Global Energy Alliance
for People and Planet
GEAPP

INNOVATION TO ACCELERATE OFF-GRID ELECTRIFICATION IN HAITI

Findings from the Alina Enèji mesh-grid

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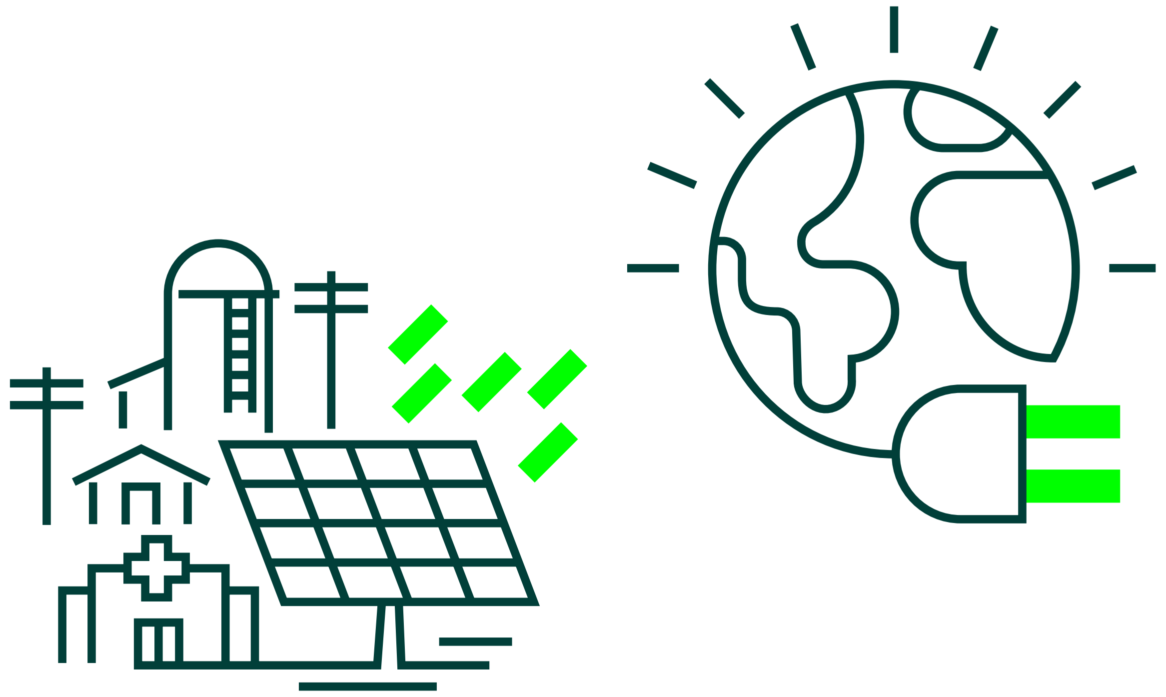
Executive Summary

Haiti faces critical challenges in meeting its electrification objectives. **The country's six million unelectrified make up nearly 40% of the total access gap in Latin America and the Caribbean.** In rural Haiti – where 2% of the population has access to electrical energy – communities rely primarily on biomass and imported fossil fuels to meet everyday energy needs. This reliance undermines efforts to improve health, wellbeing and livelihoods, to grow the domestic economy and achieve energy security, and to build resilience against the worsening impacts of climate change.

Due to the fragile financial state of the national utility, Électricité d'Haïti (EDH), Haiti has been a site of immense innovation in off-grid electrification. Though these efforts have primarily focused on mini-grids and solar home systems (SHS) are main technology archetypes, in Haiti, as elsewhere, the economics of least-cost electrification are rapidly changing.

Sustained cost declines in solar PV and batteries over the past decade have encouraged the growth of decentralized models of electricity provision. A diverse set of electricity systems can now generate electricity and store it on-site in batteries at a price that, with centralized generation, including mini-grids, is increasingly competitive. Decentralization eliminates the need for transmission lines and the expensive copper within them. In tandem, appliance efficiencies have doubled as prices decrease, making them affordable for low-income populations to use.

This paper explores mesh-grids as a bottom-up, decentralized model of electrification that capitalizes on these technoeconomic advancements. Based on real data from a mesh-grid deployment with over 3,000 connections in Haiti's Artibonite region, we evaluate the social, technical, financial and economic performance of the system. Where relevant and possible, we benchmark with mini-grid systems (both existing and planned) and SHS to provide a detailed comparison. The following sections evidence eight key findings:



The following sections evidence eight key findings:

Lighting and small electronics rapidly transition to electricity with mesh-grids, but cooking remains biomass-based.

The introduction of mesh-grids has led to a rapid transition to electricity for lighting and small electronics. However, cooking remains predominantly biomass-based, highlighting the need for targeted support to enable a shift to electric cooking among newly electrified households.

Electricity tariffs between $0.60-$0.90 per kWh provide savings over existing fuel sources.

Alina Enèji's electricity tariffs are comparable with grid-based alternatives and offer fuel savings over non-electric energy sources like kerosene and charcoal. Users also value the service for perceived improvements in quality of life. As with most newly-electrified communities, affordability issues remain which must be addressed for more vulnerable users.

Mesh-grids can accommodate a diverse range of productive activities, but require adaptation for higher-demand applications.

While mesh-grids provide sufficient energy for many household and small-business uses, increasing their capacity is key to enabling more demanding applications, particularly in agricultural and service sectors.

Mesh-grid customers have the potential to increase their energy consumption.

Current usage patterns indicate that Alina Enèji's customers are primarily utilizing lower energy access tiers (MTF Levels 1 and 2), despite the capacity for higher consumption. This underutilization represents a key challenge, but also a significant opportunity for growth and impact.

Productive users drive grid profitability, with substantial room for growth.

For 27% of Alina Enèji users, electricity has enabled new economic ventures like freezer use and phone charging, which drives increases in revenue for both users and the supplier. Support for appliance access and financing and targeted outreach to local institutions can help identify and capitalize on diverse productive-use opportunities.

Mesh-grids provide high resilience and reliability while reducing dependence on volatile fossil fuel supply chains.

Mesh-grids have demonstrated remarkable adaptability and growth in the face of Haiti's complex challenges, showcasing their potential as a scalable electrification solution for demanding environments. Their rapid installation rate, even amidst logistical hurdles and fuel shortages, underscores their resilience. While their performance during natural disasters remains to be fully assessed, their modular design suggests a promising capacity for quick recovery and repair.

Executive Summary

Mesh-grids require lower capital expenditure (CapEx) subsidies and have shown improving cost economics with scale.

Alina Enèji's mesh-grids require lower subsidies and CapEx than mini-grids, positioning them as a viable option in Haiti's electrification landscape. Continued scale-up and focus on productive use will be critical for enhancing average revenue per user (ARPU) and ensuring long-term sustainability.

Mesh-grids can be rapidly deployed with the right regulatory enabling environment.

Mesh-grids demonstrate a promising potential for rapid deployment and expansion, particularly within a supportive regulatory environment. Addressing regulatory uncertainties, establishing clear technical standards and promoting responsible waste management will be crucial in considering mesh-grids as another viable and sustainable electrification solution in Haiti.

Haiti's electrification strategy must focus on delivering cost-effective, adaptable solutions that can evolve with community needs. Mesh-grids offer a flexible, modular approach that allows for incremental upgrades as energy needs grow while avoiding the high capital costs associated with traditional grid infrastructure. Policymakers should prioritize the deployment of these systems in areas where mini-grids are not viable, ensuring that subsidies are optimized to reach the greatest number of households and businesses.

For Haiti's energy sector to grow sustainably, a multi-layered approach to electrification is essential. Mesh-grids, stand-alone solar systems and traditional alternating current (AC) grids can be integrated to form a cohesive energy network that meets diverse community needs. However, challenges such as funder preferences for specific technologies, tendering processes that limit technological choice and gaps in business-model viability assessments can impede progress [1]. Addressing these barriers through more inclusive and flexible approaches is critical to accelerating electrification efforts. Alina Enèji's tariff, while high, reflects the real cost of delivering electricity in remote areas. As mesh-grid systems expand and interconnect with other energy sources, costs can be reduced and service quality improved.

Electrification efforts must go beyond household energy access to support productive uses of electricity (PUE) that drive local economic development. In Alina Enèji's case, PUE applications have primarily focused on small vendors using refrigeration, but opportunities exist to expand into agriculture, healthcare and clean cooking. For example, electrifying agricultural processing in the Artibonite region could significantly reduce post-harvest losses, improving food security and farmer incomes. Policymakers should support initiatives that promote PUE across multiple sectors, with particular attention to sectors that improve livelihoods and reduce environmental impacts.

Haitian entrepreneurs, like those behind Alina Enèji, are leading the way in developing resilient, decentralized energy solutions. To sustain this momentum, policymakers must increase financial and technical support for local ventures. Expanding the resources available for electrification, deployed as financing tailored to meet the needs of local enterprises will be key to scaling these innovations. Additionally, integrating data-driven remote monitoring into all off-grid systems will enable continuous evaluation and improvement, ensuring that Haiti's energy future is guided by real-time insights and local expertise.

1

BACKGROUND

Introduction

Persistently low levels of electrification in Haiti undermine efforts to meet basic nutritional, health, education and, increasingly, climate adaptation needs. Although Haiti represents less than 2% of the total population of Latin America and the Caribbean, its six million unelectrified make up 38% of the regional total [2], [3], [4]. According to the Inter-American Development Bank, based on Haiti's existing rate of electrification, the country will not achieve universal electrification until 2150 [5].

Over 70% of Haiti's annual energy use is estimated to come from smoky and polluting biomass sources like charcoal and firewood [6]. Deforestation is becoming an increasingly urgent challenge in Haiti. A recent scientific study reported that 'Haiti has less than 1% of its original primary forest and is therefore among the most deforested countries in the world' [7]. This affects agricultural productivity and biodiversity and increases the likelihood of compounding climate events like flooding and landslides.

Haiti's nine non-interconnected 'regional grids' serve only 47% of its total population and have struggled to expand beyond dense urban areas [4]. Haiti's electrified population almost exclusively (99.5%) lives in the capital Port-au-Prince, or in other regional cities like Jacmel, Les Cayes, Cap-Haïtien and Port-de-Paix [4]. Outside of urban clusters, electrification rates drop to 2% [4]. In rural Haiti, less than 0.3% of the population in 2024 is estimated to use a clean-cooking fuel source like electricity or gas [8].

Grid extension has not been possible because of the fragile financial state of the national utility Électricité d'Haïti (EDH). Estimates from 2018 suggest that over 60% of electricity generated by the utility is lost to technical and commercial losses and that the entity operates at a deficit of $200 million annually [9], [10]. Institutional reform efforts have been mounting, but in the short-term, all electrification in Haiti is expected to be achieved by isolated systems.

With under six years remaining to achieve Sustainable Development Goal 7 – to 'ensure access to affordable, reliable, sustainable and modern energy for all' – the Haitian off-grid sector has been exploring an increasingly wide range of off-grid technologies and business models. These technologies must perform in a challenging context of political insecurity and low user 'ability to pay', and where private investment is scarce and costly. And, because Haiti lies outside of the geographical mandate of an SDG 7 community of practice largely focused on sub-Saharan Africa, concessional financing is limited.

The case for innovation

The question policymakers and practitioners are considering is:

which systems can be deployed agilely and provide electricity to rural Haitians at an acceptable cost and capacity while minimizing the amount of subsidy required?

Though mini-grids are, in theory, an ideal solution for many unelectrified cities, towns and villages, experience has shown that the business case is difficult, financing is scarce and the coordination of donor funding, insurance and regulatory permitting can lead to years of delays (authors' interviews). PHARES (Programme Haïtien d'Accès des Communautés Rurales à l'Energie Solaire (the Haitian Programme for Access to Solar Energy for Rural Communities)), was launched in 2019 to provide a streamlined regulatory and administrative process for mini-grid developers. To date no mini-grids have been constructed, though several are expected to break ground in late 2024.

Mini-grids have been and will continue to be a key technology to advancing electrification in Haiti. However, innovations in distributed renewable energy (DRE) system architectures may offer a more cost-effective, flexible and fit-for-purpose electrification alternative for communities that may not be densely populated enough to support a traditional mini-grid. Mesh-grids are a promising model. A local developer, Alina Enèji, has successfully grown from a pilot of 35 connections to over 3,000, with immediate plans to scale to 15,000. At that scale, the mesh-grid will provide electricity services to nearly 90,000 Haitians.

Figure 1 demonstrates the technology provider Okra Solar's mesh architecture (right) compared to a traditional mini-grid architecture (left). Mesh-grids provide individual users with a stand-alone lithium battery, photovoltaic (PV) system and Okra Pod (smart charge controller and meter). DC appliances may be used, but with some packages an inverter allows AC usage. Users that are physically clustered within 50m are connected using low-cost distribution to enable power-sharing up to 600 Watts (W). Users not within a certain proximity of other users operate as an SHS. This differs from mini-grids, where generation and storage are typically centralized and distributed to users via a low-voltage AC distribution system.

Figure 1.
Visual of PV, inverter and battery-system locations in a mini-grid (left) versus mesh-grid system configuration. Graphic provided by Okra Solar.

Mesh-grids have proven that they can be rapidly deployed and that they can achieve lower capital-expense requirements than mini-grids. This means that the per-connection subsidy required is lower, and that the total pool of available subsidy can be used to achieve a larger number of total connections. Yet there are concerns around the high cost of service provision, with tariffs ranging between $0.60 and $0.90 per kWh (depending on exchange rates) and whether users can afford to use electricity beyond basic uses like lighting and phone charging. What lacks is a systematic comparison of the mesh-grid system against mini-grids, other grid-based alternatives, and the fossil and biomass fuels that currently meet daily energy needs.

Open questions for policymakers

These and other questions are being actively debated by the government of Haiti and its partners, and it is to those discussions that this technical paper seeks to contribute. Presenting findings from Alina Enèji's recent scale-up, we address the following open questions surrounding mesh-grid deployments:

- **Are mesh-grids contributing to transitions away from high-carbon, polluting fuels?**
- **Do mesh-grids have the capacity to meet user needs now and in the future, particularly for productive uses of electricity?**
- **How have mesh-grids performed financially when compared to electrification alternatives? Is the business model sustainable?**
- **What are the key challenges and opportunities for a further mesh-grid scale-up?**

In the following sections, we present and evidence eight key findings. In doing so, we aim to place mesh-grids in perspective among the wider range of technology alternatives in Haiti, with a broader objective of contributing to the body of knowledge around off-grid technologies and envisioning a pathway for mesh-grids to help Haiti meet its urgent energy-access goals.

2

ALINA ENÈJI

— a mesh-grid case study

Pilot launch and project site

Alina Enèji began in 2021 as a 35-connection pilot project by Haitian entrepreneur Driko Ducasse. Inspired by similar projects in Africa, Mr. Ducasse's motivations were to bring energy access to under-served communities by demonstrating the potential of mesh-grid technology to provide reliable and affordable electricity to rural Haiti. Additionally, he aimed to demonstrate the potential of the Haitian diaspora to contribute to the country's development through impactful projects.

In collaboration with Okra Solar, a mesh-grid technology company, Alina Enèji launched this pilot project in the rural commune of Marchand-Dessalines, located within the Dessalines Arrondissement in central Haiti's Artibonite Department. Marchand-Dessalines is located around 25km southeast of Gonaïves and 60km south of Cap-Haïtien. Based on the most recent available demographic data, from 2015, the commune's estimated population was around 180,000 inhabitants, with 31,000 residing in the town of Dessalines and 149,000 in rural areas [11]. [1]Agriculture, particularly rice production, serves as the primary economic activity in the area, as the Artibonite Department is one of the country's primary rice producers [12], [13], [14]. Accessing the zone is challenging due to frequent gang blockades on the three main roads leading to the towns.

According to Alina Enèji, Marchand-Dessalines was selected for the pilot mesh-grid following discussions with the Energy Cell and ANARSE (l'Autorité Nationale de Régulation du Secteur de l'Energie (the National Energy Sector Regulatory Authority)). The area met two key requirements set by ANARSE: being more than five kilometers away from an EDH distribution grid and not being included in ANARSE's list of potential mini-grid sites. Notably, Mr. Ducasse was familiar with the area and had existing contacts. Informal meetings with community leaders confirmed that it was a suitable location to showcase the proposed technology and business plan.

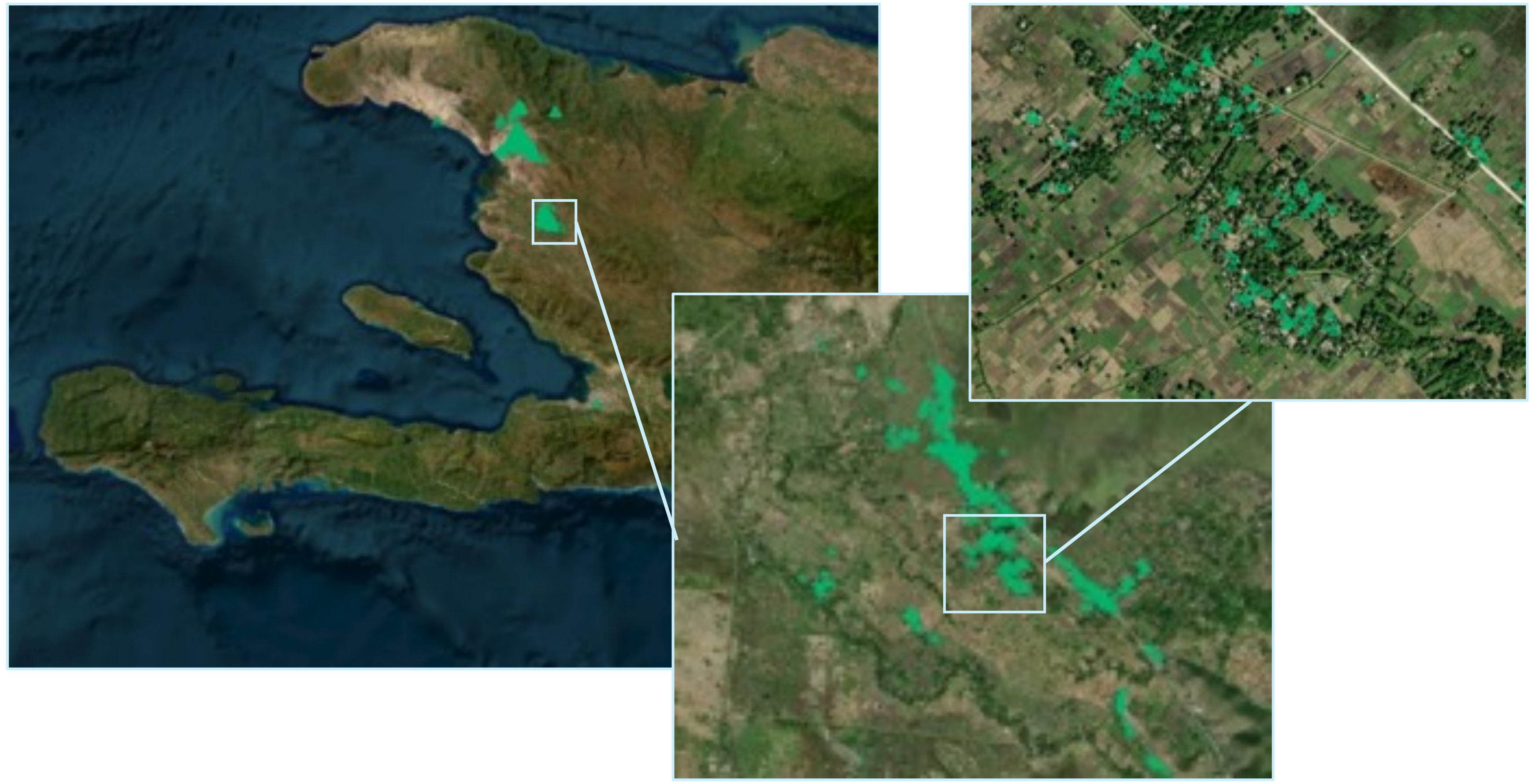


Figure 1.
Spatial visualization of mesh-grid customers in Marchand-Dessalines. Taken from Okra Solar's Harvest platform.

[1] Specific demographic data from the zone south of Marchand-Dessalines where the pilot project has been implemented is not available.

Strategic scale-up in three expansion phases

From an initial pilot of 35 connections installed in Marchand-Dessalines in July 2021, Alina Enèji has grown over the course of three expansion phases. Two expansion phases have been completed around Marchand-Dessalines, with a third and ongoing expansion taking place in a different location around the Gonaïves and Plaisance communes. **Figure 2** shows the scale-up over time. The first expansion phase was completed in August 2022 with 366 total connections. The second expansion phase reached 1,0009 total connections in April 2023. Alina Enèji is currently in its third expansion phase, and currently has around 3,300 active users. This expansion phase will expand the mesh-grid to 5,000 connections.

The expansion of the initial pilot project has been carefully calculated and incremental, allowing Alina Enèji to focus on **four key priorities that they believe to be the key to their success:**

Community involvement
Recognizing its crucial role in successful implementation.

Robust maintenance
Establishing strong routines to ensure system reliability.

Technological advancement
Acknowledging the potential for further improvements to mesh-grid technology.

Sustainability
Maintaining a laser focus on the project's long-term viability.

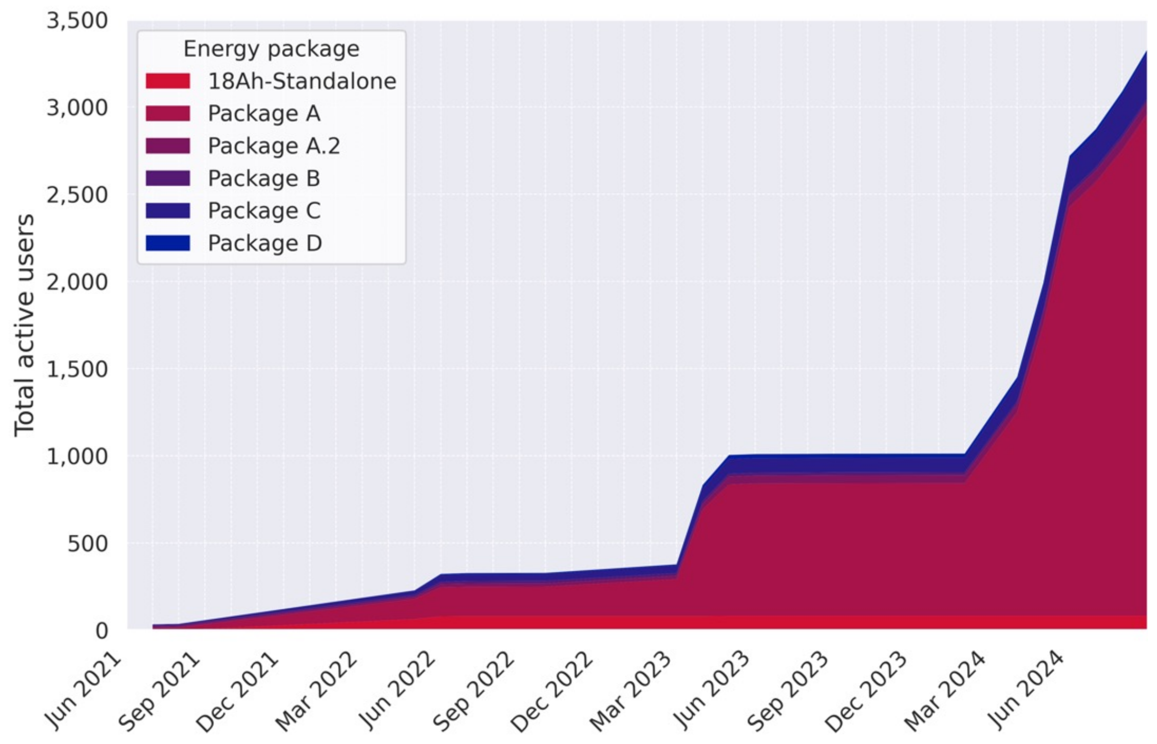


Figure 2.
Scale-up of Alina Enèji from 2021 to 2024, disaggregated by energy package.

The latest expansion is focused on exploring the technology's capabilities and gathering insights and learnings as the company scales its operations to cover a wider area and diverse contexts beyond Marchand-Dessalines.

It is noteworthy that Alina Enèji's scale-up has taken place during a period of abnormally high political instability in Haiti. Former President Jovenel Moise's assassination in 2021 created a power vacuum that has enabled gangs, based mostly in and around Port-au-Prince, to control much of the movement of goods and people along main routes in and out of the capital [15]. Alina Enèji was able to navigate these risks creatively by working with local people to determine hour-by-hour safety conditions, transporting hardware in small batches and using longer, alternative routes to reach the community.

Determining energy services through community engagement

Alina Enèji begins the installation process by engaging with the local community. The process begins with an initial survey to identify potential customers interested in their service. This serves a dual purpose: it promotes the service, and also allows the developer to estimate potential demand and match the user to the energy package that would be most suitable based on their needs. There are no installation fees or minimum consumption requirements.

Once the customers express interest and agree to participate, the Alina Enèji team handles the installations. Based on the initial survey, each customer is assigned to an energy package which determines how much electricity they can use per day. **Table 1** shows the energy packages, their daily usage limits, tariffs, and breakdown by number and percent of total users. The majority (87%) of customers use package A which offers 200Wh (watt-hours) of energy per day. Package C is also significant despite only making up 8% of customers because it reflects small and medium enterprises that consume larger quantities of energy.

In addition to the electrical services, Alina Enèji offers appliances for sale to improve their availability to customers and to increase demand. Each new connection receives three free wired light bulbs and a fan to encourage adoption and use of electricity. Alina Enèji also provides appliances on credit, with customers making regular payments until the total amount is paid. These appliances are primarily for domestic use, including freezers, fans, televisions, light bulbs, irons and cookers. **Figure 3** provides a breakdown of the appliances sold since Alina Enèji first began offering them in 2022.

Package	Daily usage limit (Wh/day)	Tariff (HTG/kWh)	Boost rate (HTG/kWh)	Users†	Percent (%)
Standalone	120	119.50	119.50	81	2
A	200	119.50	119.50	2,887	87
A.2	300	119.50	119.50	66	2
B	500	119.50	119.50	19	1
C	1,000	119.50	119.50	261	8
D	1,500	119.50	87.45	23	1

Table 1.
Alina Enèji energy packages.
† As of 5 September, 2024.

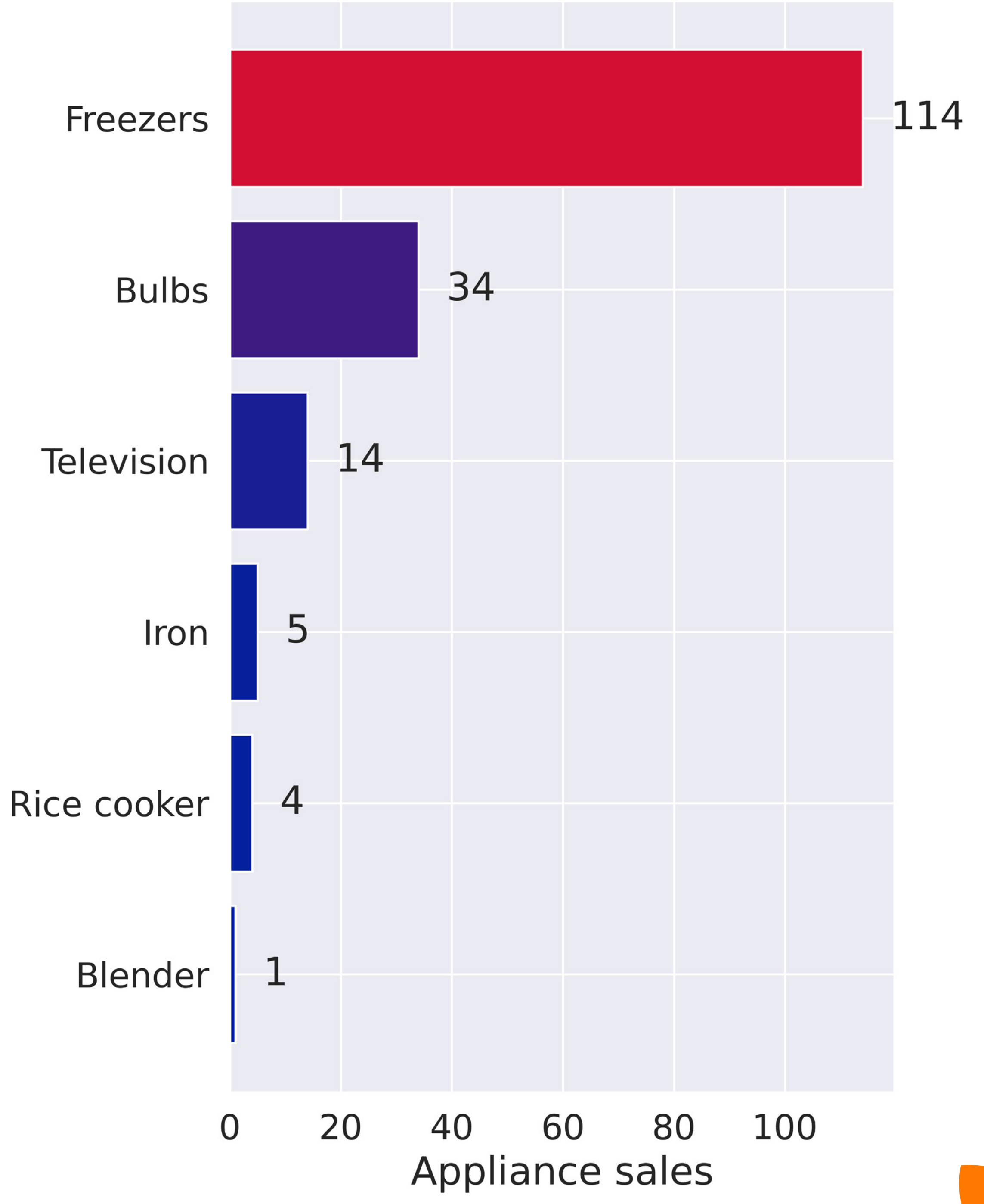


Figure 3.
Appliances sold by Alina Enèji to customers since 2022. Freezers include both five and seven cubic feet models. We note that the bulbs category includes additional sales beyond the initial four free light bulbs that Alina Enèji customers receive upon installation.

Customers purchase prepaid-energy credits through sales agents. Upon purchase, they receive an SMS confirmation. They can use electricity from the system until their credit is exhausted. If a customer hits their daily usage limit for the day, they can hit a button to 'boost' their supply and receive additional units of electricity. For higher-consuming users in Package D, the boost rate is lower to incentivize users to increase consumption. This process is designed to be straightforward and efficient for the customers. It also provides Alina Enèji with a secure payment mechanism with a transparent remittance process supported by the Harvest platform application.

Alina Enèji technicians **Wenchel Michel** (left) and **Charleron Adner** (right) install a solar panel on a new customer's roof.

Key technical and operational features

The mesh-grid technology used by Alina Enèji is designed and produced by Okra Solar.

Okra Solar is a technology company which has specialized in mesh-grid hardware and software solutions since 2016. Okra Solar serves as Alina Enèji's main partner and technology supplier in this project, and their role goes far beyond that of a typical technology supplier. They are closely involved with the project's development, considering Alina Enèji as a collaborative partner rather than just a client. This partnership entails Okra Solar providing extensive strategic and operational support to Alina Enèji, with a local team based in Haiti and closely assisting Alina Enèji's operations in the country.

Mesh-grids are an innovative approach to small-scale electrification. They employ direct current to interconnect multiple distributed energy generation systems and loads. Essentially, individual solar photovoltaic systems can connect only one customer. However, when multiple such systems are interconnected through low-voltage lines that can exchange energy, they evolve into a PV mesh-grid. Okra Solar designs and provides mesh-grid installation kits that are available in various configurations, including PV solar panels, batteries, inverters, cabling and their accompanying pods.

Okra Solar developed its Pod in-house, which serves as a multifunctional unit integrating communication, charge control and metering. Each connection within the mesh-grid has its dedicated pod, featuring connectors for PV, grid, battery and loads. Moreover, Okra has integrated metering functionality in its pods, enabling Alina Enèji to allocate specific energy units to each connection.

The Pod is programmed to automatically shut down once the consumer has consumed their allocated energy units. **As the central communication hub of the mesh-grid, the Pod relies on an internet connection to upload energy-generation data to the cloud.** Without internet connectivity, the Pod goes offline and data transmission is interrupted.

The hardware installed on a customer's premises depends on several design variables. The first is understanding the energy needs of the customers in a cluster. This will determine the energy package they require and the hardware that gets installed – a hub, spoke or stand-alone system. Customers clustered within a 50m radius are connected in a hub-and-spoke configuration. A hub comprises PV solar panels, an inverter, a battery and a pod. A spoke comprises a Pod and sometimes a battery. Each hub can be connected to up to 12 spokes. There are currently three standard kit sizes (see **Table 2**) providing energy ranging from 300Wh per day to 2,700Wh per day. As demand grows, panels, batteries and inverters can be added modularly for additional capacity. With these kits, Alina Enèji offers several categories of packages for customers, shown previously in **Table 1**.

Kit	Maximum daily energy availability (Wh/day)	Solar capacity (Wp)	Battery capacity (Wh)	Inverter capacity (W)
Spoke	300			
L45	1350	4500	1280	600
L90	2700	900	2,560	1,200

Table 2.
Alina Enèji kits installed.

Hubs may connect to other hubs, and so mesh-grids form clusters of customers based on topography. [2]This ensures efficient power utilization within the grid to meet the electricity demand of connected users. It allows each connected customer to both contribute surplus electricity to the grid and draw additional power when needed. Hubs generate excess energy to share with nearby spokes, and when interconnected, hubs can also exchange energy among themselves. Spokes receive energy via the DC grid, which is then channeled through the Pod to power the load. The pods intelligently manage each household's energy consumption.

One of the advantages of mesh-grids is their inherent simplicity in terms of system architecture and operation. Compared to larger PV systems reliant on AC, mesh-grids have fewer components and eliminate the phase synchronization challenges inherent to AC grids. Furthermore, the proximity between generation and loads in direct current (DC) mesh-grids contributes to higher overall efficiency, as losses associated with DC-AC and AC-DC conversions are avoided. However, one of mesh-grids limitations relies on their geographical coverage compared to conventional AC distribution lines, resulting in shorter distribution-line lengths. Consequently, while the need for expensive distribution infrastructure is reduced, the permissible distance between neighboring houses is also shorter.

[2] Notably, only Okra Solar's kits are guaranteed to be compatible with inter-connection. While theoretically possible, Okra currently does not incorporate equipment from other technologies into their kits or mesh-grids.

Okra Solar provides access to its monitoring platform, Harvest, for a monthly service fee of $1.25 per household to operate using 2G. Alina Enèji is in the process of transitioning to Wi-Fi-based communications systems, which will allow them to halve their monthly service fee. Harvest offers valuable insights into various aspects of the project, including technical, financial and performance indicators. Both Alina Enèji and Okra acknowledge Harvest's utility for conducting detailed analyses, providing both a quick overview of the mesh-grid's functionality and the ability to delve into specific customer data when necessary.

Okra Solar has established a solid manufacturing base in China and holds ISO certifications 9001 and 14001. It is actively exploring manufacturing partnerships beyond China to diversify its supply chain and potentially reduce costs. Okra Solar provides Alina Enèji a warranty period for system parts, as shown in **Table 3**.

Equipment	Okra Solar warranty (years)	Lifetime expectancy (years)
Solar panels	10	25
Batteries	3 (2,000 cycles)	7
Inverters	2	10
Pods	2	10

Table 3.
Equipment warranty and lifetime expectancy.

3

FINDINGS

Lighting and small electronics rapidly transition to electricity with mesh-grids, but cooking remains biomass-based.

Comparing energy use patterns before and after the introduction of a new technology is a helpful way to understand energy transition pathways and whether and how solutions are being taken up by users. In a typical household in Marchand-Dessalines, and in rural Haiti more generally, **cooking and lighting are the main uses of energy[3].**

Figure 4 shows responses on primary lighting energy sources from surveys performed before and after the mesh-grid was installed. The results point to a near-complete transition to electricity for lighting. For just over 20% of surveyed users, lighting transitioned from kerosene to electricity. The largest transition, around 65%, came from solar rechargeable lamps. However, it is likely that this category also includes flashlights powered by AA batteries, and flashlights from cell phones.

The benefits of improved lighting should not be overlooked. Alina Enèji provides each user with four free wired light bulbs upon installation. Improved lighting creates a sense of safety[4] and community wellbeing, particularly for women, and can support livelihoods by allowing shops and home-based businesses to operate after dark [16].

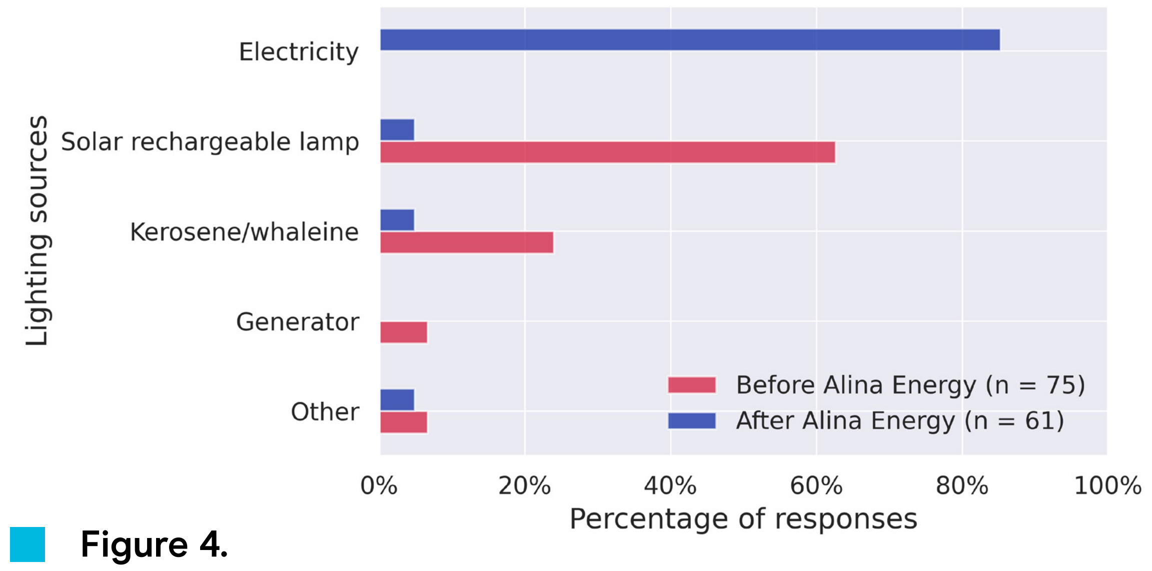


Figure 4.
Breakdown of lighting energy sources before and after gaining a connection from Alina Enèji.

However, electricity via the mesh-grid system has not enabled transitions away from biomass and fossil fuels for cooking purposes. **Figure 5** shows responses from survey participants who were connected to the Alina Enèji grid, who overwhelmingly use charcoal or firewood to cook meals. One of the photographs provided by a community researcher shows an example of a traditional cookstove in use in kitchens in Marchand-Dessalines. It is noteworthy that a small number of users reported using electricity to power some domestic cooking appliances, like electric kettles and blenders.

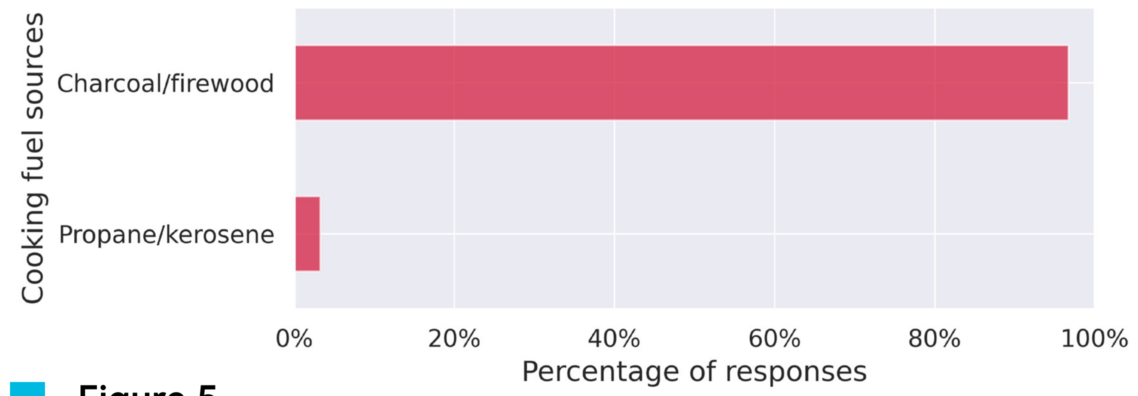


Figure 5.
Breakdown of cooking fuel sources, from respondents with a connection to the Alina Enèji mesh-grid.

[3] Transportation is another significant energy use, but is outside of the scope of this paper. Alina Enèji recently began piloting an electric motorcycle as a potential pathway for transportation electrification.
[4] Photos sent by the community researcher showed that household lighting also provided benefits for public spaces.

The low uptake of electricity for cooking (e-cooking) is not surprising among a newly electrified and low-earning population. It takes time for community members to save for and buy electric appliances and experiment with using them in new ways. For e-cooking in particular, past experience has highlighted the need for community engagement and accompaniment to build awareness around the time-saving and safety benefits and overcome negative perceptions around cost [17]. On the technical side, the capacity of the inverter for 'spoke' customers is 150W – too low to support high-efficiency e-cooking appliances like electric pressure cookers and induction stoves, which typically draw loads on the order of 800 to 1,200 watts.

In Nigeria, Okra Solar has begun experimenting with variations on its system that would enable a draw of up to 3.6 kW [18]. EarthSpark, which operates mini-grids in southwest Haiti, also saw early success with a project to pilot e-cooking among 28 households [17]. There is significant potential for mesh-grids to support a transition to electric cooking among mesh-grid users in Haiti, but targeted support is needed to supply high-quality and affordable appliances and accompany community members in the process of adopting them into everyday use.

As **Figure 6** shows, lighting was the most common use of electricity. Roughly a quarter of surveyed customers also used electricity in small businesses, which is discussed in a later section. Around 20% of surveyed users also reported using electricity to charge or power small electronics like phones, radios and TVs. These are important uses of electricity with co-benefits for education, healthcare, climate adaptation and women's empowerment [19], [20], [21], [22].

Photos

Photos shared by a community researcher on cooking practices. The photos show, from left to right, a rice cooker and blender used with mesh-grid electricity. The photo on the right shows a traditional charcoal cooking setup.

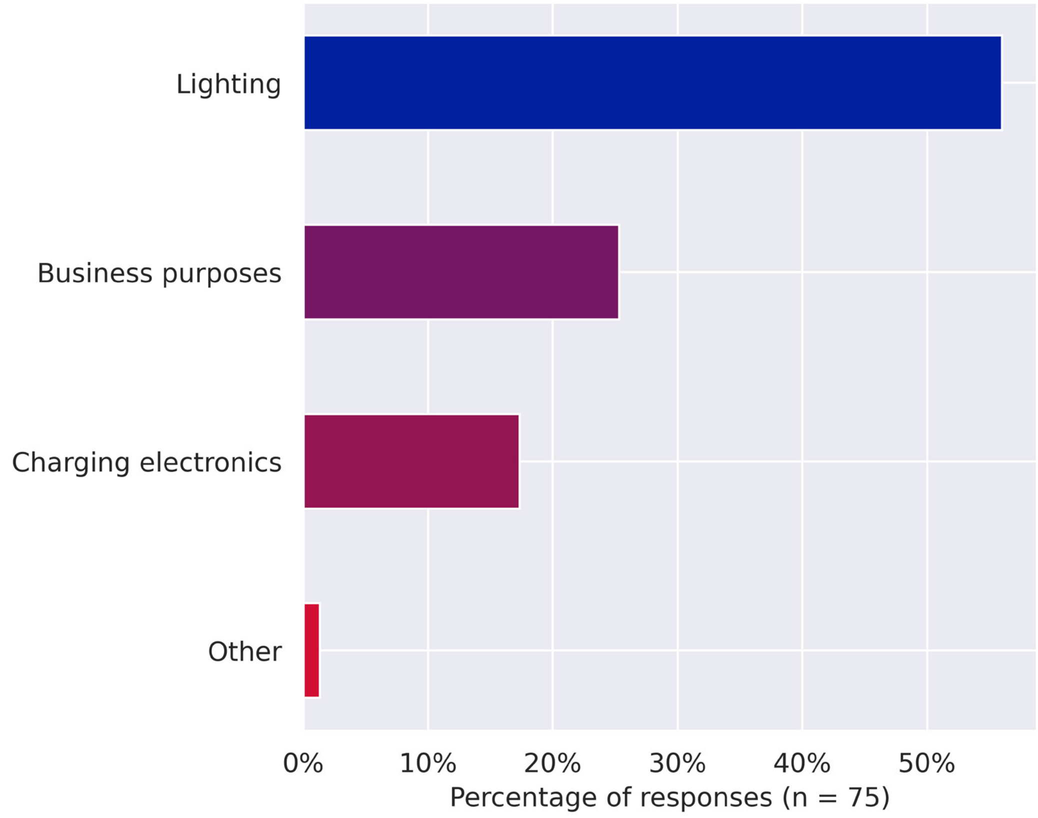


Figure 6.
Response to a survey question asking what customers used electricity for.

Mesh-grids can accommodate a diverse range of productive activities, but require adaptation for higher-demand applications.

The capacity of an off-grid system determines the types of electricity services it can provide. ESMAP's Multi-Tier Framework (MTF) provides five 'tiers' of access, with Tier 5 representing 'full access'. Access tiers are determined using proxy metrics for affordability, safety, legality, quality, availability and capacity. Technologies like SHSs are normally associated with Tier 1 and 2 access and are able to provide basic electricity services for lighting and charging electronics. Systems providing Tiers 3–5 can power an expanded range of uses, for example refrigeration, ironing and food processing.

Figure 7 shows the distribution of active Alina Enèji users along the thresholds set for the capacity dimension of the MTF. **Figure 8** shows these capacity levels in a more intuitive way, as examples of appliances that can be powered by the different energy packages. Alina Enèji's A energy package, used by 87% of all users, provides a Tier 2 level of access. Packages B, C and D, used by 8% of customers, provide Tier 3 access. The community understands the differences in capacities in terms of the 'gros plan' (big plan), which can power larger appliances like refrigerators, and the 'petit plan' (small plan), which supports a more limited range of uses. These are relatively high tiers of access compared to the solutions currently available to the community, like solar-rechargeable LED lamps and small SHSs.

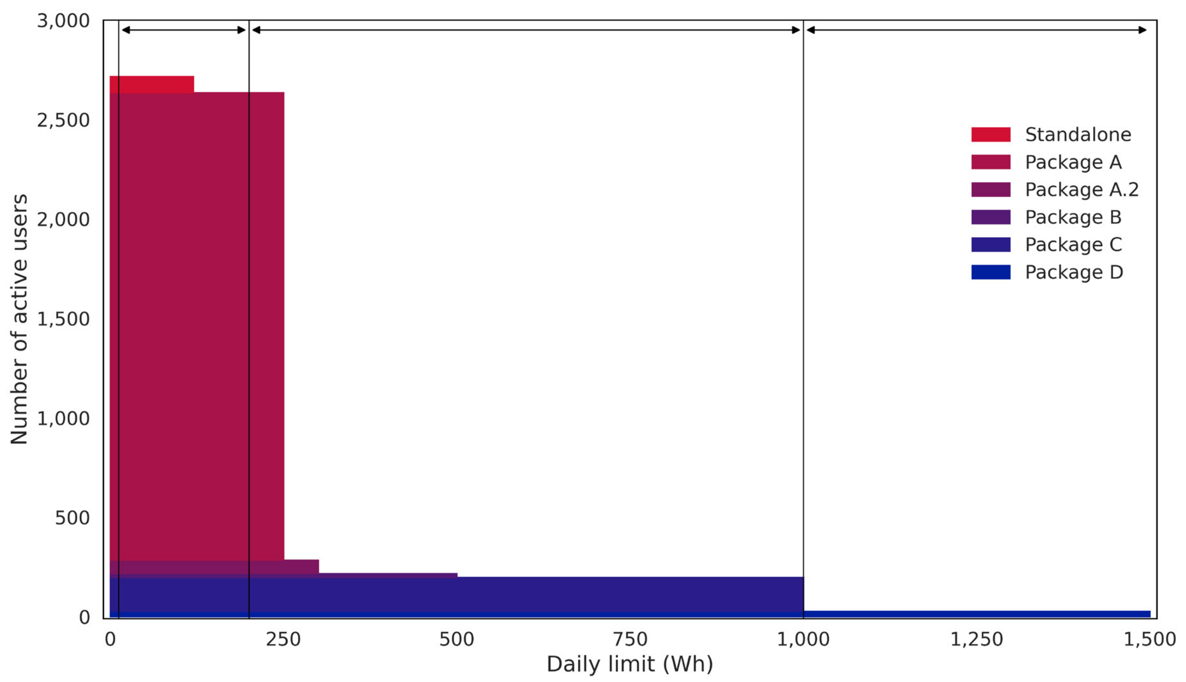


Figure 7.
Distribution of Alina Enèji's energy packages to the capacity thresholds of the MTF for measuring access to household electricity supply.

System	PV capacity (Wp/connection)	Battery capacity (Wh/connection)
Stand alone solar system 1	80	246
Stand alone solar system 2	100	300
Stand alone solar system 3	15	105
Alina Enèji[5]	146	337
Mini-grid 1	315	650
Mini-grid 2	400	720

Table 2.
Comparison of system generation and storage capacities.

Directly comparing the generation and storage capacities of the various systems can also provide insights. **Table 2** compares the basic system specifications of Alina Enèji's mesh-grid options compared to SHSs and mini-grid alternatives. The mesh-grid falls between reference points for both SHSs on the low end, and mini-grids on the high end. In this sense they can be thought of as providing a service that is somewhere between a mini-grid connection and a SHS.

Okra Solar's hub designs are modular. The exact configuration equipment depends on the hub-and-spoke (or stand-alone) design of a particular group of users. If a group of users begins experiencing outages, inverters, PV panels and batteries can be increased to grow with the energy needs of the customers. We note that the latest generation of Okra Solar equipment installed in Nigeria can supply a 3.6kW instantaneous load and provide 10.8kWh per day. Configurations up to this capacity are possible, though as of now there have not been any requests among Haitian customers for systems of this size.

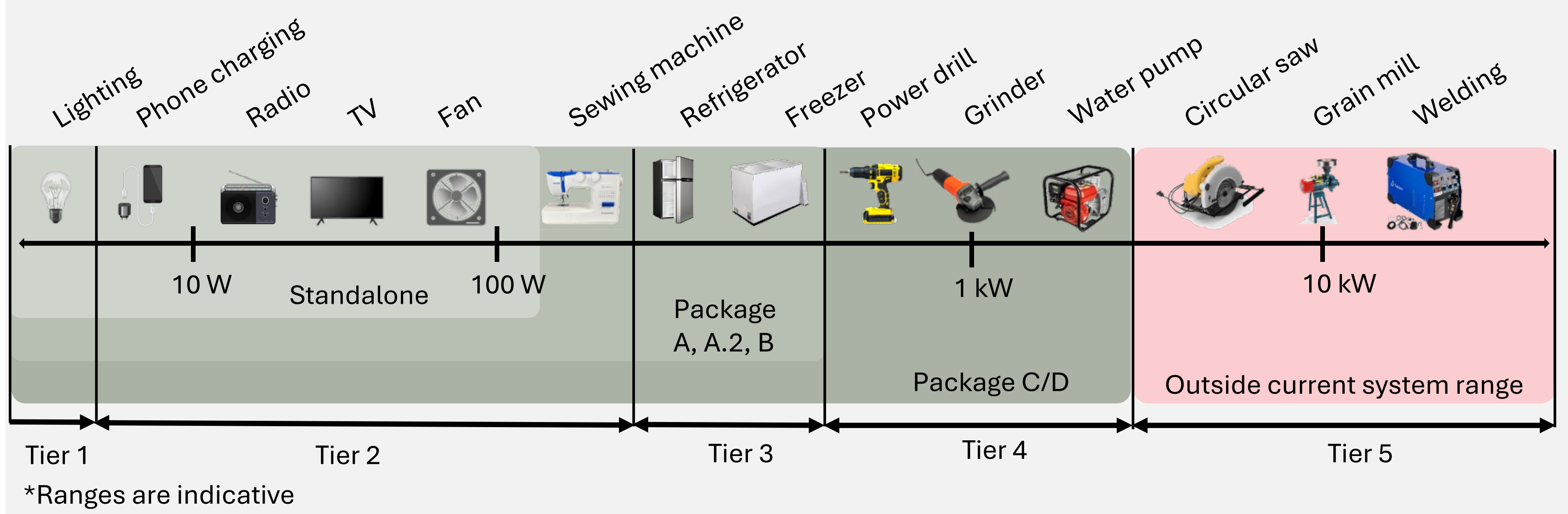
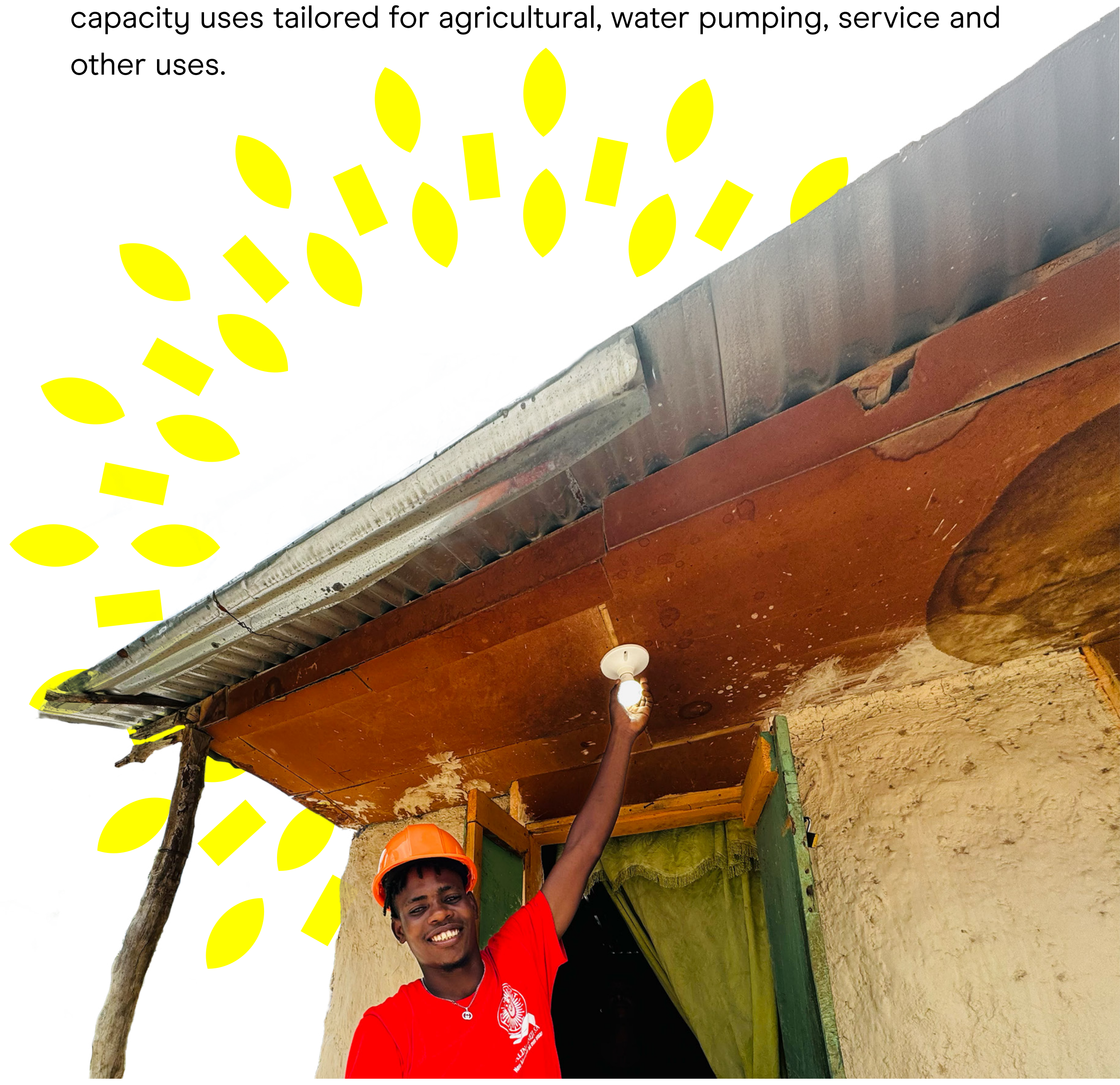


Figure 8.
Visualization of common appliances within and outside of the system range, and their corresponding MTF tier, across all energy packages.

As the following section explores in further detail, users across all energy packages are adopting electricity for a diversifying range of productive uses. Though Alina Enèji is currently charging a uniform cost across all user packages, the differentiations in capacity may later be helpful in terms of right-sizing technologies and costs to user needs. Further innovations should seek to test new configurations of existing mesh-grid components to enable higher-capacity uses tailored for agricultural, water pumping, service and other uses.



[5] These figures represent the average installed capacity per connection within each cluster. Actual capacity may vary depending on the specific energy packages chosen by individual users. All users' consumption is limited by inverter size and their selected energy package (see Table 1 for details). These numbers are intended for comparative purposes only.

Productive users drive grid profitability, with substantial room for growth.

Productive uses of electricity (PUE), per the definition from the National Renewable Energy Laboratory (NREL) are **‘activities that generate income, increase productivity, enhance diversity and create economic value through the consumption of electricity’** [23]. In rural Haiti, small, home-based PUE like printing and photocopy stores, bars and restaurants, tailoring shops and barbershops, among other examples, drive local economic activity in this sector.

Among Alina Enèji users, 27% reported that electricity has enabled new or improved economic activities. Freezers and refrigerators were the most common productive uses of electricity, with some entrepreneurs using electricity to generate income by offering phone-charging services.

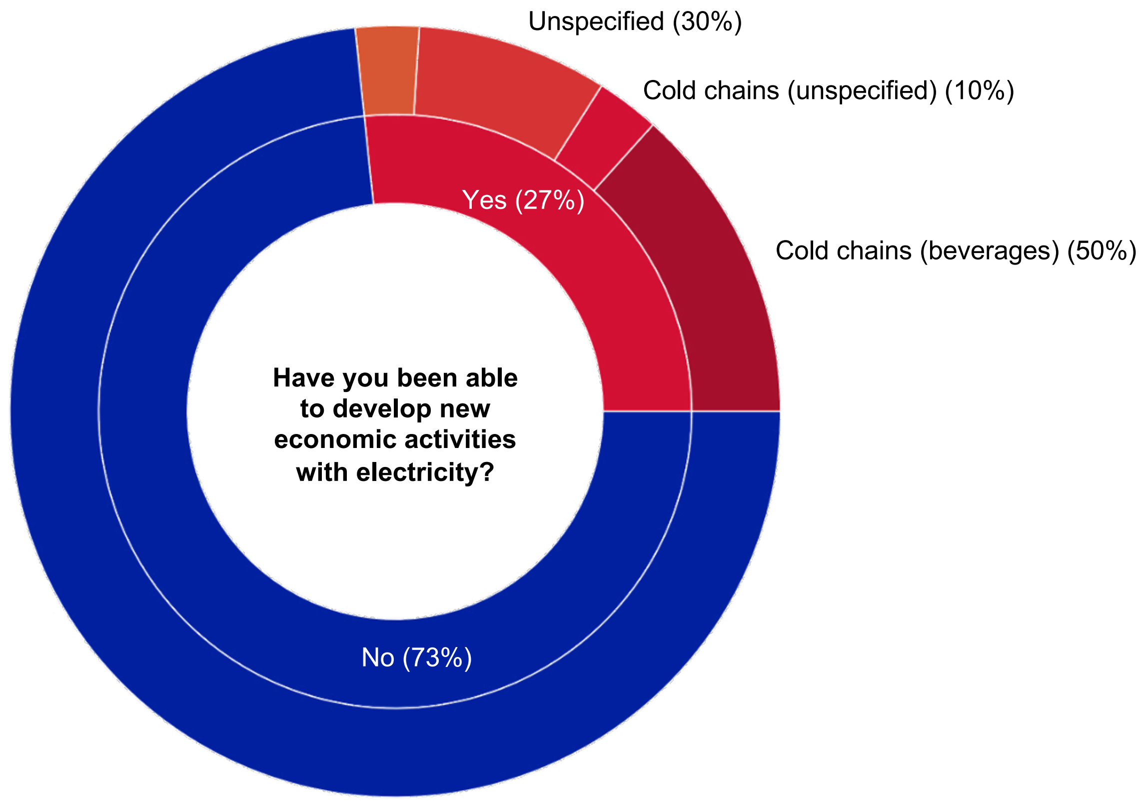


Figure 9.
Survey responses (n = 75) asking if electricity has enabled economic activities.

PUE, driven by the use of 5 and 7 cubic foot freezers, make up a disproportionate amount of Alina Enèji’s revenues. Although only 6%–7% of users subscribe to the higher-capacity energy packages (packages B, C or D), they provide on average 54% of monthly revenues. These dynamics are shown in **Figure 10**. As **Figure 11** shows, users with low-capacity systems (package A, A.2, or a stand-alone system) upload less, between $2–$3 of credit per month, compared to $22–$30 for productive users with higher-capacity systems.

Local institutions like healthcare facilities, schools, churches, agricultural cooperatives and community centers are other examples of PUE which support ‘socioeconomic opportunities, jobs and livelihoods, and quality of life’ [23], [24]. However, in Marchand-Dessalines, many institutional users have opted not to connect to the mesh-grid systems. In informal interviews, representatives of a local school and church noted that they were not connected to the system because they did not have electric appliances to power.

This points to targeted engagement with these institutions, support for purchasing and financing appliances, and collaboration with healthcare, education and agricultural development practitioners as key areas of future work. There is potential for electricity for these uses to increase the profitability of the mesh-grids while delivering important co-benefits.

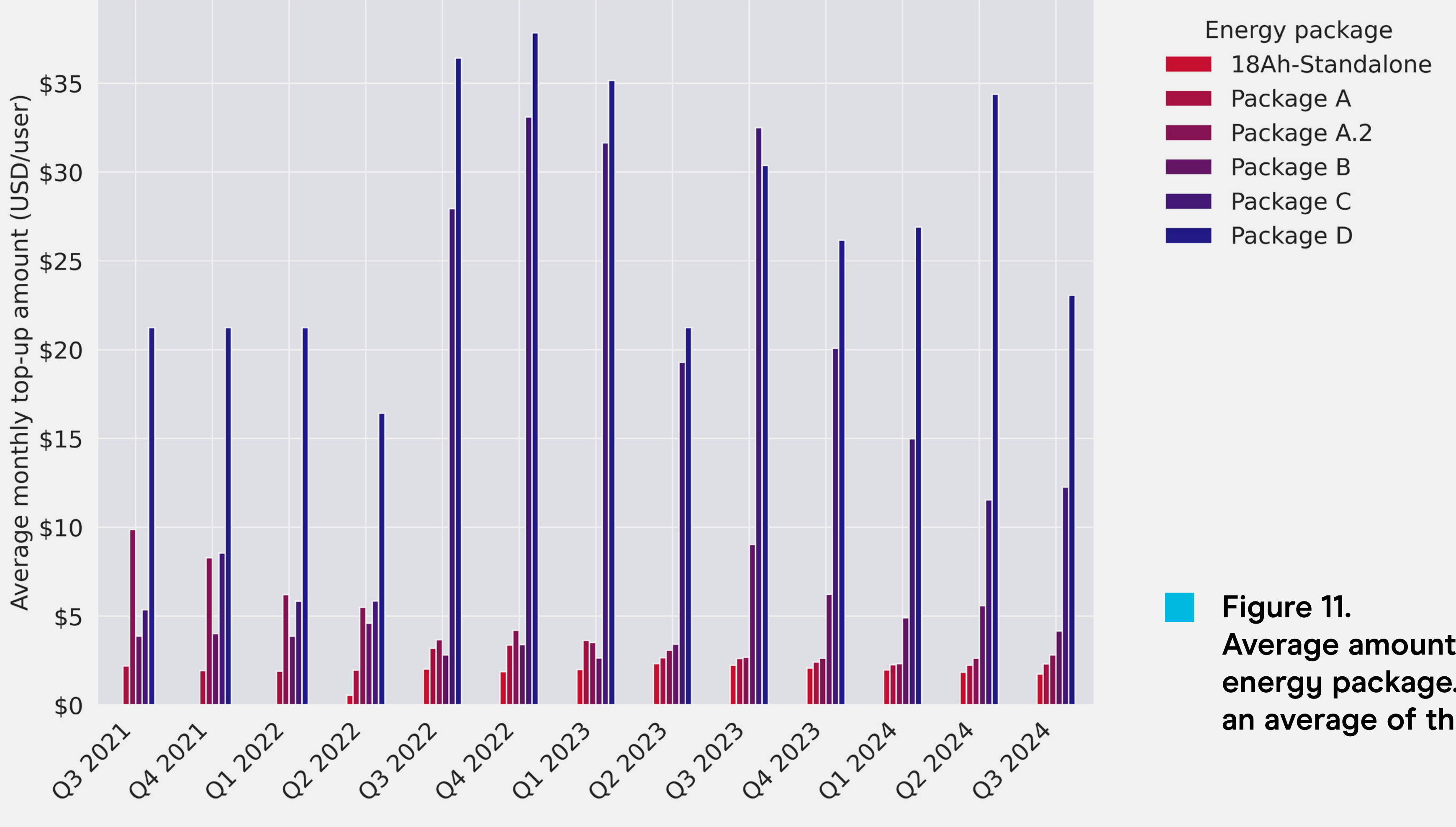


Figure 11.
Average amounts paid by users per month, by energy package. Quarter-level values represent an average of the three months in that quarter.

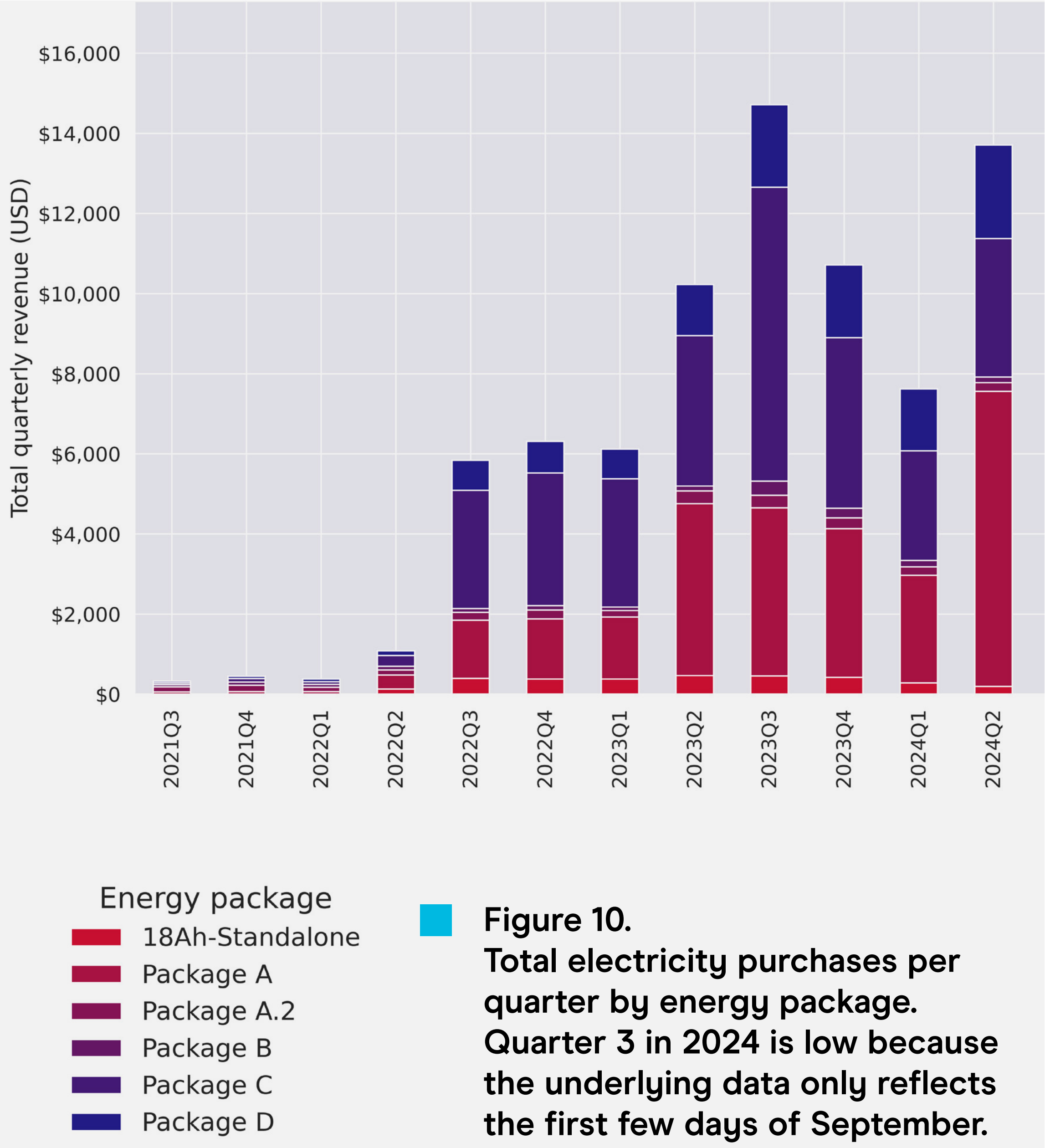


Figure 10.
Total electricity purchases per quarter by energy package. Quarter 3 in 2024 is low because the underlying data only reflects the first few days of September.

Photo
Elidor is shown with a small fridge he uses to keep cold drinks and sell them. He buys a case of 12 drinks for 600 gourdes total (50 gourdes each) and he can sell them cold for 75 gourdes each. This is a $0.20 profit per bottle. Photo and caption by Nadia Todres.

Electricity tariffs between $0.60 and $0.90 per kWh provide savings over existing fuel sources.

The cost of electricity provision via mesh-grids and how it compares to other electrification alternatives has been the topic of significant discussion among sector stakeholders. **Figure 12** shows a simple comparison of costs among existing grid-based alternatives. EDH, **the national grid, charges between $0.30 and $0.40** kWh. EDH is heavily subsidized, meaning that this tariff does not represent its full cost of production [9]. **Alina Enèji charges between $0.60 and $0.90 per kWh[6],** depending on exchange rates, with no monthly fee. Comparable existing mini-grids range from $0.40–$0.95 [17]. **As a simple levelised price, mesh-grids are not out of range of comparable systems.**

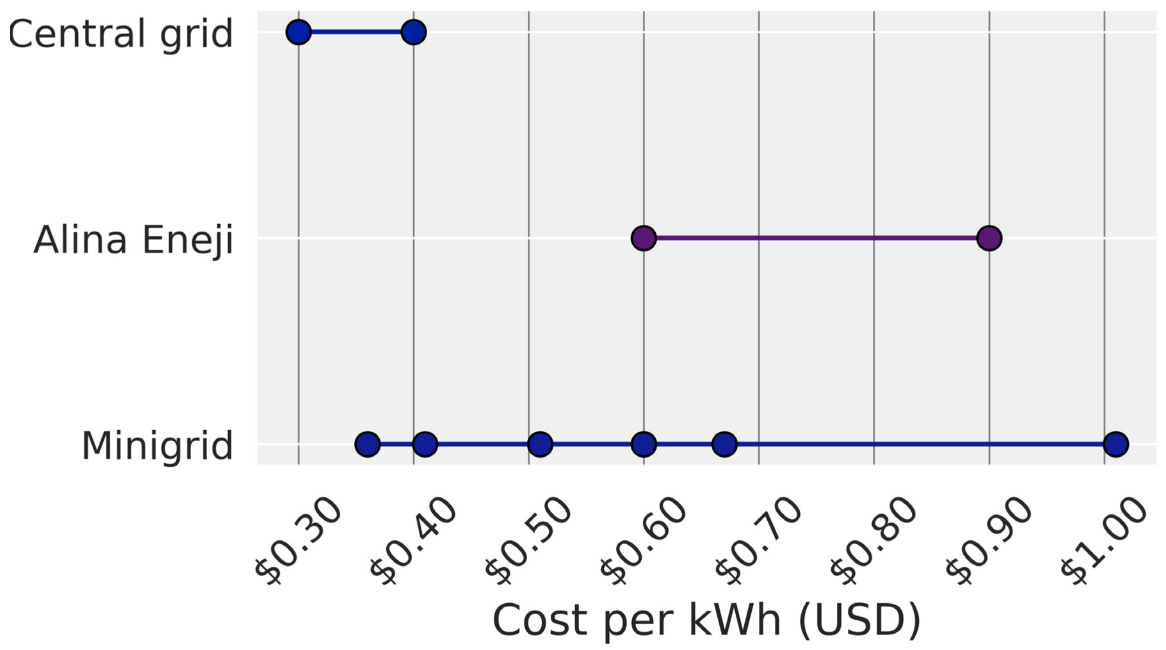


Figure 12.
Electricity tariff ranges for grid-based systems currently operating in Haiti.

[6] The price of $0.91 is derived from the original $0.75 set in January 2022, adjusted for 2.5 years of inflation based on the US Consumer Price Index, and including an additional 10% value-added tax.

Determining users' electricity burden is also helpful for understanding dynamics of affordability. A user's electricity burden is the amount of money they spend each month on electricity as a percentage of their total monthly income. We find that household users have electricity burdens in an estimated range of 1%–9%, while small businesses report higher burdens of 20%. These results should be understood as indicative, given the established methodological challenges with collecting accurate information on incomes (e.g. social taboo on divulging incomes, seasonality of incomes in agriculturally-based economies).

By the standards of ESMAP's MTF, which defines affordability as an electricity burden of 5% or less, mesh-grids are not affordable for some households [25]. For businesses, the electricity burden is of course higher given the prevalent use of freezers to sell refrigerated products. This is not altogether surprising given the extreme low incomes earned by rural people in Haiti. In Marchand-Dessalines, rough analysis of survey data suggests an average monthly income around $150 per household.

However, affordability is context-specific and must be understood in relation to other available alternatives. Rural communities like Marchand-Dessalines are too sparsely populated and low-income to offer a return on investment for mini-grid developers or for grid extension. Affordability must be compared then with realistic alternatives, which include generators, solar home systems and lanterns, kerosene and charcoal.

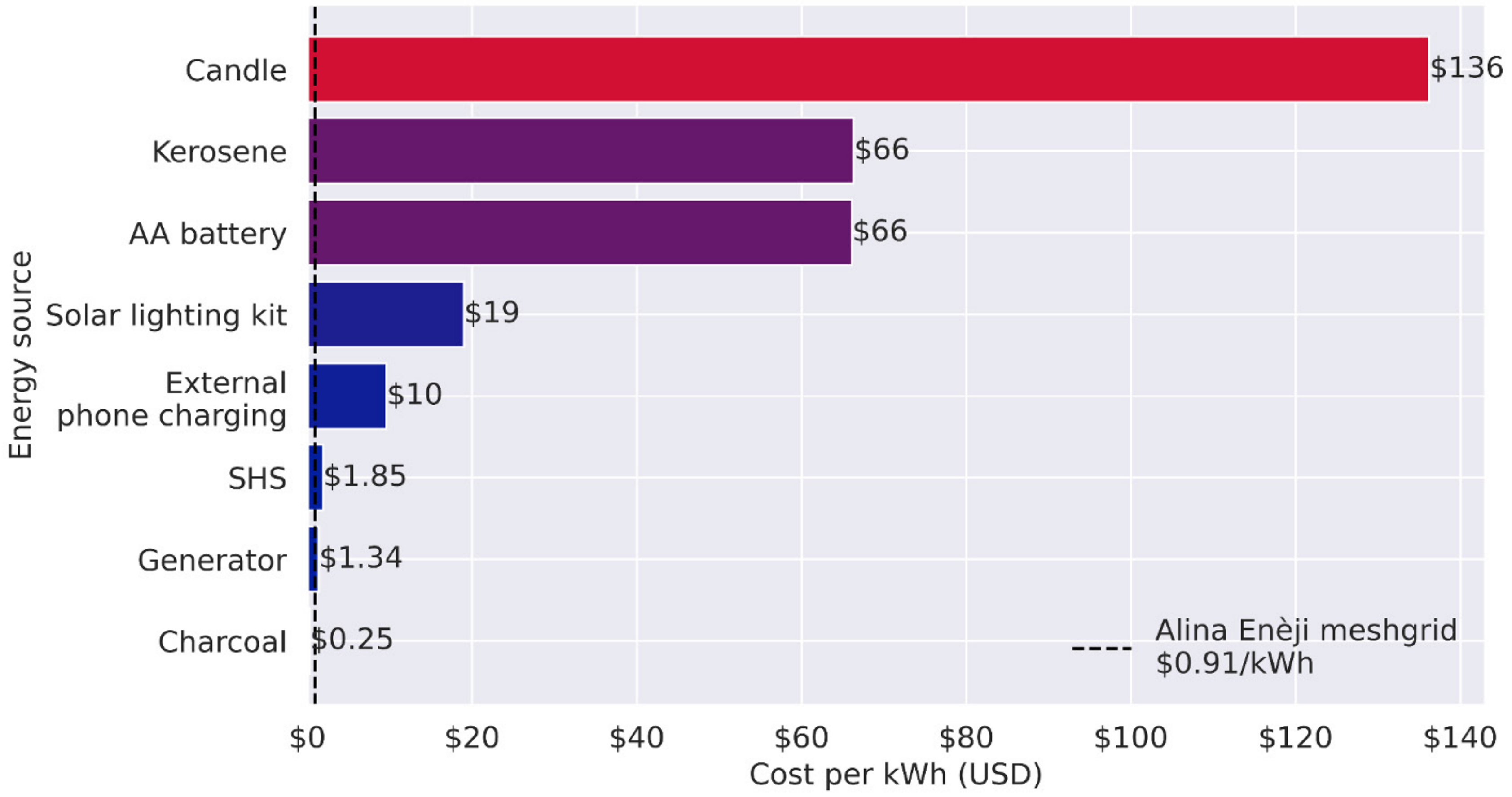
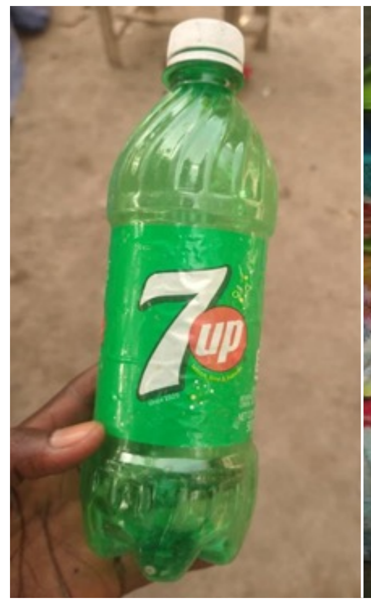


Figure 13.
Cost comparison of Alina Enèji supply with common fuel alternatives. Generator refers to a 3.2 kW portable diesel generator.

Figure 13 shows a cost comparison between Alina Enèji and other common fuel sources. The data supporting this analysis was provided directly by community members. Candles, kerosene and AA batteries are common energy sources for lighting. Converting to a per-kWh basis, their costs are an order of magnitude larger than Alina Enèji's current tariff. SHSs are the only electric-based source that are comparable at $1.85 per kWh. We estimate a levelised cost of charcoal of $0.25, which suggests that it may be difficult to transition cooking to electricity without significant tariff decreases. These simple calculations, while instructive, also do not account for differences in light quality, reliability, maintenance support and other benefits that a connection from the mesh-grid offers.



Photos
A one-liter bottle used to sell kerosene locally (left). According to a community researcher, one bottle costs 260 gourdes, roughly equivalent to $2. Kerosene is commonly used for lighting, like with the kerosene lamp pictured (center). These types of lighting solutions sometimes cause house fires within the community. Pictured right is a sack of charcoal, costing approximately $10, which can meet the cooking needs of a single household for around one month.

In soliciting feedback directly from the community, it was clear the people find value in the service. Asked in surveys, people reported that electricity improved their overall quality of life (see **Figure 14**). A community researcher noted that 'the majority of people [without lighting from Alina Enèji] tell me that they use 250–500 Haitian gourdes (roughly $2–$4) per month just to see where to put their feet during the night.' The quotes on the right show translated quotes from surveys where users explained their responses.

Responses from a question about users' satisfaction with their mesh-grid connection.

"It helps to grow the trade to give education to the children."

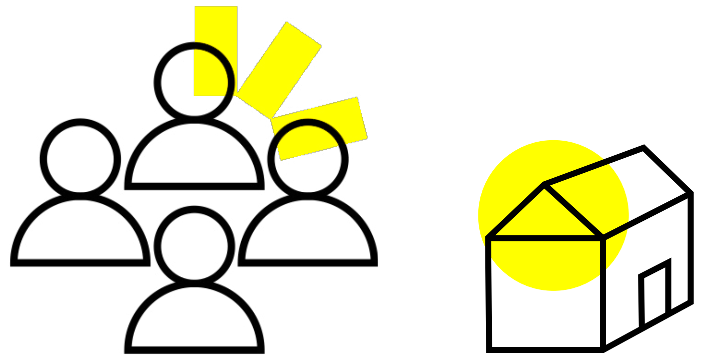
"I avoid buying gas to light my house."

"It is something that allows you to make money."

"I charge my phone in it, I don't need to send it to [other] people's houses."

"It gives me lighting and allows me to study and do my homework at night."

"It is useful to me and it helps to fight fear at night."



We do note, however, that a small number of people in surveys reported having experienced financial hardship This is supported by community-based qualitative research, which surfaced examples of users who had stopped using the system after several weeks because of an inability to pay. Although Alina Enèji's customers have a great deal of flexibility managing their expenses through a no-contract, prepaid system, moving forward there is a need for more detailed studies on ability and willingness to pay among different user groups. Affordability dynamics should be better characterized and managed to ensure that systems are affordable for vulnerable community members. As discussed in a previous section, PUE is emerging as an important revenue source, which could help to cross-subsidize lower-resourced users.

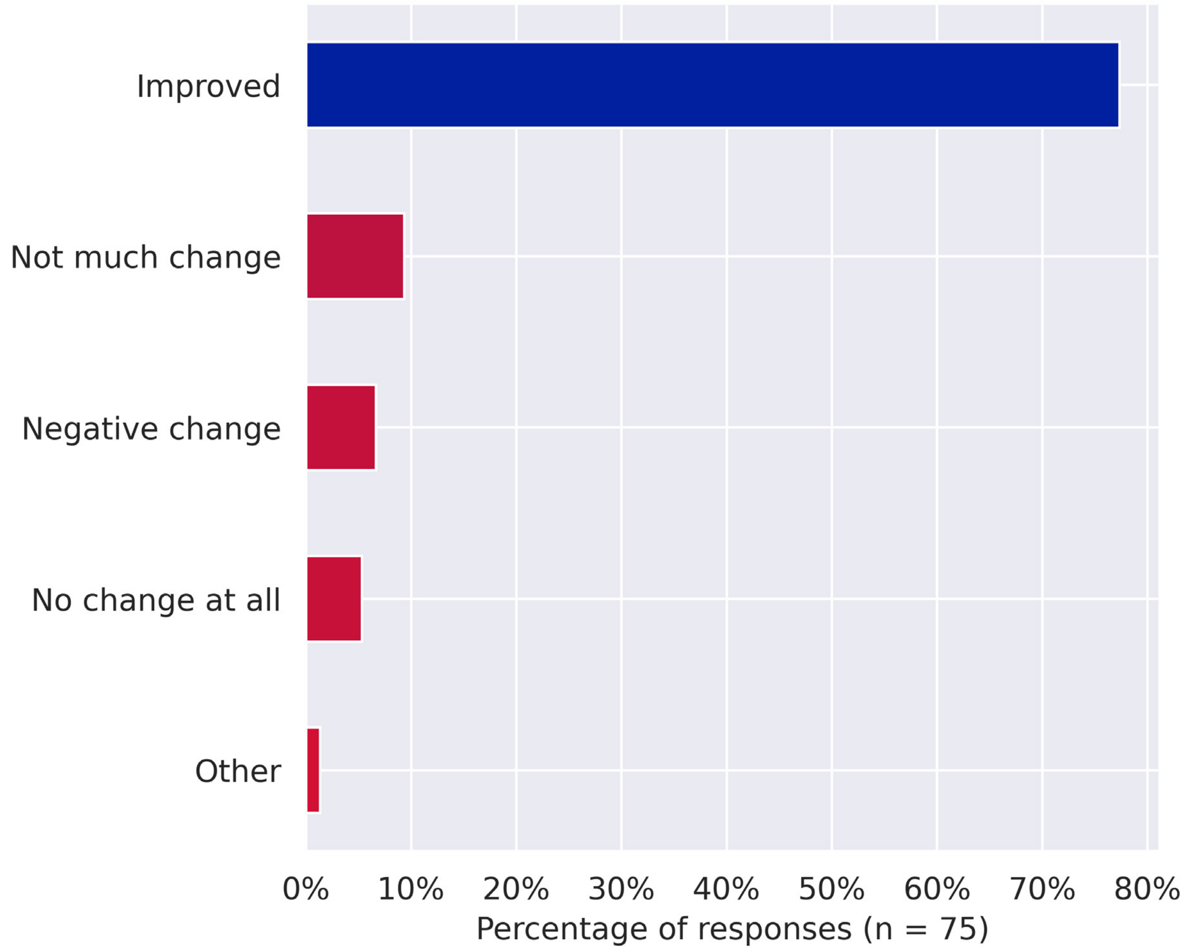


Figure 14.
Responses to survey question "Since electricity became available, how has it changed your life?".

Mesh-grids can accommodate significant future demand growth.

To analyze the energy usage among customers, we'll examine the monthly median utilization per package. The median is chosen due to the slightly skewed nature of the data distribution. A detailed breakdown of median utilization by package can be found in **Table 4.**

Energy package	Daily limit (Wh)	Median daily utilization (Wh)
A	200	80
A.2	300	102
B	500	128
C	1,000	345
D	1,500	1,115

Table 4.
Median daily utilization (Wh) per package

The graph below reveals an evolving trend in usage patterns as the project progresses through its expansion phases. The graphs on the right show the distribution of customers based on their median monthly consumption.

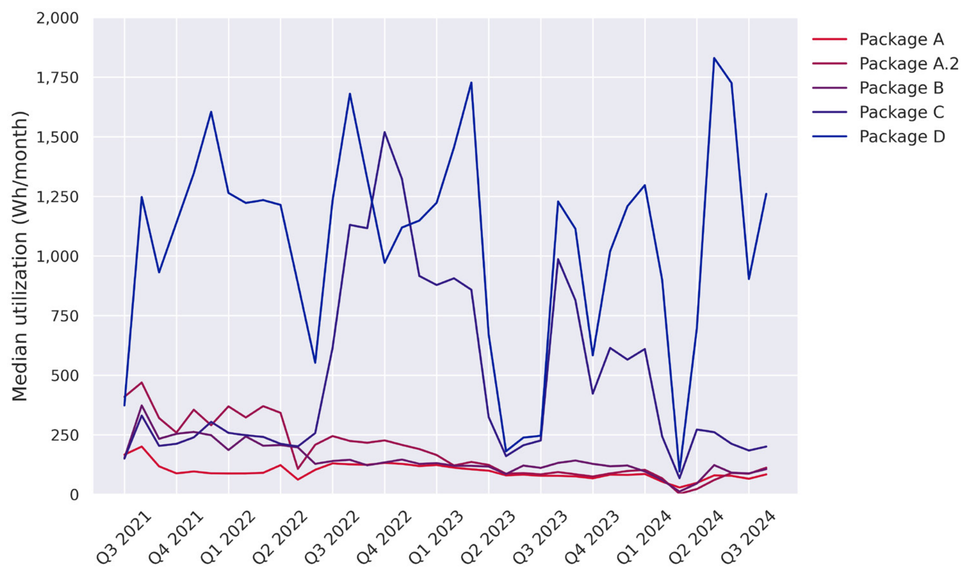


Figure 15.
Median daily energy use (Wh) per month.

To gain a more nuanced understanding, we segment customers into two clusters based on their chosen packages: lower consumption (A, A.2, B) and higher consumption (C, D). This distinction is crucial as the majority of customers opt for lower-consumption packages, while the upper-consumption packages, despite their smaller customer base, generate a more substantial portion of the project's revenue.

Most clients, irrespective of their package, predominantly fall within the lower-consumption tiers (MTF Levels 1 and 2). This observation is noteworthy, especially considering that, from a capacity standpoint, many of these customers could potentially utilize higher tiers (MTF Levels 3 and 4). This points towards a significant degree of underutilization across various packages.

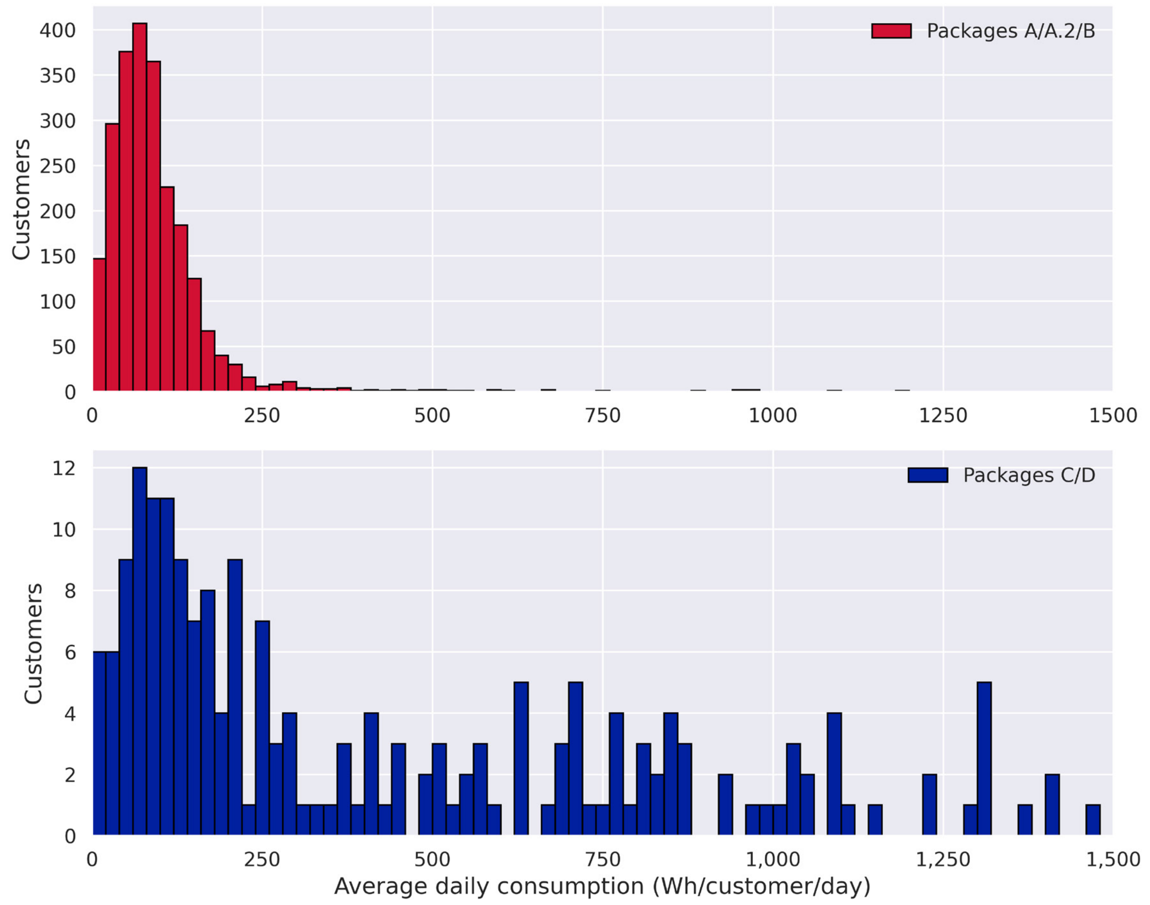


Figure 16.
Average daily consumption (Wh) of lower consumption packages (A, A.2, and B) (top) and higher consumption packages (C and D) (bottom).

Okra Solar defines 'underutilized' as active clients consuming less than 33% of their allocated energy package and under 10 Wh daily. Examining utilization data, as shown in Figures 17 and 18, since the beginning of the project, it reveals a fluctuating underutilization rate, ranging from 10% to nearly 70%.

This variability warrants closer examination, as several factors have contributed to the spike in underutilization that began in early 2024. First, this corresponds with connectivity issues related to the 2G communications network, where a significant portion of the customer base was effectively offline. During this period the remote monitoring system erroneously registers zero consumption. The second factor is the ongoing grid expansion. New customers may be registered in the system as active users several days before they begin using electricity, which similarly skews the utilization data. It is likely that the underutilization rate is much lower than data from recent months implies.

Financial constraints could also be a contributing factor. If customers face difficulty affording energy top-ups due to pricing, it is natural that their consumption would be lower. The lack of suitable appliances could limit electricity usage. If customers do not have access to or cannot afford appliances that consume significant energy, their overall consumption will naturally remain low.

Despite these complexities, the overall trend is clear: customers are not fully utilizing the system's potential. Notably, the majority of under-consuming customers are concentrated in the lower-consumption packages, while the upper-consumption packages, despite their smaller customer base, are crucial for driving the project's financial stability through their higher-consumption levels. The observed progression in energy utilization offers valuable insights into the communities. Consistent monitoring of these trends can serve as a proxy for gauging the economic and social development within the communities served by the project. To further refine their understanding of consumption patterns, a seasonal analysis could be conducted to pinpoint months with particularly low utilization. This would enable the implementation of targeted mitigation measures. Additionally, a regional study could shed light on utilization trends influenced by factors like climate, proximity to urban centers and appliance availability.

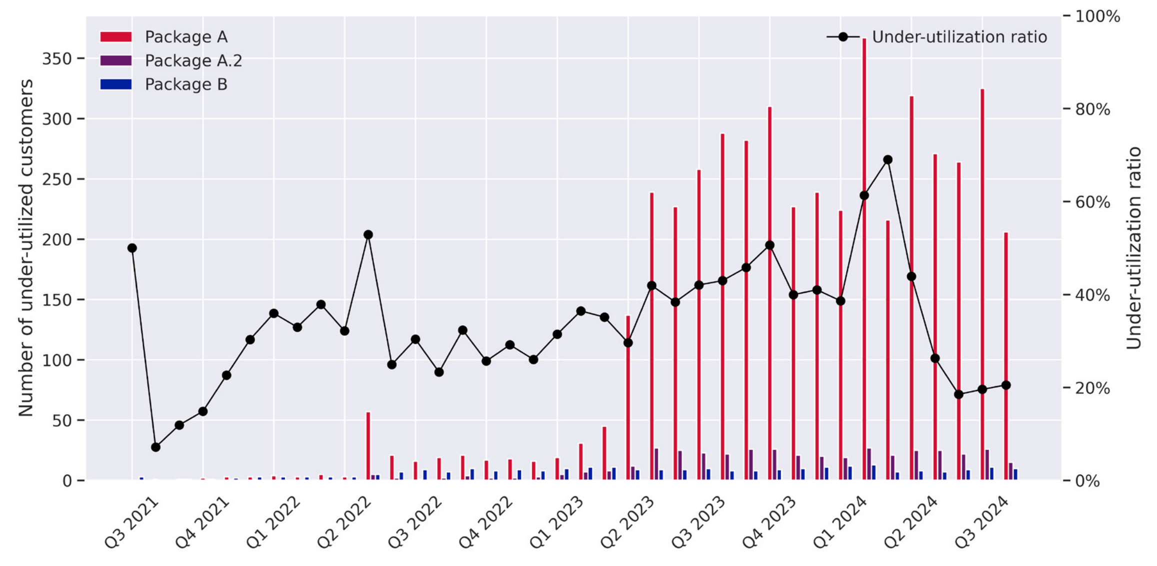


Figure 17.
Average daily consumption (Wh) of lower-consumption packages (A, A.2, and B)

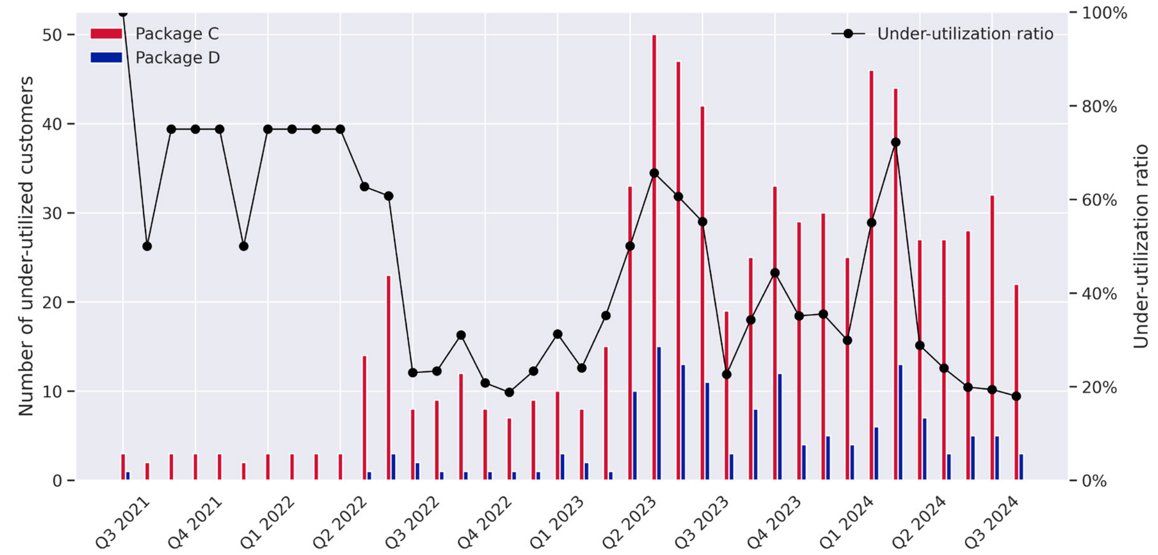


Figure 18.
Average daily consumption (Wh) of higher-consumption packages (C and D).

Mesh-grids provide superior reliability and reduce dependence on volatile fossil fuel supply chains.

Haiti's electricity access cannot be decoupled from the prevailing instability that stems from recurring disruptions in economic progress over recent years. The country has been hit by natural disasters like hurricanes and earthquakes, which have caused significant damage. Escalating gang violence has not only triggered widespread displacement, but also obstructed vital national infrastructure, hindering development initiatives. **Furthermore, fuel shortages have further exacerbated challenges, leading to the stagnation of critical sectors such as energy, a result of this being the low level of reliability of the national grid.**

The interruption of subsidized fuel from Venezuela in 2019 has triggered a cascading effect on Haiti's electricity production. Fuel shortages and price fluctuations, compounded by gang control over supply chains and fuel reserves, have severely impacted traditional power generation methods. The impact has been across the sector, from regional electrical grids such as the one in Jacmel, fuel-powered mini-grids, and generators ranging from hospital generators to small personal electrical generators. For example, the once-functioning mini-grids that worked with fuel generators saw a decline in production due to this phenomenon. This instability has stressed the inherent reliability advantage of any renewable energy production method, such as mesh-grids, which are not reliant on fuel for operation.

Mesh-grids, with their decentralized, modular, and automated design, offer a distinct advantage in terms of resilience to equipment failures or operational and maintenance errors. The distributed nature of the system ensures that issues remain localized, minimizing disruptions to only a couple of households and financial burdens compared to centralized systems like solar PV mini-grids. In the latter, vulnerabilities in energy storage systems (batteries representing 15-40% of CapEx) and inverters (6-%–15% of CapEx) can have bigger financial and technical consequences [26], [27]. Inadequate temperature control or detailed maintenance can lead to fire hazards, jeopardizing electricity access for entire communities and necessitating costly replacements.

It is important to acknowledge that with diligent maintenance and early issue detection, mini-grids can last for many years without an issue. In contrast, mesh-grids, while resilient in some respects, face unique challenges due to their distributed nature. Ensuring proper maintenance and timely identification of issues across numerous customer-sited installations can be complex. Moreover, as the equipment is located within homes, potential risks such as

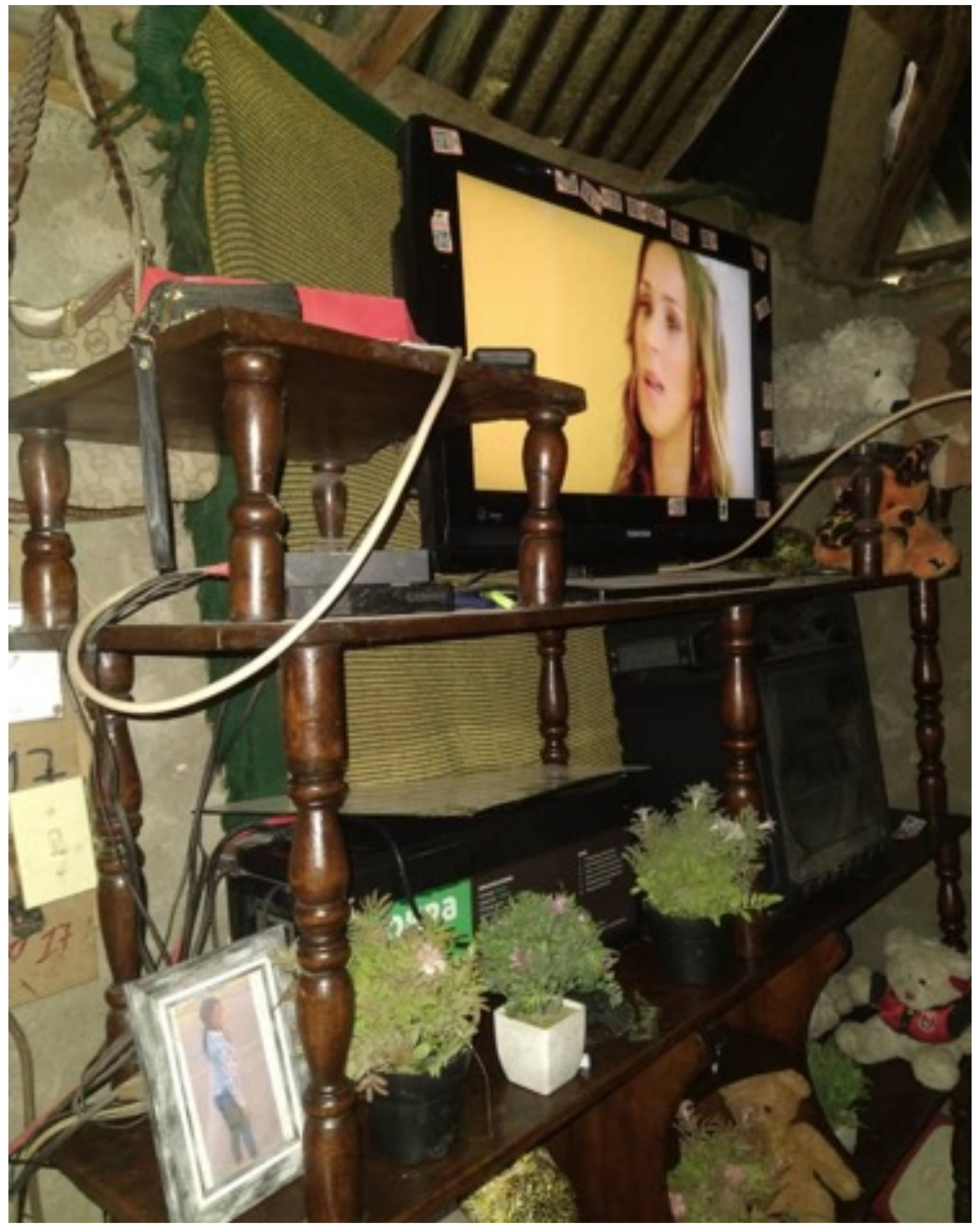


Photo
Battery in the living room of one of Alina Enèji's customers.

fire, toxic fumes and electrical discharge pose a direct threat to the households. These risks are too early to evaluate in their entirety due to the early stages of the project.

Haiti's current instability poses logistical hurdles for all development projects. Gang control over roads and transportation routes creates a volatile environment for moving goods and personnel [28], [29], [30]. While Alina Enèji has implemented its own security protocols to navigate these challenges, the risk of merchandise loss or financial setbacks remains. Fuel-dependent systems and larger infrastructure projects are particularly vulnerable to disruptions, while mesh-grids, despite requiring equipment transportation, may be less susceptible due to their modular nature.

Haiti's vulnerability to natural disasters, particularly hurricanes and earthquakes, poses a significant challenge for any infrastructure development, including energy systems. Mesh-grids, with their PV panels often installed on rooftops – typically the most vulnerable part of a house – face unique challenges in withstanding extreme weather events. In contrast, larger PV production technologies are engineered to endure winds of 100km per hour or even withstand Category IV hurricanes [31]. These provide structures of superior strength and stability, but at a much higher expense. The modular nature of mesh-grids can facilitate quicker recovery and repairs compared to centralized systems, potentially mitigating the overall impact of natural disasters.

A significant vulnerability inherent to Okra Solar's system is its heavy reliance on internet connectivity via cellular communication. When the Pod loses connection and cannot verify available credit, the corresponding household experiences an electricity outage[7]. This dependency poses a challenge in Haiti, where internet coverage is often unreliable due to limitations in the cellular network infrastructure. While Okra Solar and Alina Enèji are actively exploring alternatives to mitigate this issue, the current situation directly impacts customer experience and access to electricity. Moreover, it has financial ramifications for Alina Enèji, as customers with disconnected Pods cannot be billed, potentially undermining the project's economic sustainability.

As **Figures 19 and 20** illustrate, current coverage is quite limited, primarily confined to major cities and densely populated areas, leaving vast rural regions under-served. The images below show the coverage areas of the two major carriers, Natcom and Digicel [32].

[7] Whether a loss of telecommunications connectivity causes an outage is the choice of the developer. Okra Solar's systems also allow for electricity provision to continue offline in which case a developer would need to implement offline billing measures.

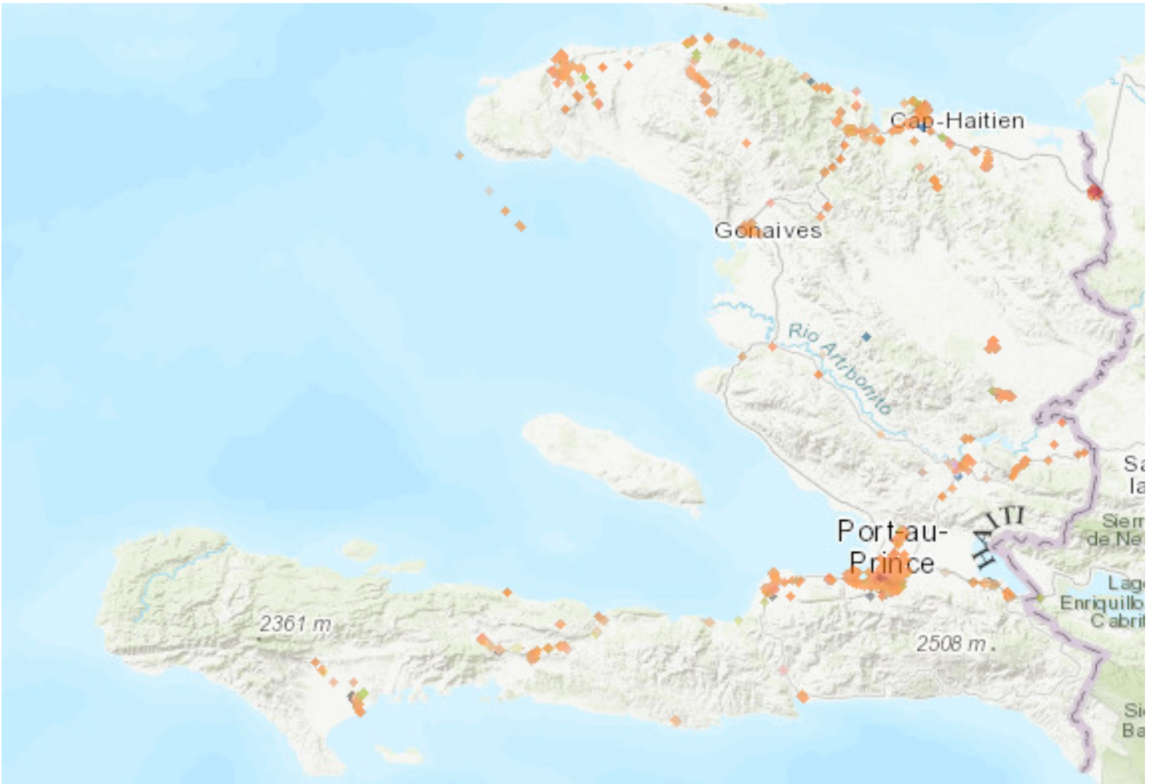


Figure 19.
Natcom antenna's positioning.

Despite the complex challenges inherent to the Haitian context, mesh-grids have exhibited impressive adaptability and growth. They have maintained a very fast pace of installations. This resilience underscores their potential as a viable and adaptable electrification solution in challenging environments. However, another test of resilience lies in their ability to withstand natural disasters. Given Haiti's vulnerability to hurricanes and earthquakes, close monitoring and assessment of mesh-grid performance during such events will be critical. This real-world data will be invaluable in informing future design enhancements and ensuring the long-term sustainability of these systems in disaster-prone regions.

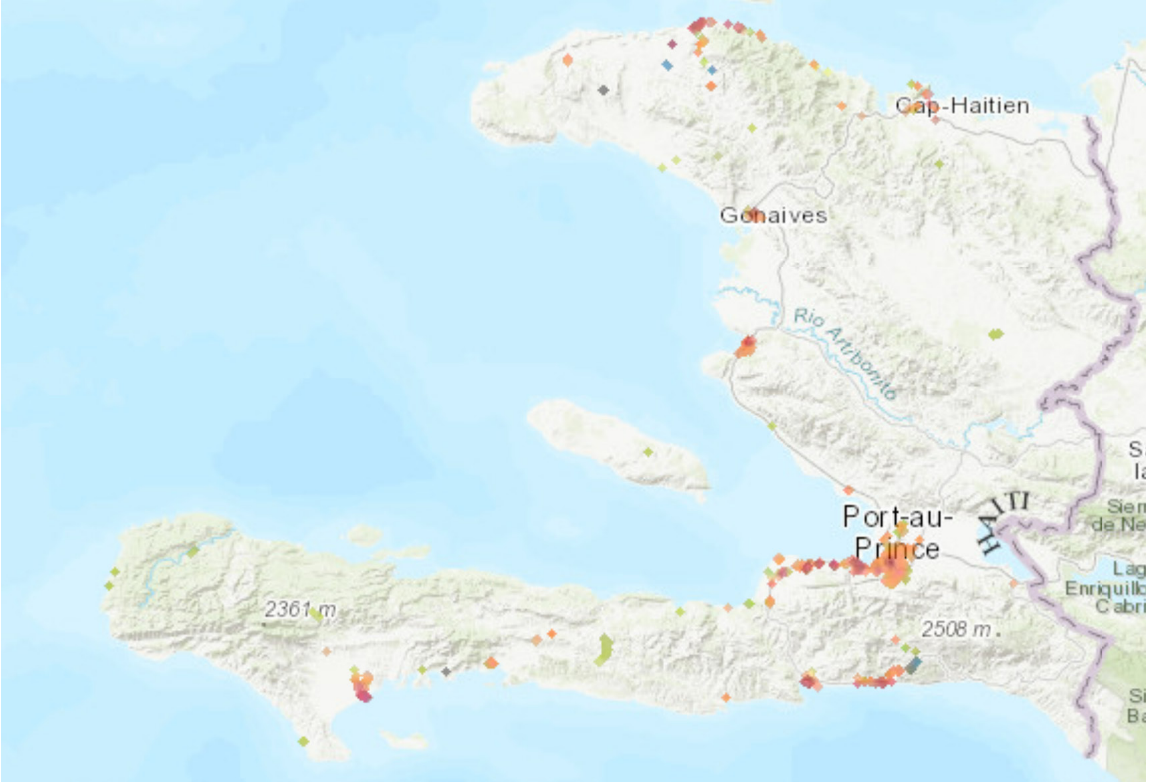


Figure 20.
Digicel antenna's positioning.

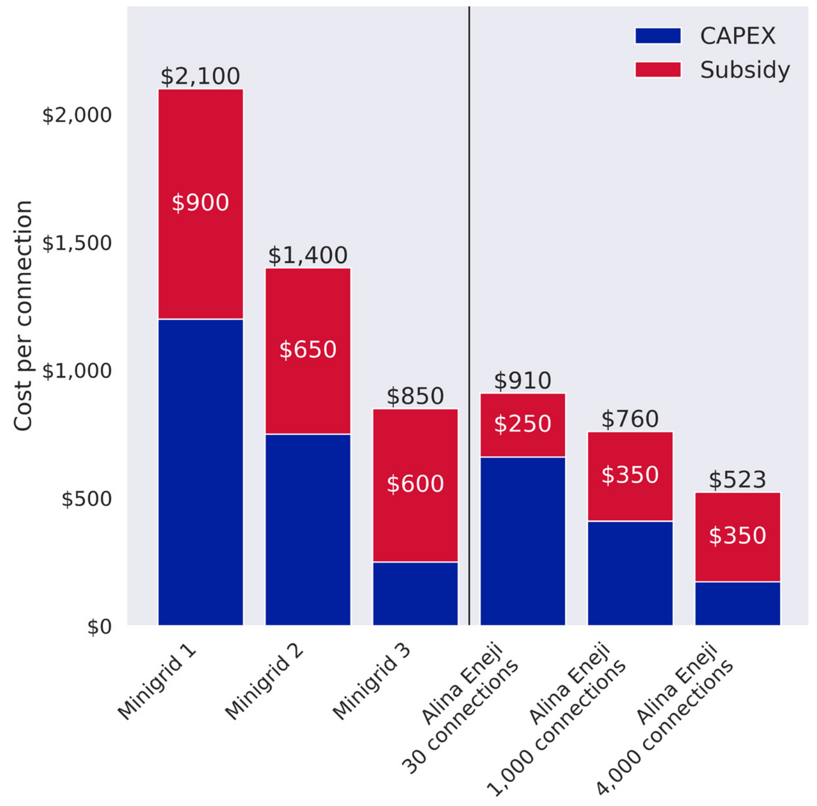
The impressive growth trajectory of mesh-grids, even in the face of logistical hurdles, fuel shortages and other challenges, speaks to their adaptability and potential for scalability. While their performance during natural disasters remains an open question, the modular nature of these systems suggests a promising capacity for swift recovery and repair. Continued observation and innovation will be key to learning and determining the full potential of mesh-grids as a sustainable and resilient energy solution for Haiti and other geographies.

Mesh-grids require lower CapEx subsidies, and have shown improving cost economics with scale.

Given the current context in Haiti, full commercial viability of off-grid systems is unlikely to be realistic in the short term. Subsidies will be needed. **The objective is to maximize the population that can benefit from the subsidies by minimizing the CapEx subsidy needed to support a viable business model.** This must be balanced with considerations of system capacity. Systems should not only be capable of meeting basic needs, but should also accommodate the PUE that are crucial to stimulating local economic development.

Mesh-grids have a CapEx comparable to SHS models currently available in Haiti. They also require only a third or a half of the subsidies required by mini-grids in Haiti. Alina Enèji's financials have also improved over time. CapEx requirements have dropped nearly $400 per connection as the company scaled from a pilot of 30 connections to a scale around 4,000 connections. A $100 increase in subsidy was deemed necessary following the pilot phase to ensure the long-term financial commercial viability of Alina Enèji. The original subsidy amount of $250 proved too low to be viable, particularly given the deteriorating political situation during this time period.

Figure 21. CapEx and subsidy requirements for mini-grids compared to Alina Enèji at various scales.



System	Country of reference	Upfront CAPEX (USD/connection)	OPEX (USD/ connection/month)	Subsidy requirement (USD/connection)
SHS†	Haiti	450	n/a	
Alina Enèji	Haiti	523	2.6	350
SHS†	Haiti	600	n/a	
Mini-grid	Haiti	850		600
Mini-grid	Haiti	1,400	5.44-7.50	650
Mini-grid	Haiti	2,100		900
Mini-grid [33]	Burkina Faso	1,500	46	

Table 5.
Cost comparison of mesh-grids versus other electrification technologies in Haiti and the reference geographies in West Africa.

† Comparison is with SHS that offers a similar service as Alina Enèji (cell phone charging, lighting, and small appliances).

Figure 21 compares mesh-grids against other electrification technologies in key financial metrics of CapEx per connection, operating expenses (OpEx), and required subsidies. We note that the figures for comparison of mini-grid systems in Haiti are based on financial plans as opposed to landed costs. Some also include other sources of concessional financing, putting the true subsidy figure potentially above $1,000 per connection.

The average revenue per user (ARPU) is a key metric to understand mini-grid economics. It describes the amount of revenue generated by each connection over a certain time period. A financial model reaches a break-even point when the ARPU is equivalent to the monthly OpEx per connection. **Figure 22** shows the progression in Alina Enèji's average ARPU and OpEx over time.

OpEx nearly halves from $5 per connection per month to $2.61 in July 2024. Declines came from efficiencies of scale in labor costs and corporate overheads. However, at the same time, ARPU steadily drops. This is for two reasons. First, there is a delay between a new user registering as 'connected' in the software and them beginning to use electricity and make payments.

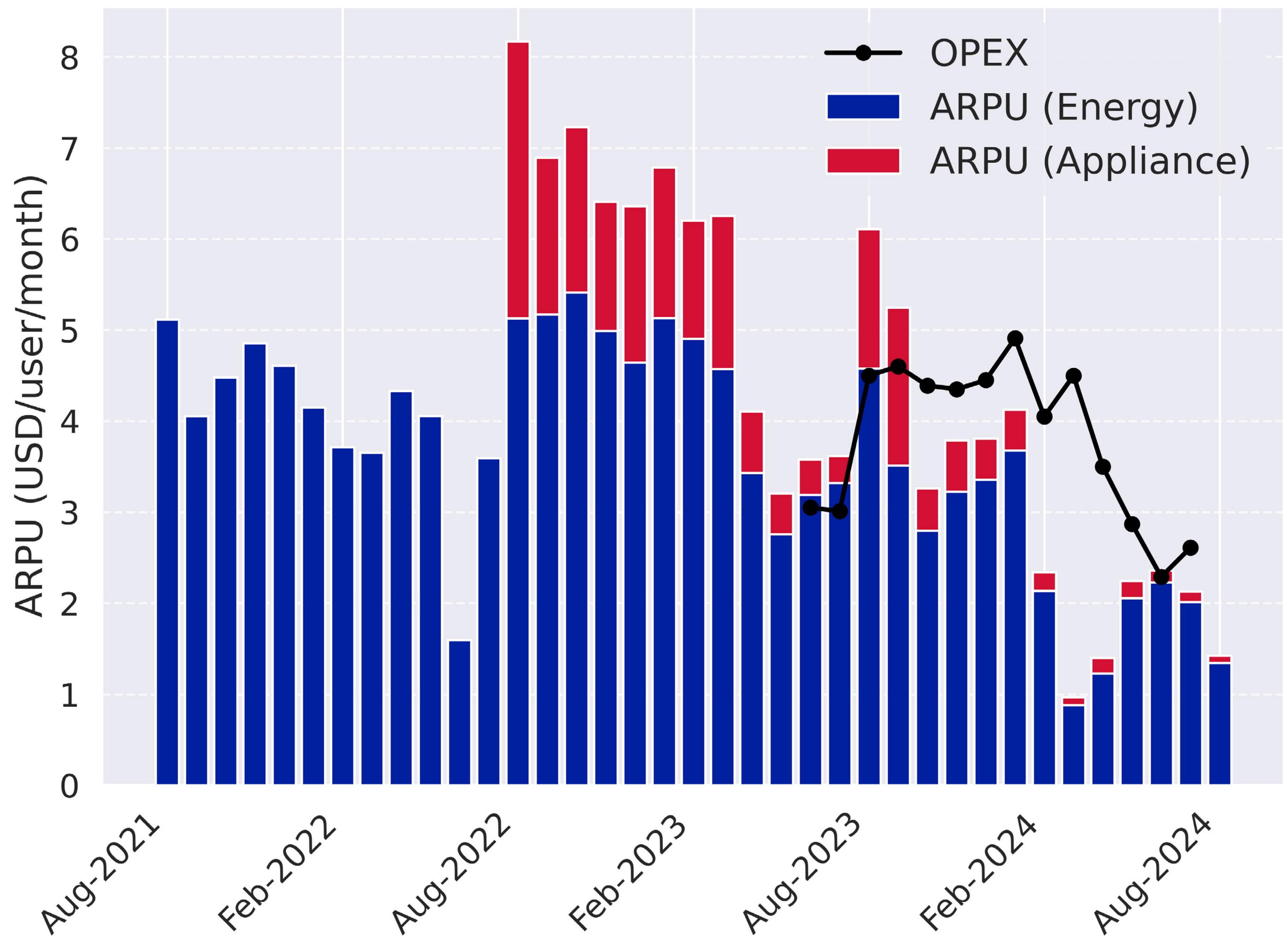


Figure 22.
Alina Enèji ARPU and OpEx over time, 2021 to 2024.

Alina Enèji has also been experiencing interruptions in telecommunications connectivity since February 2024, where the ARPU sharply declines. Digicell, the telecommunications provider, experienced a series of blackouts due to an ongoing fuel shortage in the country. This made it impossible to bill some users for several months. Nearly one-third of customers' services have still not been restored. Alina Enèji has a Wi-Fi-based solution they plan to implement with upcoming deployments.

Figure 22 points to ARPU earned from appliance sales as a potentially significant source of revenue for the company. ARPU related to appliance sales and financing is high in late 2022 but drops off over the following year. This reflects several learnings and challenges since Alina Enèji began offering bulbs, fans, blenders and freezers for sale to users. When the company first began offering customers appliances for purchase, the payment terms involved a 12-month period. High default rates prompted Alina Enèji to increase the repayment period to 36 months, meaning revenues from appliance sales dropped. Delays in importing the hardware through ports, a common challenge in Haiti, also meant that appliance deliveries and sales lagged. An estimated 300 freezers are awaiting installation, which will provide Alina Enèji a revenue bump from both appliance sales and electricity consumption.

Even with these challenges, Alina Enèji is near the break-even point. A simple ARPU-OpEx comparison, however, does not capture the full financial picture of an early-stage venture. Current business models predict that at 10,000 connections, Alina Enèji will be able to fully pay interest and overhead. However, 25,000 connections are needed to ensure the business model can make repayments on principal and provide returns on equity.

We note additional considerations that are not included in these figures but may have implications for Alina Enèji's financial sustainability. Parts like inverters and batteries may need to be replaced on a seven- to10-year timescale. Analysis suggests that over a 20-year period, these replacement costs could be as high as $330 per connection. In this case the total CapEx per connection would rise to around $850 per connection. Mesh-grids also do not have any form of insurance. Storms and other natural disasters pose an additional financial risk. Eventual disposal of electric equipment is another end-of-lifetime cost which should be considered in Alina Enèji's longer-term business plan.

Realistically, it is difficult to project replacement costs without more field evidence of system lifetimes. With systems now in operation for several years, the early evidence shows that equipment failures have been limited. Some early issues with transistor failures were easily rectified by adjusting installation procedures. PV panels and battery storage systems are also performing as expected. However, interviews of Alina Enèji customers reveal that some of its earliest customers are already beginning to experience challenges with battery functionality ('la batterie ne fonctionne pas trop bien'), which perhaps reflects the first generation of batteries beginning to reach the end of their service life within this use case.

Summarizing Alina Enèji's financial performance, mesh-grids are financially competitive with mini-grids in Haiti. They require much lower subsidies and can be installed for a lower CapEx, even considering lifetime replacement costs. Both CapEx and OpEx have decreased as the mesh-grid scales, pointing to continued scale as a key driver of commercial viability. Special efforts should seek to attract productive users who create more revenue and can help increase ARPUs even while Alina Enèji expands across a low-income user base. ARPU are likely to naturally increase over time as communities acquire appliances and become more experienced with electricity, but dedicated support to fairly source and finance appliances can accelerate this process.

Mesh-grids can be rapidly deployed with the right regulatory-enabling environment.

Thanks to the guidance, support and oversight of ANARSE's General Director, Dr. Evenson Calixte, Alina Enèji has demonstrated remarkable agility in deploying its electrification solution. The graph below underscores this, showcasing their ability to install approximately 14 new connections daily since the latest expansion started in April 2024, reaching more than 2,500 new connections in less than five months.

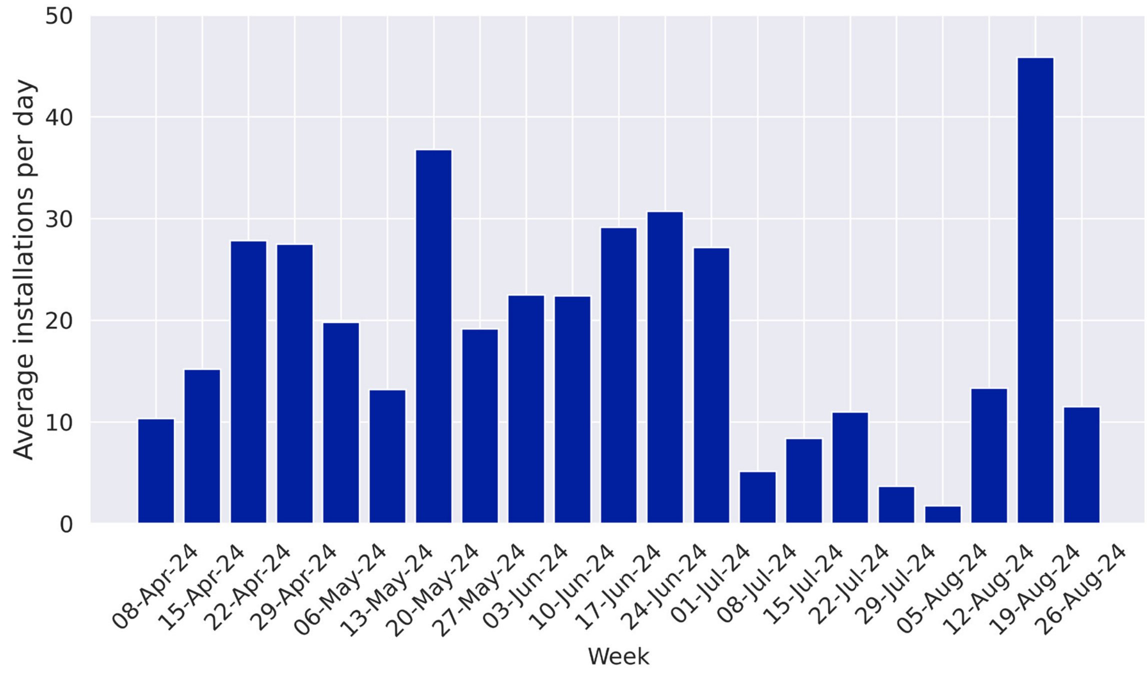


Figure 23.
Average daily installation during the latest expansion of Alina Enèji's project.

However, it's important to note that Alina Enèji's project currently operates under a special authorization from ANARSE, maintaining its pilot status. To ensure robust regulation, safeguard consumer interests and protect company assets, several considerations warrant analysis as Haiti's energy sector evolves.

Currently, the electricity sector is primarily governed by the 2016 Decree, which established ANARSE as the independent regulatory body. ANARSE and the MTPTC (Ministère des Travaux Publics, Transports et Communications (Ministry of Public Works, Transport and Communications)) are collaborating with the National Renewable Energy Laboratory (NREL) to develop specific regulations for energy systems smaller than 2.5MW. One of the goals of this initiative is to streamline requirements and approvals for mini-grids and smaller energy systems, clarify licensing, tariff setting and grid-encroachment regulations, and define technical standards. However, the implementation timeline for these new regulations remains uncertain, and given the current political landscape, modifications to the existing legal framework seem complicated. Nevertheless, their timely release would undoubtedly benefit the entire sector.

Alina Enèji's mesh-grid falls within the proposed simplified category for energy systems under 2.5MW, affording potential benefits and protections akin to other developers, including possible regional concessions. However, it is crucial to recognize the unique nature of their service model. Alina Enèji retains ownership of customer-sited equipment while providing an energy service, requiring a balanced regulatory approach that acknowledges both their role as a technology service provider and their responsibilities, such as environmental impact and end-of-life-equipment waste management.

A well-defined regulatory framework can also stimulate increased investment, enabling the project to reach a scale where subsidies and tariffs achieve a sustainable equilibrium. However, certain questions remain open, requiring further deliberation beyond the scope of this report. **Key among these are:**

- **How does the mesh-grid model align with Haiti's national electrification plan and strategy?**
- **In what ways can mesh-grids address existing technological gaps & contribute to broader energy access goals?**

4

PATH FORWARD

Haiti's electrification pathway should be guided by a focus on providing the lowest-cost solution capable of meeting the current and future needs of unelectrified communities. Alina Enèji is only one example of a growing number of Haitian-led innovations with immense potential to accelerate electrification. In summarizing our findings on Alina Enèji's performance and potential, we offer the following observations and calls to action as recommendations to policymakers, duty bearers and their partners.

Innovating along the technological spectrum

Mesh-grids fill a niche. They provide a higher capacity of electricity access than SHSs. **Although capacities are not as high as a mini-grid might offer, Alina Enèji's deployment in Marchand-Dessalines demonstrates that mesh-grids are more than adequate to meet the current needs of most rural Haitian households and businesses.** Further, given their modular design, hardware like inverters, batteries and PV panels can be added incrementally as energy needs grow over time.

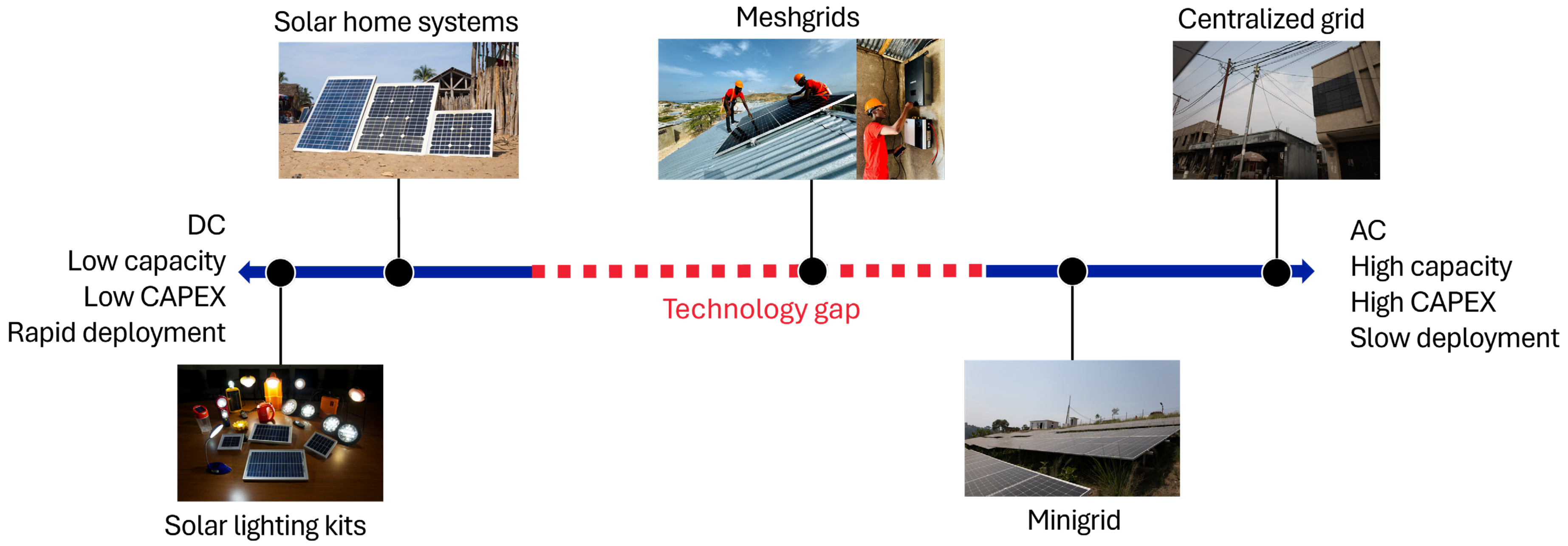


Figure 24. Visualizing the electrification technology spectrum and gap.

Mesh-grids also help address the CapEx challenge that mini-grids have faced in Haiti and elsewhere. Because they eliminate the need for costly low-voltage AC distribution networks, they can be deployed for a lower upfront cost per connection. This is valuable in a context where there is a need to stretch available subsidies across as many households and businesses as possible.

Mesh-grids are only one of many developing technologies that blur the line between SHS and mini-grids as traditional off-grid electrification technologies. Stand-alone solar-plus-battery systems with the capacity to meet an increasingly diverse range of use cases are being sold at competitive prices. Haitian enterprises like Ekotek, DigitalKap and Solengy have been successful in deploying stand-alone solar-and-battery systems ranging from 500Wp to the multi-kWp range for small and medium enterprises, residential usage and commercial applications. Targeted support should be provided for other system types (including other mesh-grid architectures) that can similarly strike a balance between adequate capacity, user affordability, rapid deployment times and optimized CapEx.

Envisioning an integrated electrification pathway

The priority for policymakers in Haiti is to ensure that energy needs are met affordably, and with high-quality and high-capacity systems that can support economic growth. Currently, the Alina Enèji's tariff is on the high end of comparable off-grid systems. However, the data shows that this reflects the real cost of providing electricity to rural communities like Marchand-Dessalines that are unlikely to be a viable candidate for mini-grids. Interactions with the community show that affordability is a challenge for users, but that electricity at the price provided by Alina Enèji can produce cost savings relative to fuel alternatives that are currently used.

Right-sizing is important when optimizing for cost and capacity. Mesh-grids perform well in this regard, as the modularity of the physical system allows for tailored configurations that can evolve with growing energy demands. This includes the addition of batteries, PV panels, or inverters, hub-to-spoke, and hub-to-hub interconnections and, potentially, interconnection with AC power sources. Further, platforms like Okra Solar's Harvest system can support the integration of multiple system types into a centralized monitoring, reporting and management dashboard. This could make it possible for a developer or multiple developers to operate mesh-grids, stand-alone systems and AC systems in parallel within a single geographic area.

The example of Alina Enèji points to a potential future of electrification that is multilayered and decentralized. A low-cost, high social-benefit pathway to electrification could involve starting with distributed generation and gradually interconnecting systems to improve affordability, capacity and service quality. Policymakers should prioritize solutions that deliver maximum benefits with minimal reliance on grants, as grant funding will always be a limiting factor. The rapidly evolving market, characterized by decreasing costs for solar PV and batteries alongside increasing transmission and distribution costs, requires continuous testing of new solutions to achieve the best value for Haiti.

Prioritizing multi-sectoral benefits

A main conclusion of this analysis is that productive uses of electricity are key to driving the financial viability of mesh-grids and to maximizing the positive impacts of electricity on lives and livelihoods. This finding is not new. The centrality of productive uses and 'anchor users' has been well-documented in electrification efforts across the African continent and in other parts of Latin America and the Caribbean.

The strategic question that remains is how PUE can best be supported to address Haiti's multidimensional development challenges like food insecurity and deforestation.
In Alina Enèji's case, PUE use has foremost been driven by small vendors operating freezers to sell refrigerated products. However, work by the Fonkoze Foundation has demonstrated the substantial potential that exists to expand the scope of PUE interventions to sectors of agriculture, health, clean cooking, education, telecommunications and beyond. Agriculture is a particularly promising sector for PUE applications, particularly in the Artibonite region where rice production is concentrated. Post-harvest losses can reach 50% due to storage conditions and the lack of processing facilities [34]. Food waste continues to worsen while over six million Haitians face acute or emergency levels of food insecurity. Electricity-enabled forms of agricultural storage and processing have the potential to increase yields and farmer incomes. Such approaches can also center women, who in Haiti often self-organize within local cooperatives and associations.

These types of approaches – where electricity is an input among broader ecosystem support mechanisms – can be extended to improve development outcomes in many other sectors. Theories of change around healthcare electrification have advanced rapidly in Africa thanks to the efforts of initiatives like the Health Electrification and Telecommunications Alliance [35]. The Clean Cooking Alliance and Modern Energy Cooking Services (MECS) have also pushed efforts around promoting high-efficiency electric cooking to ease the health burdens of indoor air pollution, particularly for women and children. Alina Enèji, and ventures like it, should seek to integrate PUE applications like these that provide win-win outcomes in terms of revenue for the developer and co-benefits for end users and the wider community.

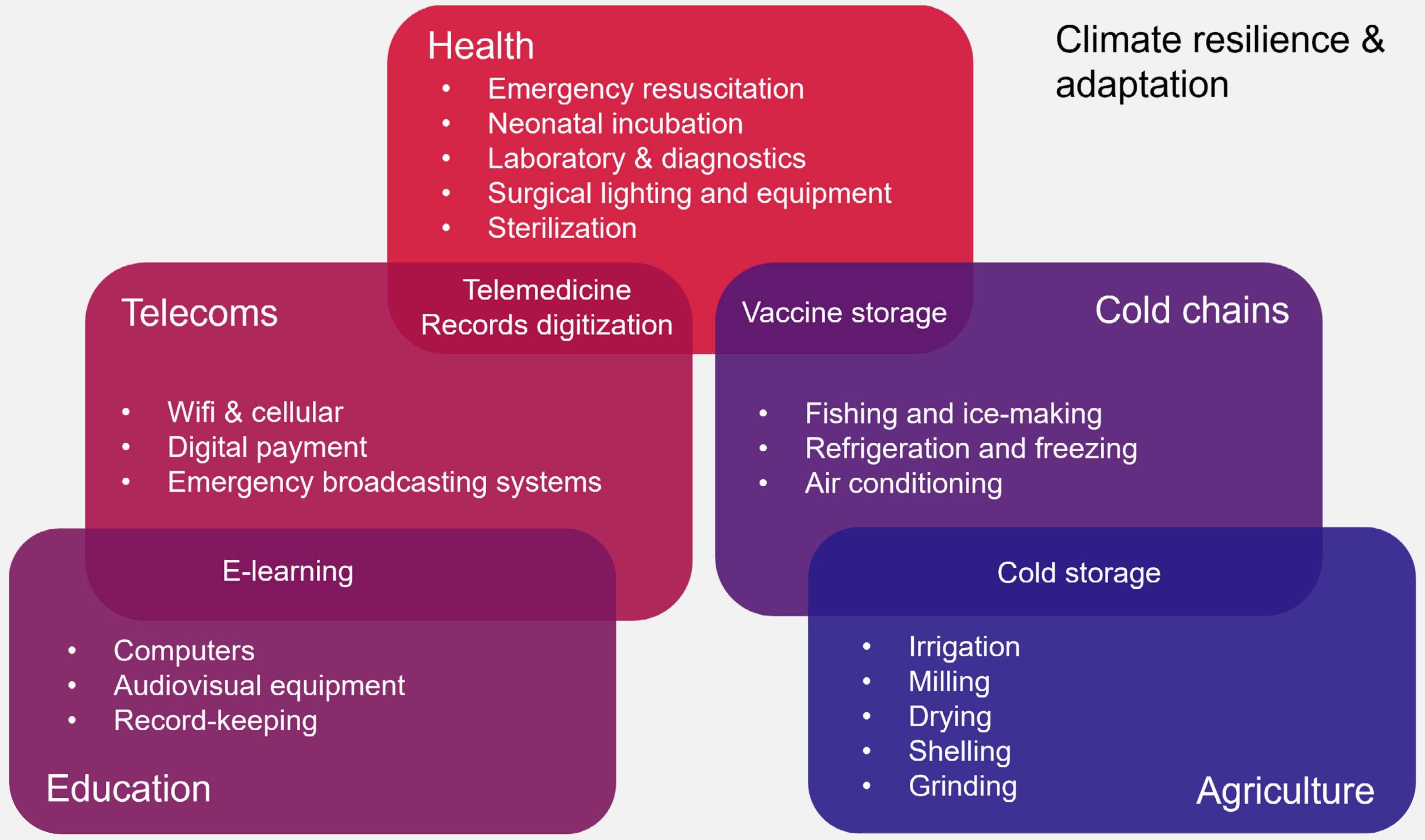


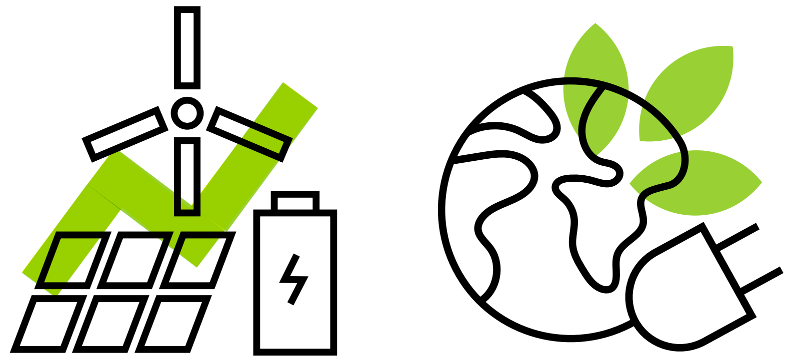
Figure 25.
Examples of multi-sectoral PUE applications and their intersections.

Accelerating a clean energy transition through Haitian-led innovation

The recent political and security crisis in Haiti has been an immense burden for the country's population and economy. However, the crisis' impacts on diesel supply chains – like the months-long blockage of the main fuel terminal in Port-au-Prince [36] – have created a window of opportunity for solar-based energy systems to flourish. **Haitian-led enterprises, like Alina Enèji, Solengy, Ekotek, and DigitalKap have demonstrated a capability to navigate the difficulties of Haiti's current operating environment while capitalizing on market conditions that are demanding resilient, decentralized energy solutions.**

Further support for Haitian enterprises can ensure this wave of innovation continues. The track record of the Off-Grid Electrification Fund (OGEF), co-managed by the Fonds de Développement Industriel (FDI)[8] and Bamboo Capital Partners, has demonstrated that funds with specific, well-defined objectives and a narrow focus can adapt to the evolving market in Haiti. OGEF's success also derives from their ability to provide bespoke financial support, combining elements of private equity, venture capital and debt lending to meet each venture's specific needs. However, additional financing for local ventures, either through OGEF or through funds like it, is an urgent need.

Rigorous data collection, evaluation, and learning processes are also central to guiding strategic decision-making in the off-grid sector. Remote monitoring technologies that provide real-time and transparent insights on system performance not just to the grid operator, but also to investors and regulators, are emerging as the gold standard. We recommend integrating this as a basic requirement of off-grid deployments moving forward. These data inputs provide sector stakeholders the tools they need to evaluate the strengths and weaknesses of technology alternatives and to understand the contexts in which they are most appropriate.
To ensure Haiti's energy future is driven by resilience and innovation, we must deepen the financial and technical support for Haitian entrepreneurs leading clean energy transitions. This begins by amplifying the efforts of local developers and scaling solutions that are already proving successful in meeting the needs of rural Haitians. The future of Haiti's energy landscape lies in harnessing the ingenuity of its people, whose innovations are charting a path towards a sustainable and independent energy future.



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THANK YOU

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