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PROJECT UPDATE

Solar4Clinics Benin

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Abstract: Within the framework of the Solar4Clinics project we monitored 20 health facilities in Benin regarding their electrical energy consumption. Amongst those, 15 sites were able to send sufficient data for evaluation. We find a wide range of energy demand from below 1 up to 60 kWh per day. Regarding the daily load profiles three different types have emerged: day-driven, night-driven and balanced. Considering peak load and time-resolved energy consumption we find that two Tiers of the monitored health facilities could be powered by A2EI's AAM-Series of solar generators.

Introduction

The project Solar4Clinics was executed by A2EI / GIZ[2] in collaboration with the Benin Ministry of Health. Based on a list of 20 health facilities (HFs) we have developed a data gathering exercise consisting of installing remote energy logging devices on-site, live tracking of consumption data via our data platform *Prospect* and subsequently evaluating individual load profiles. The geographical location of all sites is shown in Fig. 1 (a) with color coded on- and off-grid connection in pink and gray, respectively. In this report we investigate the following questions:

(i) Is there a standard load profile for off-grid/on-grid HFs?
(ii) What is the average load/pattern of usage?
(iii) Is A2EI's solar generator a suitable hardware for some of the smaller clinics? If yes, how many?

While we observed a reliable data transmission from all grid-connected HFs, solely half of the off-grid sites were capable to do so and subsequently were not considered for this study. This was mainly due insufficient GSM network connection for data transmission. According to the classification provided by the ministry the facilities are categorized regarding size and equipment ranging from Village Health Center over Subdistrict Health Center up to Community Health Center (CSC) as listed in Appendix A. In this report we will focus on exploring the on-grid facilities assuming that the respective load profiles are not being limited by energy access as it can be the case for off-grid operation. However for the sake of completeness and comparison the latter will be presented as well. The data record behind this report ranges from April to November 2022 and comprises measurements of the total energy count and the time resolved load recorded every minute.

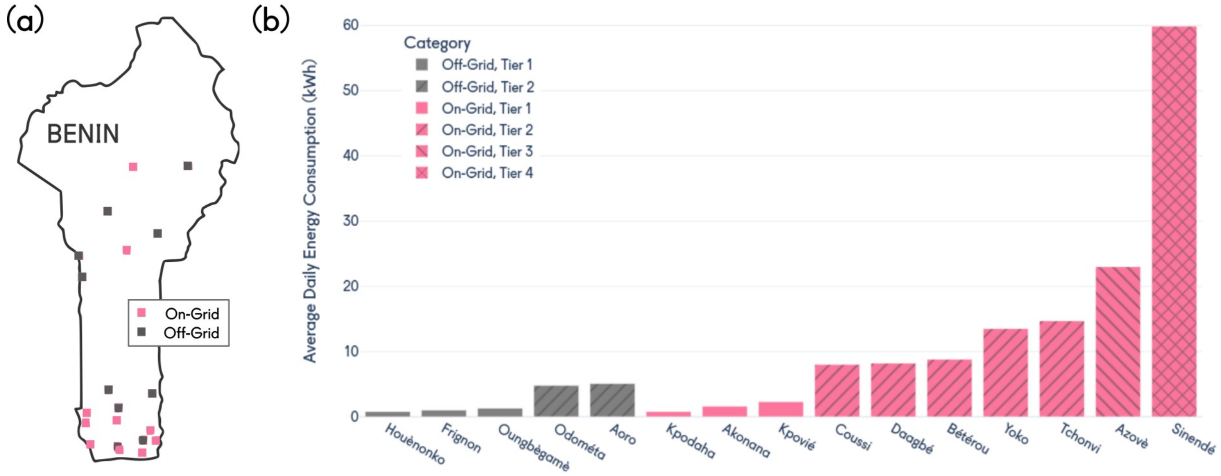

Fig.1: (a) Geo locations of selected health facilities. (b) Average daily energy consumption.

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[2] The German service provider in the field of international cooperation for sustainable development and international education https://www.giz.de/en

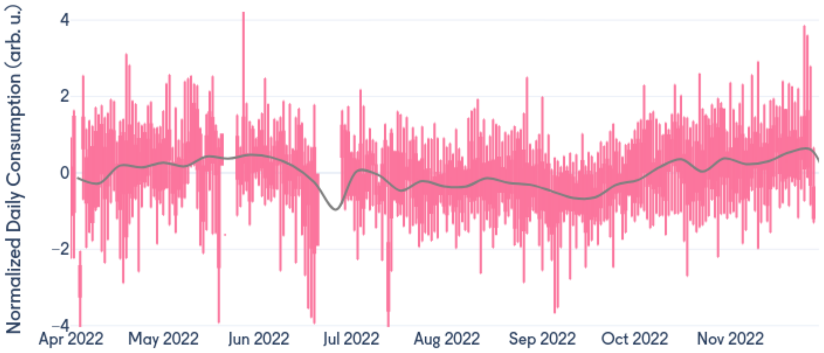

Fig. 2: Energy consumption for all health facilities normalized and aggregated per day for a time range of eight months (pink). No significant seasonality can be found in the trend line (gray).

Energy Demand

For determining individual energy demands the energy counter has been resampled to daily time chunks which were subsequently averaged over the full measurement period. The results are shown in Fig. 1 (b) with the network connection color coded in pink and gray for off-grid and on-grid facilities, respectively. The site classified regarding their extrapolated yearly demand in terms of Tiers following Ref. [1]. Marked as pattern shape in the figure we find six Tier1, seven Tier2, and one Tier3 and Tier4 HF, respectively, translating into an observed daily energy demand from around 1 kWh (Houènonko, Kpodaha) up to 60 kWh (Sinendé) per day.

At this point it needs to be stated that some of the monitored off-grid HFs own DC appliances such as 24V-fridges (see Appendix A), which were often direct-driven and not part of the AC network, thus preventing us from monitoring. Any deeper investigations focused on those type of facilities should take this into account and potentially add a set of modeled data. Also our attempt of treating all data equally throughout of course is only valid if no seasonality exists in the data. To confirm this we normalized all time series, aggregated into daily bins and analyzed the respective temporal development. As shown in Fig. 2 the trend line ranges around zero with a slight positive peak around June and a minor negative trend in September with an almost equally distributed scattering throughout the whole time range. This lets us assume that seasonality is only of minor importance in this study.

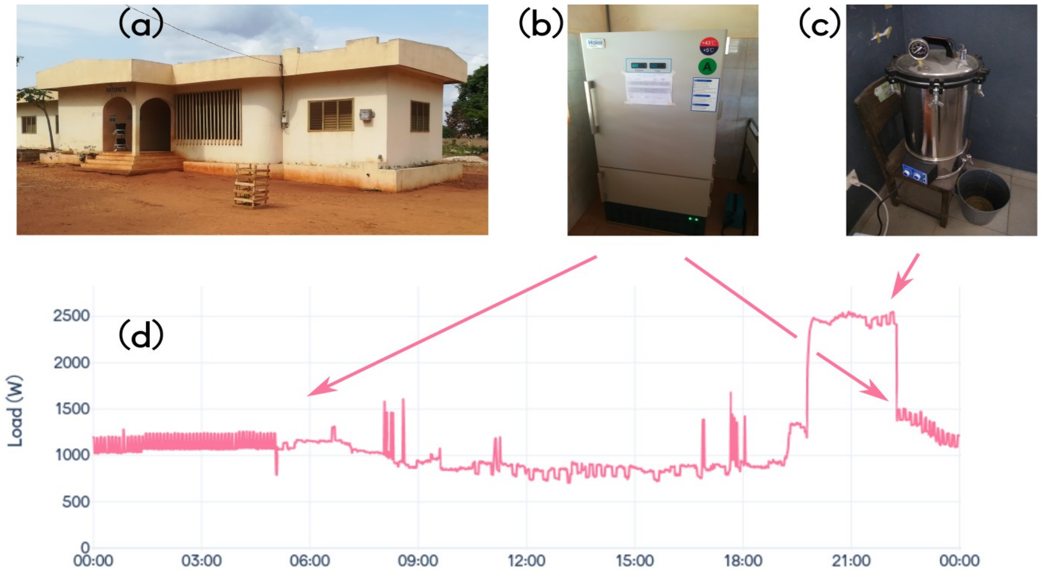

Fig. 3: Pictures of the health facility Azovè building (a), Fridge (b) and Autoclave (c) with their respective features marked in the total power consumption time series data (d).

Load Profiles

Due to individual appliances (see Appendix A) and HF types a variety of load profiles was observed. With power measurement taken on a one-minute time base we are able to detect typical appliance features in the time traces, such as:

- Illumination: Lights such as LED bulbs and fluorescent tubes represent a rather constant base load and typically show highest consumption at evening hours and a steady load during night.
- Fridges: Pharmacy fridges resemble a basic requirement for all HFs containing a dispensary. In many cases those are DC-driven and directly supplied by solar using water pack freezing capacities as battery equivalent. AC-driven fridges typically consume 200 to 500W during operation and can be identified as single-digit square wave signatures, indicated in Fig. 3 (b).
- Autoclaves and Sterilizers: Inevitable for any health facility are autoclaves which are used for sterilizing medical equipment. These typically require a constant power in the range of 2 kW and are usually running around one hour in case of dry heat sterilization [2] which is exemplary shown in Fig. 3 (c). Sterilizers however consume a similar amount of power but typically run only for several minutes and can be identified as peaks rather than plateaus as compared to autoclaves. Due to limited energy availability many off-grid HFs use LNG-powered sterilizers.

- Water Pumps: Another group of large appliances with a rated power in the order of 2 kW is represented by pumps. Typically those pumps run several hours and are usually used for filling water reservoirs. Thus they cannot be distinguished from autoclaves in case both devices are connected to the same energy meter.

In Fig. 3 we show an exemplary day of operation of the facility *Azovè* (a) in Couffo department containing features of a fridge (b) and an autoclave (c) as highlighted in the time series data (d). The distinct peaks at around 08:30 and 18:00 most likely originate from an operating printer since the demand is around 500 W and lasts for less than a minute (note here that power measurement happens instantaneously while energy measurement is aggregated). Furthermore the graph shows a minimum and peak load for that day of 700 W and 2600 W, respectively.

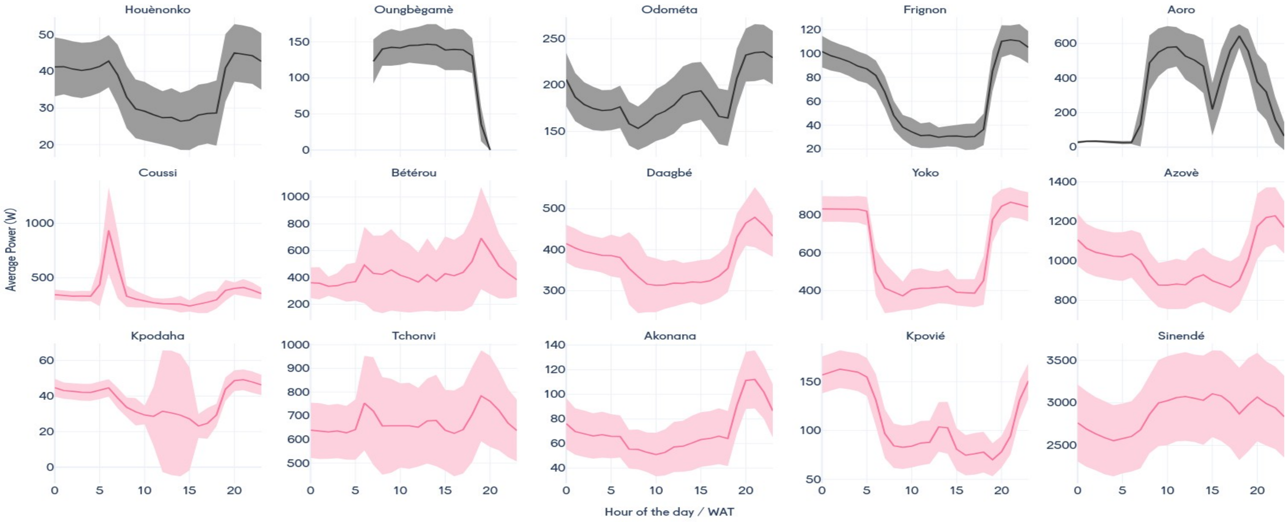

Fig. 4: Load profiles of all metered health facilities over local daytime plotted in pink (on-grid) and gray (off-grid). Solid lines represent the average power, the filled area marks the variance.

In order to identify typical load profiles and recurring patterns we aggregated all operating days of the 15 HFs and and grouped their load measurements into time chunks of one hour duration. We retrieved the hourly average load as well as the standard deviation as a measure for the scattering. In Fig. 4 we show the individual load profiles with off-grid centers plotted in gray and on-grid in pink. Solid lines represent the average load over the hour of the day and solid areas mark the standard deviation. Focusing on the relative development rather than absolute values, we identify three distinct pattern in the data, which will be discussed in the following.

Day-Consumers: The sites *Aoro* and *Ounbègame* show no or minor consumption during the night which lets us assume that either the facilities do not operate at that day time or no sufficient electric energy is available. Since both facilities contain a maternity and a number of illumination appliances the latter case is most likely due to broken battery banks.

Night-Consumers: The sites *Houènonko, Frignon, Yoko, Kpodaha,* and *Kpovié* show increased energy demand during nights when compared to day times. The consumption is thus mainly driven by illumination and no larger appliances are used during the day. For those facilities we assume that essential heavy consuming devices such as sterilizers and fridges are not really absent but rather driven either directly via DC-connected solar systems or via fuel generators and subsequently cannot be monitored.

Mixed-Consumers: A mix of the former listed cases applies for the sites *Odométa, Coussi, Bétérou, Daagbé, Azovè, Tchonvi, Akonana,* and *Sinendé*. Since those facilities seem to be less limited by energy availability we assume that those load profiles can be considered as "typical". The consumption during the day and at night differs only slightly with a major peak around 20:00 and two minor peaks and 6:00 and 13:00, respectively, which might result from special events such as lunch break and shift handovers. In contrast to day- and night consumers we observe an increased scattering of the load data during daytime. This is mainly due to a random distribution of usage times of large appliances such as pumps and sterilizers during the day. Note that the special case *Coussi* was added to this group since all features apply when neglecting the 6 o'clock peak, which explicitly originates from a water pump running every morning consistently.

Resulting Requirements

Aiming to power certain Tiers of HFs by appropriately scaled solar systems we translate the individual consumption patterns into a list of requirements. Breaking such a system down into its main components, i.e., inverter/charger, solar panel and battery the following needs have to be met:

- The installed photovoltaic (PV) panels need to be sized large enough to yield enough energy for covering the total daily consumption
- The inverter(s) need to be able to not only cover all peak loads but also accompanying surges
- The battery bank needs to minimum cover the nightly energy demand

An overview of all corresponding key metrics regarding load, energy demand and PV scaling is collected in Tab. 1 and will be discussed in the following. Note that the proper scaling of solar systems would require sophisticated modeling, which is outside the scope of this report. We will therefore limit ourselves to the provision of data added with basic processing for estimating certain needs.

PV-Panel: The photovoltaic power potential in Benin ranges from 3.6 to 4.4 kWh/kWp per day [3]. Considering the lower bound of 3.6 kWh/kWp and assuming losses of 40% in transmission and electric conversion we calculate the estimated PV panel size via:

[PV Peak Power in kW] = [Energy Demand in kWh/day] / 3.6 kWh/kWp*day * 1.4

Inverter/Charger: We consider a confidence interval of 99% of all daily peaks for estimating the inverter size. This would allow to cover almost all load spikes during operation and at the same time to not over-scale the system due to outliers. Additionally we add a safety margin of 20% originating from the recommended steady-state inverter operation of 80% of the rated power:

[Inverter Rated Power in W] = [Peak Load at 99% Confidence] * 1.2

Battery: Even though the amount of Lithium-Ion batteries in Sub-Saharan mini grids is increasing, most systems still use Lead-Acid for storing electrical energy due to low acquisition costs, fair lifetime and good recycling capability [4]. Thus assuming a typical total usability of 70% of the battery storage and adding a margin of 20% with regard to e.g. battery degradation we find:

[Battery Size in Wh] = [Energy Demand at Night in kWh/day] / 0.7 * 1.2

Usually the three discussed components do not scale fully independently.

A2EI's Solar Generators

With the A2EI not only providing on-the-ground research, but also developing solar systems and appliance prototypes tailored to specific local demands we developed the *AAM* Series solar generators. Those are designed as a hybrid uninterruptible power supply that offers a clean, reliable and cost-effective energy source for Nigerian small businesses. In essence, they can replace small fuel generators.

The systems are fully IoT enabled which allows not only for remote monitoring, but also allows for the pay-as-you-go functionality. In combination with the A2EI developed open source data platform Prospect we are able to track, analyze and visualize key performance data such as, e.g., energy production and consumption, usage patterns, and various maintenance details (see Appendix C). This allows for continuous optimization of the long-term performance as well as tracking the progress of electrification towards the sustainable development goal SDG 7.

Currently two systems are available with differently scaled inverters, charge controllers and batteries:

- 2000 W with 24 V / 50 Ah Lead Carbon batteries (880 Wh usable) / 2500 W max. PV input
- 3000 W with 51.2 V / 50 Ah Lithium batteries (2200 Wh usable) / 4000 W max. PV input

Details about the system can be found in Appendix B. Considering the specifications collected in Tab. 1 we find the potential of supplying the following Tiers of HF with the AAM systems.

Table 1: Energy demand and retrieved requirements of all monitored health facilities. Off-grid facilities are listed in gray since they might be limited by lack of energy availability rather than demand. The shading indicates facilities which could be powered by either one (pink) or two (orange) of A2EI's *AAM* series solar systems. Intervals from total energy demand mark the standard deviation.

Health Facility		Metered Demand						Resulting Requirements		
Name	Connection	Total Energy Demand (kWh/day)	Nightly Energy Demand (kWh/day)	Energy Demand (kWh/year)	Level	Base Load (W)	Peak Load / 99% conf. (W)	Inverter Rated Power (W)	PV Panel Peak Power (Wp)	Battery Size Pb (Wh)
Houènonko	Off-Grid	0.8 ± 0.3	0.5	300	Tier 1	35	120	---	---	---
Frignon	Off-Grid	1.0 ± 0.7	0.6	400	Tier 1	53	310	---	---	---
Oungbègamè	Off-Grid	1.3 ± 0.4	0.0	500	Tier 1	130	900	---	---	---
Odométa	Off-Grid	4.3 ± 1.5	2.4	1600	Tier 2	179	430	---	---	---
Aoro	Off-Grid	5.1 ± 2.6	1.0	1900	Tier 2	48	990	---	---	---
Kpodaha	On-Grid	0.8 ± 0.3	0.4	300	Tier 1	36	760	900	300	700
Akonana	On-Grid	1.6 ± 0.6	0.9	600	Tier 1	59	220	300	600	1500
Kpovié	On-Grid	2.3 ± 0.8	1.3	900	Tier 1	110	770	900	900	2200
Coussi	On-Grid	8.0 ± 1.9	4.1	2900	Tier 2	310	4000	4800	3100	7000
Daagbé	On-Grid	8.2 ± 1.8	4.3	3000	Tier 2	350	2000	2400	3200	7400
Bétérou	On-Grid	8.8 ± 2.4	4.0	3200	Tier 2	310	5000	6000	3400	6900
Yoko	On-Grid	13.5 ± 3.6	8.5	4900	Tier 2	590	2200	2600	5200	15000
Tchonvi	On-Grid	14.7 ± 3.6	6.9	5400	Tier 2	570	3600	4300	5700	12000
Azovè	On-Grid	23 ± 6	12	8400	Tier 3	990	3100	3700	8900	20000
Sinendé	On-Grid	60 ± 20	27	22000	Tier 4	2800	8800	11000	18800	46000

Tier 1: All facilities with a daily demand of up to 5 kWh can be supplied with one AAM 2000 system.

Tier 2: Depending on the load distribution one AAM 3000 systems is able to supply those facilities.

Tier 3+: Those facilities need larger scale solar systems such as mini grids for C&I installations for sufficient power supply.

Regarding the Tier 2 sites, some assumptions need to be done. First, the separation of large appliances to distinct circuit phases would enable the operation of an additional AAM system for covering higher peak power demand. As stated before, for systems with integrated charge controllers the PV panel size is directly limited by the inverter rated power. This also leads to the demand of a second AAM system in case of high energy consumption in the absence of large load peaks. We conclude that generally Tier 2 facilities with only one large appliance (autoclave, pump) and a rather lower edge energy consumption could be powered by one AAM 3000 system.

Facilities with more appliances and/or a larger base load would require a second system. We do not consider installations with more than two systems at this point since in case of bigger demands the operation of a mini grid or C&I system can be more efficient.

Summary

In this report we present a study based on the remotely monitored energy consumption data of 15 health facilities of different sizes in Benin. While observing limited consumption for the off-grid operation we were able to categorize the sites into four different Tiers regarding the level of energy demand. The individual load profiles could be classified into three different types with the main type (intermediate) being the one least limited by energy availability and thus considered as "typical" within this study. Considering the different demands we identified four sites which could potentially be powered by a solar generator from A2EI's AAM series. Additionally the combination of two such systems seems to allow sufficient supply for another four facilities, assuming the largest appliances would be separated to different electrical phases. We thus assume that one or a combination of two AAM solar generators would generally cover the demands of the first two Tiers while larger sites would require larger C&I systems or even mini grids.

References

[1] Moner-Girona, M., Kakoulaki, G., Falchetta, G., Weiss, D.J., and Taylor, N. (2021). Achieving universal electrification of rural healthcare facilities in sub-Saharan Africa with decentralized renewable energy technologies. Joule 5, 2687–2714.
[2] https://www.sciencedirect.com/topics/engineering/heat-sterilisation
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[4] Lockhart, E. et al. (2019). Comparative study of technoeconomics of Lithium-ion and Lead-acid batteries in micro-grids in sub-saharan Africa. Power Africa, NREL/TP-7A40-73238.

Funding

Appendix A – Health Facilities Detailed

Table 2: Detailed list of all health facilities. V/SD/C HC – Village/Sub-District/Community Health Center.

Name	Department	Commune	District	Type	Latitude	Longitude	Connection	Appliances			
								Appliance –	Type –	Power (W) –	Quantity
Frignon	Donga	Bassila	Bassila	VHC	9.12	1.6	Off-Grid	LED tube	AC	36	4
								Fan	AC	70	1
								Fridge	DC	180	1
								LED bulb	AC	9	7
~~Toko-Toko~~	~~Donga~~	~~Djougou~~	~~Bariénou~~	~~VHC~~	~~9.74~~	~~2.01~~	~~Off-Grid~~				
Aoro	Donga	Bassila	Bassila	VHC	8.83	1.65	Off-Grid	Fan	AC	70	5
								LED bulb	AC	9	15
Houènonko	Atlantique	Tori	Tori-Bossito	VHC	6.49	2.16	Off-Grid	LED bulb	DC	6	16
								Fridge	DC	180	1
								LED spotlight	DC	60	1
								LED spotlight	DC	10	1
								LED bulb	AC	9	5
~~Dunkassa~~	~~Borgou~~	~~Kalalé~~	~~Dunkassa~~	~~SDHC~~	~~10.36~~	~~3.15~~	~~Off-Grid~~				
Oungbègamè	Zou	Djidja	Oungbègamè	SDHC	7.27	2.02	Off-Grid	TV	AC	70	3
								Fridge	DC	180	1
								Bulb	AC	9	26
								Fan	AC	70	6
								Radio	AC	20	2
								Sterilizer	AC	2000	1
								PC	AC	60	1
								Printer	AC	510	1
								Fridge	AC	250	1
~~Zoukou~~	~~Zou~~	~~Zogbodomè~~	~~Zoukou~~	~~SDHC~~	~~7.02~~	~~2.17~~	~~Off-Grid~~				
~~Darnon~~	~~Borgou~~	~~N'Dali~~	~~Gbegourou~~	~~VHC~~	~~9.43~~	~~2.72~~	~~Off-Grid~~				
Odométa	Plateau	Pobè	Odométa	SDHC	7.23	2.64	Off-Grid	LED spotlight	DC	60	16
								Bulb	AC	9	19
								Sterilizer	LNG	-	1
								Fan	AC	70	17
								TV	AC	70	1
								Fridge	DC	180	1
								Water pump	AC	2000	1

Name	Department	Commune	District	Type	Latitude	Longitude	Connection	Appliances			
								Appliance	Type	Power (W)	Quantity
~~Kessounou~~	~~Ouémé~~	~~Dangbo~~	~~Kessounou~~	~~Dispensary~~	~~6.58~~	~~2.52~~	~~Off-Grid~~				
Coussi	Atlantique	Toffo	Coussi	SDHC	6.85	2.14	On-Grid	Fan	AC	70	2
								Fridge	DC	70	1
								TV	AC	70	1
								Water pump	AC	2000	1
								LED bulb	AC	9	27
Azovè	Couffo	Aplahoué	Azovè	SDHC	6.95	1.71	On-Grid	LED bulb	AC	3	42
								TV	AC	70	2
								Printer	AC	510	1
								Fridge (big)	AC	250	2
								Autoclave	AC	2000	1
								Fan	AC	70	24
								Stand Fan	AC	70	1
Akonana	Mono	Athiémé	Atchannou	Maternity	6.52	1.77	On-Grid	Energy saving bulb	AC	25	3
								LED Bulb	AC	5	2
								Fan	AC	70	2
								Fluorescent tube	AC	35	1
								LED Tube	AC	36	4
								Sterilizer	LNG		1
Daagbé	Plateau	Ifangni	Daagbé	SDHC	6.58	2.7	On-Grid	TV	AC	70	1
								Fridge	DC	180	1
								Bulb	AC	40	12
								LED bulb	AC	9	33
								Fan	AC	70	18
								Sterilizer	LNG		1
Kpovié	Atlantique	Ouidah	Pahou	Maternity	6.45	2.18	On-Grid	LED spotlight	DC	100	2
								Bulb	AC	40	8
								Fan	AC	70	4
								Sterilizer	AC	2000	1
								Fridge	DC	70	1
								LED Bulb	DC	8	9
								Fan	DC	45	1
								Fridge	DC		1
								LED spotlight	DC	60	2
Sinendé	Borgou	Sinendé	Sinendé	CHC	10.35	2.38	On-Grid	Sterilizer	AC	2000	2
								Printer	AC	510	4
								Desktop PC	AC	60	5
								Laptop	AC	30	3
								Air conditioning	AC	1200	3
								Fan	AC	70	10
								LED bulb	AC	9	25
								Energy saving bulb	AC	25	2
								Fridge	AC	250	3
								Fridge	DC	70	1
Bétérou	Borgou	Tchaourou	Bétérou	SDHC	9.2	2.28	On-Grid	Banknote checker (UV)	AC	15	1
								Fridge	DC	66	1
								Sterilizer	AC	2000	1
								Water pump	AC	2000	1
								LED bulb	AC	9	17
Kpodaha	Couffo	Dogbo	Ayomi	Dispensary	6.82	1.71	On-Grid	Stand Fan	AC	70	1
								LED bulb	AC	8	3
								Printer	AC	510	1
								Sterilizer	AC	1950	1
								LED bulb	AC	1	9
Yoko	Plateau	Sakété	Yoko	SDHC	6.72	2.61	On-Grid	Water pump	AC	2000	1
								Fridge	DC	70	1
								Illuminated plate	AC	36	1
								Radio	AC	20	1
								Heat lamp	AC	300	1
								Respirator	AC	100	1
								Fan	AC	70	9
								Bulb	AC	20	60
Tchonvi	Ouémé	Sèmè	Ekpe	Dispensary	6.4	2.51	On-Grid	Medical suction	AC	90	
								Oxygen concentrator	AC	450	
								Pressure sterilizer	AC	2000	
								Water pump	AC	2000	1
								Energy saving bulb	AC	25	16
								Fluorescent tube	AC	40	5
								Fridge (small)	AC	100	1
								Fridge (big)	AC	250	1
								LED bulb	AC	9	20
								Fan	AC	70	13

Appendix B – A2EI Solar Generator AAM Series Technical Specifications

TECHNICAL SPECIFICATIONS

BATTERY		
Rated battery voltage	24VDC	
Battery type	Lead-Carbon / Lithium	
Battery voltage range	(21.6 ... 32)VDC	
Rated battery capacity	50Ah	100Ah
Max. battery charging current	30A	60A

INVERTER	
Output power	2000W
Max. surge power	4000W
Output voltage	220/230VAC
Output frequency	50/60Hz
Max. output efficiency	93%
Switch time	10ms (utility to inverter) 15ms (inverter to utility)

CHARGING - UTILITY	
Utility input voltage	90 ... 280 VAC (programmable)
Utility input frequency	40 ... 65 Hz

CHARGING - SOLAR	
Max. PV open circuit voltage	395V
MPPT voltage range	80 ... 350V
Max. PV input power	2500W
Tracking efficiency	≥ 99.5%

MECHANICAL PARAMETERS		
Dimensions (H x W x D)	607.5 x 381.6 x 127 mm	
Weight	66 kg	105 kg
Enclosure	IP30	
Environmental temperature	-20°C ... 50°C	

PROTECTIONS	
PV limit current	Limits PV charging current whenever it exceeds the rated current. Note: ensure the *PV open-circuit voltage* does not exceed the *maximum PV open-circuit* voltage!
PV reverse polarity	Fully protects against PV reverse polarity
Night reverse charging	Prevents the battery from discharging through the PV module at night
Utility input over voltage	When the utility voltage exceeds 264V (configurable), it will stop utility charging/discharging
Utility input under voltage	When the utility voltage is less than 176V (configurable), it will stop utility charging/discharging
Utility input over current	Device will go into protection mode automatically if utility input current is higher than the specified value
Battery reverse polarity	When the PV array and utility are not connected, reverse battery polarity will not damage the device
Battery over voltage	Stops charging when the battery voltage reaches the *Over Voltage Disconnect Voltage*
Battery over discharge	Stops discharging when the battery voltage reaches the *Low Voltage Disconnect Voltage*
Load output short circuit	When a short circuit occurs at the load output terminal, the output will be turned off immediately
Overload	Shuts off the output if an overload of 1.3 for 10s or 1.5 for 5s occurs
Overtemperature	Stops charging/discharging when the internal temperature is too high

Appendix C – PROSPECT data platform

Prospect (https://prospect.energy) is the only open-source, open-access data and transaction platform that automatically collects, aggregates, analyses and displays data from any modern, sustainable energy solution contributing to SDG7. The platform tracks energy services ranging from small solar home systems to large mini-grids and grid-connected distribution networks. Prospect also covers productive use appliances, modern clean cooking solutions and public systems installed in health centers, schools and other institutions.

Prospect employs a unique "energy fingerprint and heartbeat" methodology that combines technical, usage and payment data streams to authenticate impact and provide a range of analytical opportunities. Prospect enables instantaneous secure data sharing, empowering users to leverage their data to gain insights, raise finance, prove results, and contribute to broader research and understanding in the energy sector.

Launched in November 2022, Prospect is being developed by the Access to Energy Institute and GET.invest with support from the European Union, Germany, Sweden, the Netherlands, and Austria.

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