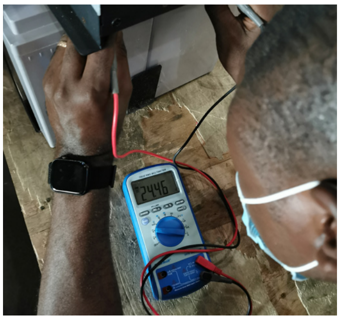
A2EI

ACCESS TO ENERGY INSTITUTE

#SKGS in Nigeria:

A2EI'S SOLAR GENERATORS GATHER PACE

Project Update & Data Release Report



Authors: Bastian Herzog, Viktoria Schaale, Fernando Chacon

A2EI

ACCESS TO ENERGY INSTITUTE

EXECUTIVE SUMMARY

Because of unreliable grids, there are millions of small fuel generators in (not only) Nigeria that emit millions of tons of CO_2 every year.

Following the analysis of the economics of these small fuel generators in Nigeria together with Dalberg (download study here), the Access to Energy Institute (A2EI) set out to provide the sector with an open source hardware solar business system that can replace the noisy, unhealthy fossil fuel generators.

Our customers call the solution the Solar Generator. We are providing those systems to the market with the brand name *AAM*.

Two years later, we have not only made the solar generator available, but already sold over 1,000 to local distributors, who are installing them, mostly at small businesses.

A solar generator customer can stop using his/her fossil fuel generator, has a much higher quality of life (no noise or fumes anymore), a way more reliable product and never has to buy fuel again. The fuel savings pay for the solar generator and over five years, which is the minimum lifespan of the solar generator, we estimate over 1,700 USD are saved.

The solar generator can be connected to the grid and thereby acts as a back-up to ensure uninterrupted energy access, but also functions as a standalone pure offgrid solution where no grid is available.

From a climate perspective, 7.5 tons of carbon are being saved per installed solar generator. Gold Standard Certificates are officially confirming the carbon mitigation.

Every solar generator is sending real time data on consumption, system state and allows the A2EI to share millions of data points with the sector as open source data.

Our work would not be possible without the support of our donors:

IKEA Foundation

STICHTING DOEN NATIONALE POSTCODE LOTERIJ

Good Energies POWER FOR A BETTER WORLD

FMO Entrepreneurial Development Bank

Project Update & Data Release Report

A2EI's solar generators gather pace

Authors: Bastian Herzog,[1] Viktoria Schaale, Fernando Chacon
Organization: Access to Energy gGmbH (A2EI), Paul-Lincke-Ufer 8D, 10999 Berlin

SKGS project update: Two years have passed since our first beta phase solar generator entered the Nigerian market. With the third generation system on the starting blocks it is timely to provide an update of our recent project proceedings. In this data release report we will describe the current state of our SKGS (*Solar Killed the Generator Star*) project and introduce our in-house-designed solar generators, or 'AAM's. On March 15, 2022, we were proud to announce reaching the milestone of selling 1,000 systems to our distributors in Nigeria. By that time 728 solar generators were installed, which translates into 590kW peak solar power distributed all over the country. While being designed to perform as uninterruptible power supply regarding grid outtages, our solar generators are fully equipped with data logging capability. This allowed us to collect more than 17 million datapoints over the course of the project so far, which we share with the sector. These include amongst other information a record of more than 90Mwh total solar yield, which roughly translates into 180 tons of carbon dioxide reduction. In this release we will introduce the design of our AAM systems as well as major key findings regarding performance and productive use after one year of data collection. In line with our open-source data policy we provide timeseries data of 82 representative systems, enabling anybody interested to perform individual analysis. We encourage them to do so.

Please download the associated data from our website:
https://a2ei.org/resources/uploads/2022/04/A2EI_SKGS_data_release_April2022.zip

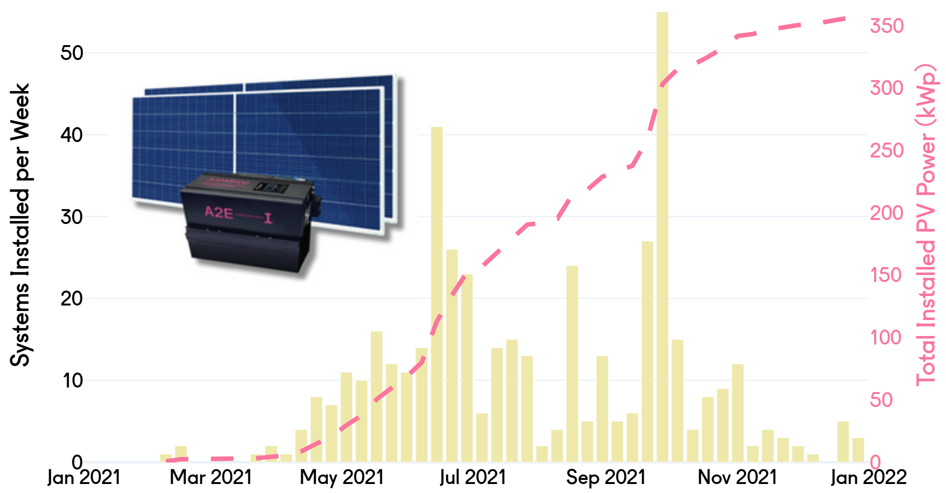


Fig. 1: Installed solar generators (yellow, weekly) and solar panel power (pink, total) in 2021.

1 bastian.herzog@a2ei.org

Introduction

The Access to Energy Institute (A2EI) is pleased to present this data release report for the Solar Killed the Generator Star (SKGS) project, aiming to substitute millions of small yet environmentally harmful fuel generators with clean solar energy. During our pre-research phase in 2020, we equipped a substantial number of generators at street markets and small shops in Lagos and Abuja, Nigeria with smart meters and monitored the respective usage. The resulting data collection then allowed us to provide factual evidence of how much the generators are used on average and to raise awareness about these results by publishing under the hashtag #StopGuessing [1]. By that time we had two key learnings. Firstly, we measured that on average the generators are running on only 22% of their respective nominal load [2]. Running the generators at a very low power load results in low fuel efficiency which, regarding our previous study, translates into a consumption in average of around 2 liters per kWh [3]. Secondly, we found that the highest used generator wattage amounts to 3kWp, while the lower 80% provide less than 1kWp. This means that the fossil fuel generators at those Nigerian markets could be very easily replaced by only two distinct A2EI solar generator types with accordingly sized inverters. The design of these systems as well as major key findings after one year of data collection will be within the main scope of this release.

AAM Solar Generators

At the end of 2020, our Tier 4 solar generators[2] entered the first commercial product phase. We targeted to manufacture and install a total of 1,000 devices before entering the second scaling phase. As stated before, our first field studies revealed that the majority of Nigerian fuel generators can be substituted by only two distinct types of solar generators [1]. Hence, we designed the systems AAM1000 and AAM3000 as solar business solutions (SBS), containing a 1 kVA and 3 kVA inverter, respectively. With a special focus on usability and affordability, our systems are intended as complete turnkey solutions equipped with a grid connection for 24/7 power supply.

A combination of a 2400 Wh battery (1200 Wh for AAM1000) and photovoltaic panels with a total power of 820Wp has been chosen to generate and store the energy needed to achieve the requirements of an uninterrupted power supply (UPS). To reach the longest lifetime, however, it is recommended that the systems run at less than 80% of their maximum load capacity in continuous operation, thus lowering wear and tear. All control components are designed and programmed by A2EI RnD in Germany while the electronics, mechanical components and batteries are supplied from China under strict quality control assured by the A2EI engineering team.

2 https://unstats.un.org/sdgs/iaeg-sdgs/tier-classification/

Technical Details

An overview of the core elements of a full system stack is sketched in Fig. 2 (a). It comprises an inverter/charger (top-left), two solar panels (top-right), two batteries (bottom-left), a solar charger (bottom-right) and a monitoring unit (center).

The **batteries** are lead-carbon type and provide 24V system voltage when connected in series. A lifetime of about 3000 cycles ensures proper performance for a minimum of 8 years (assuming one cycle per day).

The **solar panels** consist of a two-fold half-cell Mono-crystalline silicon module of 410Wp each, translating into 820Wp installed peak power. With an efficiency of 20.2% they provide a maximum of 40.7V and 10.07A charging voltage and current, respectively.

The **solar charge controller** uses maximum power point tracking (MPPT) to ensure long battery lifetimes and efficient charging through DC-DC coupling.

The **inverter-charger** works bidirectional and contains an auto-switch to select either battery/PV panel or the national power grid as input source, respectively. The former option enables the DC/AC conversion to provide a pure sine output at 230V while the latter enables the AC/DC conversion to use the grid for battery charging. The option of using those two input sources rather than pure solar was chosen in order to minimize costs while ensuring maximum availability of electricity to the user by downsizing the battery in comparison to standalone-systems. It should be noted here that the current system generation is programmed to prioritize grid usage per default (charging the batteries via grid when available). However, in an aim to not only provide uninterrupted but also green power, future versions of the AAMs will aim to maximize solar generation and only obtain energy from the grid to cover the surplus load, if any. This of course also helps customers to further decrease their electricity bills.

The **monitoring and control unit** (MCU) handles all system data capabilities and allows for collecting multiple sensor data. It runs on A2EI's specially developed firmware and additionally contains a built-in real time clock (RTC) as well as a data transmission line via a Global System for Mobile Communications (GSM) unit. The interconnectivity of the components is sketched in Fig. 2 (b).

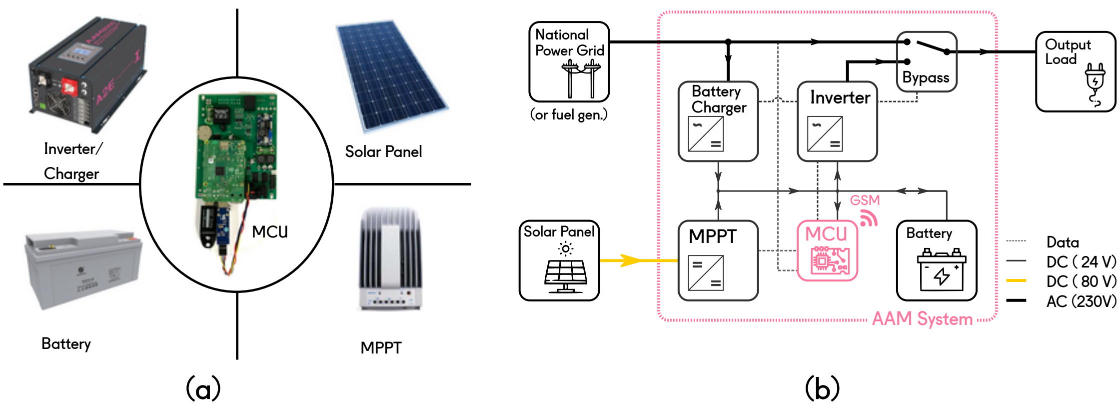


Fig. 2: (a) Main components of an AAM solar generator comprising inverter (top-left), solar panel (top right), lead carbon battery (bottom-left), solar charge controler (MPPT, bottom-right) and monitoring unit (MCU, center) . (b) Block diagram of the AAM core system with attached grid/generator input, solar input and provided output load.

Fig. 3: System data and dashboard. The AAM data collection architecture allows for real-time data monitoring on a 5-min time base.

Data Collection and Monitoring

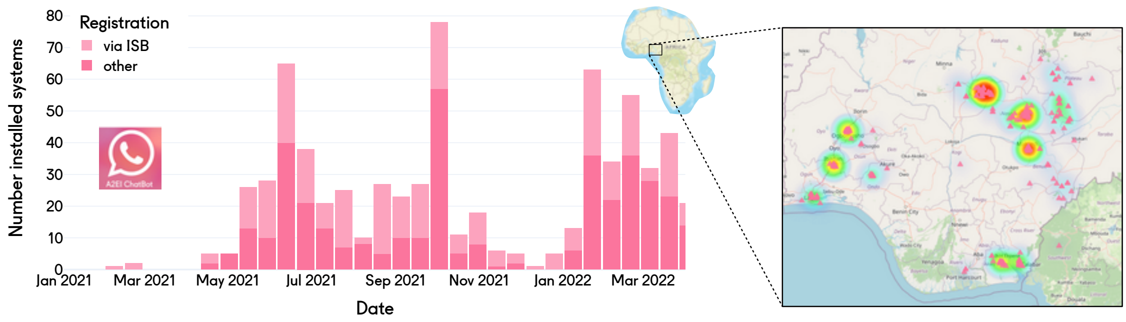
In order to enable full system monitoring for performance studies as well as to support trouble shooting and maintenance, the MCU gathers a list of time resolved sensor data from inverter-charger and MPPT. Regarding the former, this comprises the system in-/output voltage and current as well as the battery voltage and device temperature. The latter provides measurements of battery charge and discharge currents as well as the PV yield and battery temperature.

An overview of all collected data in combination with derived global metrics such as, e.g., total amount of solar yield is visualized through our A2EI designed monitoring platform, shown in Fig. 3., which we share with our partners. Despite keeping track of system performances this also allows for quick trouble shooting on-site and to provide learnings for engineering of future AAM versions. Further, regarding result based financing (RBF) programs, the platform is able to provide an estimate for ecological impact by calculating carbon-dioxide and consequently fuel consumption savings by using our solar generators.

Impact Survey Bot (ISB)

In cooperation with our agents on site, we developed a smart way of customer registration via an open-source chatbot available in WhatsApp. This bot resembles an interactive decision tree for information collection and can be used in a Q&A or structured survey format. It is available to any kind of system and the code for relevant use cases in the field is shared [4].

In Fig. 4 (a) we provide an overview of the use of our ISB during installation. Out of 728 systems installed until April 2022, almost half (326) were installed using the bot. The ISB not only spares partners from having to fill out a significant number of excel sheets, which saves administration time. The collection of anonymized information about, e.g., system location and business type helps understanding typical use cases and visualizing customer profiles. In aiming for a higher ISB utilization rate, we are about to further improve its user-friendliness and to promote its advantages to our partners. To date we find eight installation clusters: Abuja, Lafia, Makurdi, Calabar, Uyo, Lagos, Ibadan and Ogbomosho, as shown in Fig. 4 (b).



(a) (b)

Fig. 4: Utilization of the impact survey bot (ISB) for AAM installation. (a) Number of installs with and without ISB. (b) Map of Nigeria with highlighted installation clusters. The highest AAM density is found in the Abuja region.

AAM Use Cases

In order to provide a sample of data analytics capabilities, a typical "day-in-the-life" of an AAM will be presented in the following section. Two representative use cases will be introduced: i) an urban business user with numerous appliances and grid connection and ii) a rural shop with lower consumption and off-grid operation.

i) On-Grid, High Load

Fig. 5 shows a list of metrics of one AAM3000 system used at a small business located at the Wuse market in Abuja, NG. Within the 24-hour timeframe representing a typical business day at the market, a number of features are illustrated. The input voltage from the national grid is monitored by the MCU itself and plotted in (a). At the market the business day starts at 8:00 am with the main power switch turned on (1), providing the local shops with electricity, and ends at 6:00 pm by turning it back off (2). However, due to the instability of the Nigerian power grid, blackouts are the order of the day. In this sample data we observe two such events with a duration of 90 min after 9:00 am in the morning and 10 min around noon, respectively, as marked in the graph.

The output load, resembling the consumption of the respective customer, is visualized as the gray area in Fig. 5 (b) and shows an average power of 470W which is roughly constant over the whole business day. With a constant consumption of 60% of the installed PV peak power, leading to 4,7kWh per day, this customer belongs to the group of heavy consumers who's solar generator cannot be exclusively powered by solar. However, as stated before, the main goal of the AAM systems is to provide a hybrid solar and grid powered UPS. Thus, bridging the occurrences of the aforementioned blackout events is realized by the inverter via ultra fast switching to battery mode in case the input voltage drops at a value below a defined threshold.

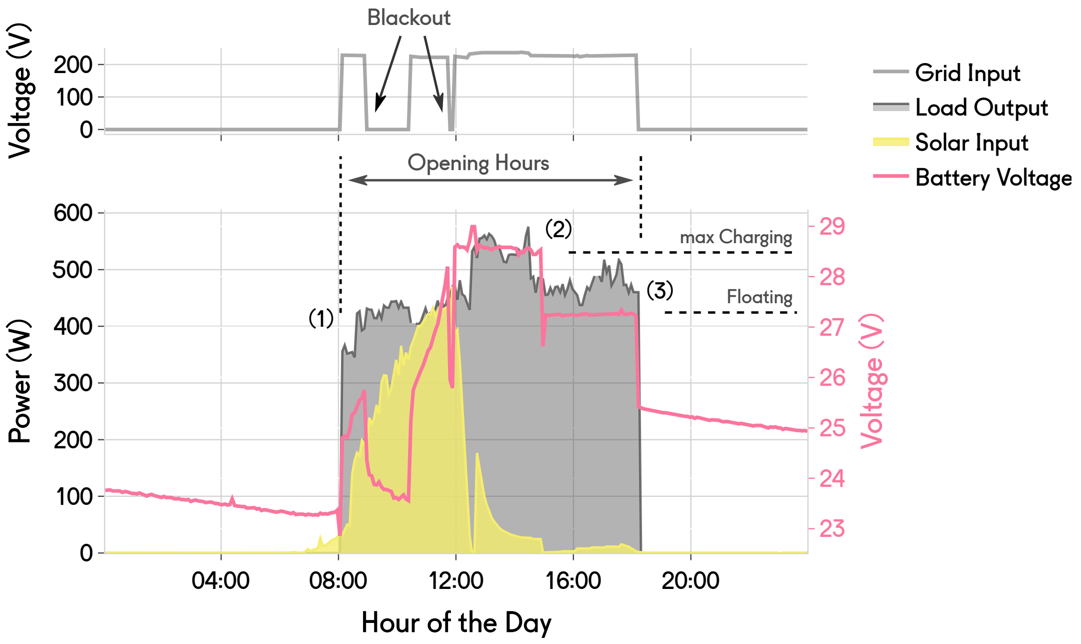


Fig. 5: Typical productive use metrics of an AAM solar business system on the Wuse market in Abuja/NG . (a) Input voltage provided by the attached national grid. This sample data shows a blackout around noon at that specific day. (b) PV input (yellow) and load output (gray) as compared to the battery voltage (pink).

The temporal development of the battery voltage is plotted as a pink line in the figure. At night a slight decrease is measured, which is due to the system's internal consumption as well as internal settling effects of the battery electrolyte during the absence of grid and solar power. After the business starts in the morning the voltage rapidly increases due to charging from the grid and minor support from the PV panel, as shown in yellow. During both blackout times the output is fully supplied by the battery which can be observed by a voltage decrease. At the point marked as (3) the battery is fully charged and the MPPT charge controller drops the voltage from 28.8V to 27.0V (floating state). After closing in the evening, the input drops to zero turning back to battery mode leading to a voltage of 25.0V and decreases while being discharged due to self-consumption. It needs to be noted at this point that the state of charge (SOC) rather than the battery voltage gives valid information about battery sizing. This however is not implemented at this phase of the project, but will be one of the main features for our next generation MCU starting soon.

At his point one remark on the solar yield of this specific use case needs to be done. Considering the temporal development until noon a typical increase of the PV input is observed. The power is used for battery charging and bridging the blackouts. However, with the battery reaching maximum state of charge at 15:00 and no further blackouts occuring in afternoon the solar yield decreases dramatically, since the output power is mainly carried by the available grid. This shows that focussing on supply assurance in fact has its costs on a lower solar yield and it is obvious that a larger solar collection would be possible through grid detachment. We thus found that many customers with mainly low energy consumption are unplugging their systems and solely rely on the solar flow. In our data those AAMs appear as alleged off-grid systems and one such system will be further described in the following section.

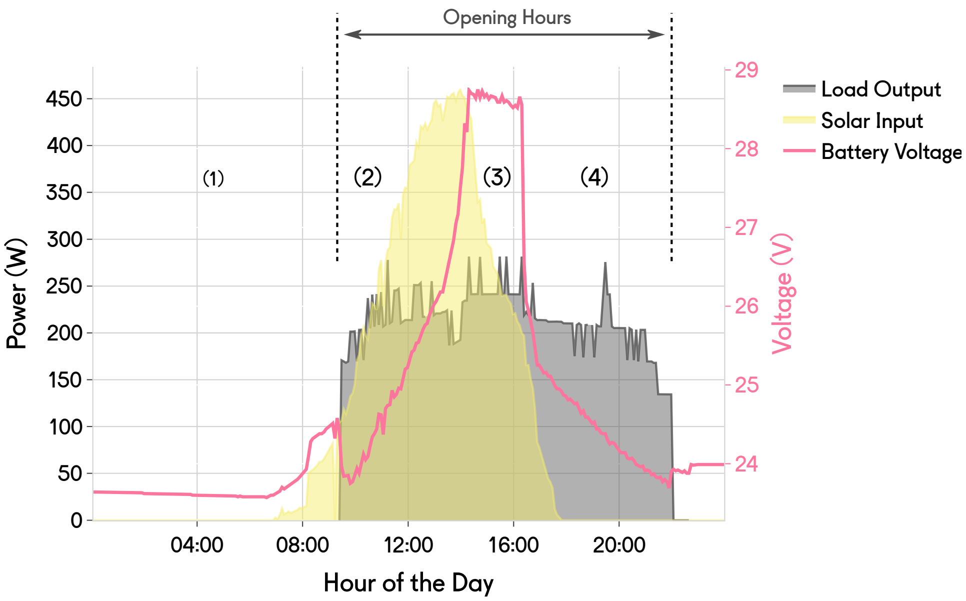


Fig. 6: Productive use case of an AAM1000 system used as off-grid system in Lafia/NG. We observe four distinct phases: (1) inverter shut down at night, (2) simultaneous load supply and battery charge via solar panel, (3) load supply only,(4) battery discharge.

ii) Off-Grid, Low Load

Even though the AAM systems are designed to work as UPS and gap grid outages, the question arises as to whether these generators are suitable off-grid solutions when increasing the battery capacity in comparison to the average load. To this end systems with a combination of 1kVA inverters and 1200Wh batteries have been installed in the field. In Fig. 6 a typical productive use case of such a system used in a small shop is shown and a number of observations will be discussed in the following. The system goes through four different stages:

(1) During the night when no load is required the inverter is shut down in order to minimize battery discharge. Thus, no inverter data is transmitted and a constant zero PV input is measured by the MPPT until 7:00 am. After sunrise the battery starts charging slightly.

(2) At 9:00 am when the PV input reached around 100W the inverter was turned on by the customer. While at that time the attached load exceeds the solar input at the beginning, the battery gets further discharged. After roughly half an hour both values have converged and with the sun further rising up, the panel is able to simultaneously supply the output load while charging the battery. This specific customer has been found to require a constant consumption of around 200W. Spikes in the load curve might be addressed by, e.g. switching on/off light bulbs.

(3) At noon, shortly after the panel has reached its maximum capacity (460W in this specific case) the MPPT reaches maximum charging voltage which results in a plateau of the battery voltage at 28.8V. At this point the battery charge reaches above 90% and the charging current is adjusted to ensure maximum health. A note: a maximum battery charge in this case is not achieved, which is represented by a floating voltage of 26.8V (see Fig. 5).

(4) During evening hours, the load exceeds the PV input and the battery starts discharging, which is reflected by a decreasing battery voltage. At low charge but not falling below the shut down voltage of 23.4V, the load is switched off at 10:00pm.

This exemplary use case has clearly shown the proper use case of an AAM system as an offgrid solution. Since the battery did exceed 90% charging status during the day while not being fully discharged at night, it is assumed to be perfectly sized for that specific use case. The output load of roughly 200W was carried over the time range of more than 12 hours without any interruption. In the event of aiming for larger load values it is recommended to install additional solar input in the form of more PV panels.

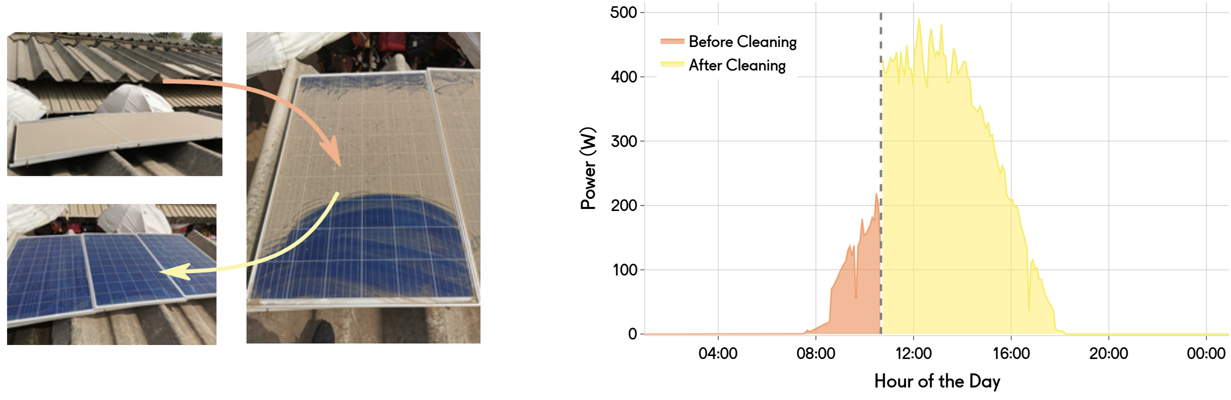
Impact of Dirt on the Panels

Since the maximum solar yield of the first sample user amounts to a maximum 470W at noon, the question may arise as to why the solar panel only reaches half of its peak power of 820Wp. Considering the deviations from standard test conditions, which are irradiance, temperature and air mass, we assume further factors impacting the yield reduction:

- Non-optimal mounting position of the panel (slope and azimuth)
- Shading by i.e. adjacent buildings
- An absorptive atmosphere due to dust, clouds, etc.
- Panel pollution

Regarding the latter point, our technicians on-site were investigating and found that the shading through dirt may amount for up to a factor of two in panel performance reduction, as visualized in Fig. 7. This effect applies especially during the Hamattan (dry) season between November and March, where dusty Sahara trade winds affect the country.

While in that particular case the impact of dirt could be easily measured, an automation of the recognition of such an event is anything but trivial. Not only is it challenging to distinguish between the aforesaid points solely through data, but additionally the decision needs to be made as to whether the effort of cleaning is worth the increase in power yield for low consuming customers whose batteries still get fully charged during the day. However, with future AAM versions with solar priorization over grid panel cleaning may gain importance.



(a) (b)

Fig. 7: Impact on dust on the PV panels. (a) Photos of the panel cleaning procedure at the Wuse market. As a result the solar yield (b) shows a twofold performance increase afterwards.

Project Statistics

The following section will treat some project statistics of all installed systems until April 2022. It comprises the evaluation of data quality development, as well as the determination of the social-ecological impact. To this end we are going to analyse the entity of all AAMs, rather than pick specific use cases.

Total PV yield

One key indicator that can be used to track SKGS project performance is the total amount of PV yield from all installed systems being online. The recorded input power into the MPPT binned into days for all systems is shown in Fig.8 as a gray filled line. We observe a slight increase in the first half of the year and a stronger increase after July. The trend saturates in October resulting in a constant yield per day and decreases in December. While the latter point raises a number of questions, it should be noted here that the amount of PV energy is not only effected by seasonal effects but also directly corresponds to both the number of installed systems as well as the amount of transmitted data per system. With the grid is also being used to charge the batteries and to supply the load directly, its availability plays a role as well. As stated before the AAM systems are designed to prioritize the national power grid (when available) for charging and load supply which additionally leads to an inversely proportional relationship of both measures. Nevertheless in April 2022 we recorded a total number of 90.8MWh of collected and monitored solar energy as shown by the pink dashed line, resembling the cumulative sum of all days over the year. Taking into account the result of our previous study in Ref. [1] where we found that the investigated fuel generators installed in Nigerian markets consume 2 liters per kWh on average, this translates into savings of approximately 180k litres of petrol fuel. Generally, assuming a 5 years minimum lifespan for our solar generators, we estimate total savings of over 1.700 USD and 7.5 metric tons of carbon dioxide per system.

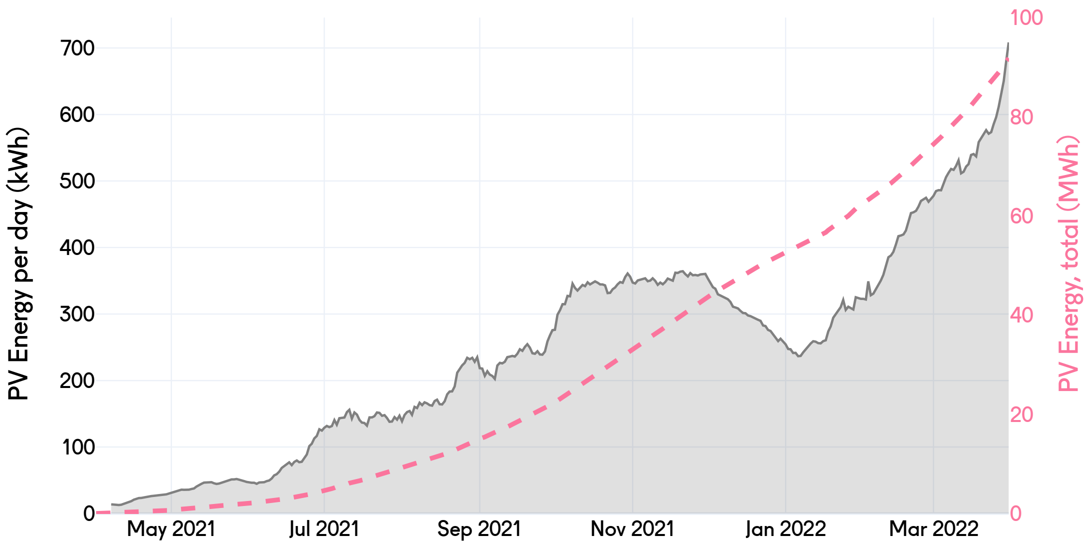


Fig. 8: Gray, solid line: temporal development of the amount of monitored daily solar yield. Pink, dashed line: integral of all system data with a total of 90.8 MWh by April 2022.

Data Quality

Regarding Fig. 8 the question arises of whether the decrease in daily PV yield results from either seasonal effects, solar cell degradation or a lack in the amount of transmitted data. To this end it is worth taking a deeper look into the data quality.

In Fig. 9 an overview of the amount of available data is given. As a reference the number of installed systems was determined from the ISB in combination with registration tables from our partners on-site and is plotted as a gray dashed line in the figure. As shown previously in Fig. 4, by April 2022 a total of 728 installed systems have been registered. With a steady rising trend, three distinct periods of intense installation can be identified: the middle of June '21, the beginning of October '21, and the end of January '22.

The number of systems sending data per day is visualized as a bold pink line and predominantly follows the trend of system installations. However, regarding the absolute numbers it can be observed that roughly half of the registered systems also send IoT data. A deeper investigation involving customer interviews has shown that installation technicians tended to bypass some MCUs due to firmware issues. That problem has been solved with an update, leading to a significant increase in data transmission after the beginning of 2022. An additional reason for a missing number of systems sending data is the case where a customer buys multiple AAM systems at once. This leads to one distinct MCU per certain number of installed systems.

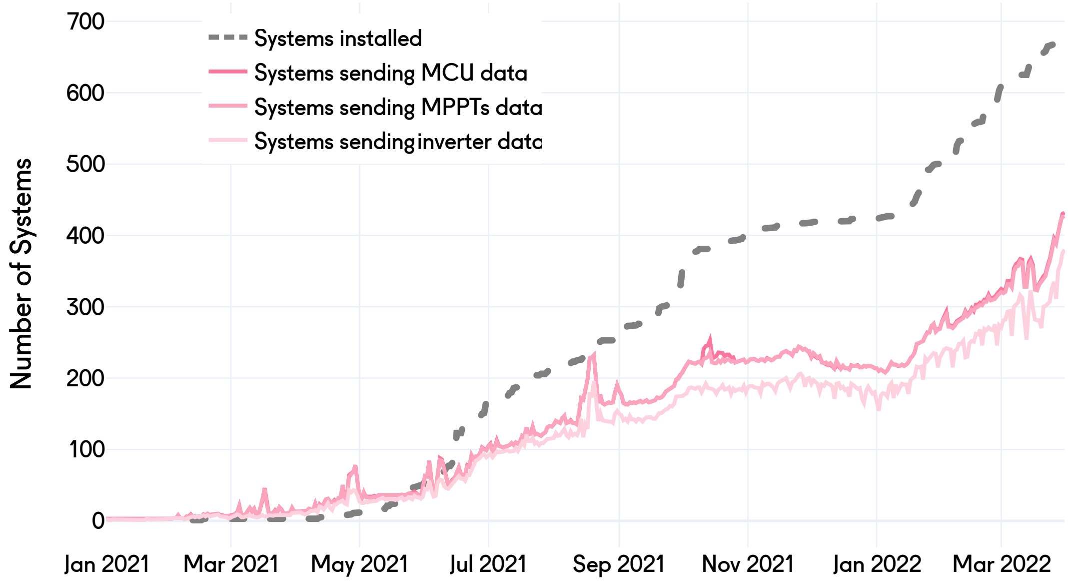


Fig. 9: Amount of transmitted data over time. The dotted line shows the number of AAMs sending data per day. The light pink line is addressed to the subgroup with proper working PV monitoring and the the dark pink line shows systems which detect a grid input at least once a day.

Additionally, it needs to be noted that the occasional peaks in the temporal development of the amount of systems being online are due to the process of flashing and testing before installation. The number of systems recording data from the solar charger are shown in light pink. The significant difference between this value and the number of systems online could be attributed to either the systems being used as UPS without solar collection, or to a number of faulty solar chargers. However, along the full period of investigation, this number consistently amounts to a single-digit value (neglecting the flashing peaks). This indicates a high reliability of the solar chargers. Referring to the previous section and Fig. 8, the apparent decrease in solar yield during December therefore does not originate from missing data and needs to be further investigated.

Lastly, the light pink line in Fig. 9 shows the number of systems measuring grid input per day. The temporal development again follows the trend of previous discussed metrics with the total number being further decreased by a factor of two as compared to the number of systems being online. As stated before, this most likely results from a manual detachment of the systems from the grid input, or by switching off the inverter.

Summary

This data release shows the latest developments of A2EI's solar generator project called Solar Killed the Generator Star (SKGS). We introduce our solar generators which are designed to provide an uninterrupted power supply based on a battery-inverter combination, driven either by solar energy and/or the national power grid. The ability to fully monitor IoT data on a 5 min time basis allows for detailed operation tracking as well as drawing conclusions about ecosocial impacts. By the first quarter of 2022 we observe the following project statistics:

- AAM systems sold: 1004 pcs.
- AAM systems installed: 728 pcs.
- Datapoints recorded: 17 Mio
- PV power installed: 590 kWp
- PV yield monitored: 91 MWh

With a new AAM generation in the starting blocks we look towards a great future for the SKGS project and are happy to keep on unplugging an increasing number of fossil fuel generators. While we are currently piloting the AAM-Series of solar generators throughout Nigera for small businesses, we are additionally developing solar generator versions for institutional use, e.g. for rural health centres in Sub-Saharan Africa.

References:

[1] https://a2ei.org/resources/uploads/2019/09/StopGuessing_ExecutiveSummary.pdf
[2]https://a2ei.org/resources/uploads/2019/06/A2EI_Dalberg_Putting_an_End_to_Nigeria%E2%80%99s_Generator-Crisis_The_Path_Forward.pdf
[3] https://a2ei.org/resources/uploads/2020/04/A2EI_data_release_no2_290420.pdf
[4] https://a2ei.org/resources/uploads/2021/06/A2EI_Impact_Survey_Bot.pdf
[5] https://gitlab.com/a2ei/impact-survey-bot
[6] https://a2ei.org/news/skgs-project-update-data-release-report