Flex-Grid Installations in Kobong and Thapaiban

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1. Executive Summary

The remote villages of Kobong and Thapaiban in Lao PDR face difficult circumstances. They are far from any national electricity supply and, thus, live mostly in the dark. In addition, they are remote and lack access to a regional market. As a result, they have little potential for economic growth. However, given this challenging starting point, the two villages are ideal candidates for a new approach to electrification - the flex-grid. Unlike the traditional mini-grid approach, which is tailored to a defined initial situation (or village), the flex-grid approach is based on the notion of electricity grids that grow organically. Thanks to modular and easily expandable generation and storage technology, the rate of growth can adapt to a local community's socio-economic development.

This Solar Flex-Grid project is one of the first in Asia to adopt a frugal approach. Simply put, such an approach involves developing solutions using very simple means: doing more with less. Even the system's installation - performed by a local solar company without on-site support from international specialists – reflects that notion of frugality. Local installation was necessary because of the coronavirus pandemic and possible thanks to the simplicity of the technology. The project's frugal character is also reflected in the system's operations and maintenance, with the local population carrying out simple tasks. This approach also lays the foundation for livelihood activities, helps the villages to generate jobs and income, and will improve healthcare and education over time.

The project demonstrates how this novel technology approach can quickly and easily electrify households in two villages where energy demand is too high for solar home systems (SHSs), but where demand for conventional mini-grids is too low. A total of 11.52 kWp of solar power and 43.2 kWh of battery storage were installed in the villages. The requirements will be monitored and re-evaluated in two to three years so that the energy infrastructure can be upgraded if necessary.

Background

The Lao People's Democratic Republic (Lao PDR) has a long-term goal for national development, set out in the Eighth Five-year National Socio-economic Plan (2016-2020) with a Vision to 2030. Lao PDR recognizes the strong link between economic development and sustainability and the need to mainstream environmental considerations, including action on climate change, in its development plans.

Lao PDR is a highly climate-vulnerable country. Its greenhouse gas (GHG) emissions totalled only 51,000 Gg2 in 2000, which is negligible relative to total global emissions. Nonetheless, Lao PDR has ambitious plans to reduce its GHG emissions while increasing its resilience to the negative impacts of climate change. Examples of such plans include:

- In terms of Lao PDR's large-scale electricity generation, the electricity grid draws on renewable resources for almost 100 percent of its output. Lao PDR seeks to use unexploited hydropower resources to export clean electricity to its neighbours. By supplying those countries, such as Cambodia, Viet Nam, Thailand and Singapore, with hydroelectricity, Lao PDR will enable other Southeast Asian countries to develop and industrialize in a sustainable manner.
- The Government of Lao PDR has also laid the foundation for implementing a renewable energy strategy that aims to increase the share of small-scale renewable energy to 30 percent of total energy consumption by 2030.

As set out in the National Strategy for Climate Change vision, Lao PDR intends to pursue its development without compromising its environment. The country has identified mitigation actions that it plans to take to reduce future GHG emissions, subject to the provision of international support.

With support from UNDP, Lao PDR has developed Nationally Appropriate Mitigation Actions (NAMA) for the country's renewable energy sector. The NAMA will contribute to efforts to provide electricity to 98 percent of the country's population by 2025. This NAMA covers one type of technical intervention – establishing mini-grids, which will focus on rural communities, tourism, agricultural facilities, health centres, and schools and literacy centres based on their demand for electricity for lighting, cooling and appliances. The mini-grids will use renewable energy sources and will provide electricity for lighting, radios and phone charging for households, and for service and production activities.

Lao PDR has been keen to initiate the NAMA implementation activities as a way to achieve the NDC targets and has obtained funding from the NDC Support Programme. Under that programme, which was signed in December 2017 between UNDP and the Government of Lao PDR, NAMA implementation targeted the two rural village communities of Thapaiban and Kobong/Sinthong. They were chosen as project beneficiaries based on factors including the number of persons to be reached, the villages' proximity to each other, potential for access to distribution and transmission lines, needs identified, and willingness to participate in the initiative. The Institute of Renewable Energy Promotion (IREP), which is responsible for renewable energy development, energy efficiency, and conservation and rural electrification efforts, is the main interface with the Lao government. In addition to participating in assessments and monitoring implementation and compliance with standards, IREP will develop the tariff, operationalize the business model and oversee flex-grid operations.

The project's missions have shown that the communities' circumstances are challenging. The villages lack a land connection to the outside world and, thus, lack direct access to a local market. The communities live on subsistence farming, so incomes are very low. There is no mobile reception, which makes communication difficult. The only connection to and from the village is the Nam Theun River, which is both a source of life and a transport route.

It was clear from the start that neither conventional models nor technologies would work here sustainably. Difficult situations call for new and innovative approaches suited to community needs.

1.1. Reducing dependency by reducing complexity

The small and medium-sized solar mini-grid technologies that serve off grid-villages today are often complex. Storage technologies must be combined with energy sources; that is, solar modules and other components, such as charge controllers, inverters and safety devices. Each component is complex in its own right. Chemical batteries must be used with the right voltage, temperature and power range. If these parameters are not followed, service life is considerably shorter than expected.

Solar modules must be operated in the correct voltage range and must not be partially shaded; otherwise, they will lose significant energy production capacity. Since solar modules are connected to strings of up to 1,000 volts DC, handling them is dangerous and should be done only by skilled personnel.

Inverters and charge controllers are complex electronic components that manufacturers design to be as universal as possible to cover a wide range of applications. However, the devices must be configured correctly and will work properly only in this configuration. If, for some reason, the situation changes (for example, after a partial failure due to a storm), the overall system can be rendered ineffective because the configurations no longer apply. On the other hand, in the event of a problem, the components report complex error messages, which maintenance personnel often do not understand.

Each component must also fit into the overall system. If individual battery cells fail, this can be addressed only to a limited extent and requires readjusting the configuration. If battery cells need to be replaced later, they must not be mixed with old cells, which, in turn, requires maintenance personnel with expert knowledge.

This overall complexity creates major challenges and raises the cost of operating and maintaining solar mini-grids for small and medium-sized villages. Costs increase accordingly if maintenance and reconfiguration cannot be performed via remote monitoring, as local personnel often lack the skills to maintain a mini-grid, while qualified employees may have to travel long distances or, even, from abroad, which results in high costs and long downtimes.

1.2. The "frugal" concept

The first mission demonstrated that conventional approaches would not be effective for this project. However, there was a clear demand for electricity and initial, small applications were observed. Small SHSs power individual light bulbs and individual televisions and refrigerators offer a glimpse of the advantages of a distant electricity-based future. However, all significant (that is, income-generating) applications, such as agricultural machinery, medical applications and individual lighting, remain unaffordable.

The project's task was to overcome these seemingly insurmountable barriers and create a sustainable power supply suited to the villages' circumstances, culture, remote location and, thus, to the need for a system that residents can maintain on their own. It would have to be technologically well-designed and economically and ecologically justifiable.

To dimension energy access, the Power-Blox team adopted the Multi-tier Framework (MTF) developed by **SE4ALL**. The team thus had to find a way to estimate household energy expectations accurately and allow for development along the tiers, should energy demand grow in coming years.

Figure 1: Multi-tier Framework (MTF) and the coverage provided by the Power-Blox solution

GROWTH PATH →

	Tier 1	Tier 2	Tier 3	Tier 4	Tier 5*
Power	≥ 3W	≥ 50W	≥ 200W	≥ 800W	≥ 2kW
Energy	≥ 12Wh	≥ 200Wh	≥ 1kWh	≥ 3.4kWh	≥ 8.2kWh
No of PBX-200 and households	1 x 10 to 50 HH	1 x 2 to 10 HH	1 x 1 HH	4 x 1 HH	10 x 1 HH
Application	Private household	Private household SME	Private household SME Farms	Private household SME Farms Schools Health centres Civil services	Private household SME Farms Food processing Cooling Schools Health centres Civil services

*The PBX-200 can cover Tier 5, but our larger products (PBX-400 or PBX-1000) are better suited to that tier.

The current energy supply in the villages was categorized, in general, from Tier 0 to Tier 2 and, in isolated cases, Tier 3 (based on existing generators).

An innovative new approach was used to address the challenges: a frugal solution. In contrast to the complex and large systems widely used in developed countries, which strive for the maximum achievable across every dimension - more power, more functions, more scope - the frugal approach seeks to meet just actual needs. By scaling solutions down to the essentials, they become affordable and manageable for populations that would otherwise be excluded from certain technological achievements. In addition, a frugal approach covers many more industries and applications in developing countries, from packaging design (small detergent packaging units) to inexpensive, battery-powered medical devices (mobile ultrasound examination) and reasonably-priced cars that do not sacrifice safety features.

This approach in our project villages involves tailoring the solution to the applications described in the upper tiers and allowing energy supply to expand when it no longer meets requirements. Instead of equipping households with SHSs and tying them to Tier 1 or 2 at a high price, we must offer them options that can increase energy coverage towards Tier 5, but do not create a cost burden. The project's limited budget also argues for a frugal approach, as it would not have allowed for a Tier 4 or Tier 5 solution.

2. Swarm electrification as a frugal solution concept

The swarm electrification concept developed by Power-Blox was applied for the first time in Lao PDR in the two village projects. With this approach, Power-Blox created a bridge between simple, but very limited, SHSs and powerful, but expensive, mini-grids. The result is the Power-Blox PBX-200 Li, a lithium ion-based battery cube that delivers conventional alternating current with 230V and 50 Hz. A cube is thus equal to an SHS that is slightly too large. However, unlike SHSs, several cubes can be plugged together based on the LEGO® principle to create an "energy swarm." The power, battery capacity and energy generated increases with each cube. Building this system does not require special knowledge and any technician or installer can complete the task.

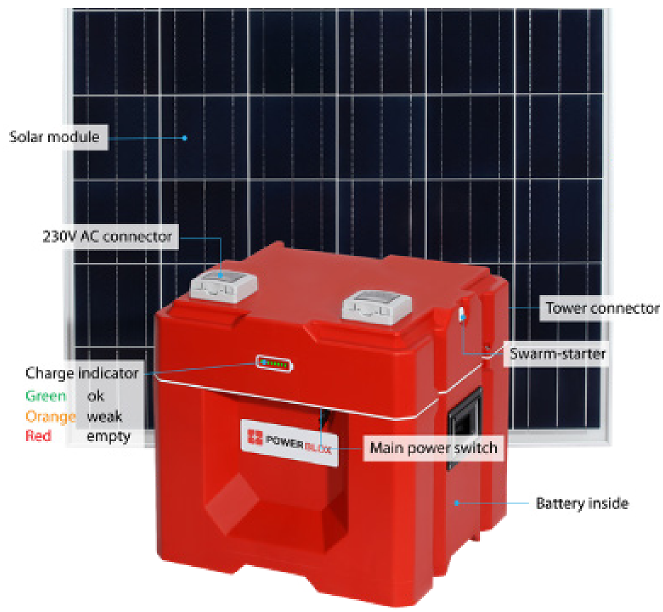

Figure 2: The worldwide first frugal battery device "PBX-200"

Since the system is modular, it adapts flexibly to the given requirements. If a village needs little electricity, only a few Power-Blox cubes are installed. If demand increases, electricity can be expanded flexibly. As the units are connected using conventional alternating current, the integrated battery technology plays a minor role. Thus, units with lead batteries can be connected to lithium units without a problem. If a new battery technology becomes commercially available in a few years – for example, saltwater batteries - it can be integrated into the existing network without configuration.

2.1. The flex-grid concept

Figure 3: An "energy swarm" can be built simply by plugging devices together like LEGOs.®

Thanks to this modular energy generation and storage system, flexible mini-grids, or flex-grids, can now be built. Flex-grids are networks that grow organically. The concept also attempts to break through the classic approach of a rigid mini-grid at the grid level and remain flexible at the distribution level. The primary goal is to achieve electrification at as low a threshold as possible. Here, too, Power-Blox has tried to combine the advantages of very flexible, but limited, SHSs with the advantages of a classic mini-grid.

The basic idea is that a level of electrification that can integrate productive use and, thus, support livelihood improvement can have dynamic effects on villages. Villages participating in other Power-Blox-powered projects in Africa have grown significantly after electrification. In such situations, both the grid and power generation need to be expanded.

Current flex-grid development envisions applying the concept to very small grids - so-called nano-grids - with a few dozen households. Under this scenario, local small entrepreneurs, for example, from the agricultural sector, become anchor customers and energy entrepreneurs at the same time. Flex-grids then directly connect the neighbouring households around these anchor customers.

Unlike conventional mini-grids, flex-grids can be combined. They can include multiple feed-in points, as all Power-Blox battery units within the flex-grids synchronize independently. The greater the number of connected sub-grids and battery units, the greater the safety reserve in terms of battery capacity and peak power.

3. Project preparation mission

A tariff model was discussed with the Government of Lao PDR and the target communities during the site visit. The tariff should ensure sustainable operation and system maintenance and finance spare parts and any necessary support work by the local service partner.

To gain initial experience with the technology in the local context and conduct initial trainings for the service partner and the local population, project management decided to first install a small system with three Power-Blox devices.

The further goals of the mission were to:

- Brief local stakeholders on the project concept to obtain their buy-in;
- Survey the on-site situation in two villages;
- Determine energy requirements and economic conditions;
- Clarify possibilities for digital communication; and,
- Identify potential areas of application for productive use to generate income.

3.1. The energy situation in the target communities

The two project sites, Kobong and Thapaiban, are located in the Nakai-Nam Theun National Biodiversity Conservation Area (NBCA). These sister villages are only a few hundred metres apart and are separated by the Nam Theun River, which can be forded on foot when the water level is low.

In addition to private households, the area hosts one health centre, four shops and one school. The health centre already draws power from solar systems, but would welcome additional electricity so that it can offer more services to the community. Around half of the shops also have SHSs.

TARGET GROUP	NUMBER	MAIN APPLIANCES	ESTIMATED CONSUMPTION
Private households	154	Phones, lighting, flashlights	50 W
Health centre	1	Lighting and refrigerators	310 W (currently)
Shops	4	Lighting, phone charging, radio	50 W
School	1	Fan and speaker	250 W

Prior to the project intervention, many very small SHSs provided a few watts of solar power, a few larger SHSs provided about 100 watts of solar power, and individual generators were in use in both villages, Together, these offered a basic energy supply. The generators were used to operate agricultural machines, while the medium- sized solar systems powered musical equipment and the village chief's home. As mentioned in chapter 2.2, current energy solutions ranged between Tier 0 (no access) and Tier 3 (>= 200 W). The fundamental objective could thus be defined as providing broad coverage for each household to least at Tier 2 (>=50 W).

Figure 4: Old solar home system in Kobong

An energy supply was thus created for each of the two villages. The following table provides an overview of the battery systems, solar modules and total power.

VILLAGE	NUMBER OF POWER-BLOX	NOMINAL AC POWER [KW]	BATTERY CAPACITY [KWH]	NUMBER OF PV-MODULES	TOTAL PV POWER [KWP]
Kobong	20	4 kW	24 kWh	20	6.4 kWp
Thapaiban	16	3.2 kW	19.2 kWh	16	5.12 kWp

The system is designed with a starting point of 16 or 20 Power-Blox, as described in the previous chapters. This is the basis for a frugal supply, in keeping with the MTF model, with the goal of achieving Tier 2. The modular swarm approach guarantees at least a Tier 1 supply, even in the event of a disaster, if, for example, a storm destroyed individual devices.

As noted, this design is a starting point and should be reviewed after the first two or three years of operation. If energy requirements increase during this time (that is, move towards Tier 3 or 4), the energy infrastructure should also be upgraded. This can be easily achieved by using additional Power-Blox devices.

3.2. Commercial buildings

Only two commercial buildings – two small stores - could be identified in Kobong. Since they do not have special equipment, such as computers, cash registers or refrigerators, the expected electricity demand for lighting, radio and telephone charging is also low. Thus, they could be treated as households at the time of design, but with the option of an early upgrade to Tier 3 or, even, 4. However, due to the low purchasing power of the local population, such a change is not expected in the short term.

3.3. Households

The two villages have a combined total of 154 households, with 91 in Kobong and 63 in Thapaiban.

Each household has installed two LED 5W bulbs and one plug socket and used their own energy meters and circuit breakers to calculate and record each household's energy consumption.

3.4. Automation as the basis for rapid scaling

Achieving universal access to affordable, reliable and sustainable energy will require a huge effort, including innovations in energy systems that can be installed quickly and easily, such as the Power-Blox swarm systems, and in planning, as mentioned in the previous chapter. Power-Blox will thus continue to expand its grid planning tool so that it can autonomously detect roof areas from high-resolution satellite data based on a pattern recognition algorithm. To expand the tool's application, these AI algorithms will be trained in the areas of household affiliation, estimated energy consumption and probability of productive use applications.

Such cloud-based applications can significantly shorten the time needed to plan off-grid electrification projects and, in a further step, compare real data with planning data. This would train the algorithms further to improve future planning results and prevent idle times.

The two systems described above – automatic detection of rooftops and households and automatic mini-grid design and optimization - will be integrated via a cloud-based, easy-to-use interface, similar to the off-grid tool developed by **GIZ in Mozambique**.

3.5. Project situation analysis and drone-mapping

Unlike SHSs, the two flex-grids require adequate planning of the local grids to calculate the materials to be transported to the project site. It is difficult and, even, impossible to procure additional materials in a short time, particularly in remote project locations.

Mini-grid planning involves these five steps:

1. Rough analysis of the situation using satellite data;
2. Pre-assessment in the village by recording drone data;
3. Manual marking of households on the drone maps;
4. Automatic design of the swarm network with the Power-Blox design program; and,
5. On-site verification of the satellite and drone-based planning and adjustment when the lines are laid.

To support the planning process, Power-Blox has developed special software that can automatically create an optimal mini-grid design. This tool, which was developed as part of a master's thesis at the Swiss Federal Institute of Technology (ETH) in Zurich, optimizes cable costs using a special algorithm. Using this pattern recognition process and an artificial intelligence-based algorithm that is trained accordingly, roof surfaces can be recognized automatically and assigned accordingly. Households will also be recognized based on certain parameters and individual roof surfaces can be assigned to households. In addition to identifying houses and households, various parameters will automatically determine expected energy consumption. Those parameters include roof size, material, colour, shape and regional specifics (for example, the roof types usually found in the region and in which income group).

A rough allocation based on the MTF system presented in chapter 2.2 is adequate at this point. At this stage, the main objective is to identify a sufficiently accurate starting point for village electrification, which will provide a reasonable energy supply for an initial period of one to two years. After this theoretical (but very efficient) planning phase, the actual measurement data from the energy meters will provide a solid basis for further expansion.

These automatic analyses also allowed an initial estimate of the required quantity of cable, calculated to total approximately 1.5 km of main lines and 6 km of connecting lines for the two villages.

Phase 1 of the above-mentioned planning process quickly showed that the resolution of the available satellite imagery of the region was not high enough to identify the households with reasonable accuracy. However, determining which buildings belonged to which household and, therefore, needed their own electricity meter could be done immediately after the on-site assessment, using the drone map produced in the process.

At this stage, households are identified manually, but when later versions of the software are available (now being refined), this function will be automatic. This will allow local swarm networks for villages to be planned quickly. South-South knowledge transfer will make the functionality available to local solar companies so that they can design flex-grids independently.

The Power-Blox algorithm for network design tries to find the best possible design by running through different iterations and comparing the costs of each design variant with the remaining designs. The total cost of cables and meter hubs is calculated for each variant and compared with the others. The more expensive variants are sorted out and the most favourable design is proposed.

This **video** explains how the algorithm works and optimizes costs.

**The simulation uses these essential elements:

POWER HUB	FEED-IN POINT TO THE LOCAL SWARM GRID
Meter hub	Nodes from which individual households are connected to distribution boxes with the meters in the meter hubs
Households	One connection point for each household, which has its own meter; a household can also be a group of buildings, which pay the consumed electricity together
Main power supply cable	Represents the main distribution cable for energy in the village network and connects all meter hubs (red lines in the map below)
Distribution cable	Connects individual households and links them to meter hubs (green line in the maps below)

During the design process, manual interventions are possible and often needed, since an automatically designed grid does not always produce the most feasible solution. Certain basic conditions, such as roads, rivers, trees and rocks, must be considered and are controlled by manual intervention and specification of certain fixed points.

Adjustments based on the expected growth of the village constitute another important step that requires manual intervention. For example, it may make sense to equip a household on the periphery of the village with a metre hub so that the main grid can expand from there as the village grows.

Figure 5: Automated mini-grid design based on drone map of Kobong

Figure 6: Automated mini-grid design based on drone map of Thapaiban

4. Technical Design of the Flex-Grid

4.1. Methodology

Power-Blox batteries provide the energy needed in both villages. Based on the LEGO® principle, these are simply plugged together. In Kobong, 20 Power-Blox were needed (total power 4kW), while Thapaiban used 16 (3.2kW power). If a village's energy requirements increase in the future due to development, these could be easily supplemented by further Power-Blox batteries at any time. This supports village energy development following the MTF system as described in chapter 2.2.

A major advantage of the new technology is that new battery systems can be used alongside old ones. If new technologies, such as the more environmentally friendly saltwater batteries, are to be used in the future, they can be mixed with existing Power-Blox systems. As noted, installation does not require configuration or complex technical knowledge, as the systems are completely self-organizing and self-optimizing. Should individual systems fail, they can be separated from the rest and delivered to Sunlabob, a company based in Lao PDR that specializes in renewable energy solutions throughout the developing world, for repair. The village technician assigned can then re-installed them independently. The goal of this approach is to create compatibility among manufacturers in the future, so that individual components can be connected easily to form complete systems.

Power is generated by standard PV modules (320Wp per module), which are directly connected to the Power-Blox battery systems. The advantage is that partial shading, for example, by trees, has a less significant impact on power generation than, for example, in the case of a single, large solar array.

Standard solar modules with commercially available outputs were chosen for the design. They are less expensive and can be replaced more easily. If individual solar modules are replaced or additional modules added, any module in approximately the same power class can be used. This contrasts with conventional systems, where all of a plant's modules must be the same type, which can quickly result in total failure, especially in a storm in which individual modules break and cannot be replaced easily and quickly.

Figure 7: The Power-Hub as a central location for the energy infrastructure

4.2. Battery storage

Lithium iron phosphate (LiFePO4) batteries were chosen as the battery technology for the storage system. In an environment with high outdoor temperatures of up to 35° C, they operate well without active cooling (except some simple ventilation) and have a high cycle stability. Depending on use, a service life of eight to 10 years or more is thus expected. However, to guarantee this long service life expectancy, the energy system must be checked periodically against local energy requirements so that the batteries are not loaded to the maximum possible depth of discharge (DoD). The optimal DoD value is about 40 percent to 50 percent, as shown in Figure 8 for a comparison project in the electrified village, Mabime, Mozambique.

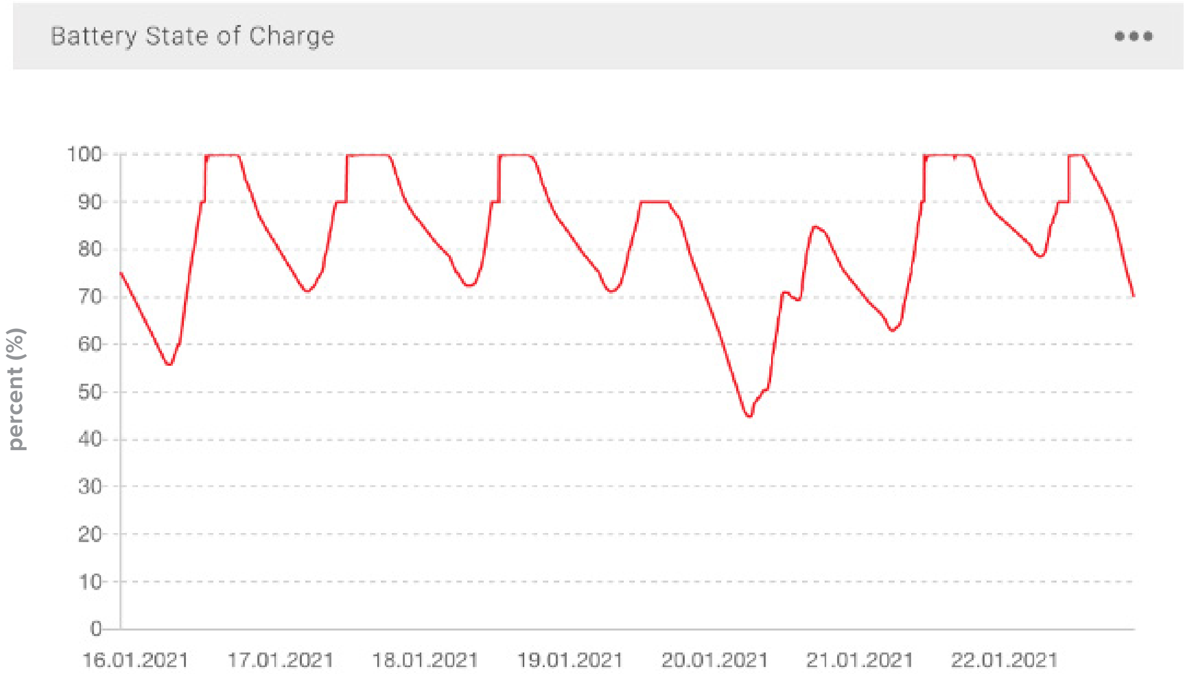

Figure 8: Appropriately sized Power-Blox storage system with sufficient storage capacity reserve

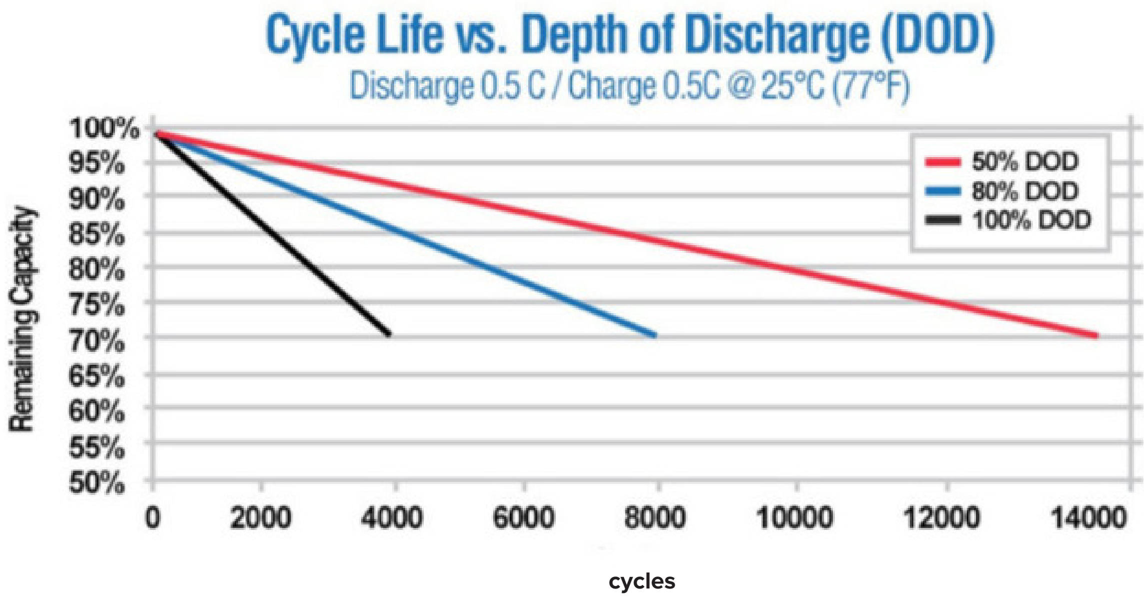

Figure 9: Example of a cycle life of a LiFePO4 battery (Source: Relion batteries: https://relionbattery.com/products/lithium/rb20)

In addition to the discharge rate (C-value) and other factors, such as operating temperature, the DoD of a lithium battery has a direct influence on service life, as each cycle ages the battery. Total service life is thus the sum of all cycles with their respective depths of discharge. To extend battery life, Power-Blox units are set to limit the maximum depth of discharge to 90 percent DoD. Since a typical calculation is based on one cycle per day (charging during the day, discharging during the night), this results in a target of at least around 2,900 (8 x 365) cycles that the battery should achieve if it is to reach eight years of service life. With fewer discharge cycles, for example, only 50 percent as measured in the Mozambique project above, service life increases accordingly and may extend well beyond 10 years.

A swarm-based storage system consists of an alternative current-coupled group of multiple individual systems. In our case, this involves a number of PBX-200 units, each with a lithium battery of 1.2kWh storage. Each Power-Blox cube has its own battery. The configuration of the cube is matched to its own battery and optimized for it. In contrast to conventional systems, which work with battery banks (combinations of many batteries to form an entire battery bank), this concept offers significant advantages:

- The overall system design is much simpler and the villagers can change it on their own, for example, when a single battery needs to be replaced.
- An individual battery failure does not cause the entire system to collapse.
- Different - even future - battery technologies can be combined with the existing system, helping to ensure that the investment is secure.
- The system can be expanded infinitely at will and, thus, grow with the future energy needs of the village.
- In the event of a disaster (e.g., flooding), the battery systems can be brought to safety very easily and quickly and can even be used as individual stand-alone units in an emergency.

One of the most important factors to mention here is that we see lithium batteries as a reasonable compromise for the current project, but are convinced that in a few years, new and more environmentally-friendly battery technologies will come on the market. Those include the saltwater battery,[1] which is promising. The swarm approach allows battery technologies to be mixed. If the system is expanded later, other technologies can thus be used without negative impacts on system operations, unlike in a traditional, DC-coupled battery system.

The lithium batteries currently in use have their own battery management system (BMS), which is installed directly in the batteries. Safety functions at battery level protect the battery against overheating, short circuits, deep discharge or overcharging. These protective functions are important if, for example, the batteries are to be replaced on site and are transported without Power-Blox devices. Furthermore, there is no way to prevent one of the lithium batteries from being used for a different purpose. If that occurred, it would be important to protect the internal and sensitive lithium cells and ensure that they do not cause a fire in any application. The batteries are certified based on industry standards, particularly UN 38.3 and EN 60950, and are intrinsically safe.

All lithium batteries can be transported back to Europe at the end of their operating life of eight to 10 years and recycled properly. If Lao PDR has its own recycling plants within a few years, they will also be able to recycle the batteries.

1 https://www.bluesky-energy.eu/en/greenrock-home-2/

4.3. The flex-grid

Every household in a village has its own energy needs and load profile. The local grid that connects these households plays an important role: it balances the load profiles of individual households, which can be very different. This is true for the total amount of energy required, as well as over the course of the day and at peak power demand. Distributing several households over a larger battery system uses the infrastructure more efficiently. To achieve this requires a local network (flex-grid) with a certain number of households.

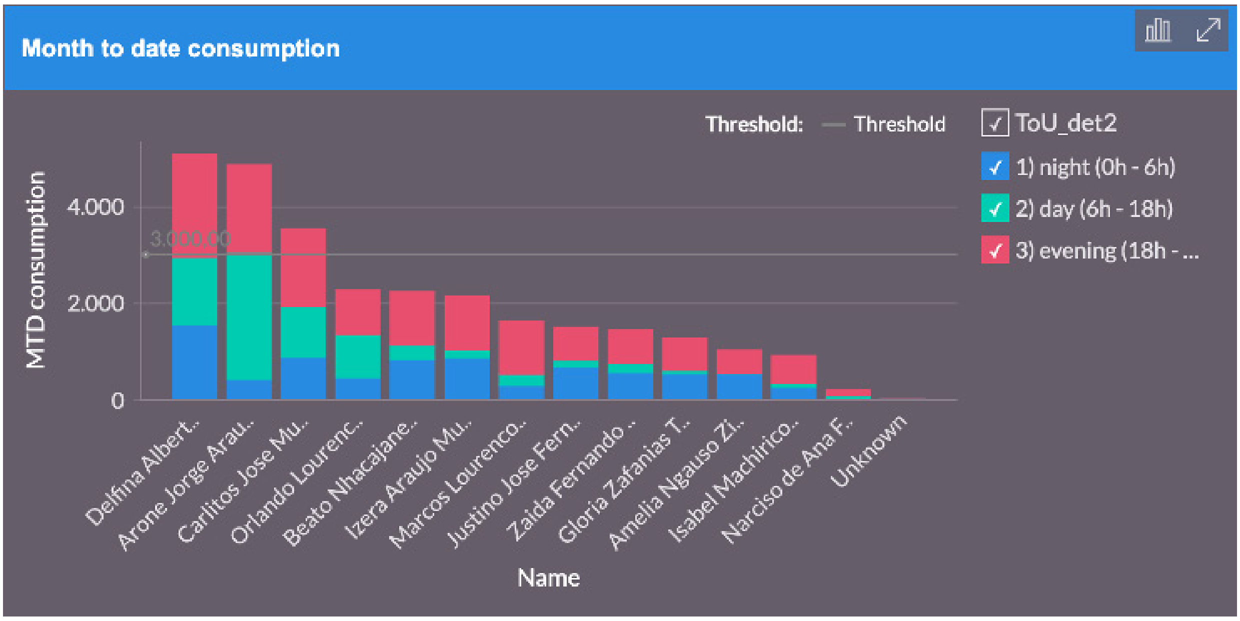

Figure 10: The mini-grid compensates for the different energy needs in a Mozambican village.

Due to its modularity, the swarm approach however offers greater flexibility than a conventional mini-grid design. In conventional mini-grids, the battery inverters follow a centralized topology and feed a star- or ring-shaped grid from one point. However, under the swarm grid approach, the feed-in points of the battery systems can, theoretically, be chosen with complete flexibility. Experience has shown that an overly distributed architecture is not very practical because all battery cubes synchronize both in a more centralized topology and a fully distributed arrangement, ultimately providing a unified supply network. For example, it does not make sense to equip every house with a Power-Blox and connect them all in a network, even if this were technically possible. Power-Blox tested this architecture in the early stages, but discarded it because of the disadvantages:

- A completely decentralized architecture is more difficult to design in terms of safety because the power is fed in from several sources. If one source is switched off, other sources could remain active, which could lead to accidents if inexperienced personnel are involved. For example, if in a completely decentralized architecture (not the case in this project), only some of the Power-Blox devices were switched off, the system would assume that the mini-grid is powerless.
- Equipping each household with its own system led households to disconnect from the overall grid. As a result, the advantage of the communal energy swarm - in which each Power-Blox contributes to total demand – is lost.
- A highly distributed architecture is very difficult to maintain as access to all battery systems must always be available. Some Power Blox could be widely dispersed and located in locked households. Thus, they could not be maintained.
- Troubleshooting in a distributed system is very complex.

Practice has shown that the design of the flex-grid is similar to the classic mini-grid design. Thus, in most cases, the feed-in point is located at one point in the mini-grid. Power is distributed from that point to all households. Ideally, it is located in the centre of the village to reduce the distance to each household, thereby avoiding voltage drop. If the households in a region are widely distributed and the density of connection points is thus low, the overall grid can also be divided into individual independent sectors via segmentation. Each sector is supplied by the Power-Blox systems (power hub) from its own feed-in point. We note that the peak power of the individual segments is lower than if all battery cubes are connected to a single large swarm network. Conversely, however, the total number of cables needed to connect all households is lower if such distributed village topologies are subdivided into segments.

Figure 11: Digging trenches for the mini-grid

Flexible segmentation becomes particularly interesting in novel "nano-grid" concepts around productive use anchor customers, which Power-Blox is piloting in Africa.

On the other hand, if households in a village are widely dispersed and the voltage drop is noticeable over the entire distance along which they are distributed (along a road, for example), the impact of the voltage drop can be reduced by distributing the Power-Blox devices over two or more power hubs. Since the Power-Blox devices carry the greater portion of the load closer to a peak load and support the supply voltage at that point, the maximum voltage drop is limited.

4.3.1. Technical design of the two flex-grids

The two villages were connected with two individual networks. As shown in chapter 4.5, each grid has a main power supply cable, which form the backbone of the village grid. A 3x16mm2 VCT cable was chosen as the basis for this. In Kobong, 713m of this cable of type was laid and 573m was laid in Thapaiban. Individual houses were connected from the main cables via 3x4mm2 distribution cables. Of these, 3,764m were laid in Kobong and 2,249m in Thapaiban. All cables were laid in PE-40 electrical conduits at a depth of 50cm for protection and the cable path was marked with small concrete poles to avoid digging in the area of the grid.

4.3.2. The photovoltaic plan

A PV module array comprised of 320W solar PV panels is installed on the ground in two rows near the Power-Hub buildings. The PV modules are mounted on an aluminium frame, secured to the ground by a coated steel structure. The PV modules are installed facing the sunlight in an area that is not shaded by trees or buildings so that they PV modules receive full sunlight.

4.3.3. Power-Blox storage – the Power Hub

The project started by evaluating the placement of the Power-Blox batteries. The most obvious approach was to use a vacant house in the village. However, during the first mission, the team discovered that there were no vacant houses. Together with the village chief, the decision was made to construct a special building for the battery systems, the "Power Hub." One was built for Kobong and one for Thapaiban.

Figure 12: The Power-Hub as central place for the energy infrastructure

The Power Hubs, which measure about 6m x 1.2m, were built on stilts using traditional construction methods to protect them even during floods. The buildings can be locked and are ventilated to maintain temperatures at a reasonable level. (If the Power-Blox battery systems are heated to more than 45 degrees Celsius, the lithium batteries will age excessively.)

The buildings can be locked to protect the system from tampering. Only the village electricity manager (VEM) has access to the building and conducts regular checks to ensure that the equipment is operating properly.

4.3.4. Remote monitoring

A business model based on a pay-as-you-go system with remote monitoring was originally planned. However, given the lack of a mobile network and of digital communication options, another solution had to be found until the village is connected to the mobile network and digital communication is available. Alternatively, a connection to a satellite communication solution can be made later.

The project team agreed with all stakeholders that standard single-phase offline energy meters (5A, 230V) should be implemented here to measure energy manually and bill users based on consumption. They are not as convenient as online meters, but with careful monitoring by the VEM, they can still serve as a basis for billing and statistics.

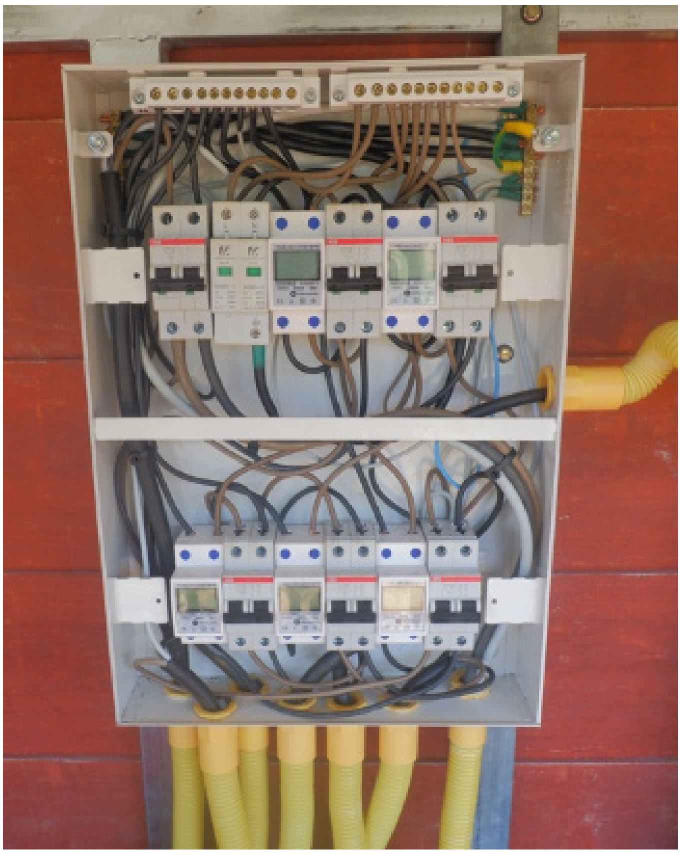

Figure 13: Meter hubs with standard electricity meters

Because no communication solution could be found at the project site, the original concept and business model had to be completely changed. On the technical side, the concept of "meter hubs," presented in chapter 4.4, was chosen. However, these hubs were equipped with the offline standard meters described above, not with the planned smart meters. Unfortunately, as a result, monitoring could not be performed in real time. The system was replaced by a partially automated approach so that energy consumption and system performance data could still be collected. Consumption data are meticulously recorded during regular manual readings of the off-line meters and used as a basis for billing. On the system performance side, the automatic data loggers of the Power-Blox devices are used. These continuously record all performance and environmental data, which can then be read out and evaluated during SunLabob's maintenance visits. Data that can be collected include:

- charge levels of each individual battery;
- temperature of the battery and the power electronics;
- inverter power;
- solar power; and,
- error messages.

These integrated data loggers thus provide solid data used to verify faultless and optimal operations of the energy infrastructure during maintenance visits. In particular, the data can help determine whether the safety reserve is adequate or whether the system should be expanded if energy consumption has increased.

5. Training

An essential part of the project was to train the local solar technology provider, Sunlabob, and the village residents. Sunlabob's training was conducted during the first mission, fortunately before COVID-19 restrictions were imposed. More advanced training, such as replacing electronics, was conducted via video-based training on YouTube.

Figure 14: Video-based training for more complex work as an alternative after Covid travel restrictions

Because the villages are remote, training is particularly important as it can take considerable time for Sunlabob experts or Power-Blox representatives to reach the site after a storm, when the route may be blocked, or in the case of system failure. Thus, the more familiar the VEMs are with the new technology, the better and more flexibly they can respond to problems. Unlike conventional and very complex mini-grid systems, which should preferably be operated and maintained only by experienced and trained specialists, swarm systems are designed to be worked on by local technicians.

Figure 15: Training the two villages' responsible technicians

Sunlabob first equipped the two teams of technicians from Kobong and Thapaiban with the tools needed to perform basic repairs independently. All key maintenance work was then explained in a comprehensive training course. These tasks include primarily removing and adding individual Power-Blox devices and cleaning the solar modules. The training also included reading and recording the electricity consumption values of each individual household and calculating each household's electricity bill. The training did not include collecting electricity fees, as the final model had not been adopted at that time. However, the relevant principle and the necessary calculations were explained.

Presentation of and training on the new swarm technology were particularly important parts of the project because this technology is fundamentally different from other solar technologies. While other technologies require a high degree of technical understanding due to their complexity and, thus, leave users fearful of contact, handling a Power-Blox device is more like working with a diesel generator. Both operation and maintenance can be performed more easily and require less technical expertise than a complex mini-grid system. This means less reliance on outside experts and more flexible applications. However, these two pilot villages will offer new and important experience in remote project locations without communications access. At the end of the initial one-year project period, it will be particularly exciting to investigate the changes and adjustments made to the original project design.

Operation and maintenance costs

As mentioned in previous chapters, one of the project's goals was to implement a sustainable business model that provides for at least 10 to 15 years of operation and that can also finance the procurement of spare parts (especially batteries) and the support of service partners.

Discussions were thus held with the local population and IREP during the mission to determine the villagers' ability to pay for electricity and how the planned expenses could be covered. The following demographic and economic information was obtained, grouped by relative levels in these communities:

Kobong	83 households, 86 families
Thapaiban	65 households, 69 families

5.1.1. Kobong economic levels

Level 1 – low:	12 households
Level 2 – middle:	65 households
Level 3 – high:	9 households

5.1.2. Thapaiban economic levels

Level 1 – low:	8 households
Level 2 – middle:	52 households
Level 3 – high:	5 households

5.1.3. Operational structure

Institute of Renewable Energy Promotion (IREP)	Government agency with overall responsibility for village electrification
Village Advisory Board (VAB)	Supreme body at village levels and official representative of the two village communities. Arbitrates all electricity-related disputes.
Village Electricity Manager (VEM):	Responsible for collecting monthly fees, transferring them to the village fund account, follow up technical issues on a daily bases, communicate with district, province and IREP to obtain support in case of complex issues.
Sunlabob:	Service provider providing support upon request for technical issues.

5.1.4. Tariff structure

During discussions with both village heads, they stated that Level 1 households (poorest) could pay 8,000 kip/month (approximately US$1), Level 2 could pay 15,000 kip/month (approximately US$2) and Level 3 could pay 25,000 kip/month (approximately US$3).

When this report was completed, IREP, the responsible authority, had not yet approved the final business and tariff model. However, according to its latest information, the tariff would be 1,000 kip/kWh (approximately US$0.11). This would allow a family at the lowest income level to purchase about 8kWh/month, or about 260 Wh/day. With the 5W LED lamps installed, this would provide 52h of light per household. With three lamps operating at the same time, it would still provide 17h of light, which corresponds to an adequate level of basic service.

IREP calculates that this tariff model would provide income of US$60 to $70/month. However, that amount would cover only part of the costs of the VEM and would not pay for any support from Sunlabob in the event of technical issues. These revenues are also insufficient to replace the battery, which will be necessary after about eight years.

Based on the current business model, an annual subsidy of about US$2,300 will be needed to maintain electricity in both villages (combined) over a long period of time.

6. Income-generating activities

Energy provides the foundation for improving livelihoods. It serves as a catalyst for local economic potential, whether in a regional, supra-regional, national or, even, international context. Only where real, developable and addressable markets exist can villagers respond with appropriate goods and services. Only where viable transport routes and accessible sales points exist can value creation be promoted and - also thanks to electricity - new income be generated.

6.1. Current situation

Villagers rely mainly on subsistence livelihoods: rice cultivation; slash-and-burn practices; wildlife hunting; and collecting non-timber forest products. Local small-scale enterprises include rice hulling and milling, small animal husbandry, pineapple and broom weed plantation, motorcycle repair and mat weaving. While these businesses exist, they are not profitable because of logistics, as the nearest market is a day's walk or boat ride away (the latter is expensive because of the fuel costs).

In addition to the limited commercially viable economic activities, some activities are very time consuming because of the lack of electricity. This, in turn, leaves no scope for other economic activities. For example, Figure 16 shows two women stamping grain, which takes several hours per day.

Such activities could launch new local services. For example, a small energy efficient grain mill could provide a local milling service. However, such local services must be based on the real purchasing power of the local population, otherwise they will not be used and will not improve villagers' livelihoods.

Although all aspects of and possibilities for improving the livelihoods of the village population within the framework of this project could not be analysed, recommendations were proposed. They can be investigated and developed further in the approved follow-up project, "Improve the Livelihoods and Preservation of Community Forests (iLaPF) in Kobong and Thapaiban Villages of Nakai-Namtheun National Protected Area (NPA)." This project will be implemented in partnership with the Green Community Development Association (GCDA).

6.2. Demand and market

This report recommends starting on the demand and market side, which can be done in a regional context because the cost of transporting goods to market must be affordable. Goods that are sought after outside the villages and that can be transported easily may generate additional income. This would improve local livelihoods and purchasing power and enables further local energy-based services.

Products in demand on the international market are particularly relevant for generating income. Implementing the full trade chain and transporting goods from the village to international customers is very expensive and requires a corresponding promotion and implementation project. This report recommends conducting a comprehensive analysis of possibilities that are compatible with the rules and objectives of the national park. One example might be honey production, which could be an in-demand product, at least nationally or regionally.

Figure 16:Pounding grain is time- and effort-consuming.

Figure 17: Current generators to run agricultural machines

6.2.1. Local shops

Commercial activity underway prior to the project launch includes shops offering everyday items and snacks. Although local purchasing power is limited, the shops have survived and constitute an initial economic base that could be developed further.

Such shops can also develop into local service centres that offer services, in addition to goods for sale. Those services may include:

- Letter writing;
- Graphic design (posters, etc.);
- Copying;
- Laminating;
- Mobile phone charging;
- Photo printing;
- Passport photo printing; and,
- Copying music and burning CDs.

Figure 18: A local shop in Kobong

6.2.2. Grain grinding service (small quantities)

Tamping of grain daily takes a lot of time. As described above, a local cereal milling service for daily needs could offer certain opportunities on the local market and would be relatively easy to implement.

However, certain cultural aspects should be considered. For example, women often mill the grain in pairs, creating a forum for a lively exchange of information. This would probably be limited severely if women switched to an electric milling service, which could have negative social effects.

6.2.3. Village poultry production

Village poultry production contributes to food security in many developing countries and provides income to poor farmers, especially women. Electricity can help intensify and professionalize poultry farming. For example, energy-saving incubators could be used to hatch eggs and sell the chicks to other farmers, who could then raise them and use them to produce eggs and meat.

Figure 19: Local poultry production as business opportunity

6.2.4. Honey production

Honey could be a promising export product for a national and regional market. Electricity could be used to extract honeycomb, print labels and perform other tasks involved in developing a commercially viable economic activity. Through the UNDP Small Grants Program, which expands the electrification project in the two villages, livelihood activities are promoted to generate additional income for households. Over a 12-month period, the communities would be trained to conduct livelihood activities in the fields of beekeeping, integrated family farming, livestock raising and grassing. Sales opportunities for honey, which could be produced locally, will be examined in detail.

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