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Final Report:

Solar power for Mali

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1 Summary

The current energy supply situation in Mali is precarious, especially in rural areas. 12'000 villages still lack access to electricity. As in many other regions, the only viable solutions are mini-grids for larger villages, or solar home systems for individual households. There has been a technological gap between these solutions, which Power-Blox is trying to close with its innovative swarm technology. In a pilot phase in 2017, a first village was electrified based on the "swarm electrification" solar battery system developed by Power-Blox. However, there was some room for improvement, both for Power-Blox and their partner Flex-Grid.

The main goal of the project was to solve all existing problems and create the basis for broad scaling.

Parallel to the project, other projects were also launched in other focus countries, mainly Vanuatu, Lao People's Democratic Republic, Uganda, Guinea, Senegal and Ethiopia. The projects in these countries should also benefit from the outcome of the project in Mali.

In Mali, 4 villages were electrified (Koyan, Mion, Kénié Marka and Zambougou Fouta), providing electricity to 1'400 people. In Rwanda, 1 village was electrified (Ndego), providing electricity to 280 people.

During the implementation, extensive improvements have been made to the product and swarm concept: Improvement of the Powerhub (a metal structure for the installation of the solar modules and solar battery systems), the development of a lithium-ion battery instead of lead-acid batteries, the development of the Flexmeter (energy consumption meter) and the FlexCloud technology, and the development, installation and testing of the Power-Blox Gateway (a device for remote monitoring of the solar battery systems). With these expansions, the basis for larger electrification programs could be created and used in projects in other countries.

Unfortunately, the general conditions changed significantly during the implementation period and posed new challenges:

Because of the military coup, the Corona pandemic and customs formalities, there were significant delays in the implementation of the project. The security situation was often worrisome, which, for example, led to Power-Blox personnel being unable to travel to the target area and only being able to accompany the implementation from a distance. The long delays and additional work required by the complex remote support also resulted in additional costs.

Despite all the difficulties, the main goal of the project was achieved: The numerous technical improvements successfully created the basis for a scalable model that could be applied in Mali as well as in other countries.

Despite the main goal achieved, there are still some more challenges to be solved. It will be important to have a greater focus on productive use and small businesses. These improve the profitability of the network due to the higher energy demand. But at the same time, solutions must be found for larger energy consumers in this environment that cannot (yet) be covered by swarm technology.

Another big issue is finding suitable financing solutions to further scale the model. Here Flex-Grid is in preparation for the next expansion phase with 20 - 50 villages and in negotiations for grants with the African Development Bank and the UEF (Universal Energy Facility).

2 Starting Point

At the starting point of the project, Flex-Grid had implemented 1 pilot village in Mali, with 70 households connected, positively impacting the lives of 500 people.

The Power-Blox 200 device used for this first pilot village had only been completed a year earlier and still had some disadvantages. In particular, the lead battery technology was not very suitable for the Malian temperature conditions.

On the business model side, the problem at the beginning was that the cost of energy (LCOE) was too high, which put pressure on the profitability of the model.

3 Objectives

The overall project objective is to reduce the risk profile of the business model by demonstrating the ability to scale up and roll out quickly, generate the expected returns, in line with installed capacity and investment, and finally attract further private investors to create a solid basis for the start of the next phase of expansion:

- the electrification of a further 6,400 households in Mali
- the basis for the market entry in Burkina Faso (another 150 villages) in cooperation with the local partner Solektra (Akon Lighting for Africa)
- in Kenya, where another 10,000 households could be electrified with Power-Blox /FlexGrid technology

Based on this, the following main objectives have been defined:

1. Solving all problems identified in the pilot phase to date (see chapter 3.2)
2. Reduction of LCOE costs to the usual market level
3. Provide proof of the profitability and scalability of the "FlexGrid" business model

3.1 Solving the existing problems

At the beginning of the project, various problem areas were identified, which were subsequently divided into these areas:

a. Business model and profitability
b. Technology
c. Operations and logistic

a. Business model and profitability

- LCOE costs are still too high
- Proof Profitability and scalability of the business model
- Very fast increasing consumption -> The expansion cannot follow the growth in demand

b. Technology

- Suboptimal Mini-Grid topology -> In case of an error, the Mini-Grid would not yet be black start-able
- Solar module selection is not yet optimal, since the modules do not reach the required voltage range when it is very hot (> 35°)
- Battery temperature -> the current concept of the inverter houses (power hub) is not optimal and causes increased battery temperatures of almost 50 degrees Celsius
- Problems with the Pay-as-you-go system from Steama.co

c. Operations and logistics

- The supply chain from Switzerland to Mali still needs to be optimized for deliveries to arrive at given target dates

4 Activities in the project to solve the problems with the business model and profitability

4.1 Reduction of LCOE:

With increasing competitive pressure and growing subsidies from competitors, pricing pressure is currently increasing rapidly. One of the goals of the project was to find ways to become competitive and reduce LCOE. Certain aspects could be implemented in the project, but most importantly they helped to plan further projects and gave important inputs for the further development of Power-Blox products.
To achieve lower LCOE, the following measures were implemented and and strategies adapted in the project:

1. focus on Productive Use and daily consumers.
Daytime consumers, especially in the Productive Use environment (small businesses), lead to higher consumption during the times of day when energy can be cheaply generated directly from solar and used without the detour via batteries. The project taught us to put more focus on such consumers here in the FlexGrid business model.

2. integration of micro and solar inverters
In order to reduce the LCOE in future projects, Power-Blox has specified the successor product PBX-400 to be able to connect a higher solar power of 300W per Power-Blox and to integrate AC coupled micro and solar inverters. This allows daytime consumers to be served very cheaply without loading the batteries, which substantially reduces the LCOE.

3. combination of nano-grids and direct-drive machines.
In the previous projects, we always assumed that the Power-Blox in the Nano-Grids can cover all power requirements for all consumers. This is not always required in certain practical applications - especially in processing agricultural equipment and cooling applications. Here, the project has provided a significant impetus for the future integration of so-called "direct drive" machines. These are machines that can be powered directly by solar energy via appropriate electronics, without the need for batteries. The operation is of course only possible during the day and in good weather conditions, but then at very low costs, thanks to very low LCOE. In the idle times of the machines, when no energy is needed, the energy in the Nano-Grid can be used by the Power-Blox devices. In this area, a cooperation with the manufacturer empo-ni.de has been established during the project.

4.2 Proof Profitability and scalability of the business model

An important goal of the project was to demonstrate the profitability of the FlexGrid business model.

Unfortunately, major political difficulties arose in Mali during the course of the project, which fundamentally changed the originally assumed framework conditions. The Covid pandemic also caused negative effects in the project. Above all, implementation and operating costs have developed negatively, which has put heavy pressure on profitability. Also, Power-Blox product costs could not be scaled and reduced to the extent hoped for at the beginning of the project. These reasons have meant that profitability in the Mali model has not yet been achieved.

At the same time, however, all the lessons learned from the Mali project have been incorporated into other Power-Blox and Flex-Grid projects. Especially in projects in

Mozambique, Vanuatu and Uganda. Technical improvements as well as optimizations of the business model have been implemented. It turned out that in politically more stable countries, the further developed model will be profitable. In the case of Vanuatu, even without the need for additional grants.

4.3 Fast increasing consumption

During further implementations of the projects, it was found that consumption was highly dependent on billing. Electricity was still provided free of charge in the pilot project, which favored high consumption. After the introduction of the tariff model and the billing of the electricity, the increase was only within expected limits. This step was possible when the technical problems with the PAYGO meters could be solved on the technical side.

Another measure to counter fast growing consumption could be found in the implementation of an additional reserve of solar panels and Power-Blox devices. If a fast-growing consumption is identified, the energy infrastructure can be expanded quickly and the service quality can be raised back to the required level.

However, this step can only be implemented when larger financing can be found and the buffer stock for the rapid expansion can be financed accordingly. This could not yet be implemented during the project implementation. Nevertheless, the findings of the project were incorporated, for example, into the budgeting and rollout planning in a project in Mozambique, where around 30% of Power-Blox and modules were reserved for rapid expansion. These were then budgeted either for the development of new villages, or the expansion of existing villages, depending on what the energy monitoring of the already implemented villages revealed.

5 Activities in the project to solve technical problems

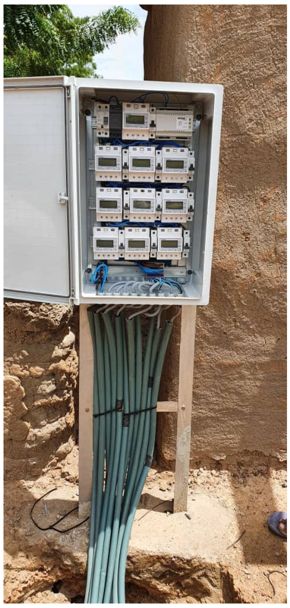
5.1 Mini-grid topology

The topology of the mini-grids was not yet optimally selected in the first pilot project. Flex-Grid had worked with a very distributed structure, in which several so-called power hubs were distributed and interconnected at suitable locations in the village:

This topology of the first pilot village had some disadvantages, especially regarding the fast expandability with additional Power-Blox devices and regarding the easy maintenance. The stations with 1-3 Power-Blox devices per power hub were too small for real needs and were therefore further developed. In a first phase, dedicated Power-Hub houses were chosen, which offer space for more

Power-Blox, have a lower internal temperature and provide good protection for the Power-Blox infrastructure.

From the power hub buildings, cables were then built to the distribution boxes where the smart meters were installed. A house was then connected to each smart meter in a star configuration.



This topology has also proven successful for the other villages in Rwanda and Mali, but the Power Hub buildings have been optimized. The fixed buildings still had some disadvantages, which were to be solved in the course of the project:

- The building uses land that can no longer be used by the villagers.
- It is a fixed and not expandable installation
- The cost of the building is higher than the originally calculated sheet metal construction

With the concept of flexible power-hub constructions, which will be presented later in this report, the disadvantages described above could be eliminated.

5.2 Black-start ability

The black start capability of the Power-Blox was a weighty issue at the beginning of the project. The Power-Blox devices lost the synchronization again and again, which had to be prevented by a further development of the firmware. However, the problem was also recognized that in the event of a loss of synchronization (e.g. due to an overload within the local power grid), the Power-Blox devices could no longer start, since the full power is only available again after synchronization has taken place.

To counteract this disadvantage of the swarm approach, an additional circuit with a time delay relay was installed.

In the event of a village power failure, the time protection relay will cut off power for one minute, allowing the Power-Blox devices to resynchronize and perform the black start. In addition to the time protection relay, type1+2 overcurrent arresters were also included to protect the Power-Blox devices from AC coupled overvoltage.

5.3 Solar module selection

When selecting the other solar modules, great importance was attached to the selection of suitable modules. In particular, the negegative voltage-temperature coefficients were taken into account. Since the voltages of the solar modules are specified at standard test conditions (STC) and thus at 25°C, and thus Vmpp is much lower in reality than specified at STC, the voltage values for solar modules for Mali for Power-Blox must be selected higher, since otherwise the minimum voltage of 30V is no longer achieved. This in turn would have the consequence that the batteries cannot be fully charged.

5.4 Battery temperature

Mali has very high temperatures which have a critical effect on the choice of battery temperature. This had to be painfully recognized in the first phase of the pilot project, so that the lead batteries used had to be operated far above the permissible temperature range, which resulted in rapid aging of the batteries.

Power-Blox was faced with the challenge of finding an alternative battery technology here. In a first step, retro-fit batteries were found from the manufacturer GreenLife, which could replace the previously used Hoppecke batteries both in terms of dimensions and electrical specifications. The big advantage of the GreenLife batteries is that they are based on LiFePO4 cells and, according to the data sheet, can be operated at temperatures of up to 60°C. The batteries are also suitable for use in the field. However, the battery could only be seen as a temporary solution, as this battery also has a weighty disadvantage: Since two batteries must be connected in series to reach the internal Voltage of 24V, unequal charge levels can occur in the two batteries. Unlike lead-acid batteries, however, these charge levels can no longer be automatically compensated, which can lead to performance losses or even the shutdown of a battery by the internal BMS.

To address this renewed problem, Power-Blox worked with Ronda, a manufacturer in China, during the project to develop its own 24V battery. This is also based on LiFePO4 cells and therefore has the same temperature resistance, but only a BMS which balances the cell charges and thus solves the problem of the GreenLife batteries.

5.5 Problems with Pay-as-you-go system from Steama.co

The first pilot project already revealed various problems with the SteemaCo pay-as-you-go smart meters used. Measuring and selling energy was only possible to a limited extent due to the unreliable results. Especially the LoRa based communication was unreliable. Individual meters could not be read and a reliable solution had to be found.

After several attempts to fix the problems, FlexGrid decided to develop its own metering system. This was developed after the pilot phase was completed and was already available when the other villages were implemented. This system was also successfully used in other projects in Mozambique and Vanuatu.

6 Project Review

6.1 Project Implementation

The project was carried out by Flex-Grid and Power-Blox as key partners. As a result of the political difficulties already mentioned and the pandemic situation, there were delays in implementation of around three years and additional costs of 112k Swiss francs. Despite these difficulties, the project was successfully implemented in the end. Especially important developments, learnings and improvements could be carried out to enable scale up in other project countries.

The local development, grid lay out and sourcing, customer relations, relations with government, embassy, Import of the equipment was done by Flex-Grid. The organization also took care about international relations, as well as relations with (potential) funders.

Sinergie SA (In Mali) and Solektra (In Rwanda) Is a contractor for Flex-Grid and has been Involved in the Installation of the pilot villages: they were responsible for internal logistics In Mali/Rwanda, installation of the grid, In-house equipment and second level O&M (in case local operator could not solve a problem).

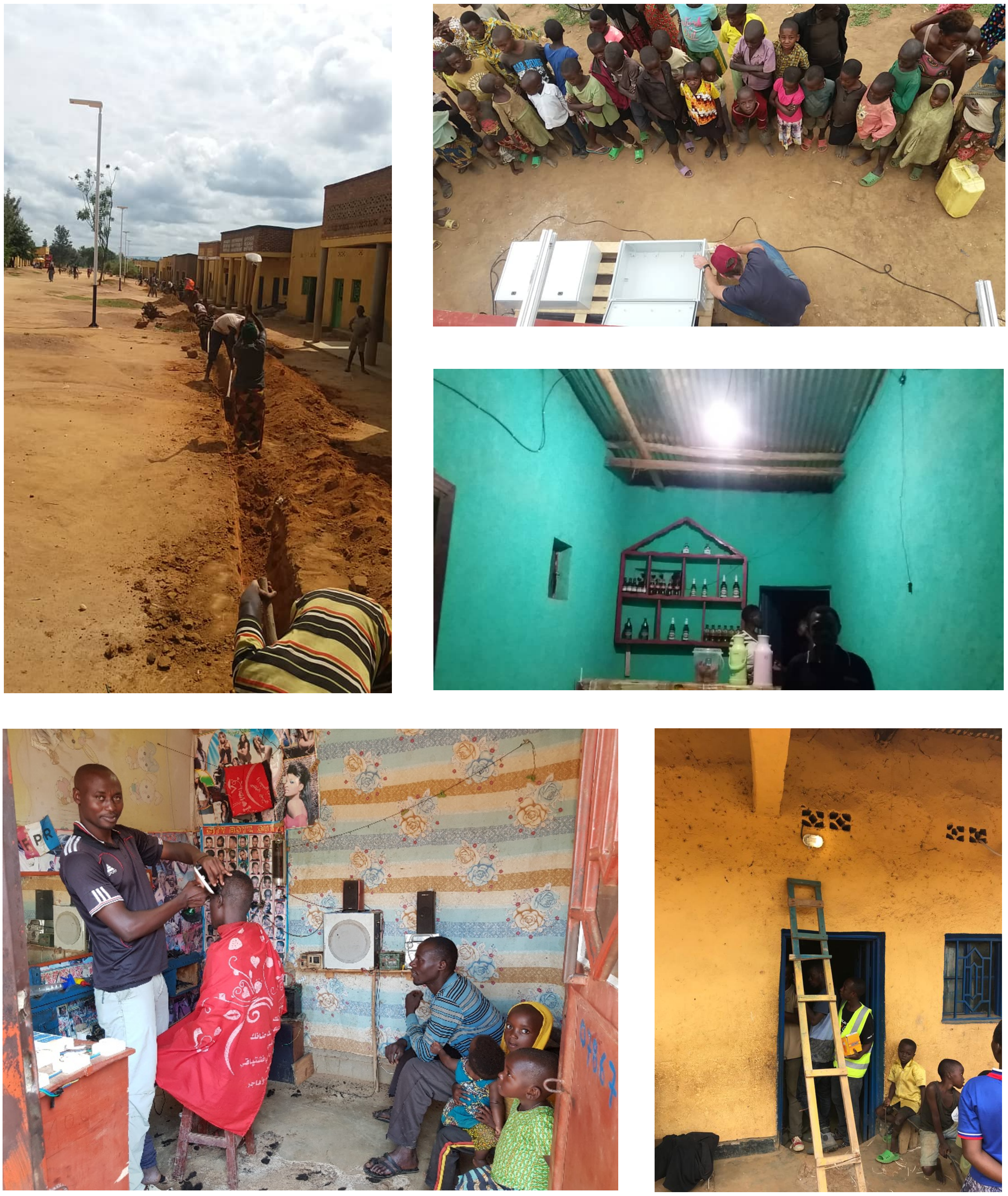
Please find hereunder the different steps undertaken to Implement the project. Note that we apologize for the delays occurred, though we were confronted with tree main events:

- the breakout of covid In March 2020
- the political coup in august 2020, follow by the closing of the border
- the terroristic attacks and kid knapping by Islam extremists in the northern part of the country: even as today the zone were we Implemented the mini-grids are a red zone.

Still, despite these 3 events we can proudly say that we managed to connect our mini-grids, from a distance, proving that our “plug and play” concept can be implemented and maintained with local people, no engineering skills are needed, and monitoring can be done from a distance. These are mayor key elements for a successful implementation and fast roll out in rural Africa.

An overview of the project milestones, their results, and the timeline:

Milestones	action	who	results	start	finnish
electricifaction of Ndego					
village selection	assessment	FXG	agreement with AER/Solektra	1/10/2018	31/10/2018
engineering - grid layout	site visit, engineering, sign up customers	PBX/FG	grid layout/BOM/list of customers	31/10/2018	20/11/2018
ordering equipment	collect 3 offers, compare conditions	PBX/FG	supplier offers//contracts	20/11/2018	20/12/2018
shipping equipment/import	order//organize shipping company	PBX/FG	materials arrived/custom cleared latest on	20/12/2018	18/02/2019
site preparation (digging trenches - civil works)	organize subcontractor	SUB	trenches prepared, civil works done	1/01/2019	31/01/2019
installation Powerhub and meterhubs	ship materials to site/organize teams	SUB	powerhub installed	1/01/2019	31/01/2019
inhouse installation (plugs, lamps, circuit breakers)	ship materials to site/organize teams	SUB	inhouse	18/02/2019	28/02/2019
installation grid and connect households	ship materials to site/organize teams	SUB	lay MV cable, install & connect Flexmeters	18/02/2019	28/02/2019
training and commissioning	select village operators, organize on site training	PBX/FG	training materials, operators & technicans instr	28/02/2019	10/03/2019
concession	deliver proof of village electrification to AER	FXG	receive the concession validation	28/02/2019	28/06/2019
site visit follow up	technical improvements	FXG/PBX		3/12/2019	10/12/2019
Monitoring	monitoring and follow up in our FlexCloud	FXG	comprehensive reporting of the kWhs, revenues and CO2 savings		
electricifaction of 4 villages in Mali : Koyan, Mion, Kenia Marka, Zambougou Fouta					
Planning, engineering phase (4 villages)					
village selection	select first 4 out of list of 50 v/ infosessions	FXG	agreement with AMADER	1/01/2020	30/06/2020
engineering - grid layout	site visit, engineering, sign up customers	PBX/FG	grid layout/BOM/list of customers	30/06/2020	30/09/2020
ordering equipment	collect 3 offers, compare conditions	PBX/FG	supplier offers//contracts	30/09/2020	29/11/2020
shipping equipment	order shipping company	PBX/FG	materials arrived/custom cleared latest on	29/11/2020	30/04/2021
Import equipment	custom clearance	PBX/FG	Huge delay due to materials blocked in customs	30/04/2021	15/09/2021
Execution village 1 (Koyan)					
site preparation (digging trenches - civil works)	organize subcontractor	SIN	trenches prepared, civil works done	1/09/2021	16/09/2021
installation Powerhub and meterhubs	ship materials to site/organize teams	SIN	powerhub & meterhub installed	16/09/2021	1/10/2021
inhouse installation (plugs, lamps, circuit breakers)	ship materials to site/organize teams	SIN	inhouse	16/09/2021	16/10/2021
installation grid and connect households	ship materials to site/organize teams	SIN	lay MV cable, install & connect Flexmeters	16/09/2021	21/10/2021
training and commissioning	select village operators, organize on site training	PBX/FG	training materials, operators & technicans instr	21/10/2021	31/10/2021
concession	deliver proof of village electrification to Amader	FXG	receive the concession validation	21/10/2021	,,,
Monitoring	monitoring and follow up in our FlexCloud	FXG	comprehensive reporting of the kWhs, revenues and CO2 savings	ongoing	
Execution village 2 (Kenia Marke)					
site preparation (digging trenches - civil works)	organize subcontractor	SIN	trenches prepared, civil works done	1/02/2022	16/02/2022
installation Powerhub and meterhubs	ship materials to site/organize teams	SIN	powerhub & meterhub installed	16/02/2022	3/03/2022
inhouse installation (plugs, lamps, circuit breakers)	ship materials to site/organize teams	SIN	inhouse	16/02/2022	18/03/2022
installation grid and connect households	ship materials to site/organize teams	SIN	lay MV cable, install & connect Flexmeters	16/02/2022	27/03/2022
training and commissioning	select village operators, organize on site training	FXG	training materials, operators & technicans instr	27/03/2022	1/04/2022
concession	deliver proof of village electrification to Amader	FXG	receive the concession validation	27/03/2022	,,,
Monitoring	monitoring and follow up in our FlexCloud	FXG	comprehensive reporting of the kWhs, revenues and CO2 savings	ongoing	
Execution village 3 (Zambougou Fouta)					
site preparation (digging trenches - civil works)	organize subcontractor	SIN	trenches prepared, civil works done	1/03/2022	15/03/2022
installation Powerhub and meterhubs	ship materials to site/organize teams	SIN	powerhub & meterhub installed	15/03/2022	30/03/2022
inhouse installation (plugs, lamps, circuit breakers)	ship materials to site/organize teams	SIN	inhouse	15/03/2022	14/04/2022
installation grid and connect households	ship materials to site/organize teams	SIN	lay MV cable, install & connect Flexmeters	15/03/2022	14/04/2022
training and commissioning	select village operators, organize on site training	FXG	training materials, operators & technicans instr	14/04/2022	20/04/2022
concession	deliver proof of village electrification to Amader	FXG	receive the concession validation	14/04/2022	,,,
Monitoring	monitoring and follow up in our FlexCloud	FXG	comprehensive reporting of the kWhs, revenues and CO2 savings	ongoing	
Execution village 4 (Mion)					
site preparation (digging trenches - civil works)	organize subcontractor	SIN	trenches prepared, civil works done	23/04/2022	8/05/2022
installation Powerhub and meterhubs	ship materials to site/organize teams	SIN	powerhub & meterhub installed	8/05/2022	23/05/2022
inhouse installation (plugs, lamps, circuit breakers)	ship materials to site/organize teams	SIN	inhouse	8/05/2022	7/06/2022
installation grid and connect households	ship materials to site/organize teams	SIN	lay MV cable, install & connect Flexmeters	8/05/2022	7/06/2022
training and commissioning	select village operators, organize on site training	FXG	training materials, operators & technicans instr	7/06/2022	12/06/2022
concession	deliver proof of village electrification to Amader	FXG	receive the concession validation	7/06/2022	,,,
Monitoring	monitoring and follow up in our FlexCloud	FXG	comprehensive reporting of the kWhs, revenues and CO2 savings	ongoing	



Implementation of the cable trays for the connections to the households and the Meterhubs (meter distribution boxes) in Mali. The access to electricity is being used for lighting and small businesses as this hair salon.

6.1.1.1 Modifications of the main objectives during the project

The biggest modification made was the delayed timeline due to the closed borders and the military coup and unstable political situation in Mali, customs difficulties, the corona pandemic, etc.
Because of these difficulties many things had to be done remotely instead of locally with the necessary organisation and delays that go with it.

For example, Power-Blox was only able to visit the project area once in person and had to perform all further work remotely, which resulted in significant additional work, especially to solve the problems identified in the first phase.

With regard to the target for reducing LCOE, comprehensive analyses and simulations have shown that the target can only be achieved if

a) The necessary scaling can be achieved to bring Power-Blox prices to a competitive level.
b) Increased productive use and thus daily consumption, as well as integration with direct drive applications are integrated.
c) Additional flexibility for the integration of additional solar power on the technical side is created.

The third main objective to prove profitability had to be changed in that the experience from the REPIC project was incorporated into other projects using the same approach (e.g. the electrification of Lelepa Island in Vanuatu) where profitability could be proven.

6.2 Achievements of Objectives and Results

Objectives regarding the business model and profitability

Problem	Results	Fulfilled
LCOE costs too high	This objective has been partially solved, the cost price per village is now well-known, predictable, and accurate budgeting (CAPEX & OPEX) can be done now. Though cost optimization and LCOE reduction will mainly be realized by scale. However, optimizations could be made and further optimization possibilities could be identified, as already shown in chapter 4.1.	Partly fulfilled
Proof of profitability	Demand is still lower than initially forecasted (though increasing), due to the lack/absence of productive use: the switch from generators to electrical productive use appliances (such as welding devices, pumps, mills….) demands additional investment and takes time. Therefore (and due to increasing costs of equipment) the rural electrification projects now need 60% subsidies (CAPEX) where initially Flex-Grid targeted 30% subsidy. The aim of FlexGrid was to build up a portfolio of villages demonstrating the sustainability of our bottom-up model. At this moment however, the five villages installed do not demonstrate that. Rather than increasing our portfolio with other villages that demonstrate the same, we will focus our investments and expansion on the current villages installed, to achieve "the demonstration of sustainability".	Not fulfilled
Fast increasing consumption	Various concepts have been developed to cover this aspect. These were both in the planning of the	Fulfilled

	infrastructure and in the development of a more powerful version of the PBX-200 device – the PBX-400 - with twice the performance of the initial device. During the project, this new product was not yet available, but will be available for further project phases and other countries.	

Objectives regarding the improvement of the technology

Problem	Results	Fulfilled
Suboptimal Mini-Grid topology	The topology approach could be fundamentally revised and all disadvantages of the initial situation could be eliminated via a new power hub concept. The concept has also already proven itself in other projects in other countries.	Fulfilled
Black-start ability	The black start problems could be solved by a fundamentally revised firmware of the Power-Blox, as well as an additional time relay which is used as standard for all larger installations.	Fulfilled
Optimization of the solar module selection	The solar module selection was newly carried out according to Power-Blox specifications and corresponding problems could thus be solved.	Fulfilled
Battery temperature	Via an intermediate step, it was possible to switch from lead technology to lithium iron phosphate, thus significantly reducing temperature sensitivity. The new technology has since proven itself and has been invested in the development of an own LFP battery.	Fulfilled
Problems with the PAYGO-Meters	The SteemaCo meters originally used were replaced by FlexGrid's own development (FlexCom) and the problem was thus solved.	Fulfilled

Objectives regarding operations and logistics

Problem	Results	Fulfilled
Supply chain from Switzerland to Mali	Improvements were achieved through the use of reliable freight partners, but the additional difficulties and unreliability of suppliers during the pandemic partially offset these improvements. However, we expect this situation to normalize over time.	Partly fulfilled

Some of the further actions we see that need to be undertaken are the following:

- Detailed monitoring of consumers to identify if electrification will lead to more income and productive business for locals
- Integration of solar direct drives, to further reduce LCOE
- Ability to integrate more solar modules in the Nano-Grid
- Monitoring of swarm grid systems to offer further inputs and suggestions for advancing the technology
- Monitor energy consumption in the villages to be able to monitor the viability of the business models used
- Maintaining some Power-Blox systems and finalizing the conversion of battery technology to lithium
- Expansion of productive use in collaboration with GIZ (training, productive use equipment, etc)
- Expansion of in-house lamps and sockets: currently only the house of the "chef de famille" is equipped, but the dormitories behind it also have a need for electricity

- Further expansion of connected households within the villages (and increase electricity capacity): We have a waiting list of people to be connected: Flex-Grid is currently looking for additional funding to be able to cover the development
- Ongoing negotiations with the African Development Bank and the UEF (Universal Energy Facility) for additional grantsPreparation of the next scale up phase: 20 – 50 villages, ongoing negotiations for grants with African Development Bank and UEF (Universal Energy Facility).

6.3 Multiplication / Replication Preparation

Preparatory work that was carried out for the multiplication and replication within the project's framework:

- Flex-Grid:
  - The main preparatory work carried out by Flex-Grid, consists of the preparation of a detailed business plan and investment memorandum, based on the extrapolation of the results of the pilot villages. This business plan served as a basis to obtain the License agreement, which was signed with AMADER for the electrification of 50 villages. For the roll out of those 50 villages, Flex-Grid prepared a strategy for dedicated project-based financing for rural electrification. In order to proof the ability and willingness to pay, a BI reporting based on the data gathered in the Flexcloud-portal is set up.
  - Further preparatory actions taken for the scale up, replication phase are the extensive contacts with grant providers and debt providers for scaling up in Mali, and the participation in a call for proposals for Result Based Funding.
  - In the meantime, Flex-Grid also managed to receive a donation by the Belgian government of 3500 FlexMeters to AMADER, to allow prepaid metering (avoiding cash collection & theft) and near real time monitoring on consumption, CO2 savings, revenues.
  - Besides the multiplication efforts in Mali, Flex-Grid also managed to obtain result based funding for the electrification of 7 villages in Benin as well a market entry study and pilot preparation was done for the Democratic Republic of Congo.

- Power-Blox:
  - Power-Blox was able to perform essential design and development work based on this project, which can be applied in Mali and other project countries
  - The results and lessons learned have been continuously incorporated into other projects, mainly in Mozambique, Rwanda, Guinea, Uganda, Laos and Vanuatu.
  - On the one hand, the most important improvements include the development of the gateway product, which allows detailed performance monitoring of Power-Blox devices. However, above all, the development of the successor product PBX-400 and its own lithium battery.
  - Further development of metering concepts and consumption behavior of electrification in refugee camps with the self-grid approach (Simpler model with all cable and installation costs removed from the business model, metering costs minimized, and the whole model adapted to a lease-to-own model)
  - Further development on the clustering of households and electrification of housing with the Powerhub- and Meterhub-concepts.
    - For example: since the battery systems in Mali got too hot, they had to be protected from the heat (and from water and other weather conditions as well). This was initially done by using local small metal storage sheds. These were not an optimal solution, so Power-Blox developed an easy-to-build and scalable metal Powerhub structure that can be locally made and quickly installed. FlexGrid successfully manufactured and

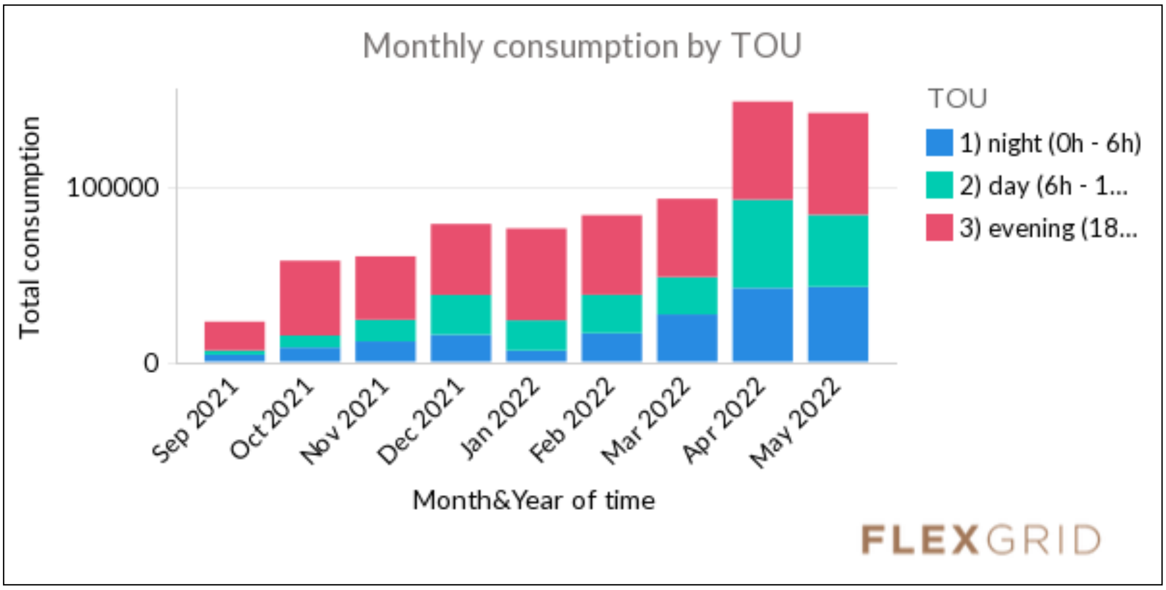
implemented them in the villages. They’re currently being tested, and further improvements will follow.

On the left: the process from design to implementation of the Powerhub containing the Power-Blox solar battery systems. On the right the Meterhubs containing the Flexmeters monitoring the consumption of the household connections.

6.4 *Impact / Sustainability*

Following analysis focuses on Koyan (first REACT village installed in September 2021). The other villages seem to follow the same trend.

Observations:
1) People are satisfied with the service. We have a list of over 70 households that want to be connected (currently we have 47 connections in Koyan)
2) Monthly consumption is growing.
3) Monthly revenue is currently too low to be a sustainable model



The above graph shows the consumption (Wh) by month in Koyan. One notices that total consumption is steadily growing. Initially this growth was mainly achieved in the evening consumption but is now also clearly visible in day and night usage.

Ecological	**Unit**	**At the REPIC Project's Completion**
Installed renewable energy capacity	[kW]	10 kWp
Renewable energy produced	[kWh]/year	16'500 kWh
Amount of fossil fuel energy saved	[kWh]/year	16'500 kWh
Greenhouse gas reduction	[t CO_2-eq]/year	96 ton
Newly collected and separated waste	[t]	NA
Newly recycled waste	[t]	NA
Economic		
Energy costs (LCOE)	[ct/kWh]	38 ct/kWh
Triggered third-party funding/investments	[CHF]	190'000 CHF equity 500'000 USD 3rd party
Local private income generated	[CHF]	Still difficult to quantify at this stage

Social		
Number of beneficiaries	[Number]	1'680
Number of new jobs	[Number]	10
Number of trained personnel	[Number]	8
N° of productive users served	[Number]	6

7 Outlook / Further Actions

7.1 Multiplication / Replication

What are the next planned steps?

- Promote the productive use in the electrified villages, in cooperation with GIZ to substantially increase the consumption, and to actively promote the switch from diesel generated appliances to electricity driven equipment.
- To promote the productive use, a cooperation has been set up with German GIZ in the existing villages. GIZ is also promoting, subsidizing the productive use appliances such as welding equipment, mills…
- Further promote and expand the use of electrical lamps and plugs in the residential houses: typical in one rural Muslim family, 3 to 4 families live together. As for now mainly only the “family chief” house has been electrified, though there is a need to also electrify the connected residences. The ability and willingness to pay needs to further examined.
- In all villages, there is already a substantial backlog of households demanding to be connected (on average a similar number of the already connected households). This is a proof that in general the existing customers are happy with our services. Thus, as a next step, we want to intensify the use of the grid by connecting additional households and increasing the power of the mini-grid (in line with the unique feature of our technology).
- Expand to other villages:
  - Electrification of a further 6400 households in Mali: finally, a proof of concept has been delivered, and our partner Flex-Grid is in further negotiation with potential grant providers and debt providers for a further roll out. Amongst them are the UEF facility, the African Development Bank, RVO, Cross Boundary and Oiko Credit.
  - Also Flex-Grid managed to sign a contract with Amader (Malian agency for rural electrification) for the delivery of 3500 prepaid meters.
- Expansion to two other markets:
  - Due to increasing political instability in Mali, an expansion into other markets becomes more crucial to spread the company risk.
    - Finally, a pilot was done in Rwanda, iso Burkina Faso, the reason being that the Burkinabe tariffs are fixed, resulting into too low margins for commercially viable mini-grids.
    - Flex-Grid is in the running for the electrification of 7 mini-grids in Benin (RBF provided by the Universal Energy Facility, based on the proven track record of Flex-Grid in Mali).

What is being done to promote multiplication / replication?

- General:
  - The “Solar power for Mali” project has helped putting nano-grids on the map as a viable village electrification solution in between SHS and mini-grids. Organizations as GIZ, with their EnDev (Energising Development) program, have added nano-grids to their list of solutions thanks in part to this project.[1 2 3]

- Power-Blox:
  - The concept of electrification in Mali was improved, adapted, and applied in pilot projects in Vanuatu, Mozambique, and Laos
  - Applied and currently in the running for an LTA on nano-grids and swarm electrification at UNDP with the “Solarpower in Mali” project as reference

- Further development of the nano-grid swarm electrification, the rentability of the business model, the clustering of households and electrification of housing with the Powerhub- and Meterhub-concepts, the metering concepts and consumption behavior of electrification in refugee camps with the self-grid approach
- In Vanuatu, an analysis of the electrification of the 17,000 remaining households without grid connection was carried out jointly with UNDP and the Department of Energy based on the experience of the REPIC project. Since the pilot project could be successfully implemented and profitably operated, the government supports these plans. Power-Blox plans to apply for a rollout to scale the project and extend the pilot to other islands
- With our partner Africa GreenTec we are also preparing major projects in Senegal and Zambia. This involves around 50 villages in Senegal and 2500 households in Zambia. These projects are also based on the nano-grid principle, which was first comprehensively tested on the basis of the REPIC project in Mali
- The findings from the project have also triggered further development projects. In Senegal and Mali, for example, we are in the process of linking the nano-grids with direct-drive applications to reduce LCOE. In addition, we have started a joint development with the organization ADES in Madagascar, for an electric stove that does not overload the nano-grid or mini-grid and thus enables an improvement in daily consumption

- Flex-Grid:
  - The main preparatory work carried out by Flex-Grid, consists of the preparation of a detailed business plan and investment memorandum, based on the extrapolation of the results of the pilot villages. This business plan served as a basis to obtain the License agreement, which was signed with AMADER for the electrification of 50 villages. For the roll out of those 50 villages, Flex-Grid prepared a strategy for dedicated project-based financing for rural electrification. In order to proof the ability and willingness to pay, a BI reporting based on the data gathered in the Flexcloud-portal is set up.
  - Further preparatory actions taken for the scale up, replication phase are the extensive contacts with grant providers and debt providers for scaling up in Mali, and the participation in a call for proposals for Result Based Funding.
  - In the meantime, Flex-Grid also managed to receive a donation by the Belgian government of 3500 FlexMeters to AMADER, to allow prepaid metering (avoiding cash collection & theft) and near real time monitoring on consumption, CO2 savings, revenues.
  - Besides the multiplication efforts in Mali, Flex-Grid also managed to obtain result based funding for the electrification of 7 villages in Benin as well a market entry study and pilot preparation was done for the Democratic Republic of Congo.

Which hurdles need to be overcome to have successful multiplication / replication?

- General:
  - Finding more suitable financial instruments to get the necessary funding/investments, since the project financing is one of the main hurdles, both for FlexGrid as for Power-Blox. This also has been the case for many other mini- and nano-grid projects or companies, as described in the Cross Boundary report ‘Open Sourcing Infrastructure Finance for Mini-Grids’.[4] This shows us that this is a problem that needs solving at a higher level.
  - Business models are not successful enough and pay back times are too long, caused by difficult investment programs in Europe that expect a too high ROI and demand the wrong investment structures for these type of impact projects.

  - Since the solar battery system needed space to be installed in the village, this might sometimes be perceived as land grabbing by the local authorities. Good communication at the project start is therefore a necessity.
- LCOE:
  - The experience in Mali has shown that one challenge of the nano-grid approach is the relatively high LCOEs
  - To address this, measures had to be taken on both the development side and the production pricing side of the Power-Blox. In the future, production will be relocated to Asia, which means a saving of almost 50% in production costs
  - On the development side, models were sought to enable stimulation of daily consumption for rural villages. This could be found mainly in the area of post-harvest processing of agricultural goods, in the area of refrigerated storage, in the area of solar irrigation as well as in the area of electric cooking
  - For the areas of post-harvest processing and electric cooking, as well as refrigerated storage, developments have already been initiated
  - On this basis, LCO of well below 20 € cents per kWh could be calculated for the scaling phase, based on a discount rate of 8%. Under good conditions (good running times of the post-harvest machines, many daily consumers), we even achieve LCOE of 15 € cents per kilowatt hour on the basis of the optimized Power-Blox models, based on the learnings from the REPIC project in Mali.

- Mali:
  - The political situation is currently unstable, therefore finding private investors is rather difficult.
  - The logistics have been very difficult, due to corona first and later the military coup and subsequent boycott by the Ecowas countries. The borders are now open again, and the worldwide logistics need to normalize soon to enable a smooth and affordable logistic chain.
  - The average consumption and spending per HH/month are lower than expected/budgeted, key question is if the consumption will grow or not in the next months.
  - Consequently, to have a sustainable, profitable business the subsidy % must be increased from 30% (initially budgeted) to 60% of the CAPEX
  - The negotiations are ongoing with UEF (Universal Energy Facility) and African Development Bank, to set up an RBF program for Mali.

- Benin:
  - Receiving the ABERME license for 7 villages and get the tariff approval

7.2 Impact / Sustainability

What are the sustainable effects (environmental, socio-economic aspects, CO_2 relevance, resource efficiency, etc.) expected during the multiplication phase, in the medium term?

In September 2015, the 194 countries of the UN General Assembly adopted a set of 17 Sustainable Development Goals (SDG's) to be achieved by 2030.

FlexGrid and Power-Blox directly contribute towards SDG 7 and indirectly to several other SDG's as electricity access is vital for the achievement of many of the other sustainable development challenges, notably: health, education, food security, gender equality, poverty reduction and climate change.

80 percent of people without access to electricity are living in just 20 high impact countries, Mali being one of them. Most of those living without access reside in rural areas.

Therefore, off-grid solutions are vital for achieving universal electricity access. The innovative approach taken by FlexGrid and Power-Blox offers an unprecedented high-impact opportunity for private investors to accelerate universal energy access in a region that is lacking behind most.

Serving the Base of Pyramid

- FlexGrid serves the base of pyramid: no non-usage fees, no subscriptions, no minimum consumption obligations, as those would unfairly over-allocate costs to low-use customers. FlexGrid only charges a price per Wh consumed.
- Tiered price model aligned with customers' willingness to pay. FlexGrid provides energy services at a price point that is less than consumers current spending on kerosene, candles, batteries, and other low-quality energy services.
- Home lightning (2 lamps, 5 hours a day) will cost around 3 EUR / month in the most expensive price tier.

100% Healthy/Clean Energy

- When kerosene burns it emits a thick black smoke which is bad for the environment and for people's health. FlexGrid and Power-Blox replace unhealthy, poisonous kerosene lamps by clean energy, at no extra cost for the people.
- Schoolkids will be able to do their homework in the evening in good, healthy conditions
- People will safely exit their houses during nighttime
- Our power is 100% generated by solar energy, no fossil fuel driven diesel generators
- As for the CO_2 emissions, the same number of households connected to diesel generators instead of a FlexGrid would amount to:
  - 78 TCO_2/year equivalent for the project (pilot phase)
  - 390 TCO_2/year for the phase 1 scale up (1500 HHs)
  - 1650 TCO_2/year for the phase 2 scale up (6400 HHs)

  *(Emissions are calculated as follows: TCO_2 = Electricity/household (~36 kWh/HH/year) * households * 6.8T/MWh / 1000)*

Local Employment & Training

- FlexGrid is hiring a local workforce for the construction and operations in the villages as well as at management level.
- FlexGrid has an intensive training program and will support its subcontractors in training their employees on communication skills, technical skills and on health & safety regulations.
- FlexGrid will create > 2000 jobs by training and subcontracting local electricians. Stimulating Entrepreneurship
- FlexGrid will enable small businesses to start up or extend their activities: small bakeries, farming, fruit & vegetable drying, sewing companies, small shops selling cold drinks, welding shops…

Gender Equality

- Energy access is increasingly being recognized as a vital factor for gender equality and women's empowerment.

- Without access to energy, women and girls spend much of their time completing domestic tasks which often limit their available time to pursue education, formal employment or to start a business.
- Access to modern energy benefits nearly every aspect of women's lives – from meeting their basic needs, like having electricity for food refrigeration and light for reading, to increasing their capacity to enroll in school or start a small business

Power-Blox Targets

- Power-Blox has defined the following goals with its further partnerships (for example with the government of Vanutu, Africa GreenTec, etc.)
- Our current plan is to electrify 90,000 households and 4,500 small businesses over the next three years includes the creation of 1,800 direct jobs and around 23,000 indirect jobs
- This will also improve the situation of 450,000 people. However, this is mainly limited by access to infrastructure investment. As the technology can be implemented very quickly and widely, given available investment, these savings could easily be doubled or even tripled
- As an example, we would like to mention our project for the electrification of the island state of Vanuatu, where the electrification of around 17,000 households alone could save around 24,000 tons of CO2 yearly
- By 2030, we plan to have electrified around half a million households and save a quarter of a million tonnes of CO2 annually. As our projects are less risky and will be more profitable than conventional mini-grid projects, we could also succeed in landing even much higher investments and electrify a substantial share of the 930 million people and save correspondingly higher shares of CO2

8 Lessons Learned / Conclusions

What are this project's main findings and conclusions?

The Project's main findings and conclusions:

- The customers are happy with the technology and the service provided
- The system (both the Power-Blox solar battery system as the Flex-Grid prepaid metering) is working well, and no mayor outages have occurred
- Lead-acid batteries are too temperature sensitive and too heavy for the FlexGrid application. They were switched for Li-ion batteries, that can cope better with high temperatures than lead-acid batteries
- LCOE still has to be improved, to improve profitability and attract more investors
- Li-ion batteries need to be reactivated/equalized after a longer period of standstill/storage/transportation. Therefore the original Li-Battery model with 2 x 12V batteries with two BMS has been exchanged with 1 x 24V battery approach with one BMS and no equalization need
- The battery system needs to be protected from direct sun (heating up) and rain (water). This basically seems to work well with the Powerhub structure. Further improvements will be made.
- Demand is under expectations, and not (yet) in line with the business model (based for example on Energy4Impact studies)
- It takes time for productive users to switch from diesel driven appliances to electrical appliances (they need to buy new equipment, or rebuild the devices)
- A Flex-Grid with Power-Bloxs can start small and scale up, though to absorb the peak loads of productive use, a minimum base capacity must be installed
- Land grabbing can be a sensitive topic for local authorities, which asks for a well informing project start.

Which recommendations can be made for similar projects, or within this context?

- Flexibility, modularity and scalability are key factors in rural electrification and should be counted in during the technology evaluation
- OPEX is a key cost parameter in a rural electrification project: travelling in Africa is expensive, time consuming and sometimes dangerous. Logistics of spare parts is slow and expensive
- Therefore reliable, high-quality equipment with low failure rate and easy maintenance is mandatory.
- Remote monitoring and problem solving is key to keep the systems up and running and the costs under control. Further it helps to do remote analysis and provide remote support
- Scale is important to reduce the costs and optimize logistics, but is extremely difficult to achieve

Interesting observations within the project's context: Which of your personal impressions would you like to share?

The populations' expectations are quite high, as they have been dreaming of having access to electricity for a long time. Once the installation is done, they are very thankful and happy, which personally is a huge motivation. Though the journey doesn't stop at providing the power: smart partnerships (with NGO's, rural development agencies….) are needed to guarantee the useful use of the mini-grid. No development without power, but no power without further development.

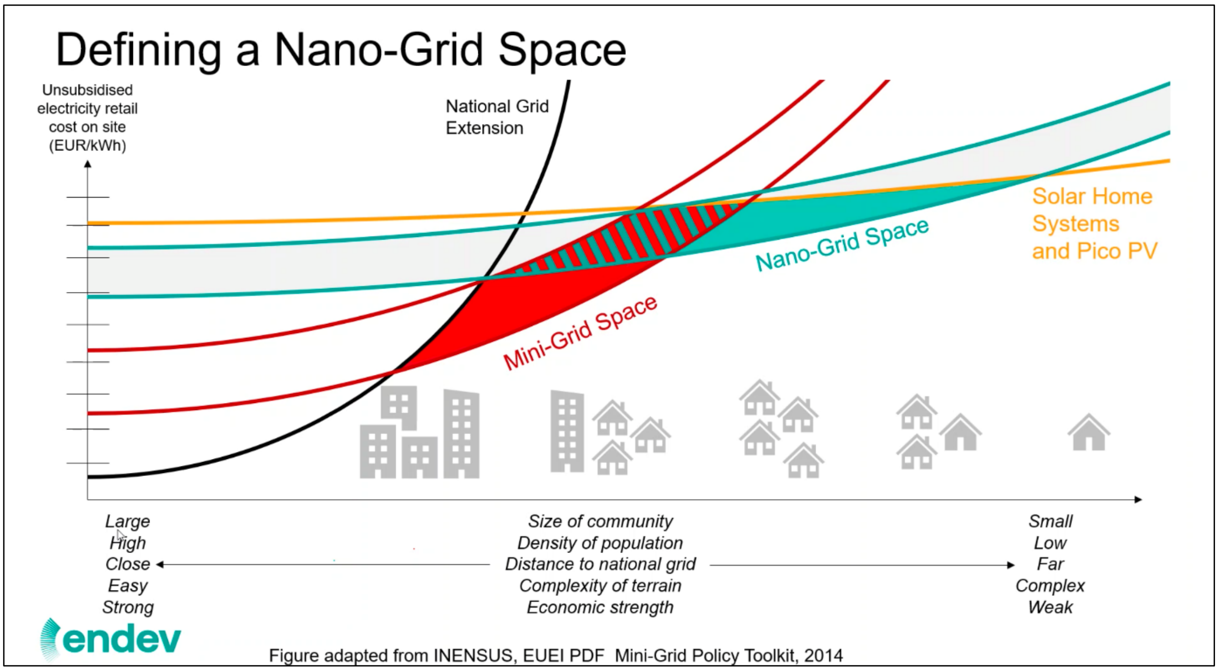
Rural electrification should thus be seen as a dynamic process. Electrification triggers a development that must be met on the service side, otherwise economic development may be prematurely stifled. Power-Blox has therefore further developed its electrification approach to the extent that a dynamic development from the nano-grid to the integrated public grid can be carried out without a technological break, depending on the current energy needs of the population.

Nano-Grid Mini-Grid Public-Grid

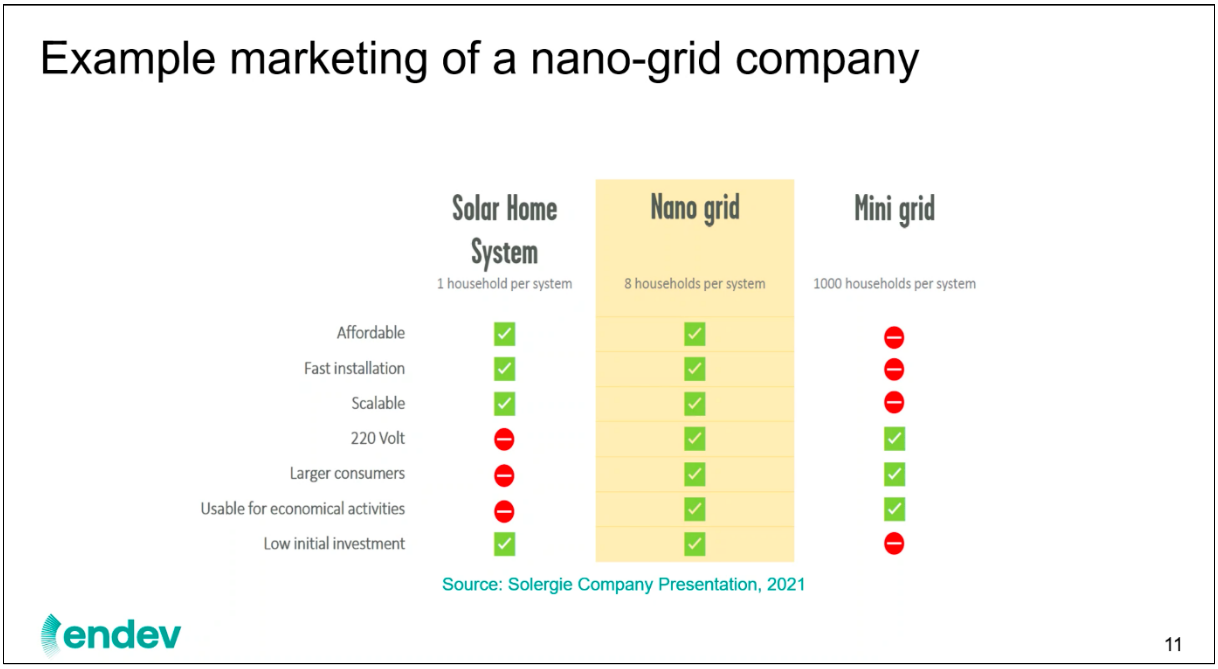
9 References

References list of publications, reports, etc.

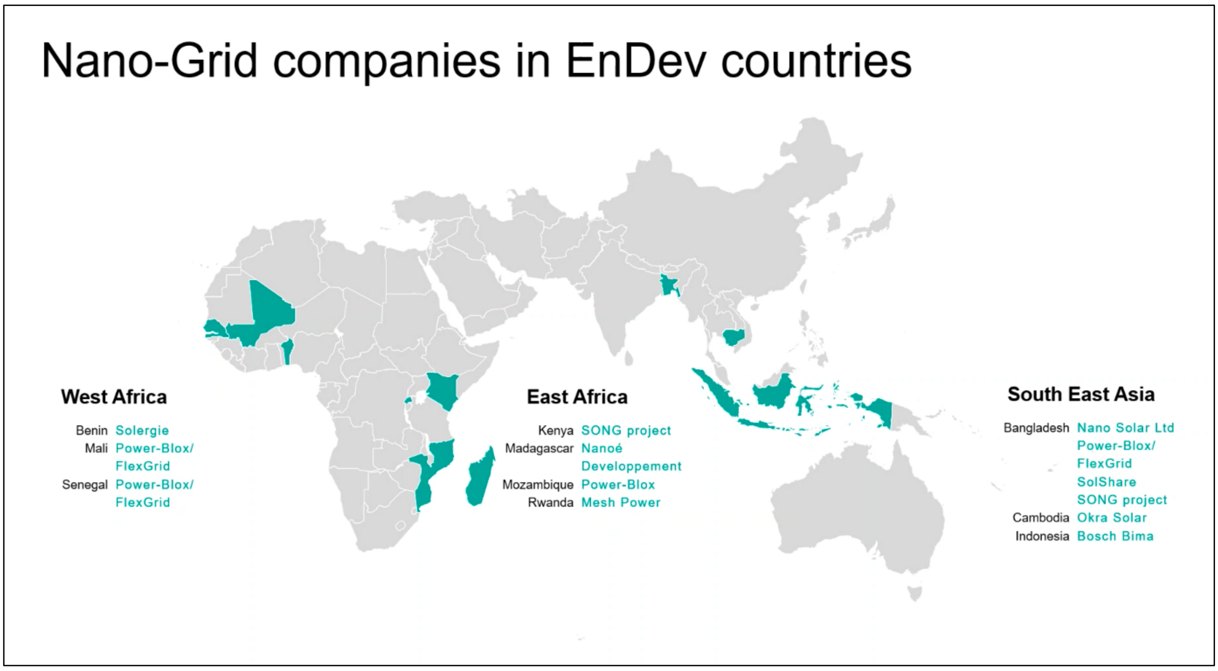
[1] GIZ adding nano-grids to their EnDev program (Energizing Development)



[2] GIZ adding nano-grids to their EnDev program (Energizing Development)



[3] GIZ adding nano-grids to their EnDev program (Energizing Development)



[4] Cross Boundary report 'Open Sourcing Infrastructure Finance for Mini-Grids'
www.crossboundary.com/wp-content/uploads/2020/12/Project-Financing-Mini-Grids-Online_Pages.pdf

10 Annex

When available: Reports, press articles, brochures, test results, etc

- A podcast with Servaas Van Den Noortgate from FlexGrid: https://shineon.buzzsprout.com/856645/9642887