the different clusters were analysed in their entirety and compared to one another. In the next step, each cluster can be examined in more detail, with the customer categories further divided by their sub-customer categories. While it would be too extensive to analyse all clusters in detail within this report, the cluster of small/medium markets will be examined partially as an example in the following sections. The data for the other clusters can be found in the "Cluster Deep Dive (Second Level)" dashboard in Prospect. In general, the deep dive into the different clusters offers the same key factor analysis as the cluster overview, but it is split up in more detail. Only the Load and Usage Profile over the day and week are new in this detailed cluster analysis. This more in-depth analysis of the small/medium markets cluster will provide valuable insights into the specific characteristics and trends within this segment. By examining the sub-categories and the distribution of off-grid and on-grid generators, the report can offer a comprehensive understanding of the dynamics and opportunities within this important cluster.

The small/medium markets cluster is divided into 4 main sub-categories (more than ten installation) and 3 other categories. The sub-categories and the number of observed FFGs, divided by off-grid and on-grid generators, can be seen in Table 2.

CUSTOMER SUB CATEGORY	OFF GRID	ON GRID	TOTAL
Services & Repairs	57	18	75
Retail & Provision	6	4	10
Fashion and Apparel	2	24	26
Tech & IT	1	13	14
Food Production	2	4	6

Table 2: Number of observed FFGs in small/medium markets

4.2.1 Power Patterns

The daily and weekly power usage profiles of different clusters provide valuable insights into the utilization of FFG in various market segments, as illustrated in Figure 24 for small/medium markets. The x-axis of the heatmap represents the time of day, while the y-axis depicts the days of the week, from Monday to Sunday. The color-coded cells in the heatmap display the average power consumption at the specific time and day, with darker blue shades indicating higher average power levels. It is important to note that the average power values are calculated on a per-system basis and then averaged, but only when the generator is actively running and powering appliances. This means that periods when the FFG is turned off are not included in the average, as the chart aims to show the power requirements at specific times rather than the frequency of FFG usage.

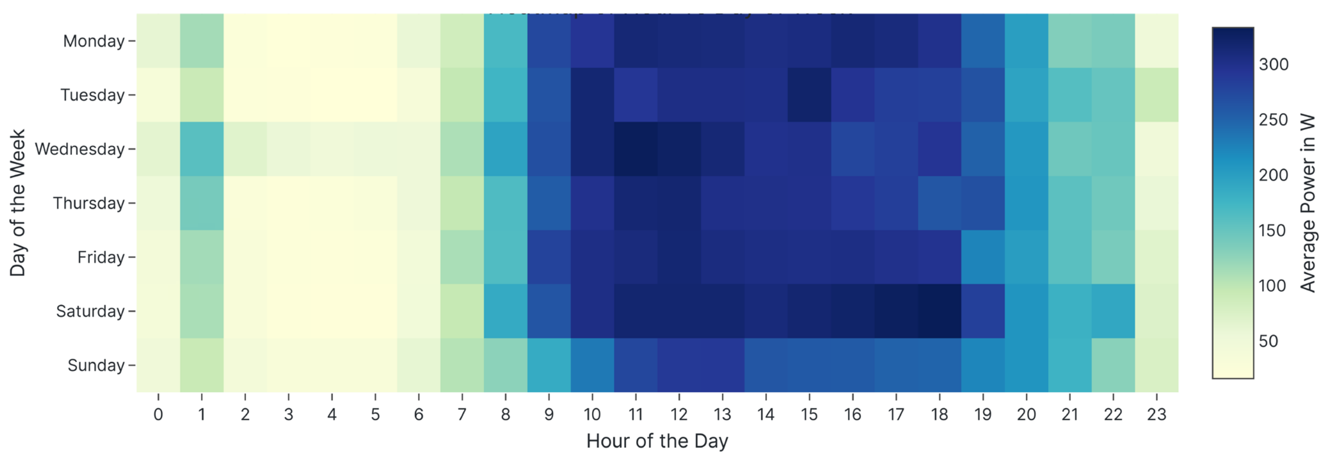

Figure 24: load profile of small/medium markets

The heatmap reveals several interesting patterns. During the daytime, the average power consumption is generally higher than at night, which can be attributed to the operation of higher-power appliances and equipment used in the small/medium market setting. The outliers observed at 01:00 can be attributed to data anomalies and can be safely ignored. Interestingly, there is a noticeable difference in power usage patterns between weekdays and weekends. On weekdays, the average power consumption remains relatively constant, while on Saturdays, it shows a marked increase. This can be explained by the fact that Saturdays are the busiest days for small/medium markets, as more people have the time to visit various shops and establishments. Conversely, on Sundays, the average power consumption is lower than on other days, likely due to the closure of many businesses. These insights into the day/night and weekday/weekend power usage patterns can be valuable for understanding the energy requirements of different customer categories and can inform the design and optimisation of FFG systems to better meet the specific needs of small/medium market operations.

The detailed Cluster analysis provides a comprehensive examination of the power consumption patterns across different types of shops. Unlike the previous Cluster comparison, this analysis delves deeper into the nuances of power usage by focusing on the specific sub-clusters, which in this case represent the various categories of shops. One notable aspect of this analysis is the selective inclusion of only those clusters with more than 5 samples. This decision ensures the data set is robust and representative, allowing for more reliable insights to be drawn.

The Boxplots on the left-hand side of the Figure 25 offer a visual representation of the power consumption characteristics for each shop type. Fashion & Apparel Shops, for instance, exhibit a relatively low power average and variation, suggesting a more consistent and moderate energy usage profile. In contrast, Tech&IT or Services & Repairs shops demonstrate a higher average power consumption, which can be attributed to the increased reliance on additional appliances and equipment necessary for their business operations.

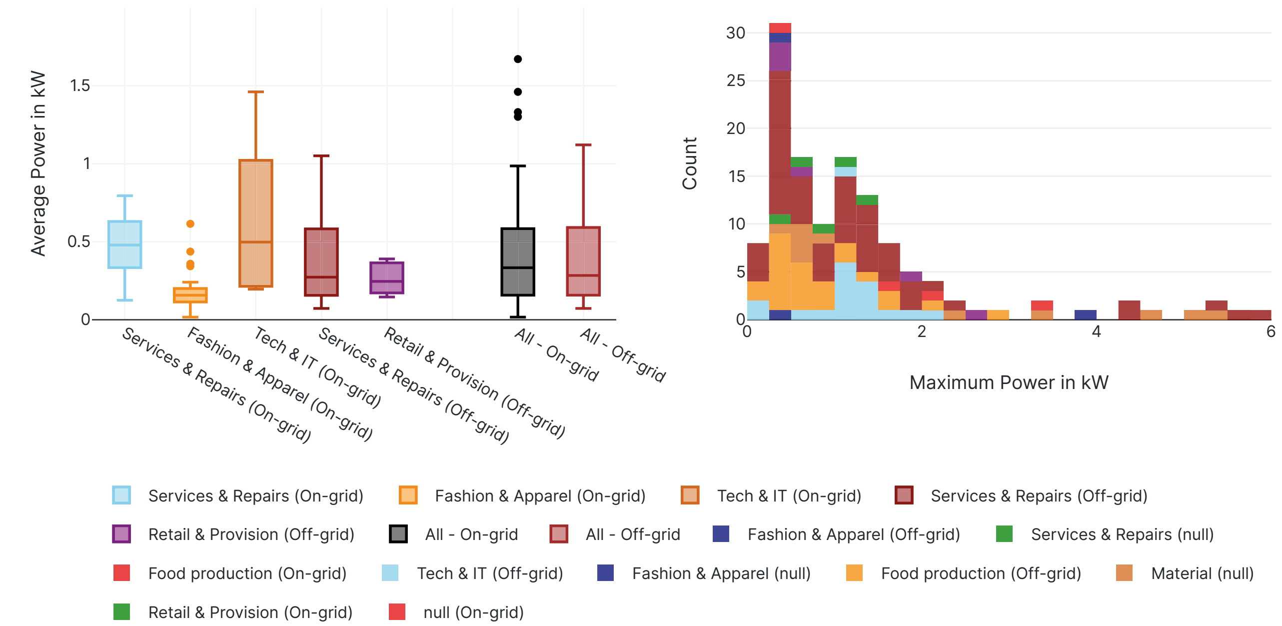

Figure 25: average and maximum power distribution of small/medium markets

Interestingly, the maximum power value across the majority of the shop types is found to be below 2kW (see on the right side of Figure 25). This observation implies that a single-size inverter solution could potentially cater to the power requirements of most of the establishments. This would mean that fewer different system sizes would need to be offered which simplified the infrastructure planning process.

4.2.2 Usage Patterns

The Usage Profile, similar to the Power Profile, has been calculated over the course of the day and the days of the week (Figure 26). The Usage Profile examines the average usage in different time segments, first calculated for each observed FFG and then averaged across all systems. The percentage value indicates the average proportion of FFGs (out of all observed FFGs in the cluster) that are in use during a specific time period. This information helps to understand when the generators are being utilised by the people.

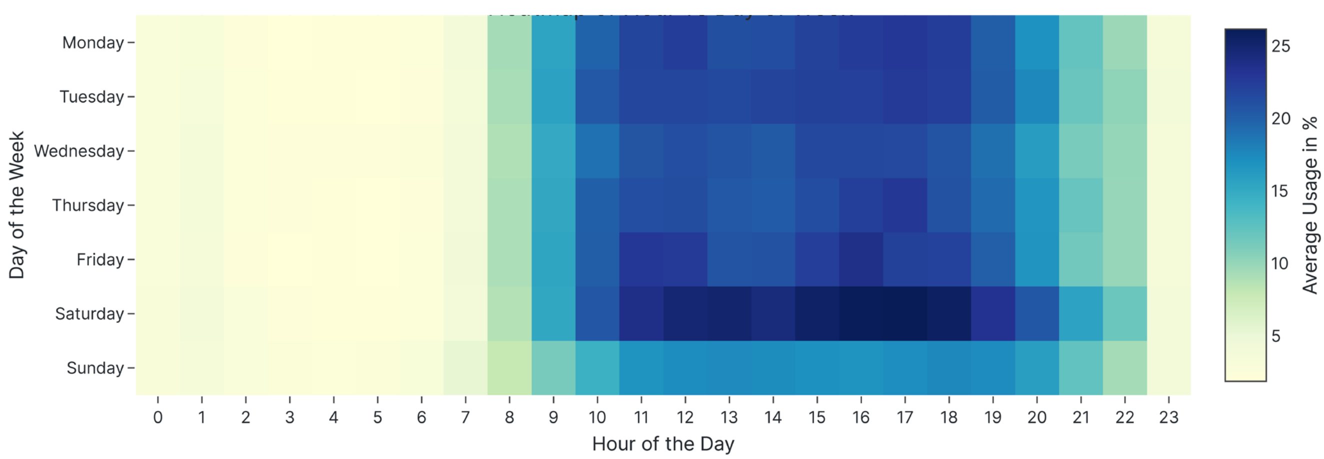

Figure 26: usage profile of small/medium markets

The results of the average usage profile are similar to those of the average power profile. The generators are predominantly used during business hours and experience relatively low usage during the night. On weekdays, the usage patterns are quite consistent, with no significant differences between individual weekdays. However, Saturday stands out as having a significantly higher usage, likely due to it being a primary business day for many establishments. Interestingly, on Sundays, the usage decreases but does not drop to zero. This suggests that some shops or facilities may remain open on Sundays.

Besides the usage profile per day and weekday the active hours per day and the monthly usage is interesting and presented in Figure 27. This provides valuable insights into the operational patterns of FFGs observed in small to medium-sized markets. This information can be leveraged to better understand the market opportunity and tailor product offerings to meet the diverse needs of FFG users in these specific market segments.

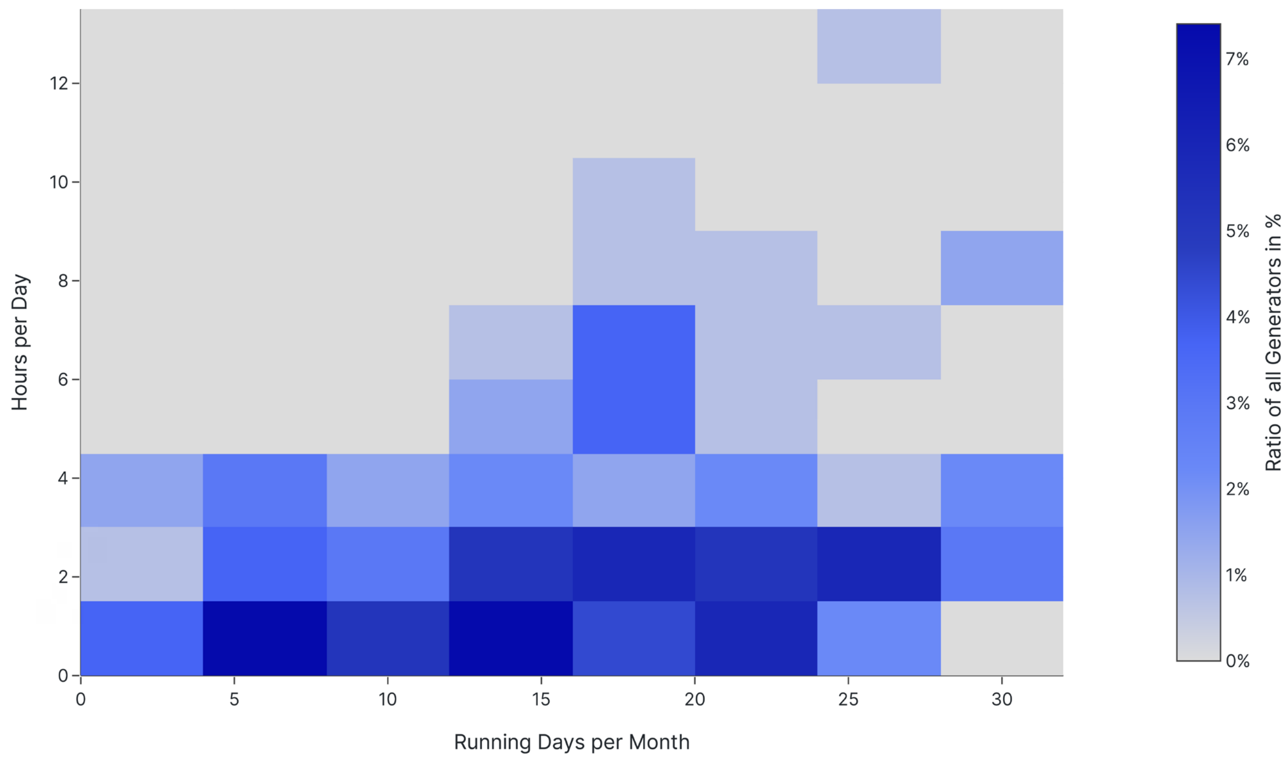

Figure 27: relation between hours per day and running days per month of small/medium markets

The chart illustrates the distribution of FFG usage in terms of daily runtime hours and the number of active days per month. As can be seen, the majority of the FFGs in these markets are observed to operate for less than 3 hours per day, with a significant number of generators running for more than 3 hours per day. The shading of the chart indicates the concentration of FFGs within each usage segment. The darker shading represents a higher number of generators falling into that particular combination of daily runtime hours and active days per month. This data suggests that while there is a predominance of FFGs with lighter usage patterns, there is also a substantial market for generators that can handle more intensive operational requirements. Understanding these nuanced usage profiles is crucial for manufacturers and service providers looking to cater to the specific needs of small to medium-sized FFG markets.

4.2.3 Energy Patterns

The detailed analysis presented in Figure 28 provides invaluable insights into the energy consumption patterns of different types of shops within small/medium markets. This information is crucial in designing the appropriate battery capacity and the number of solar panels required for a solar generator as a replacement system. The chart displays the energy consumption per day on the y-axis, plotted against the Daylight ratio on the x-axis. It is observed that the majority of FFGs generate less than 2kWh of electrical energy per day. However, it is noteworthy that there are several outliers, particularly among the technical shops, which exhibit significantly higher energy requirements.

Interestingly, the analysis reveals that there are no significant differences in energy consumption patterns between the different types of shops in general. This finding suggests that a standardised solar generator solution could potentially cater to the energy needs of a wide range of business establishments, simplifying the design and implementation process. One of the most striking observations drawn from the analysis is the extensive utilisation of the systems throughout the day, coinciding with the business hours.

This finding is particularly significant, as it suggests that the energy consumption patterns align closely with the availability of solar power generation during daylight hours. This synchronization between energy demand and solar energy supply presents a favourable scenario for the implementation of a solar generator system, as it can effectively meet the energy needs of the establishments without the need for extensive energy storage or complex load management strategies.

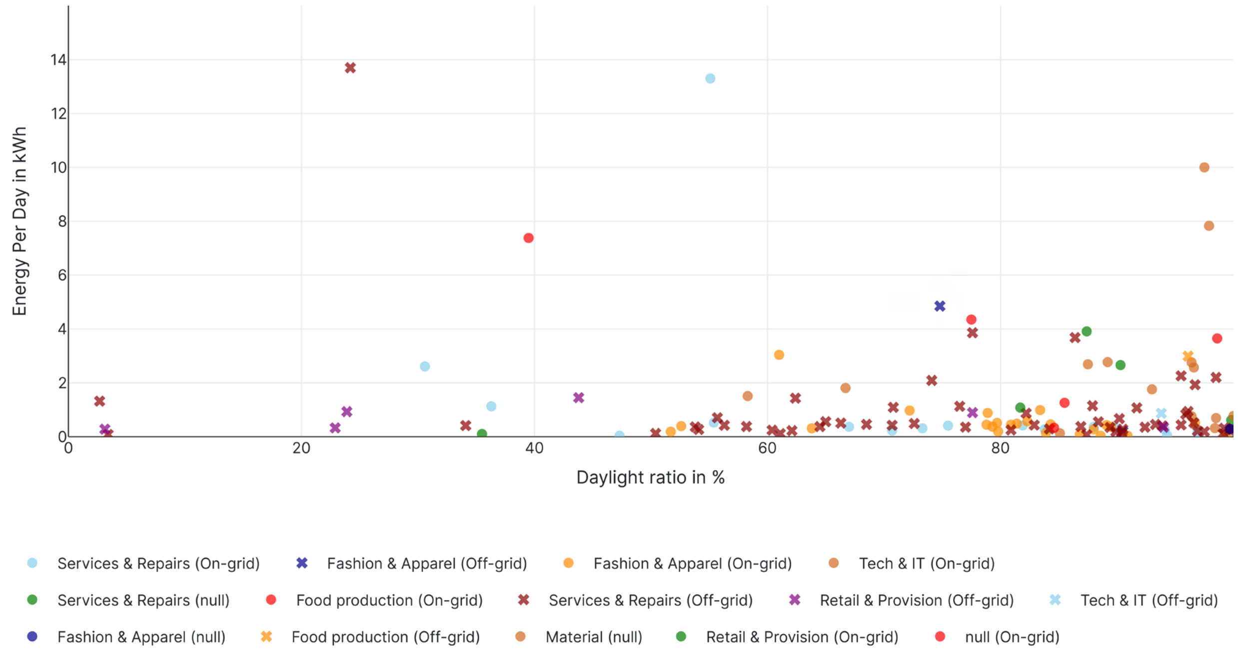

Figure 28: interdependencies between energy per day and daylight ratio of small/medium markets

By thoroughly examining the nuanced energy consumption profiles of the different shop types, this detailed analysis provides a solid foundation for designing the optimal solar generator system. The insights gained can inform the sizing of the battery capacity and the number of solar panels required, ensuring a tailored and efficient solution that caters to the specific energy needs of the diverse business landscape within the small/medium markets.

5 CONCLUSION

The comprehensive research carried out over the past year offers rich and meaningful insights into the use of fossil fuel generators across Nigeria. This extensive study made possible through the deployment of 500 smart meters in diverse customer settings – including small/medium markets, households, hotels, health centres, and schools, both on-grid and off-grid – has generated a substantial body of data. It allows for a deep understanding of the usage patterns of FFGs, presenting a unique opportunity to support the transition to cleaner alternatives. In parallel, a detailed survey was conducted to assess the public's perception and experiences with fossil fuel generators. Coupled with over a full year of real-time data collection, the findings provide a holistic view of how Nigerians rely on these systems.

While the majority of findings are presented in this report, all data and more detailed analyses are available on Prospect – an open-source data platform where the results are openly accessible for everyone with an interest in Nigeria's energy landscape.

One of the key insights from the survey is that older fossil fuel generators remain widely used. However, they often require frequent repairs, often on a monthly or even weekly basis. This leads to substantial additional costs that are added to fuel expenses, which have surged in recent years. These operational burdens highlight a critical opportunity: the market is ready for cleaner and more reliable alternatives such as solar generators, which have a lower repair frequency. Interestingly, the research reveals that approximately 20% of participants have already discontinued the use of FFGs due to the rising cost of fuel. This trend underscores an urgent issue: these individuals now have even more limited access to electricity.

When energy is both expensive and unreliable, it directly affects the well-being and economic potential of communities. The solution lies in expanding access to clean, affordable alternatives. Encouragingly, the study also found that 5% of former FFG users have successfully transitioned to solar energy, a clear sign of growing public interest in sustainable energy solutions. Survey responses further support this shift: 100% of respondents express strong interest in adopting clean energy alternatives. Moreover, over 99% agree that accessible financing options are essential to make this switch a reality. These findings make a compelling case for stakeholders to prioritize the development of tailored financing mechanisms to facilitate widespread adoption.

Alongside survey data, the study collected and analysed real-time usage data over more than one year. These findings provide a nuanced understanding of power consumption across different customer groups. On average, power consumption remains around 0.5kW, with peak demands seldom exceeding 2.5kW. This information is crucial in the design and sizing of solar alternatives, particularly in defining the specifications for solar inverters. It is also important to note that if clean energy were more accessible, demand could increase as usage barriers diminish.

Usage patterns differ significantly across customer categories. Hotels, for instance, report the highest energy demands, averaging 3 to 4 hours of generator usage daily, for approximately 20 days each month. Meanwhile, off-grid markets tend to use their FFGs more frequently than their on-grid counterparts. Conversely, on-grid households and hotels show a higher dependence on backup FFGs. These insights highlight targeted opportunities where clean energy solutions can seamlessly replace existing fossil fuel systems, particularly since these usage profiles can be adequately met by solar generators.

The data shows that most users consume less than 1.5kWh per day, although there are some outliers with higher energy demands. Additionally, the time-of-day energy consumption analysis reveals that small to medium markets and schools predominantly use energy during daylight hours. This reduces the required battery storage, making solar adoption more straightforward. On the other hand, households, health centres, and hotels typically use electricity in the evening or at night, necessitating larger battery capacities. In summary, while energy needs and patterns vary by customer type, the specifications for a solar generator remain relatively consistent. A solar generator with a 2.5kW maximum output, paired with 1kW of solar panels and a 2kWh battery, can meet around 85% of the energy requirements for the observed customer base. However, this is not a one-size-fits-all solution. Distributors and system designers must evaluate each target cluster's unique needs to determine whether a smaller or more expandable system would be more suitable.

This research has been made possible thanks to the vital support of the ZE-Gen Initiative, which seeks to better understand real-world energy usage in Nigeria. The findings provide critical, data-driven insights that enable energy providers and policymakers to grasp how FFGs function as backup systems, and more importantly, how these systems can be effectively replaced. This level of understanding is essential to drive a successful and inclusive transition to cleaner energy sources. By making this dataset publicly available, the ZE-Gen Initiative empowers a wide array of stakeholders – including policymakers, local distributors, and manufacturers – to make informed decisions. These stakeholders can now develop and implement energy solutions tailored to the specific needs of each customer cluster. Importantly, the research also contributes to a more enabling environment where clean energy alternatives are not only viable but also attractive, sustainable, and scalable.

The next step is to widely disseminate the findings of this report. Policymakers, manufacturers, distributors, and other relevant stakeholders should be made aware of these insights to accelerate the energy transition. One of the most significant takeaways is the need for innovative financing and incentive mechanisms. As clearly stated by survey participants, financial accessibility is the primary barrier to switching to clean energy. Future phases of the research could extend data collection to different regions within and beyond Nigeria. Energy use patterns can vary greatly due to local policies, environmental conditions, and economic contexts. A broader dataset would provide an even more comprehensive understanding, supporting cross-border learning and the adaptation of solutions to diverse settings.

The insights from this research are invaluable for Nigeria's energy future. They highlight both the challenges, and the immense opportunities associated with moving away from polluting, costly fossil fuel generators. With this strong foundation of real-world data, energy solution providers, regulators, and advocates are now better positioned to support millions of Nigerians in accessing clean, reliable electricity. Ultimately, this research marks a significant step forward in building a more sustainable, equitable energy system. The pathway to a cleaner future is not only possible but already in motion. With continued support and collaboration, solar and other clean technologies can become the standard – bringing affordable, dependable energy to every corner of Nigeria and beyond.

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