Feasibility Study for the Electrification of a Village in Pyinsalu, Myanmar

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Abstract

Currently around 1.5 billion people worldwide still do not have access to electricity in their homes. An estimated 80% of these people live in rural areas and most have low possibility of gaining access to electricity in the near future. Mini-grid systems are the most promising way to accelerate the access to reliable energy sources, where the distance from the national grid is too long and the demand not enough to reach critical mass. Nevertheless, mini-grid projects often lack a deep understanding of the socio-cultural context, compromising the ability to provide sustainable solutions to energy poverty and improving livelihoods. Community participatory strategies can gain a more holistic understanding of the community and enable a more inclusive approach to community energy design and planning, in a common effort towards sustainability. The case-study described shows how such approach has created a two-ways collaboration that has facilitated the collection of information and the engagement of the community members. In particular, The Minigrid game, developed by Energy Action Partners, has achieved enthusiastic participation and increased community understanding of energy-related concerns. However, the economic assessment of the proposed solutions has highlighted the unviability of the project for private investors, as well as with incentives partially covering the capital costs. The best scenario is represented by a mini-grid fully donated by a public entity or a donor. In this case, the community is expected to be able to sustain the cost of operation, maintenance and replacement, although paying an electricity tariff higher than usual Myanmar’s prices.

Keywords:

Electrification, Mini-grid, Community Participatory Approach, The Minigrid Game, RETs, Feasibility Study

Resumo

Actualmente, cerca de 1,5 milhares de milhões de pessoas em todo o mundo não têm ainda acesso à electricidade nas suas habitações. Estima-se que cerca de 80% dessas pessoas vivem em zonas rurais e na sua maioria, a possibilidade de virem a ter acesso num futuro próximo é baixa. Os sistemas de micro-redes são uma forma promissora de acelerar o acesso dessa população a fontes de energia fiáveis, quando a distância de ligação às redes de energia nacionais é grande. Os projectos muitas vezes não têm em conta o contexto socio-económico, comprometendo a capacidade desses sistemas melhorarem as condições de vida. As estratégias de participação comunitária podem proporcionar uma caracterização mais holística da comunidade e permitir uma abordagem mais inclusiva à concepção dos sistemas de energia mais sustentáveis. Esta tese analisa um caso de estudo em Myanmar, demonstrando como esta colaboração facilitou o processo de recolha de informação e o envolvimento dos membros da comunidade. O jogo Minigrid desenvolvido pela organização Energy Action Partners foi recebido de forma entusiástica pela população e aumentou a percepção da comunidade sobre a a utilização de energia e os respetivos custos. Foi feita a avaliação económica com base em diferentes modelos de financiamento, desde projectos totalmente privados até projectos com incentivos governamentais. O meljor cenário resulta de um projecto cujo o investimento é feito por uma organização dadora, mas onde a comunidade faz a gestão do sistema com base num custo de energia sustentável, ainda que superior ao preço actual praticado no país.

Palavras-chave:

Electrificação, Micro-redes, Estratégias de Participação Comunitária, The Minigrid Game, Energia renovável, Estudo de Viabilidade

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Abbreviation

ADB – Asian Development Bank

CAPEX – Capital Investments

DC – Direct Current

EHS – Energy Home System

ESMAP – Energy Sector Management Assistance Program

GNESD – Global Network on Energy for Sustainable Development

HPS – Husk Power System

LCOE – Levelized Cost of Electricity

MMK – Myanmar Kyat

NEP – National Electrification Project

O&M – Operation & Maintenance

OPEX – Operational and Maintenance Costs

PHS – Pico-Hydro System

PPA - Power Purchase Agreement

PV – Photovoltaic

REA – Renewable Energy Agency

RET – Renewable Energy Technology

SHS – Solar Home System

T&D – Transmission and Distribution

USD – United States Dollar

1. Introduction

Currently around 1.5 billion people worldwide still do not have access to electricity in their homes [1]. By 2030, according to International Energy Agency projections, this number is not likely to drop because of population growth. An estimated 80% of these people live in rural areas [1] and most have low possibility of gaining access to electricity in the near future. Reliable access to electricity is crucial for improving people's living conditions in rural areas, for enhanced healthcare and education, and for growth within local economies. The international community is taking actions to minimize this inequality of energy services between developed and developing countries.

The new energy era is characterized by the concept and framework for global action known as "energy trilemma". Actions need to address simultaneously three key policy drivers: energy security, climate change mitigation and energy equity, to ensure long-term sustainability of global energy systems [2]. Deep structural changes to energy systems will be required to align technology, infrastructure, policy, scientific knowledge and social and cultural practices towards achieving the same goals. Renewable energy technologies (RETs) have been identified as potential tools to address all three forces constituting the trilemma.

Since the poorer communities are the most vulnerable to the increasingly evident consequences of anthropogenic climate change, energy poverty has become an increasingly important issue on the international institutions' agenda. Therefore, a dedicated industry has grown to address the tripartite challenge to accelerate energy access for the world's poorest communities: appropriate technology, scale and financing.

Several technological solutions have been tested and implemented. The first approach is simply to **extend the national grid**. In many countries, however, this solution is usually unfeasible because of the high cost of extending the transmission lines to rural areas far from the national grid [1]. The terrain of the site can also increase costs. As an example, mountainous areas are often difficult to access for machinery, requiring more time and resources. Another important factor is the size of the demand, which determines the cost per kWh of expanding the grid. These projects need a critical load to be viable, but rural areas have generally small size and very low energy consumption. For this reason, potential demand must be calculated precisely, in particular if the village has no access at all to electricity. Although the connection to the national grid have advantages including cheaper costs, economies of scales, there are some important issue to consider [1]:

- Costs for extending the grid in rural areas are dramatically higher than in urban areas, whereas the electricity tariff is the same. Therefore, the overall price of the electricity for both urban and rural would be increased by costly grid extension projects.
- The electricity supply in developing countries is often unreliable and low quality. Blackouts are common and the access may be guaranteed in limited hours. The increase in demand caused by the extension of the grid

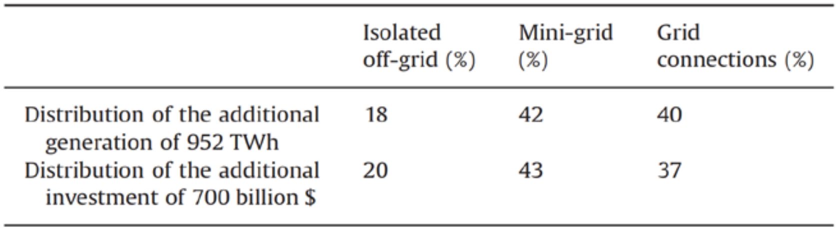
may not be followed by an increase in the energy generation capacity, aggravating the situation and reducing even more the quality of the service.

- Grid extension is often a political tool [1]. Policymakers tend to prioritize the connection to the grid of suburban areas in order to strengthen their political support. More generally urban populations that are more politically active and organized than rural ones are more likely to receive grid access. Moreover, unrealistic political promises of future connection to the national grid encourage people to wait for the grid for many years without looking for alternative solutions, supporting off-grid solutions. At the same time, these promises may discourage companies' investment in off-grid solutions [1].

Where the distance from the national grid is too long and the demand not enough to reach critical mass, off-grid systems are the most cost-effective solution , whether is Energy Home systems (EHD) or Mini-grids. **Energy Home Systems (EHS)** are very small solution that can be installed at the household level. This solution is taken into consideration mainly depending on the dispersion of the households and the types of load required. Where the population is scattered on a large area, high distribution grid costs often make small power systems, owned by the villages, unfeasible. In these cases, stand-alone solutions, such as Solar home systems (SHS) or pico-hydro systems (PHS) can be a better solution, providing energy access to isolated households and eliminating transmission and distribution costs. Nevertheless, the lack of economies of scale hinders the decrease of the total cost of energy. To keep prices affordable capacities are low, around 100W for SHS or 200W for PHS, mainly powering small DC appliances, such as lights, mobile phones, small televisions and radios. This limited power availability often do not support income generating activities, which enable a village to create productive services and jobs [1].

Mini-grid are small centralized system where the electricity is generated at a local level, creating a village-wide distribution network. Mini-grids are the most promising technological approach to accelerate rural electrification. Capacity is provided for both domestic and productive use, enhancing the community living conditions and supporting local businesses and economic development. Small-scale decentralized energy systems have the potential to serve rural and urban consumers in ways that are flexible, timely and can grow with their increasing demand for energy [3]. Ultimately, they can be connected to the national grid. Electricity can be generated via renewable energy technologies, such as PV, wind or small hydro power, utilizing the great natural conditions offered by many locations. Using locally available renewable energy sources has the advantage of low running costs, greater energy security, and lower environmental pollution. Diesel genset can be used as main source or integrated in renewable mini-grids as a backup, when renewable energy sources are not enough, increasing the reliability of the system. Table 1 shows the universal modern energy access case for the 2010–2030 scenario [4], which suggests that 60% of the additional generation capacity and 63% of the total investment budget will be done on mini-grids and EHS. This indicates that off-grid and mini-grid systems are emerging as the solution to improve welfare and socio-economic development of small isolated communities, as islands and remote villages [5].

Table 1 - Universal modern energy access case for the 2010–2030 scenario [4]



	Isolated off-grid (%)	Mini-grid (%)	Grid connections (%)
Distribution of the additional generation of 952 TWh	18	42	40
Distribution of the additional investment of 700 billion $	20	43	37

However, the deployment of mini-grids has resulted to be extremely challenging and many projects have turned out to be unsuccessful after the installation. The bottlenecks for the sustainable success of mini-grids are often not technological, but financing, management, business models, sustainable operations, maintenance, and socio-economic conditions [1]. Each community is described by a complex set of characteristics and interests that determine technical and strategic solution according to local financial, social, and environmental terms. For this reason, it is important to pay attention to the specificities of the local context to design appropriate technologies. Site-visits and community surveys are necessary to gather preliminary information that are crucial for the development of a feasibility study. Community engaged strategies and participatory methods can help to enable a direct engagement, to increase understanding and participation on the community’s side and elicit community needs. An energy system design based on this approach usually reflects the local reality and leads to better supported and longer lasting social changes.

This document wants to provide to energy service companies and other donors who are planning to invest in rural development and rural electrification a feasibility study for a sustainable energy system in Pyinsalu, Myanmar. At the same time, it proposes a methodology for collecting data through community engaged strategies and participatory methods. In particular, the usefulness of The Mini-grid Game, developed by Energy Action Partners, will be demonstrated, by the analyses of results and benefits on the community. The aim of this approach is to gain an understanding of the local context, including available resources, existing institutions, stakeholders, issues and challenges. The methodology also allows to estimate community energy needs, expectations and opportunities, altogether with willingness to pay for the electricity, income-outcome and productive activities. Furthermore, several technological solutions will be suggested according to data and information collected on-site. Finally, the sustainability and feasibility of these options will be assessed, identifying potential technological design and business model.

In particular, this first chapter gives an introduction to the energy poverty issue and the related technological solutions currently employed. The second chapter will summarize the current state of the deployment of mini-grid for electrification, explaining the existing ownership and business models, the barriers to an extensive implementation and the policies and regulatory frameworks that could support it. Then, the third chapter will firstly provide an overview about the Myanmar energy sector, focusing on the electricity sector and the national electrification project. Secondly, the chapter will describe the methodology used during the site-visit and the results obtained. Afterwards, technical solutions will be proposed in the fourth chapter, with optimal design and economic assessment in different financing situations. Finally, conclusions and further work will be given.

2. Mini-grid Deployment in Rural Areas of Developing Countries

2.1 Community Study and Needs Evaluation

2.1.1 Preliminary Studies

Developing an appropriate energy system is one of the key challenges to accelerate a sustainable access to reliable and resilient electricity supply. The long term sustainability of a solution not only depends on the standard and integrity of its technical design and installation, but additional attention must be given to the socio-economic and cultural context of the environments in which these systems are installed and operated [6].

Electrification of rural communities has been often framed within "a top-down technologically-driven framework" [7] that compromise the ability to provide sustainable solutions to energy poverty and improving livelihoods. Key actors in the sector often imagine and construct energy projects according to a set of universalized energy futures, developed via particular sociotechnical imaginaries. Energy interventions are "too frequently reverse-engineered through the lens of particular combinations of technologies, financial models and delivery mechanisms, rather than by attending to the particular energy needs/aspirations of individual communities" [7]. This linear, top-down technological approach that inform the design, development and implementation of RETs can lead to numerous obstacles and limitations. The lack of a deep understanding of the sociocultural context may lead to an implementation that does not follow local communities vision of their own futures and the role of energy in it [7].

As an example, the Solar Electrification by Concession Approach in Limpopo Province and Eastern Cape in South Africa [8] faced many difficulties because it did not give proper consideration to local community needs, expectations and capacity at its inception. After the deployment of 6,000 SHS, more than three quarters of them were taken back by the supplier because of missing payments by the users. Miscommunication about the capacity of the devices left the users unsatisfied, therefore not willing to pay. Similar problematics have been observed at the Mutale Local Authority pilot project [9], which involved in the installation of 582 PV systems. Only 13 survived in good working conditions. 20 PV arrays were stolen and 549 PV systems were recorded as faulty [9]. Underestimation of support requirements, including the provision of no indigenous training in basic PV systems maintenance, and failure to preserve the security of the equipment have been identified as the main reasons [6].

Therefore, it is critical to perform a preliminary study to collect all the information that can influence, hinder or facilitate the implementation of a mini-grid in a specific location. In the planning and design phase, these are the minimum required information [10]:

- current and future energy demand and productive uses of energy;
- willingness to pay;
- community commitment to the project;

- community organization for management of the mini-grid as well as possible need for support and assistance for funding a community-owned mini-grid; and
- potential legal and common rights issues (e.g., land ownership, rights, rights of way)

Preliminary studies are critical to generate a deeper understanding of rural demand to inform community engagement approaches and community pricing models. Furthermore, such studies are useful to inform energy service companies and other donors who are planning to invest in rural electrification programs in the design of suitable mini-grid systems based on rural demand with a trajectory of increasing productive use. Consequently, they can help attracting ESCOs and other players, such as micro-finance institutions, to participate and support the mini-grid market. Furthermore, they generate analyses that can be used for government engagement and advance policy dialogue and government decision-making. Finally, feasibility studies can contribute to decision-making on demand-side and supply-side business models, interventions and investment [11].

2.1.2 Participatory Energy System Design

The drive for lower cost and increased standardization of mini-grid deployment tends to create pressure on project developers who compete on price and project duration, causing them to limit the time and effort spent on stakeholder inclusion and community engagement during project design and planning. This lack of engagement impacts mini-grids in many ways. It contributes to poorly designed systems and poor cost recovery, leads to unmet needs and mismatched expectations, and ignores the social and management-related issues that arise during system operation.

Participatory energy planning can improve the quality of the data collection, overcoming social, cultural and educational barriers that often compromise the truthfulness of basic structured interviews and community surveys. Local communities should not be viewed as just targeted beneficiaries, but as important partners in the development process. Active involvement of the community in program planning gives to people the opportunity to express also their willingness to participate and the level and type of benefit they require to ensure satisfaction and commitment. In such a way, "the implementation evolves into a process of realizing a goal that has emerged as a genuine response to a felt need" [12].

Meetings with local government leaders and public consultation meetings with household heads cannot be considered as community involvement. In fact, this type of activity often remains a one-time event to delivery provide information that are too technical and conveyed using communication methods and language that are hardly understandable for poor rural people [10]. Participatory activities are more than a public consultation meeting, they need to actively engage the community in a two-way communication, which is crucial for building mutual trust, and forms the foundation for cooperation and contribute to project effectiveness and sustainability [10]. The mini-grid project developer should organize regular participatory meeting with community members, invest on existing local organizational structures, and establish a community committee to manage the project and the system operation after it is installed [10]. Governments and NGOs should work to ensure that as the community’s capacity increases, the external groups will withdraw from their active role and finally assume the role of a facilitator, offering information or guidance to the community-operated mini grid [12].

TFE Consulting [13] has participated in collaboration with PACT Myanmar to the collection of data for a demand scenarios for mini-grids in Myanmar, particularly in the Myanmar dry zone. The company used Human-Centered Design (HCD) workshops to gather useful qualitative insights from focus groups of individuals directly related to the outcomes of the study. Four different workshops have been held, respectively with the goal of: collecting necessary data, building a scenario based on the information gathered, test the scenario for further improvements and finalizing the results [11]. This approach has differed from general survey methods as it is non-statistically representative [11].

2.2 Mini-grids Deployment: Current State and Actions Needed

2.2.1 Ownership Models

Mini-grid ownership changes from project to project. There are three main actors that can own, install, manage, operate and maintain the system: local communities, governments/utilities or private entrepreneurs. Different models are used according to local institutional arrangements and regulations. The four most common ones are Community-based, private-sector, utility-based and hybrid.

Under **community-based models**, the mini-grids is owned by the local community which also takes care of tariff collection and operation and maintenance. Often, the system is designed and installed by an outside organization, while a public entity or donor provides grants or financial assistance. After the installation the community takes control, often creating local jobs for community electricity cooperatives or other local organizations. Although enforcement and ensuring payment can be challenging, communal ownership can sensitize the beneficiaries, facilitating proper management and delivery of high quality service.

Community based ownership models are favorite where private companies and utilities do not have the incentive to electrify remote communities since tariffs may not be enough to cover investment costs. This model is more likely to succeed when enhanced electricity access support income generating activities and local businesses, increasing community members revenues. Over time, demand and availability to pay increase, making the mini-grid more financially sustainable.

Nevertheless, community self-management may not be conducted in a proper way. Financial viability of the project can be compromised if the tariff level is set too low. Moreover, corruption can divert resources or decrease community support.

Examples of local communities operating mini-grids are scattered around the world. In India, the West Bengal Renewable Energy Development Agency (WBREDA [14]) creates local cooperatives and beneficiary committees to serve as its partners in mini-grid development. As of 2016, communities own and operate more than 23 mini-grids throughout West Bengal [15]. In Indonesia, the government-led Green PNPM program involved local villagers in operating and maintaining micro-hydro projects [15].

In the **private-sector model**, a private investor pays to install, operates and maintains the mini-grid. Funding often comes from private equity and commercial loans. Currently, there are few examples of models entirely funded by private sources [16]. Private investors typically get involved in countries with supportive policies and simple licensing procedure. In these countries, it is easier for entrepreneurs to access credit, financing, subsidies and technical assistance. In a supportive environment, concessions and output-based subsidies can be provided as government incentives. Improvements in technology, innovations in finance and development of customer-management platforms have contributed to an increasing focus on private sector operating mini-grids [17].

In Tanzania, for example, the government is working to attract private investment in mini-grids by creating a framework of policy, regulatory, legal and financial support instruments for the private sector. This framework has achieved cost-reflective tariffs and increased the amount of capital provided by local banks [17].

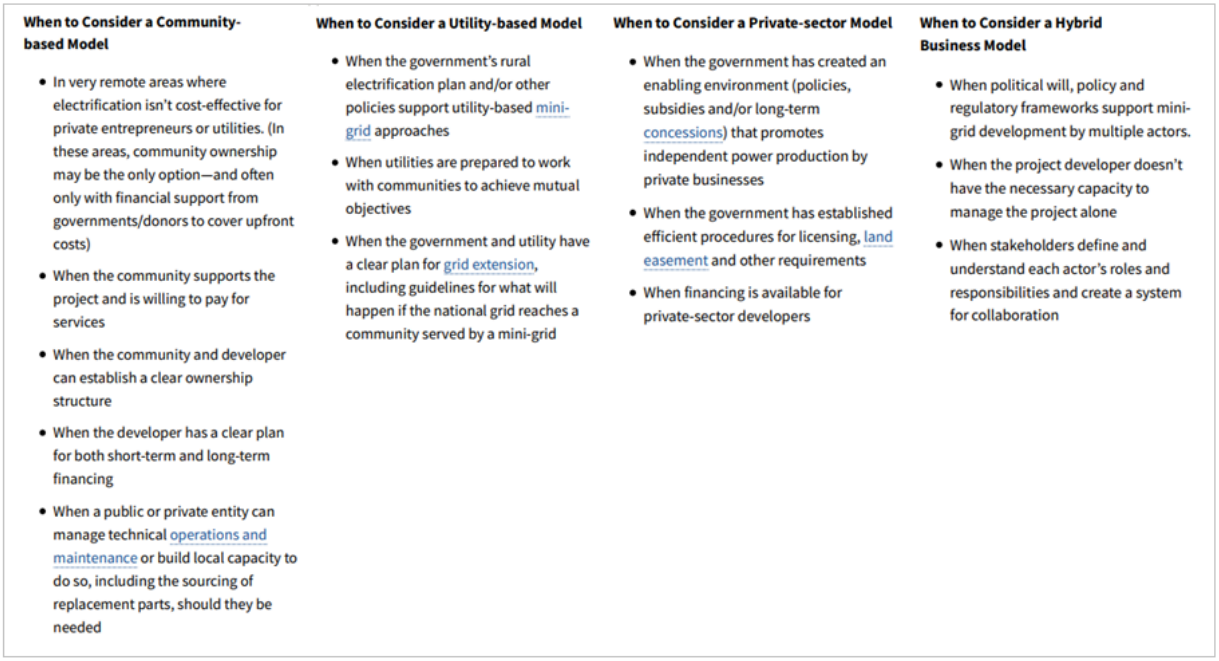
Government regulations regarding mini-grids can influence both positively and negatively ownership models. In regulated countries, private actors must meet technological, financial and quality requirements. Although these requisite may increase the quality of the projects, transaction costs can get too expensive deterring the participation in mini-grid markets. In unregulated countries, the lack of transaction costs can make projects financially viable. In Cambodia, for example, effective deregulation has created a successful environment for private mini-grid operators. Nevertheless, the absence of regulations can cost investors more if private companies do not have constrains. In Somalia, where the sector is largely unregulated and private companies set tariffs, the price that consumers pay for power is often very high [15].

Over the **utility-based model**, mini-grids are owned by traditional state-owned utilities, which operates in the same way as the national grid, but on smaller scale. Sometimes utilities contract with local ESCOs to manage part of the project. Even though costs are higher for rural mini-grids clients, utilities often use the same tariff as in the national grid, covering the remaining costs with subsidies.

Utilities have strong technical expertise, maintenance capacity and financial management system. They often have good access to legal services and system to manage regulations. Finally, if the investment is sustainable, they can scale up operations connecting other villages and eventually the national grid. Nonetheless, Utilities need to engage local communities and promote a sense of local ownership to avoid lack of trust, payments and sometimes failure. The inclusion of mini-grids development in government’s national electrification strategies facilitate the utility-owned model. For example, India’s Rural Electrification Policy describes where utilities should use distributed generation instead of grid extension to achieve rural electrification objectives [15].

Tanzania's national utility, the Tanzania Electric Supply Company Limited (TANESCO [18]), implements a successful utility-owned mini-grid project that uses cross-subsidization and contracts with local energy service companies. In Kenya, where the utility-based ownership model is common, the Rural Electrification Authority develops mini-grid sites throughout the country. Kenya Power, the national utility, then manages, operates and maintains the mini-grids [16].

In appropriate contexts, **hybrid ownership** can be an effective approach. A combination of the three principal actors (local communities, private investors and utilities) collaborate to manage, operate and maintain the mini-grid, taking advantage of the strengths of each partner. One common solution is for a utility to install and own a mini-grid and give the management responsibility to a community-based organization, with technical maintenance provided by a private company.



When to Consider a Community-based Model

- In very remote areas where electrification isn't cost-effective for private entrepreneurs or utilities. (In these areas, community ownership may be the only option—and often only with financial support from governments/donors to cover upfront costs)
- When the community supports the project and is willing to pay for services
- When the community and developer can establish a clear ownership structure
- When the developer has a clear plan for both short-term and long-term financing
- When a public or private entity can manage technical operations and maintenance or build local capacity to do so, including the sourcing of replacement parts, should they be needed

When to Consider a Utility-based Model

- When the government's rural electrification plan and/or other policies support utility-based mini-grid approaches
- When utilities are prepared to work with communities to achieve mutual objectives
- When the government and utility have a clear plan for grid extension, including guidelines for what will happen if the national grid reaches a community served by a mini-grid

When to Consider a Private-sector Model

- When the government has created an enabling environment (policies, subsidies and/or long-term concessions) that promotes independent power production by private businesses
- When the government has established efficient procedures for licensing, land easement and other requirements
- When financing is available for private-sector developers

When to Consider a Hybrid Business Model

- When political will, policy and regulatory frameworks support mini-grid development by multiple actors.
- When the project developer doesn't have the necessary capacity to manage the project alone
- When stakeholders define and understand each actor's roles and responsibilities and create a system for collaboration

Figure 1 – Summary of the conditions that favor each ownership model [19]

The West Bengal Renewable Energy Development Agency (WBREDA [14]) in India and the Monte Trigo Solar PV mini-grid in Cape Verde are good examples of collaboration between the private and the public entities, since government agencies implements mini-grid projects and local cooperatives manage them.

Another hybrid model is when a private company signs a power purchase agreement (PPA) with the national utility. The private investor generates the power and sells it for distribution to national grid consumers.

A national utility can also generate and sell power to local utilities at wholesale prices for onward distribution to consumers. Different actors can generate and distribute energy locally, since generation and distribution businesses are separated. In Tanzania, TANESCO and TANWAT provide energy through a power purchasing agreement. TANWAT generates power while TANESCO transmits and distributes power to end consumers. Figure 1 summarizes the conditions that favor each ownership model.

2.2.2 Business Models for Private Sector

Developing scalable business models for mini-grid is one of the main challenges for private developers. However, creative and innovative approaches can reduce the risks and make the investment more attractive and financially sustainable. Here, are some the business models that can help achieve scale:

One of these is **the Franchise approach**. The franchiser covers all the management costs, minimizing the costs for the franchisee. If the franchiser has many franchisees, the marginal cost of adding a new one is lower, creating economies of scale. This approach has the potential of improving the market efficiency and reach scalability [16]. This model has been used mostly in India. An estimates of 37,000 franchises were operating in the country by 2012, managing more than 200,000 villages [20]. Husk Power Systems (HPS) is one of the franchisers that started to pilot this approach in 2014 [21]. HPS also provides to local entrepreneurs training, motivating them to own and operate the mini-grid [21].

Over the **Anchor, Businesses, and Consumers (ABC) model**, the developer can secure a commercial client with a constant and reliable energy demand, such as a telecom tower or a manufacturing plant, that provide an anchor load and a stable cash-flow. A stable revenue can have a positive impact on the sustainability of the project and help improving the bankability [22]. The remaining capacity is supplied to local business and community households, as additional source of revenues. The ABC model has been successfully implemented in India [23] and it has a high potential in sub-Saharan Africa [24]. Decentralized Energy Systems of India (DESI power) and Haiti Earthspark both used the anchor-load approach to develop viable mini-grid projects. One of the problems is that households often receive the residual power, available after the consumption of the anchor customer, which may not meet the needs of the community. This limits the positive impact of electricity on people's lives.

Finally, the **Clustering approach** consists in organizing non-interconnected mini-grids, located in villages close to each other, as part of one operational and management unit, centralizing the management structure and consequently reducing the costs. In India, the Chattisgarh Renewable Energy Development Authority (CREDA) uses a cluster approach to reduce the transaction costs in mini-grid projects in remote areas [21]. Each cluster includes one technician, an assistant technician, an operator and a village energy committee. These teams are supervised by higher management of the company [25]. However, management of clusters requires high levels of both technical and management skills, particularly as load factors increase. Therefore, the scarcity of trained human capital in rural areas could be a problem. Furthermore, clustering communities can also lower the cost of capital for operators. In fact, there is a larger availability of funding for bigger scale projects.

Additionally, some companies have developed their own innovative business model. Digital finance, increased connectivity and smart technologies may help to overcome some of the barriers to mini-grids deployment.

For example, Powerhive [26] developed a cloud-based software platform, called Honeycomb, that automates account management tasks, remotely monitors and controls mini-grid operations, and runs real-time data analytics. Honeycomb communicates with any mobile money service for customer payment processing and remotely connects or disconnects a customer's electricity depending on the account status. A smart meter is installed in every client, allowing energy measurements, flexible tariffs and pricing, load balancing and performance monitoring. This solution guarantees a better efficiency and reliability of the system and an accurate analysis of the evolution of power demand.

Pay-as-you-go and mobile integration developed alongside smart metering devices may facilitate revenue collection where conventional electricity bills often remain unpaid. Sigora [27] has implemented this approach in Haiti, installing micro-grids in the north-west department of the country.

Okra [28] and SolShare [29], respectively operating in Cambodia and Bangladesh, aim at creating scalable peer-to-peer smart micro-grids. The electricity is exchanged among household connected to micro-grid. Money transactions are effectuated with mobile money operators or crypto wallets, often achieving <1% transaction costs [28]. Moreover, the systems are modular, so they can begin with a small number of households, panels and batteries, and the network can grow to match the growing energy needs of the community over time. As network grows, it can be connected to the national grid, operating in island mode when the grid is unavailable, and receive power from the grid when it is available, metered at a single location.

2.2.3 Mini-grids Tariff

Tariffs are a controversial and complex challenge in the successful deployment of renewable mini-grids. High capital costs, low capacity factors, financing and investment bottlenecks, lack of economies of scale, remote location and low demand are among the several variables that make mini-grids generating costs higher than the national grid one. Historically, governments have been relying on the support of donors, while the involvement of the private sector has been far more limited [30]. Therefore, the focus has been on socio-economic and technological aspects of mini-grids, while sustainable business models have often been missing. [31]. Consequently, many current operating systems continue to rely on subsidies and support. Tariff regulatory frameworks have a key role in the financial sustainability of mini-grids projects. Tariffs need to be affordable for customers but they also need to generate adequate revenues to cover operation and maintenance expenditures and other liabilities and, if possible, recover the capital cost of the system to be fully commercial.

Regulated tariffs may require that the electricity generated by mini/grids is sold at the same tariffs charged by the central electricity grid, although generation costs are relevantly different. In such cases, the projects need governmental subsidies to remain financially feasible. These payment, either in form of subsidies or incentives, need to meet the operator requirement and to be provided in a reasonable amount of time.

The roles of regulators in setting tariffs for mini-grids vary in different countries. For example, in India and China, tariffs for mini-grids established by the government are set by local communities through village committees. In Brazil, both grid-connected and off-grid tariffs are under the responsibility of the regulator Agência Nacional de Energia Elétrica. In Tanzania, the tariffs need to receive the approval of both community and regulator. In Cambodia, the national regulator provides licenses for distributed systems, giving rights to generate, distribute and retail electricity in a specific geographic area and guaranteeing the validity of the license also in case of extension of the grid to the region.

Private sector usually sets higher tariff rates than government sponsored mini-grid, because they depend on equities or investments that require higher returns. This means that private mini-grids primarily operate in areas where customers have higher ability to pay and tariffs can meet the production cost [32]. Areas that are closer to larger population centers are more likely to meet this requirement since they often have more vibrant economies and potential higher profits. Furthermore, the collection of revenues in in rural areas is more challenging because the ability to pay and the demand in these areas are lower than in urban areas.

Sometimes energy access is overly subsidized, highlighting the political nature of tariff settings. In example, the local electricity monopoly in Indonesia charges for electricity at a flat rate much lower than the willingness to pay, hindering the investments the development of mini-grid based solutions and, at the same time, providing a low-quality supply.

2.2.4 Policy Framework to Support Deployment of Mini-grids

Mini-grids have been identified as the most potential option to accelerate rural electrification. Renewable mini-grids have also specific benefits, including speed of deployment, additional private sector growth, and flexibility of technical and operational models as well as energy security. However, with some exceptions, they have been unsuccessful in reaching people without access to electricity.

Current main barriers for mini-grid deployment are not related to technology, but to economic, financial, regulatory aspects as well as institutional and human capacity. To stimulate the deployment of renewable mini-grid and attract private investments, governments need to create a supportive policy and regulatory environment. Through the establishment of appropriate policies to test, develop and implement sustainable business models that are scalable and alleviate investment risks, private actors may be more interested in investing in this solution. This would accelerate the expansion of RETs across rural areas in developing countries.

There are several policy and regulatory conditions that have been identified in the literature, and have been advocated by most bilateral and multilateral donors to support the transition from a state led to a private-sector mini grid development model.

2.2.5 Laws and Licensing Arrangements

Laws and licensing arrangements include all the activities that a prospective investor needs to fulfil, such as company registration, suitable land, building permits and licenses to generate, distribute and retail electricity. Although it may appear easy on paper, obtaining licenses and permits is time consuming and costly [17]. For example, licensing cost can be greater than 10% of a project's capital cost.

Governments need to specify various stakeholders and bureaucratic agencies involved and define their roles. They also need to provide transparent and streamlined regulations covering mini-grids and simplify the licensing process. Dedicated digital platforms are a valuable tool to facilitate the access to such information and reduce the cost of collecting information for potential investors. An example is the mini-grid portal in Tanzania (www.minigrids.go.tz), which is managed by the government. Another facilitator that has often been supported by donors is the development of renewable energy agencies (REAs) for rural electrification that can advocate private companies, acting as intermediaries with the governmental institutions [16].

Furthermore, accurate information about national grid extension plans have to be provided by the governments, through for example rural electrification master plans with location and time-frame of grid extension. A lack of such information may discourage investors and decrease the investment in mini-grids [17]. A better incentive is to develop compensation mechanism or an assurance of grid inter-connection if the grid arrives in the mini-grid area.

2.2.6 Cost Recovery and Tariffs

Tariffs setting is often politically sensitive for governments in developing countries. Tariffs regulations can impact the viability and sustainability of mini-grids by controlling the mini-grid electricity selling price. Governments have to set a regulatory framework that keep tariffs affordable for end-users and not prohibitive for potential investors.

Some governments allow small-scale mini-grid operators to settle tariff levels in consultation with the local communities. For larger systems, potential operators tend to opt for formal mechanism for tariff settings in order to avoid disputes in the future. Standardized methodologies, such as a cost-plus method, are more transparent and provides potential investors with some certainty.

In case tariffs above the national rate for grid-connected consumers are not allowed, governmental financial support is needed and revenues for the private sector are shorted. A study by ESMAP in Ghana highlights that keeping the electricity rate equal to the availability to pay of the local people would require subsidies for more than 50% of the CAPEX. If tariffs were capped to the national level, 100% of the capital cost of the project would have to be covered by subsidies. This shows that there is a clear disjuncture between equity concerns of governments and the expected financial returns for potential private actors [16].

Private mini-grid operator would need some measures to achieve greater profitability, such as:

- Allow electricity tariffs above the national tariff rate;

- Allow the cross-subsidization between different groups of customers;
- Increase the freedom of the mini-grid operator to decide the terms of the power sale contracts with corporate customer;
- Allow mini-grid operators to set a tariffs structure which suit the most their technology and business models.

2.2.7 Facilitating Access to Finance

Governments also have to take actions to attract capital into the mini-grid sector to scale-up the deployment. To do so, they need to facilitate access to finance for mini-grids projects, setting an enabling policy and regulatory environment to develop bankable mini-grids projects and measures to address specific gaps in financing. Governments as well as multilateral development agencies can provide support by facilitating the access of entrepreneurs to debt, equity , or grant financing. It is necessary to mitigate risks relatively to business models that discourage financing and investments. Public financial support needs to be design to incentive private capital and ensure sustainability of projects over their lifetime.

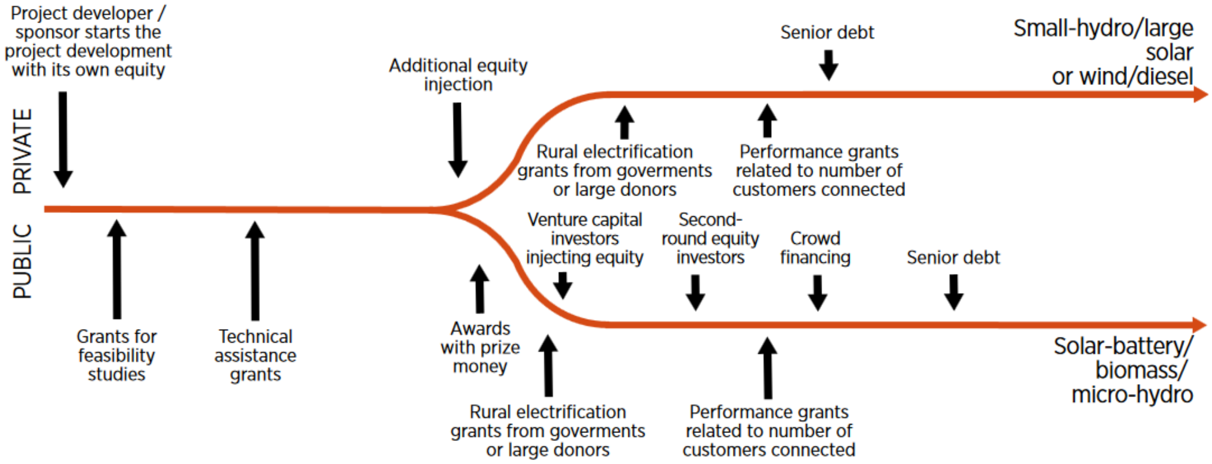


Figure 2 - Examples of financing needs along the project-development chain

Private mini-grids have different phases of development with different financing needs until they are installed and commissioned. They have been classified in three broad stages: project development, proof of concept, and project rollout. Figure 2 shows typical financing requirements along the different phases for large (up to MWs) and small mini-grid projects.

The project development phase usually includes the preliminary study to assess variables such as location, initial contact with the community, community needs and eventual cultural barriers, demand and demand projection, legal frameworks and development of the business model.

The proof of concept has been divided into two streams based on the size of the mini-grid. If the mini-grid project is of a larger capacity, there is often a proof of concept study which evaluate the theoretical and commercial business case and give essence to the main feasibility study. In the case the mini-grid has a smaller capacity, there is an extended proof of concept phase to specifically assess the condition and develop a suitable business model.

After a successful proof of concept, the project rolled out is ready to start. In this phase the project needs to be commercially attractive for potential equity investors and commercial lenders such as banks. Moreover, a clear tariff structure, agreed with the regulator, should have been already established to have revenues proportionate to the risk profile.

3. Case-Study – Ar Wa Karr Village, Pyinsalu Island, Myanmar

3.1 Myanmar Energy Sector

Myanmar has a Gross Domestic Product of 69,322 million of USD, ranking 72 out of 200 countries [33]. Its GDP per capita amounts 1298 USD. Since its major reforms in 2011, Myanmar has been reconnected with the world economy, showing a promising economic development. The Asian Development Bank expects strong economic growth in all sectors of the economy. Compound annual growth rate projections range from 4.8% to 9.5% with a most likely growth scenario of 7.1% [34]. This optimistic projection is supported by the presence of abundant natural resources within the country; the strategic location at the crossroads of Asia; and a large, youthful population [35]. Still the country needs to successfully implement extensive reforms and integrated policies, build basic infrastructure, and tackle many bottlenecks in order to fulfill the forecasts, and the development of energy sector is crucial for the country's future.

The lack of financial and technical capacity and global isolation have limited the development of the energy sector. Furthermore, inadequate power supply has emerged as one of the most serious infrastructure constraints for the country's sustainable economic growth [35]. Myanmar has one of the lowest per capita electricity consumption in the world, accounting 216 kWh per capita per year in 2014 [36] which is much lower than the world average per capita of 3,000 kWh per year. In terms of energy intensity, Myanmar was ranked 191 in 2011, making it one of the least energy consuming countries in the world [37]. Due to a scarce access to conventional energy resources, rural people mostly rely on traditional biomass (firewood and agricultural wastes) for cooking and lighting, which impacts in their welfare. After the country's reforms in 2011, the limited energy infrastructure has been under pressure because of the raising demand for energy from industry, commerce, and residential sectors.

The low accessibility of modern energy resources does not support the improvement of living standards and industrial activities. To tackle such constraints, the government shifted its policy toward increasing domestic energy supply and improving policy frameworks to encourage greater investment in the energy sector, opening the opportunities for extensive international assistance, including public–private partnerships [35].

3.1.1 Myanmar Energy Balance

The total primary energy production was 22.5 million tons of oil equivalent (mtoe) in 2013.The two most important resources are biomass and gas, that account respectively for 46% and 43%. The remaining share is covered by hydropower, oil, and coal. Figure 3 shows the evolution of the consumption of primary resources between 2000 and 2013. Gas production experienced a rapid growth between 2000 and 2007, with an overall increase of 2.4 times in volume. Biomass production has grew by 26% over the period from 2000 to 2013. Hydropower production, although a relatively minor component, had steady growth with a more than fourfold increase during the same period. Coal production experienced a peak in 2006 but subsequently declined. The primary energy produced is largely exported.

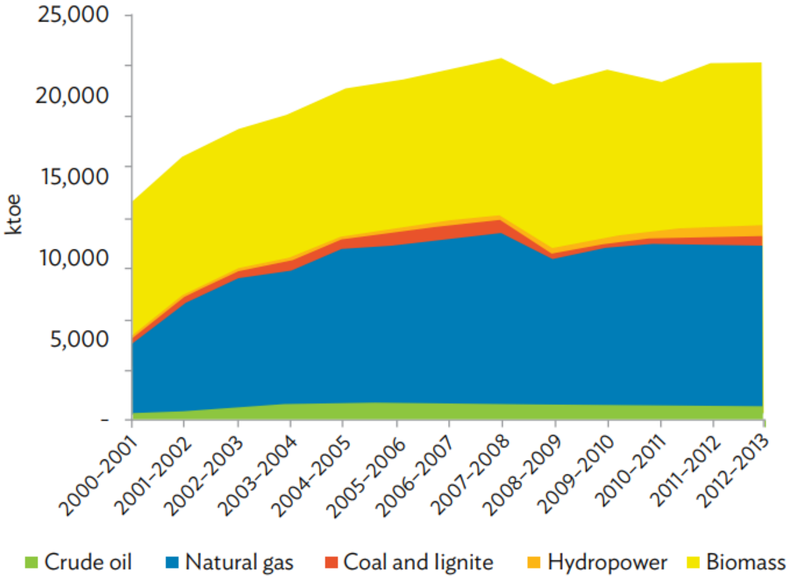


Figure 3 - Total Primary Energy Production in the period 2000-2013 [35]

For example, only 21.2% of the produced gas is utilized domestically. Figure 4 shows the Total Primary Energy Supply (TPES) for the period 2000-2013. In 2013, the TPES increased by 35% compared with that in 2000, amounting currently around 18 Mtoe. Throughout this period, the biomass share dropped to 50%, the hydro share almost tripled and the gas share increased by about 2%.

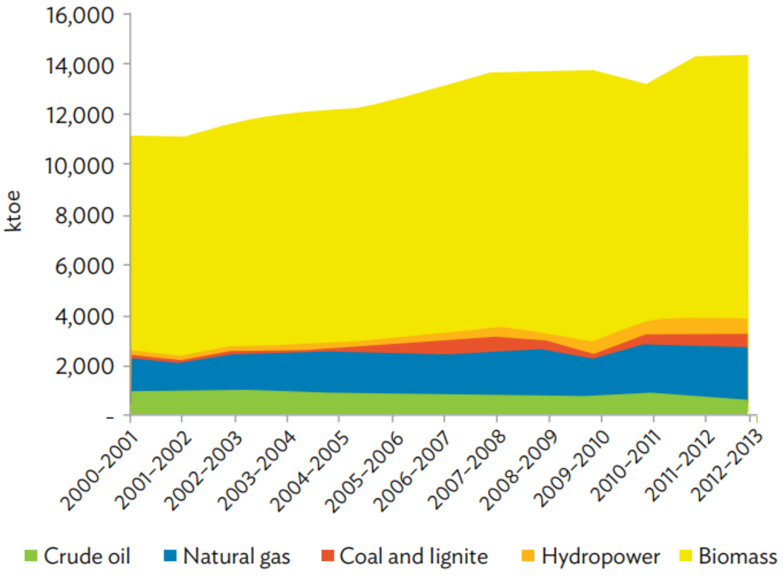


Figure 4 - Total Primary Energy Supply in the period 2000-2013 [35]

The residential sector is the largest consumer of energy, with 75% of total consumption in 2012, mainly in the form of biomass (fuelwood and charcoal), followed by the industry sector (9%), transport sector (8%), and other sectors

(6%). As illustrated in Figure 5, during the period 2000-2012, the energy consumed by the commercial sector had the highest growth with 5.8%. Residential and industry sector follow respectively with 1.4% and 1.2% increase. The transport sector, however, had a negative annual average growth (–3.0%) for the same period. Overall, the energy consumption grew slowly at an annual average of 2.3%.

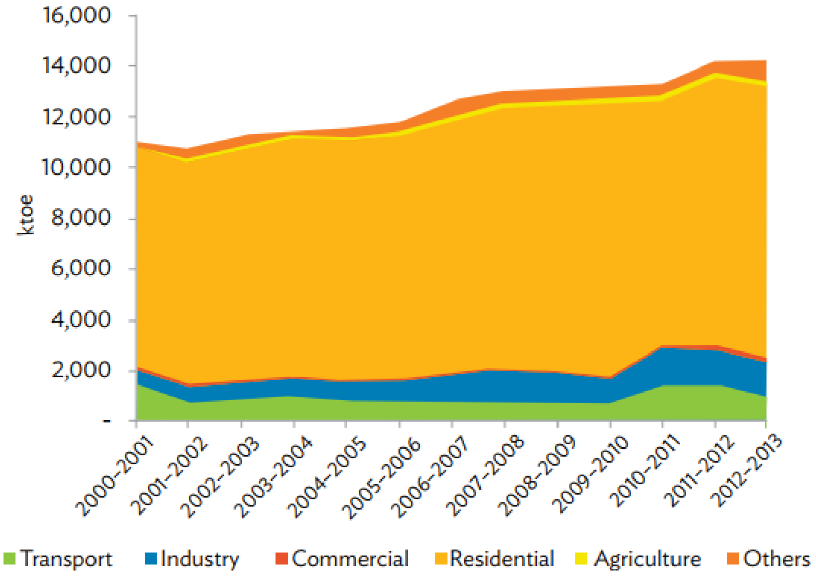


Figure 5 - Final Energy Consumption in the period 2000-2013 [35]

3.1.2 Government institutions

The energy sector institutional and regulatory framework of Myanmar is fragmented in six ministries related to the energy sector (See Table 2), with the Ministry of Electricity and Energy (MOEE) serving as the focal point for overall energy policy.

Table 2 - Ministries related to the Energy Sector

Ministry of	Abbreviation	Activity
Electricity and Energy	MOEE	Electricity policy and operation
Industry	MOI	Energy efficiency and energy saving
Education	MOE	Renewable energy and nuclear energy sector development
Border Affairs	MOBA	Micro hydropower and solar systems
Natural Resources and Environmental Conservation	MONREC	Fuel wood, climate changes and safeguard requirements
Agriculture, Livestock and Irrigation	MOALI	Rural electrification

MOEE was formed to cope with the inconsistency and continuous changes of the Myanmar's electricity and energy development sector. On 15th November 1997, the Ministry of Electrical Power was organized with three departments: the Department of Electrical Power, the Myanmar Electric Power Enterprise and the Department of Hydropower. On 15th May 2006, the ministry was split into two sections, and on 5th September 2012, they were composed again into one Ministry as the Ministry of Electrical Power (MOEP) under which were three departments, two enterprises and two corporations [38]. On 1st April 2016, the MOEP was joined with the Ministry of Energy to form the Ministry of Electricity and Energy (MOEE) [38]. The ministry has four departments, five enterprises and two corporations. Figure 6 shows the structure and the tasks of the MOEE.

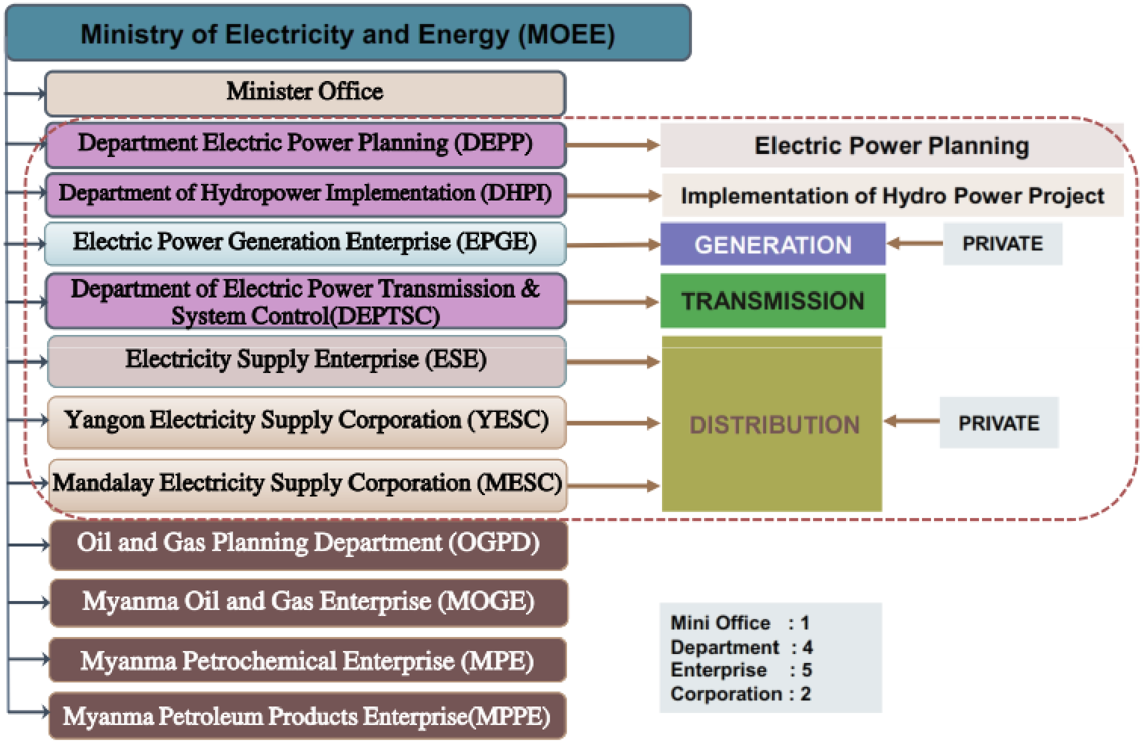


Figure 6 - Structure and the tasks of the MOEE [38]

The Ministry of Energy & Electricity (MOEE) is responsible for overall energy policy and leads the power sector development. Within MOEE, the Electric Power Generation Enterprise (EPGE) alongside the Department of Electric Power Transmission & System Control (DEPTSC), operates and plans the Myanmar National Grid System, buys electricity from both public and private producers and then sells the electricity to distributors. Hydropower Generation Enterprise (HPGE), alongside the Department of Hydropower Planning and the Department of Hydropower Implementation, operates and maintains large-scale hydroelectric facilities for the public sector.

Three government-owned distribution utilities take care of the distribution: Yangon Electricity Supply Corporation (YESC) and Mandalay Electricity Supply Corporation (MESC), which cover Myanmar's two most populous and urbanized Regions, and the Electricity Supply Enterprise (ESE) for the rest of the country. The Government limits the role of these distribution utilities to medium voltage (MV) primary distribution, leaving low voltage (LV) secondary distribution open for private sector participation including through village initiatives and direct private investments.

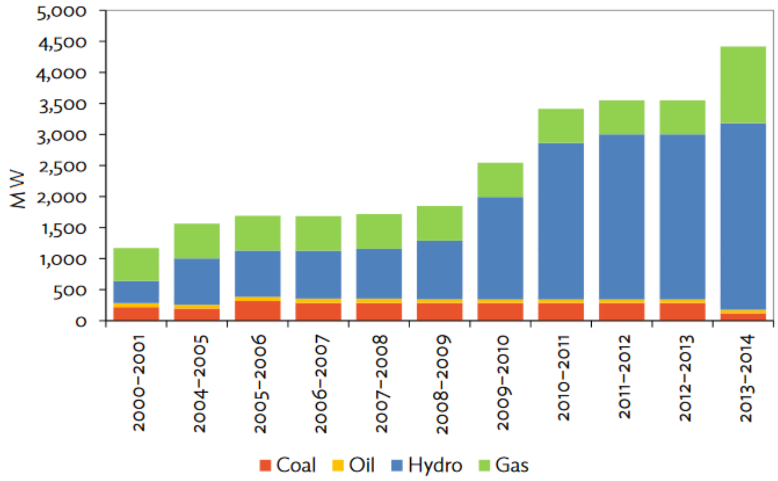
Overall, Myanmar has a complex energy policy environment. The Ministry of Industry, Ministry of Education (Science and Technology) and the Ministry of Agriculture, Livestock and Irrigation are jointly entrusted with promoting renewable energy, and the Ministry of Natural Resources and Environmental Conservation, and the Ministry of Agriculture, Livestock and Irrigation dealing with all biomass-related energy issues. This complicated structure of responsibilities creates slow decision-making and approval processes and creates challenges for coordination of joint efforts done by the above authorities.

To strengthen coordination and cooperation between the ministries responsible for the energy sector, the National Energy Management Committee (NEMC) was established in January 2013 [38]. The primary objective was to unify the fragmented activities pursued by the eight different ministries. The NEMC is a minister-level committee including representatives of the eight ministries concerned and resides under the Vice-President. The NEMC Secretariat is composed of staff seconded from the energy-related ministries led by the Deputy Minister of Energy and Deputy Minister of Electric Power and the office functions are currently directed by the Ministry of Energy. An Energy Development Committee (EDC) was also created in early January 2013, composed primarily of deputy ministers and is broadly responsible for monitoring the activities in implementing policies and plans laid down by the NEMC. The NEMC serves as the government's minister-level energy coordination body, but is a strategically oriented group that does not have operational responsibilities.

Currently, off-grid rural electrification is exclusively managed by MOALI via its Department of Rural Development (DRD), whereas, MOEE is responsible for all issues regarding grid-connection of rural areas.

3.1.3 Myanmar Electricity Sector

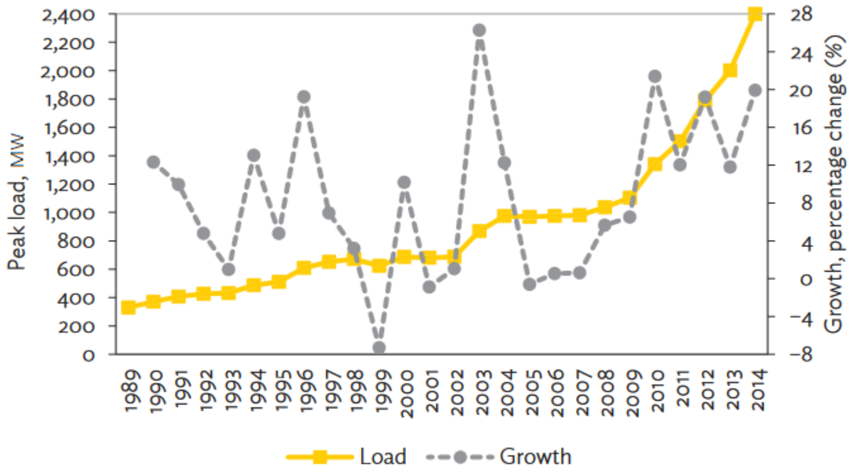
The total installed capacity at mid-2016 is 4,764 MW, with 2,820 MW (59.2%) from hydropower, 1,824 MW (38.3%) from gas, and 120 MW (2.5%) from coal. The MOEE owns about 75% of total installed capacity and the rest is owned by private sector, which has demonstrated a strong interest in developing more commercially operated power plants. The net available capacity represents however only approximately 50% of the total installed capacity. Gas and coal power plants are not fully operated due to poor maintenance, and during the dry season hydropower is reduced. During the dry season, available capacity falls to around 36% of the installed capacity. Furthermore, 520 MW of the hydropower capacity are exported to China. Several new projects are under development for completion by 2020.



Note: Coal includes 165 MW steam, while gas includes 3.72 MW biomass.
Sources: For 2010–2011: Central Statistical Organization 2011. For 2011–2012: Naing 2013. For 2012–2013: Ministry of Electric Power as presented in ADB 2012a subsequently updated in ADB 2013c, ADB Forthcoming.

Figure 7 – Installed Capacity by Fuel Type

Peak load has been rising over the last 7 years, increasing 15% on average in the period 2009–2014 (see Figure 7). As shown in Figure 8, peak load reached 1,790 MW in 2012, 2,001.3 MW in 2013, and 2,400 in 2014. The demand for power exceeded the available capacity of the system and coupled with unstable frequency control, frequent load shedding has been a common occurrence. In some regions the power supply is highly unreliable, with blackouts lasting 12 to 16 hours [35]. Limited and unreliable supply of electricity constrains private investment and limits economic activities of the population.

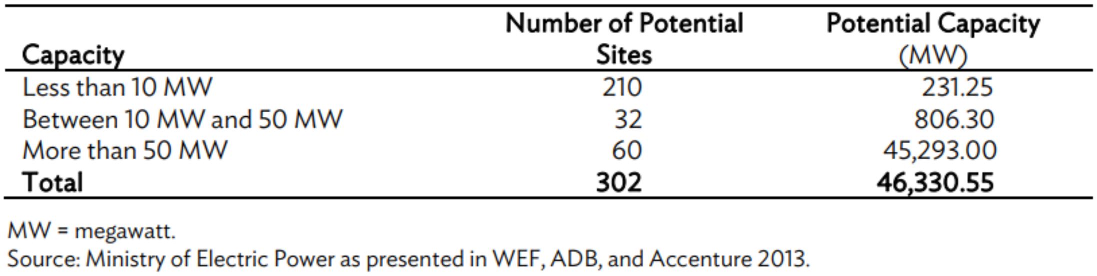


Sources: For 1989 to 2011: ADB estimates; Ministry of Electric Power as presented in ADB 2012a. For 2012: ADB 2013a. For 2013: Ministry of Electric Power. For 2014: ADB Forthcoming.

Figure 8 – Growth in Peak Load

Increasing the power supply remains a government priority. Through the exploration and exploitation of hydropower resources the MOEP has identified 302 potential hydropower project sites with a combined capacity of 46,331 MW, making hydropower the major source of power generation. Table 3 summarize the potential capacity of small, medium and large size hydropower projects. Moreover, the country's borders with Thailand and China could be explored and developed to boost existing capacity and to expand export potential. Myanmar has also started implementing renewable sources such as biogas, solar, and wind power. Wind and solar energy pilots have been installed in collaboration with the private sector to increase power generation sources. Biogas digesters of 5 kW, 15 kW, and 25 kW capacities have been installed all over the country. Wood chip gasifiers of 30 kW and 50 kW capacities have been researched and tested in rural areas and universities. Yet, despite the abundance of resources, Myanmar has not developed these because of concerns about environmental impact, resettlement and ethnicity-related issues, and the large capital requirements for implementation.

Table 3 - Hydropower resource in Myanmar



Capacity	**Number of Potential Sites**	**Potential Capacity (MW)**
Less than 10 MW	210	231.25
Between 10 MW and 50 MW	32	806.30
More than 50 MW	60	45,293.00
Total	**302**	**46,330.55**

MW = megawatt.
Source: Ministry of Electric Power as presented in WEF, ADB, and Accenture 2013.

The transmission system consists of an interconnected overhead grid of 230 kV, 132 kV, and 66 kV. Most of these lines lead from the northern part of the country, where most hydropower plants are, to the southern load centers, particularly the Yangon area. Transmission lines are generally still in good condition, but transmission of power over long distances through the 230 kV lines has resulted in significant decreases in voltage of up to 10%. Annex 1 – Myanmar Transmission and Distribution Lines shows the existing lines in 2013. The government plans to introduce the 500 kV transmission lines that will connect the majority of the country's generation facilities with the main load centers. Additional 230 kV, 132 kV, and 66 kV transmission lines are planned to be constructed. On the distribution side, the system comprises a network of 33 kV, 11 kV, and 6.6 kV transmission lines and substations. The majority of the existing 6.6 kV lines, mostly in Yangon, are already outdated and need to be phased out and replaced with lines that could carry higher voltage to improve the efficiency of the distribution network and reduce losses. Connections are often inappropriate, resulting in high losses and possible failure of the conductor. Although distribution losses have improved over the last 5 years, they are still remarkable accounting 12.5% in 2013. Combining technical and nontechnical losses of both transmission and distribution system the percentage of loss was as high as 20% in 2013.

The retail tariff is set at 35 – 50 MMK/kWh (0.023 – 0.032 USD/kWh) for households and 75-150 MMK/kWh (0.048 – 0.097 USD/kWh) for industry, depending on the consumption level [35]. Although the tariff was raised in 2014 by an average of 40% from the previous one, it is still among Southeast Asia's lowest. Nevertheless, this price does not reflect the true cost of generation and it is not sustainable in the long run. The Myanmar government spends about

185 billion MMK annually to cover both generation and distribution costs [35]. The estimated cost per kilowatt should be at least 125 MMK/kWh (0.081 USD/kWh) [35]. These subsidies are provided to sustain the continuous operation of power plants and to increase the affordability, but they strain fiscal capacity and discourage private power producers from investing and expanding operations.

3.1.4 National Electrification Plan

Myanmar has one of the lowest electrification rates in Asia, as only 57% of the population has access to a modern form of electricity. In rural areas the electrification rate is even lower, dropping to 40% [39]. The national grid mainly provides power in the central part of the country, leaving the rest of the country disconnected from the grid. The power provided by the national grid is often not reliable and users experience many power outages with frequency and duration depending on location and season. Accumulated delays in investments in power infrastructure, over-reliance on seasonal hydropower production, together with a rapid increase in electricity demand (which tripled over the last decade), are the main drivers of the experienced electricity shortages. To face this problem, in September 2015, the Government of Myanmar approved an ambitious new target for the country in the form of a new National Electrification Plan (NEP).

The Myanmar National Electrification Plan (NEP) aims to electrify 100% of the country's households by 2030. The NEP would need the electrification rate milestones of 50% in 2020, 75% in 2025 and 100% in 2030. It is planned to achieve the 15% - 20% share of renewable energy in the total installed capacity by 2020. Most of renewable energy sources other than large hydro will be used for rural electrification purposes. It would take almost 40 years to achieve full electrification with the current rate of electrification (approximately 190,000 additional households every year). Such a slow rate of progress is not acceptable to the Government and the people of Myanmar.

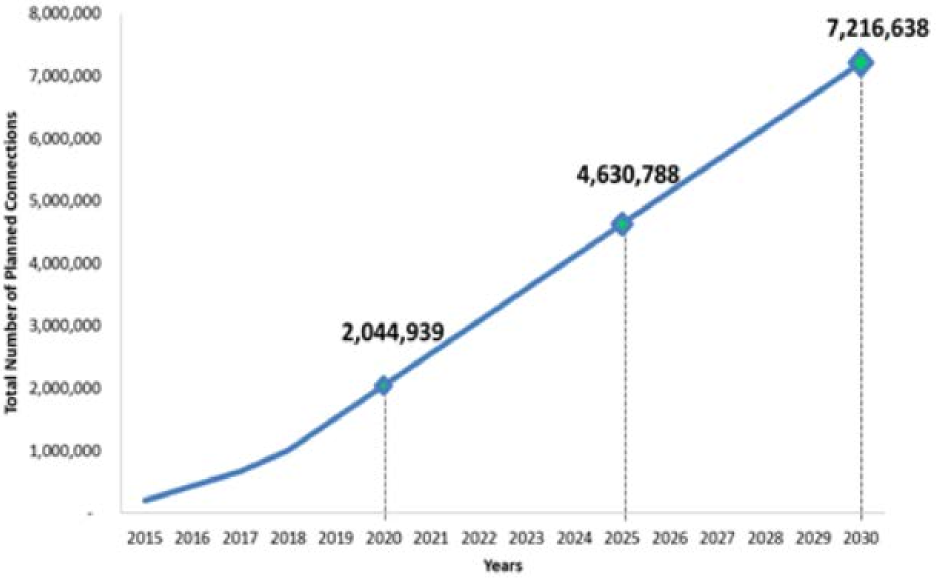


Figure 9 – Expected roadmap for the number of additional connections [35]

Approximately 7.2 million household connections will be required in the next 16 years to fulfill the vision of universal electrification by 2030, increasing the rate to an average of 450,000 a year over the next 16 years [35]. Figure 9 describes the expected roadmap for the number of additional connections. An initial comprehensive geospatial plan for the roll-out of electrification estimates that over 90% of the total new connections will be grid-based.

The total capital cost of the electrification over 15 years is estimated to be 5.8 billion USD to extend the transportation and distribution grid and electrify off-grid areas, and $20 billion to develop the required additional generation capacity [35]. It is expected that the cost of connections per household will continue to rise with the increasing penetration of electricity towards less populated areas. NEP has developed a geospatial least-cost plan based on an optimal combination of grid and off-grid solutions, in order to ensure a maximum number of connections with the limited financing resources available. Figure 10 shows the intended development plan phases.

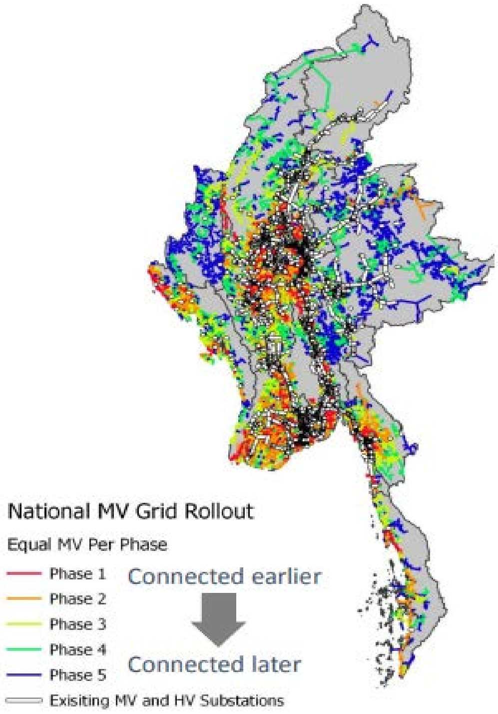


Figure 10 - Intended development plan phases [35]

The electrification of Myanmar has unlocked many investment and business opportunities related to the generation, transmission and distribution of electricity. In order to meet the NEP targets, 7,623 km of transmission network, 41,495km of distribution network and more than 20GW of generation capacity will need to be installed before 2030. The generation capacity is going to be mainly composed of hydropower, as there are plans to develop 49 new site with a total generation capacity of around 35GW [35]. All sites are going to be developed under Build Operate Transfer (BOT) and Joint Venture (JV) agreements between the government and local and foreign companies.

Even if the expansion of the grid through Myanmar's National Electrification Plan goes according to plan, many areas will still remain under-electrified for many years to come, particularly rural villages. Currently, more than 30,000 rural villages across Myanmar are not connected to the national grid. Decentralized solutions such as mini-grids can play a major role in creating a modern, reliable, decentralized energy system. If powered by renewable sources, they can also ensure that new electrification at the village level is environmentally sustainable. Most importantly, by providing readily deployable, high-quality electricity access, mini-grids can greatly accelerate economic productivity and related development gains.

3.2 Case-study Context and Description

Pyinsalu island is one of the numerous islands in the Irrawaddy delta, located in the Ayeyarwaddy region, Myanmar. The island can be reached taking a ferry or a boat-taxi from the closest city Labutta. The island has a main town, called Pyinsalu, and 11 villages in the rest of the territory, accounting overall for 4 000 inhabitants. It currently does not have access to the national electricity grid and there are no governmental plans to connect it in the future, due to the considerable distance from the main land. Therefore, off-grid electrification projects will be necessary to provide access to electricity to the population.

The feasibility study has been performed by Energy Action Partners [40] in collaboration with the University of Lancashire and facilitated by Sunlabob Renewable Energies [41]. It will focus on the small village Ar Wa Karr, located in the South East part of the island. The village has 25 households and it is approximately 20 minutes by motorbike from the main town.

For the preliminary study the location has been visited to conduct community mapping and engagement activities. To collect data, the team has used semi-structured interviews, ethnographic mapping and an innovative mini-grid planning tool and process called The Mini-grid Game. This participatory approach is aimed at engaging a two ways communication with the community, increasing community understanding and participation, defining the needs and starting cooperation. Results from this preliminary study will be used to inform the design and planning of mini-grid systems on Pyinsalu Island.

Finally, possible solutions have been designed, proposed and compared to evaluate their and feasibility within the studied context.

Figure 11 - Pyinsalu location

3.3 Preliminary Study

3.3.1 Methodology for data collection and elaboration

Community engaged strategies

During the on-site visit participatory methods have been used to collect data and engage the community in the energy design and planning process. As extensively explained in section 2.1.2, such methods allow ordinary people to play an active and influential role in the decisions that will affect their lives, increasing the trust in the visiting organization and the overall community satisfaction about the project. The collection of data is simplified by the direct engagement, since people are more willing to share opinions, comments and provide accurate information. An energy system design based on this approach usually reflects the local reality and leads to better supported and longer lasting social changes.

First, semi-structured interviews have been conducted within the village. The team has visited each house of the village to personally make the survey. A questionnaire (See Annex 2 – Set of talking points used to guide semi-structured interviews) has been prepared to guide the interview, despite it has not been strictly followed. Conducting the conversation freely let the households express their concerns, problems and familiar situations.

Figure 12 - Participatory Community Mapping

Then, participatory mapping activities have been organized to collect information about social structures, economic activities, services and lifestyle in the village. Such activities also help to confirm data about the size of the community and the dispersion of the households in the territory. The participants (about 25 community members [42]) have been divided in groups and a different topic has been assigned to each of them. The topics assigned were the following [42]:

- Institutional map: existing groups, associations, organizations operating in the community,
- Seasonal calendar: a calendar showing seasons, major events, festivities in a year

- Time use diary: daily activities according to gender, age and job,
- Income and expenditure map: average income of jobs and usual household expenses,
- Geographic map of the village: location of services and infrastructures and,
- Mobility map: movement in the village, available transportation with relative duration and price.

Each group has presented its results in front of the others, leading to a constructive debate within the community that help clarify and correct the output of each group.

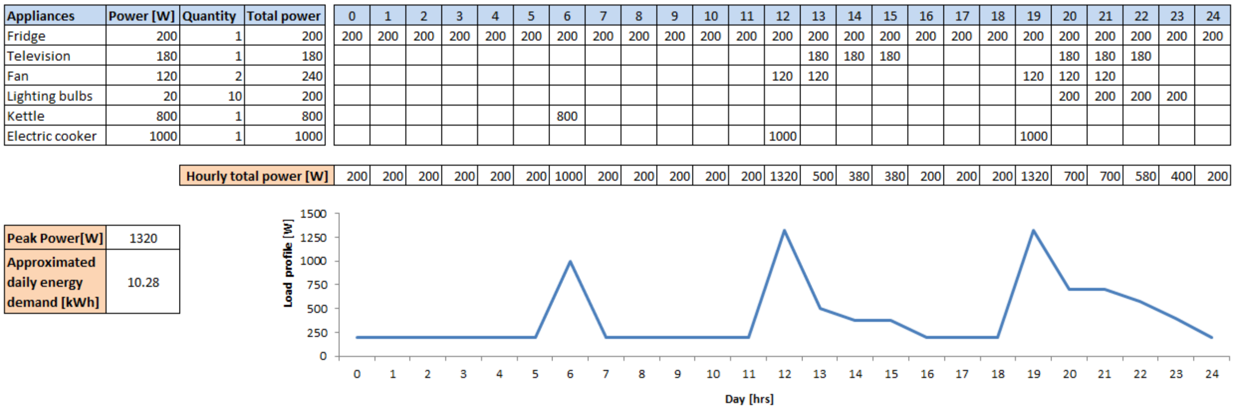
Finally, a session of *the Mini-grid Game,* developed by Energy Action Partners, has been conducted following the participatory mapping activities. Around 30 inhabitants of all ages participated to the game session, grouped into smaller teams of 3 to 4 people. The game simulates a micro-grid setup, enabling real-time discussions around energy-related decisions of both household and community. In the game, the participants purchase the appliances needed and run them during a networked simulation as they wish. A game facilitator plays the role of 'system operator' and at the end of the simulation each household receives an electricity bill related to the selected appliances and the use of them. Between the simulations the users can modify their daily energy behavior according to their financial situation [42]. Therefore, after few simulations the electricity bill of each user will tend to converge to their actual willingness-to-pay. The game actively engages the participants collecting information about their daily energy routine and their willingness to invest money for electricity services. Furthermore, it raises awareness about the importance of using efficient devices and conducting an intelligent energy behavior, giving a visual representation of the consumption related to each appliance. Annex 4 – The Minigrid Game process [42] shows the Mini-grid Game process [42].

Figure 13 - The Minigrid Game Session

Load estimation

The estimation of an accurate load profile is crucial for an appropriate sizing of the energy system, avoiding oversizing and meeting the expectations and needs of the users. For this purpose, a deep understanding of existing energy services and consumption is required.

A list of all the existing household appliances, relative power and time use allows to estimate an approximate load profile for the house, creating a daily trend of the power required. A spreadsheet organized as shown in Figure 14 can help identifying peak load and daily energy demand.



Appliances	Power [W]	Quantity	Total power	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Fridge	200	1	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200
Television	180	1	180														180	180	180					180	180	180		
Fan	120	2	240													120	120						120	120	120			
Lighting bulbs	20	10	200																					200	200	200	200	
Kettle	800	1	800							800																		
Electric cooker	1000	1	1000													1000							1000					
			Hourly total power [W]	200	200	200	200	200	200	1000	200	200	200	200	200	1320	500	380	380	200	200	200	1320	700	700	580	400	200

Peak Power[W]	1320
Approximated daily energy demand [kWh]	10.28

Figure 14 - Example of table to estimate load profiles

In this example, the time step has been chosen equal to an hour, but the value can be modified. The smaller the time step, the more accurate is the estimation of load profile and energy demand but, at the same time, the more difficult is to foresee small variation in the daily routine of the users. The hourly total power is computed summing the power of all the appliances used in the assumed time step. The peak power corresponds to the maximum power consumption during the 24 hours. The multiplication of the power consumption by the duration of the time step (in Hours) gives the energy demand (Wh) of the time step and the sum of all of them results in the daily energy demand. Correction factors can be applied for weekend days and public holidays in case of variation of the appliances use. In case of existing electricity grid, the data collected can be cross-checked with the electricity bill or through the temporary installation of an electricity meter.

The information has been collected during the households interviews. Two different cumulative load profiles have been computed: current situation and potential future situation with extended access to electricity and new appliances. The following assumptions have been taken:

- The running time of the appliances during the day has been estimated according to the information collected during the household interview and the daily routine poster elaborated during the mapping activities (See **Annex 9 – Community Daily Routine**).
- The additional appliances have been selected according to expectations and whishes expressed by the households during the interviews.

- A transition to efficient LED lighting has been taken in consideration, due to the formation that will be provided to the community.
- Corrective coefficients (Ks) have been applied to take in account possible variation in the number of appliances connected.

3.3.2 Results and Considerations

Community numbers and existing institutions

The village Ar Wa Karr has 25 households, accounting for 109 people equally divided between male and female. The village is divided into two main parts, one located along the shoreline, and the other along the main road. The majority of the community lives permanently on the shore. Only 9 households own a house in the part along the main road and 6 of them seasonally move to a house on the shore. The distance between the village and the shore is around 2 km.

During the mapping activities, the community listed the organizations operating on the territory as follow:

<u>External Organizations</u>

1. Cooperative Organization
2. PACT
3. Link Emergency Aid & Development (LEAD)
4. Solar Lighting Team
5. Save the Children

<u>Village Organizations</u>

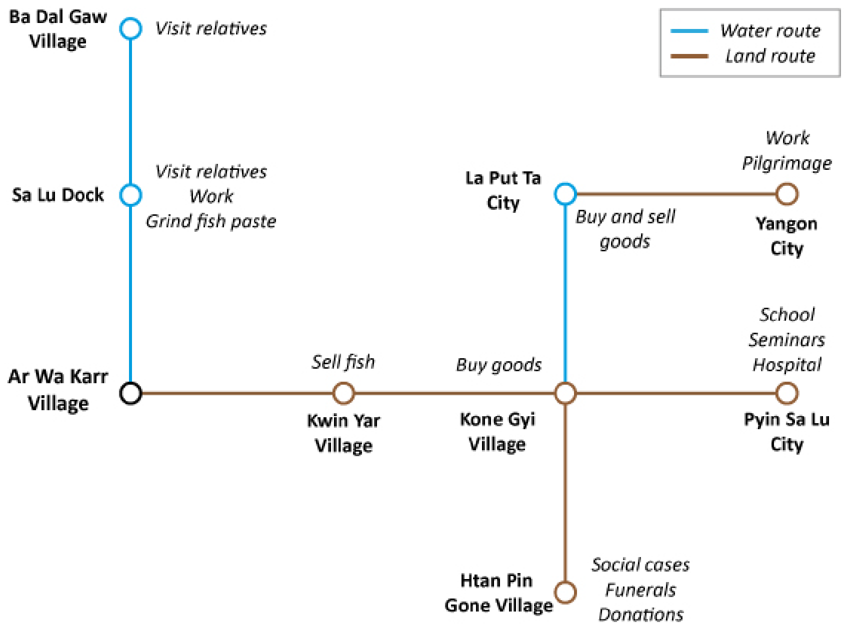
1. Pagoda Trustee Group
2. Fire Fighting Team
3. Moe Myint Kyal Zin micro loan (micro Loan)
4. School Committee (school and children)
5. Women's Association (children)
6. Forest planting and protection group
7. Decision-Making Committee in community

PACT and LEAD are microfinance organizations that have been working in the community for many years and have existing committees in the community to support their operations. Members of LEAD have advised and supported the project team's activities in the community and helped co-facilitate the Mini-grid Game session. Finally, the Decision-Making Committee in the community oversees the other village-based organizations. The community does not have a village head.

Other than the community's Decision-Making Committee, the community has no other governance structure. The village also does not have many community-owned assets or resources, and have limited experience with community-based management of common resources. Therefore, careful assessment and trainings would be required in case of a community-based micro-grid system.

Existing Infrastructure, Services and Transportations

The village has a primary school and a small monastery. The nearest high school and a small hospital are in Pyinsalu. The main roads are not paved, but in good condition. The path from the village to the shore has sandy parts that may cause trouble to cars or trucks. The transports can be via land or water routes. Figure 15 shows the transports available for the villagers, estimated time and price.



Origin	Destination	Transport	Duration [hours]	Price [MMK]	Origin	Destination	Transport	Duration [hours]	Price [MMK]
Ar Wa Karr	Kwin Yar	Motorbike	00:10	500	Ar Wa Karr	Sa Lu	Boat-taxi	01:45	5000
Ar Wa Karr	Kone Gyi	Motorbike	00:20	1000	Ar Wa Karr	Ba Dal Gaw	Boat-taxi	02:00	10000
Ar Wa Karr	Htan Pin Gone	Motorbike	00:30	1500	Ar Wa Karr	La Put Ta	Ferry	04:00	2000
Ar Wa Karr	Pyin Sa Lu	Motorbike	01:00	3500	La Put Ta	Yangon	Bus	06:00	5000

Figure 15 - Mobility Map [42]

Water Availability

The water wells are dug manually. The village members complain about the quality of the water because it often contains sand and animals swim in it. Most households would like to have reliable and cleaner sources of water. A proper water well would improve the hygienic conditions and prevent related health problems.

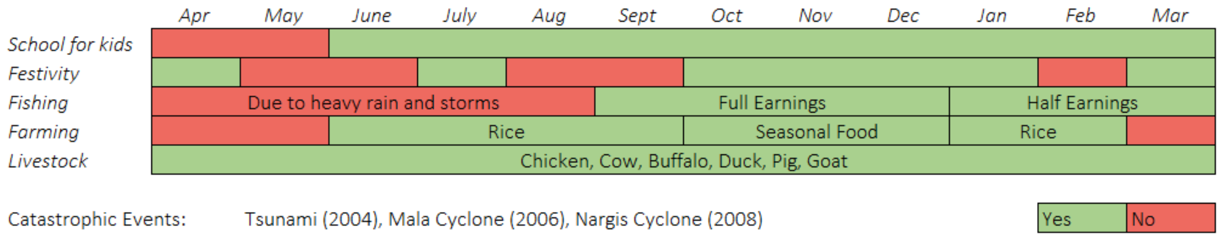
Existing Energy Services

The majority of the community relies on rechargeable lead-acid batteries, mainly for lighting. As many as 11 households currently use solar home systems. Only 7 of them have PV system with inverter and batteries large enough to power also a television. Small generators are used by three households. The remaining would charge at the homes of friends and family (sometimes a small fee is charged).

Income and expenditure

The main sources of income are farming (rainy season), fishing (dry season) or running small shops. Complementary incomes come from trapping and selling crabs and fishes, making traps and selling tiger prawn hatchlings. The villagers would sometimes sell their domestic animals mainly cows, pigs, chicken, ducks and goats as well as engage in casual labor for additional income. Specifically, 17 households are fishermen, 2 households are farmers and the remaining 6 households do not consider themselves fishing households but engage in casual labor as their main source of income. According to the households interviews, the average income of a family in the village is around 233,000 MMK (150.32 USD) per month. 76% of the households rely on a loan from an investor living in a close-by island. The interests range between 1% and 20-30%. These families are forced to sell the fish exclusively to the lender and, in case they are unable to repay their loan, the lender controls the price of their catch, typically setting lower prices than market rates. The majority of the jobs are seasonal (see Figure 16) and when it is not the job season most of the families heavily relies on the loan to survive.

Figure 17, Figure 18 and Figure 16 show some of the results of group participatory ethnographic mapping related to job activities, incomes and outcomes.



	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar
School for kids	🟥	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Festivity	🟩	🟥	🟥	🟩	🟥	🟥	🟩	🟩	🟩	🟩	🟥	🟩
Fishing	🟥 Due to heavy rain and storms	🟥	🟥	🟥	🟥	🟩 Full Earnings	🟩	🟩	🟩	🟩 Half Earnings	🟩	🟩
Farming	🟥	🟥	🟩 Rice	🟩	🟩	🟩	🟩 Seasonal Food	🟩	🟩	🟩 Rice	🟩	🟥
Livestock	🟩 Chicken, Cow, Buffalo, Duck, Pig, Goat	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩

Catastrophic Events: Tsunami (2004), Mala Cyclone (2006), Nargis Cyclone (2008)

🟩 Yes 🟥 No

Figure 16 - Seasonal calendar [42]

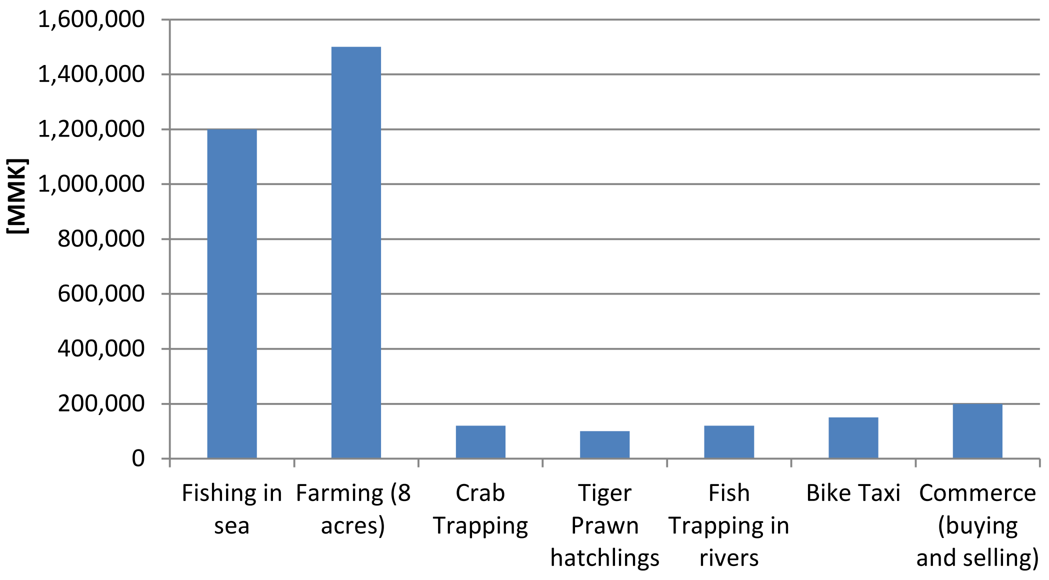


Figure 17 - Annual potential income from different income-generating activities in the village [42]

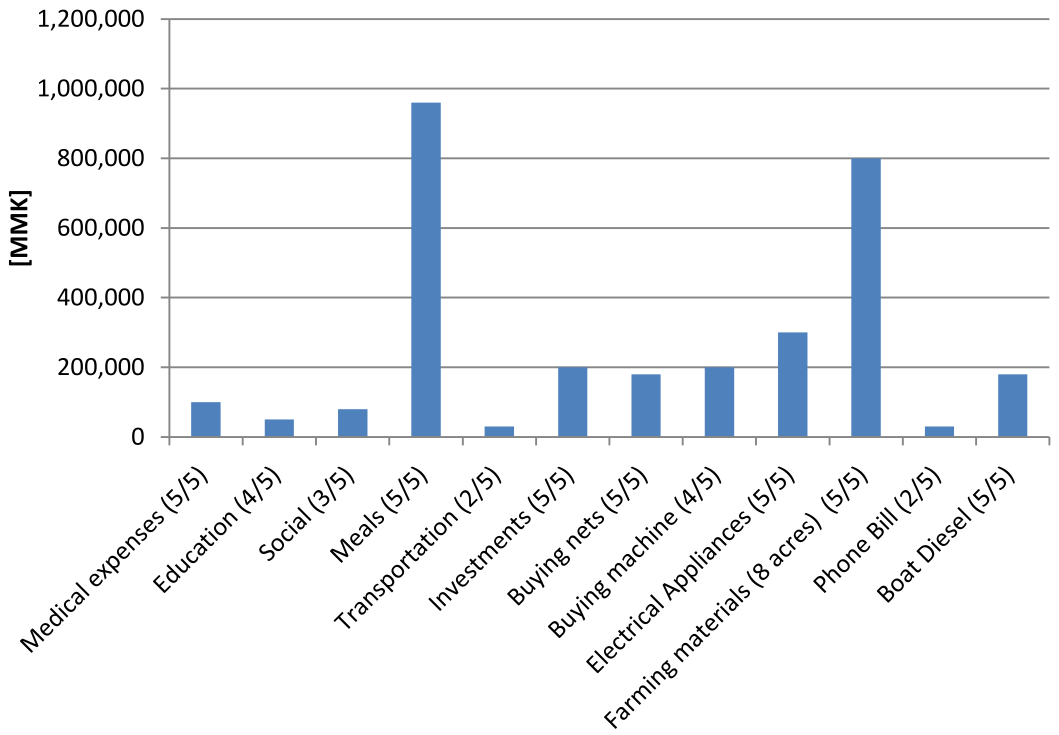


Figure 18 - Average household expenditure based on different activities [42]

Household Load Profile

Existing domestic loads in the village consists of mostly lighting, televisions and DVD players. According to the interviews, there are some electrical appliances they would like to add if there was a constant energy supply: rice cooker, electric stove, iron, fan and freezer. Most households reported that they would consider better lighting to be the most important improvement. The availability of a refrigerator or freezer would allow for food storage, while rice cookers and electric stoves would reduce the dependence on firewood and charcoal (which is how the community currently cooks food).The current cumulative load is very low, with a peak power of 2.4 kW. Figure 19 shows the estimated community load profile.

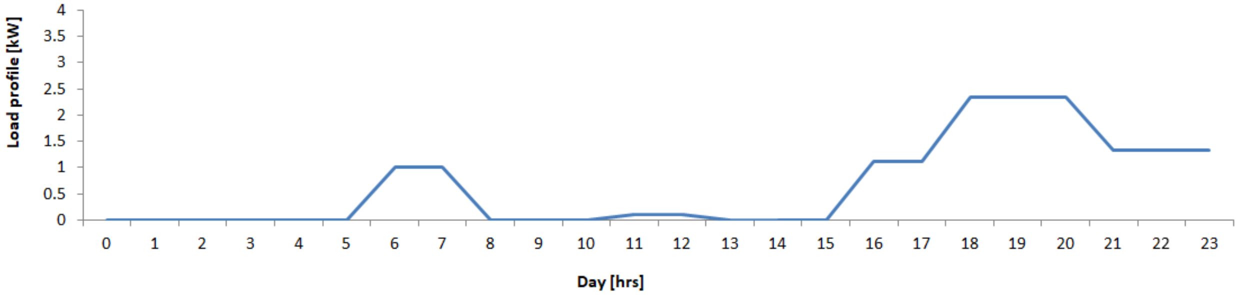


Figure 19 - Current Cumulative Load Profile [42]

The future cumulative load would see the addition of cooking tools, better lighting and some freezer or refrigerators (see Annex 8 – Load Profiles for quantities and daily use). The penetration rates of TV, fridge, radio, rice cooker and fan have been assumed respectively 60%, 28%, 72%, 52% and 60%. As it can be noticed in Figure 20, the peak power would be 10.9 kW. The main barrier would be the upfront cost of the new appliances.

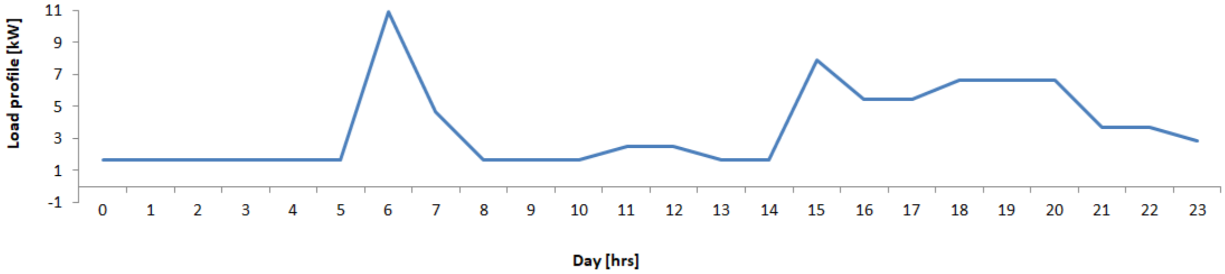


Figure 20 - Future Cumulative Load Profile [42]

Community Opinions on Centralized Grid and Solar Energy Technologies

Most of the community have experienced national grid electrification from visits to the city of Labutta. They consider grid electrification to be reliable and affordable but are skeptical it will ever arrive in their village. They view their village as too small and remote to ever benefit from grid electrification. The community shows an interest and a high degree of trust in photovoltaic technology. However, they believe that it is crucial to have a reliable installer or project developer to manage operations and maintenance and have not considered community-based management of a micro-grid system. They have also been visited by NGOs and companies selling solar home systems, but to date, no concrete plans have been made to improve their access to energy services.

They mentioned two solar projects in neighboring villages: one system that suffered from a malfunction which decreased its production capacity, and the other was a company that collected payments for solar home systems which were never delivered.

Productive Use of Energy

There are no existing telecom towers, factories or manufactures activities for anchor load.

Fishery could be improved with freezers for fish storage and ice and fish grinders to produce fish paste. The availability of these appliances in the village would decrease transportation costs to other villages for food processing, while providing more opportunities for income generation activities. Increasing livelihoods and incomes would consequently reduce villagers' dependency on loans and free up some case to spend on electricity and appliances. Solar dryers might also accelerate the drying process, especially at the end of the summer when the sun does not shine.

Furthermore, although there are crops that do not need a lot of water, farming is now limited to the rainy season because in dry season the cows cannot stand the hot weather. A tractor could solve this problem and extend the farming season to the whole year, creating new jobs and incomes.

Currently, there is no direct trading with Yangon. The daily boat that used to connect Pyinsalu and Yangon ceased operations after the 2008 cyclone. Resuming this boat route could also help facilitate market expansion for Pyinsalu Island's fish and seafood products.

During the site-visit, the team has noticed the lack of young people from around 14 to 30 years old. In fact, young people often move towards in-land more prosperous cities, specially Labutta and Yangon, seeking their fortune and sending some money back to their families. Developing new economic activities and improving trading towards bigger cities may help to reduce this migration.

Expressed Willingness to Pay

The average expressed willingness to pay is 7,720 MMK (4.98 USD)per month. The values range between 2,000 MMK (1.29 USD) and 30,000 MMK (19.35 USD) per month. The household are willing to pay between 1% and 18% of their income for a reliable supply of electricity.

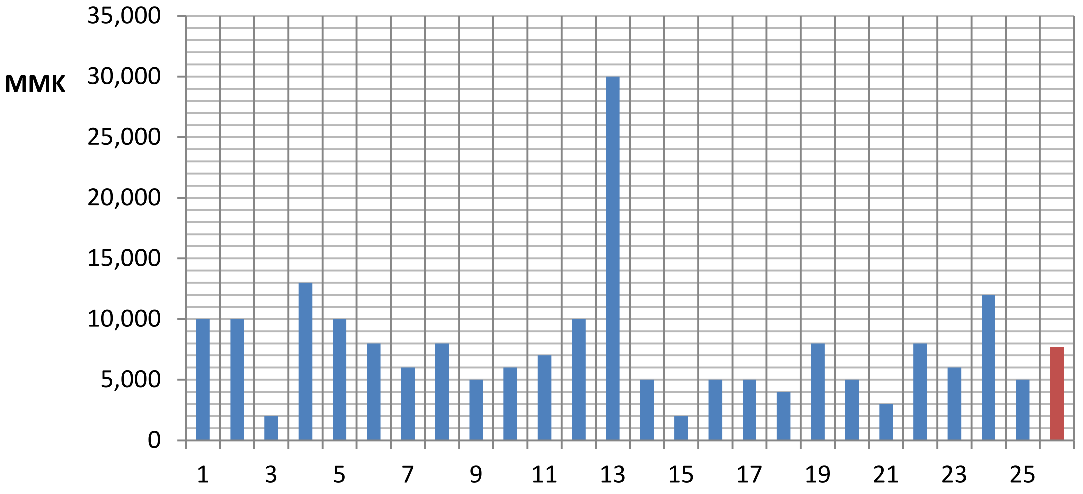


Figure 21 - Interview's Expressed Willingness to Pay [42]

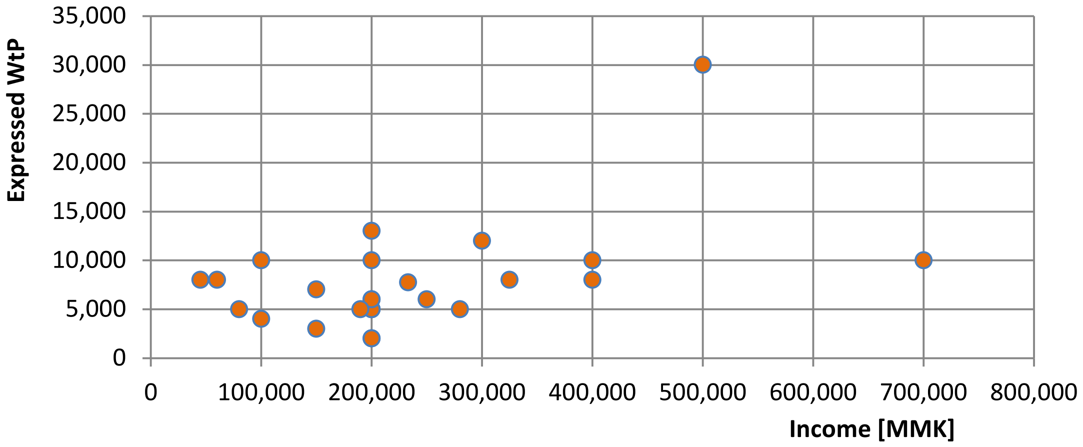


Figure 22 - Expressed WtP against monthly incomes [42]

During the interviews, many households expressed a willingness to pay for the access to a solar-mini grid lower than the current expenditure for unreliable energy sources. This shows low understanding of the proposed energy access and low awareness of their energy-related expenses.

Pyinsalu Electricity Access

In 2008, Japan International Cooperation System (JICS) donated an 80 kW diesel generator to the Myanmar government, which was located in Pyinsalu. The government provides only 320 gallons per month for the generator, which consequently can only be run 3.5 hours per day (from 6pm to 9.30pm) [42]. The project team was informed by the local authorities that this area receives one of the lowest amounts of fuel of the region. Electricity is supplied to the main town Pyinsalu, covering 300 household. After the 2008 Cyclone Nargis, half of these houses are uninhabited. The 11 villages outside the town are not connected to the grid.

Those who have access to the local grid pay a power tariff according to the appliances they have in the house. I.e. a light bulb costs 500 MMK/month, the TV costs 2500 MMK/month and charging a battery costs 100 MMK. The local representative of the ministry of energy has a register of all the appliances in each household and bills are collected monthly. The register has not been updated over the last few years, losing track of new appliances purchased by the users.

Assuming that a household owns 6 light bulbs, a TV and charges the battery once every three days, the monthly electricity bill would be of 6500 MMK (4.19 USD). Nevertheless, the supply is heavily restricted to 3 hours period.

Mini-grid Game Results

Approximately 30 people between the ages of 10 and 50 participated to The Minigrid Game session, grouped in team of three to four people, totaling 9 groups. Each group represented a 'household' in the game.

The Ar Wa Karr Minigrid Game workshop participants played two game-rounds, focused mainly on [42]:

- Helping participants understand their individual load profiles and power consumption of different appliances.
- Helping participants understand the cost of their energy consumption and determine willingness to pay.

Initial parameters and settings used in the game such as type of appliances, prices and ratings can be found in Annex 5 - The Minigrid Game's appliance settings, while initial incomes and energy budgets used in the game can be found in Annex 6 - Initial household cashbox amounts and salaries for Minigrid Game. Appliances used in the game were as follows:

- Incandescent light
- LED light
- CFL light
- Radio
- TV
- Phone charger
- Computer
- Refrigerator
- Kettle
- Rice cooker
- DVD player
- Fan

After the initial familiarization round, the total load profile for nine households, Day 1 of the first game-round is shown in Figure 23. The total load profile peaked at 9.97 kW in the afternoon.

By Day 3 of this round, participants' system load has the profile shown in Figure 24, with a peak of 8.81 kW in the morning. The peaks in the load profiles correspond to the approximate times of day when cooking and food preparation occurs. For these nine 'households', the total cumulative load did not exceed 10kW.

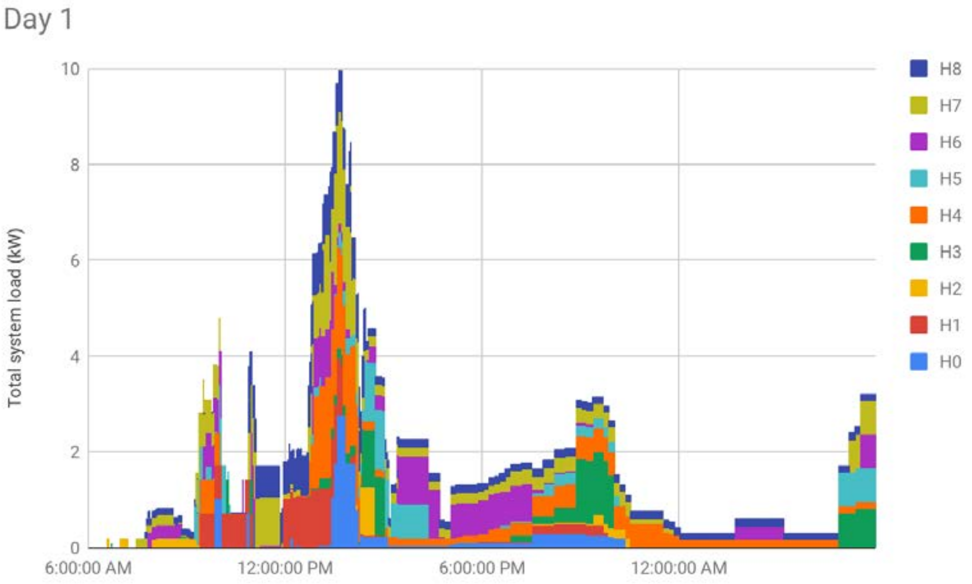


Figure 23 - Day 1 cumulative load profile [42]. H_i represents the Mini-grid game households.

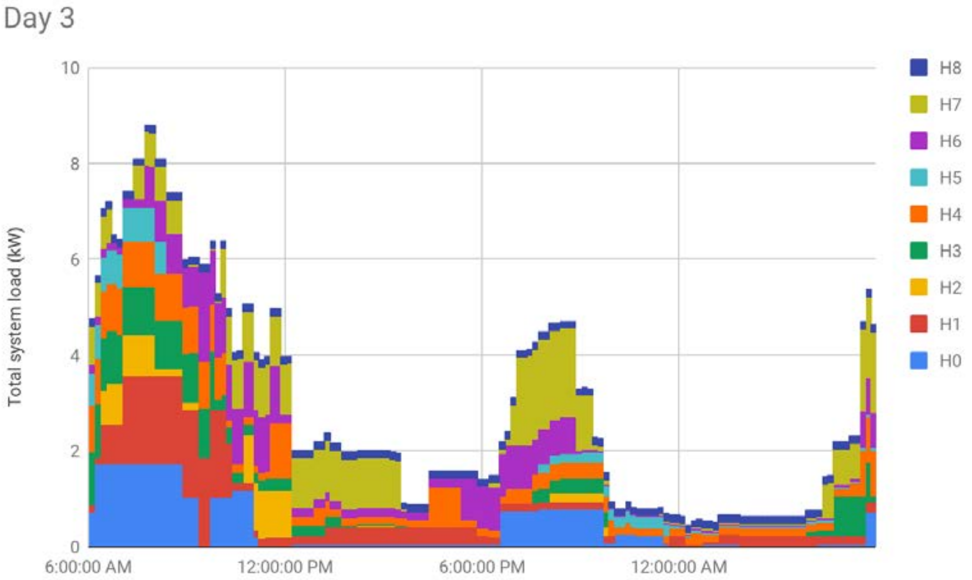


Figure 24 - Day 3 cumulative load profile [42]. H_i represents the Mini-grid game households.

Participants were encouraged to take note of highs and lows in their individual household profiles as well as observe the relative increase (and decrease) in their load profiles as different appliances were turned on (and off). Community members were able to deduce that incandescent and CFL lighting, although cheaper to acquire than LED lighting, used higher amounts of power and energy. They were also able to determine that electrical appliances with heating elements such as the rice cooker, iron and kettle used a significantly higher amount of electricity than other appliances.

A key objective of this Minigrid Game workshop was to determine participants' willingness to pay (WtP). Salaries in The Minigrid Game ranged between 60,000MMK (38.71 USD) to 125,000MMK (80.65 USD), with monthly electricity bills coming up to between 10,965MMK (7.07 USD) and 61,358MMK (39.59 USD). The average monthly bill charged in the game was 36,300MMK, with seven out of the nine households paying their electricity bill. After running a second round of the game, participants discussed an average monthly bill amount they would all be comfortable with and converged on 20,000MMK (12.90 USD) [42]. They explained that they would be willing to pay this higher amount as long as electricity access was reliable and sufficient enough for them to be able to use electrical cooking appliances. The amount is much higher than the WTP expressed during the interviews (around 7,720MMK), highlighting a better understanding of the potential future energy access and the relative expenses.

Note on Data Gathering

Collection of data in the case-study area has often faced challenges. Sometimes household heads were away working, and family members were unable to confidently recall the information requested. Gathering data on energy and household expenditure was particularly challenging. In fact, the feedback from the respondents was very weak, leaving considerable gaps in the project's energy spend data – for example, longevity of batteries, sources for charging, existing PV systems' details. Such gaps have also been observed in similar surveys conducted in other parts of the world [11]. These challenges have been compensated by working with assumptions where possible, relying on observation, organizing data in a more meaningful way and drawing on participatory planning strategies.

Potential Issues

The Ar Wa Karr community would benefit greatly from improved energy services. However, there are several unique issues to consider:

- The seasonal migration between the shoreline and the inland village may be an issue. To keep energy services affordable, a community-sized system can only be installed in one location, which would require part of the community to relocate to only one general area in the village in order to access the system. This would require strong cooperation and agreement from the community.
- Increasingly frequent natural catastrophes should be carefully taken into consideration. An energy system or distribution lines on the shore are more exposed to storm and cyclones that can cause severe damages and failures. The resilience of the mini-grid is very important in a zone subject of ordinary and extra-ordinary natural events. Pyinsalu was severely hit by the cyclone Nargis storm surge, causing devastations and the loss of more than half of the island inhabitants.
- The community members may not afford the purchase of new and more consuming appliances, such as rice cookers and refrigerators. Lack of load growth seriously endangers the sustainability of the projects.

4. Proposed solutions

The outputs from the preliminary study can be used to inform further planning of the different energy options for Arr Wa Karr Village. The energy systems that will be taken in account are the following:

- Case 1: Micro-grid - Current community load;
- Case 2: Mini-grid - Potential extended community load;
- Case 3: Solar Home Systems;

This chapter will highlight pros and cons of these solutions and evaluate their economic sustainability. The selected technologies will be sized according to the information gathered during the preliminary study.

4.1 System Design

The size of the different cases has been estimated and optimized with the software Homer Pro, inputting the load profiles estimated in the preliminary study.

4.1.1 Homer configuration

Homer Pro, is a software for optimizing micro-grid design in all sectors. It simulates viable systems for all possible combinations of the considered equipment that could meet the input load profile, simulating the operation of a hybrid micro-grid for an entire year, in time steps from one minute to one hour. HOMER examines all possible combinations of system types in a single run, and then sorts the systems according to the optimization variable of choice, identifying least-cost options for micro-grids or other distributed generation electrical power systems.

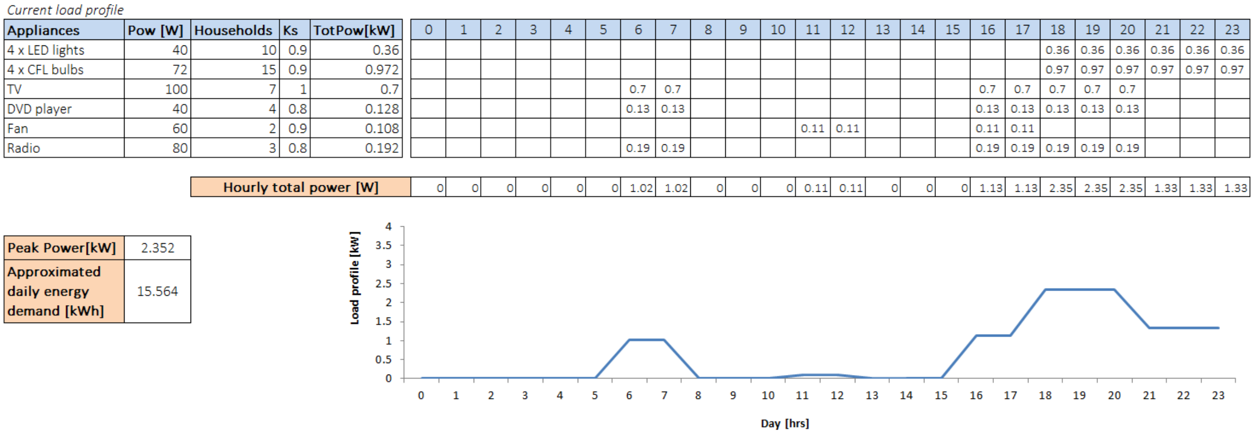
The location has been approximated to the coordinates 15°49' North, 94°44' East. The respective resources data are automatically taken by the software from “NASA surface meteorology and Solar energy database” as monthly averaged values over a 22 year period (july 1983 – june 2005).

The unmet load has been limited to 10% per year, in order to provide high system reliability. The flexibility of the load profile has been set to 5%.

The components considered by the software have been limited to generic PV panels, lead-acid batteries and auto-sizing generator.

4.1.2 Case 1

The load profile inputted in the software can be seen in Figure 25. The peak load is between 6pm and 8pm, accounting for 2.35 kW. The daily energy consumption for the community is estimated to be 15.56 kWh, corresponding approximately to 0.62 kWh per household.



Current load profile

Appliances	Pow [W]	Households	Ks	TotPow[kW]	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
4 x LED lights	40	10	0.9	0.36																			0.36	0.36	0.36	0.36	0.36	0.36
4 x CFL bulbs	72	15	0.9	0.972																			0.97	0.97	0.97	0.97	0.97	0.97
TV	100	7	1	0.7							0.7	0.7									0.7	0.7	0.7	0.7	0.7			
DVD player	40	4	0.8	0.128							0.13	0.13									0.13	0.13	0.13	0.13	0.13			
Fan	60	2	0.9	0.108												0.11	0.11				0.11	0.11						
Radio	80	3	0.8	0.192							0.19	0.19									0.19	0.19	0.19	0.19	0.19			
Hourly total power [W]					0	0	0	0	0	0	1.02	1.02	0	0	0	0.11	0.11	0	0	0	1.13	1.13	2.35	2.35	2.35	1.33	1.33	1.33

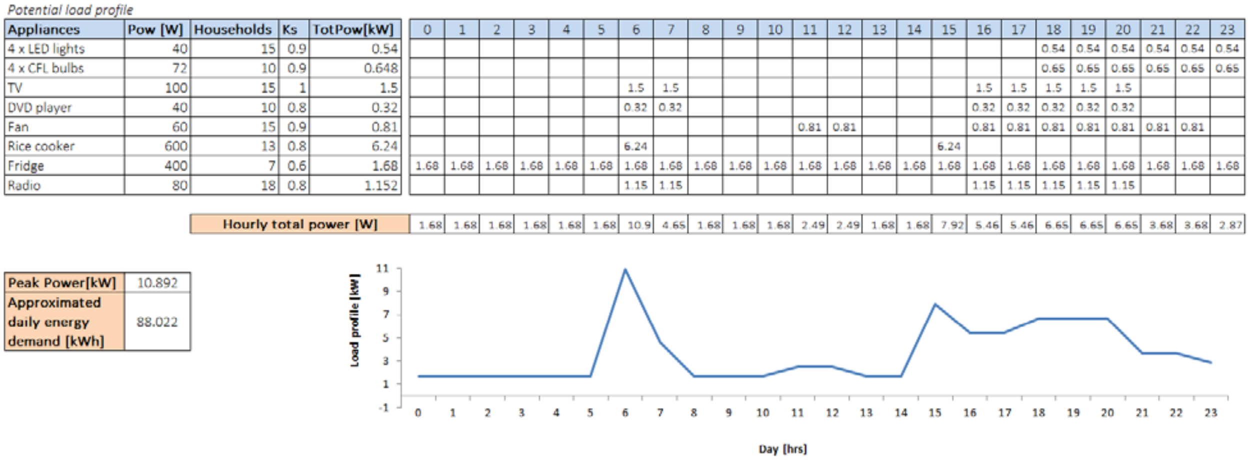
Peak Power[kW]	2.352
Approximated daily energy demand [kWh]	15.564

Figure 25 - Current load profile structure

The results of the software simulations are presented in Table 4. Two different configurations have been taken into consideration, the first without a backup diesel generator, while the second includes it. Although the NPC increases by 10%, it can be noticed that the addition of a generator in the system maximizes the reliability of the system, meeting 100% of the load. Furthermore, it allows the system to operate also in case of a temporary failure of the PV components. For this reason, hybrid mini-grids are usually preferred for remote areas.

4.1.3 Case 2

The load profile inputted in the software can be seen in Figure 26. The peak load is at 6pm, accounting for 10.9 kW. The daily energy consumption for the community is estimated to be 88 kWh, corresponding approximately to 3.5 kWh per household.



Potential load profile

Appliances	Pow [W]	Households	Ks	TotPow[kW]	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
4 x LED lights	40	15	0.9	0.54																			0.54	0.54	0.54	0.54	0.54	0.54
4 x CFL bulbs	72	10	0.9	0.648																			0.65	0.65	0.65	0.65	0.65	0.65
TV	100	15	1	1.5							1.5	1.5									1.5	1.5	1.5	1.5	1.5			
DVD player	40	10	0.8	0.32							0.32	0.32									0.32	0.32	0.32	0.32	0.32			
Fan	60	15	0.9	0.81												0.81	0.81				0.81	0.81	0.81	0.81	0.81	0.81	0.81	
Rice cooker	600	13	0.8	6.24							6.24									6.24								
Fridge	400	7	0.6	1.68	1.68	1.68	1.68	1.68	1.68	1.68	1.68	1.68	1.68	1.68	1.68	1.68	1.68	1.68	1.68	1.68	1.68	1.68	1.68	1.68	1.68	1.68	1.68	1.68
Radio	80	18	0.8	1.152							1.15	1.15									1.15	1.15	1.15	1.15	1.15			
Hourly total power [W]					1.68	1.68	1.68	1.68	1.68	1.68	10.9	4.65	1.68	1.68	1.68	2.49	2.49	1.68	1.68	7.92	5.46	5.46	6.65	6.65	6.65	3.68	3.68	2.87

Peak Power[kW]	10.892
Approximated daily energy demand [kWh]	88.022

Figure 26 - Potential load profile structure

The results of the software simulations are presented in Table 4. Two different configurations have been taken into consideration, the first without a backup diesel generator, while the second includes it. The addition of the generator leads to the same consequences as in case 1, higher price and maximized reliability.

Table 4 - Summary results Homer Pro's simulations

	Current Load		*Future Load*	
	Result 1	Result 2	Result 1	Result 2
PV size (kW)	7.12	8	41	35.3
System converter (kW)	10	10	30	20
Battery capacity (kWh)	33	35	135	116
Type of battery	Lead-Acid	Lead-Acid	Lead-Acid	Lead-Acid
Genset size (kW)	/	4.5	/	21
NPC	USD 36,777.00	USD 40,845.00	USD 156,691.00	USD 173,388.00
Yearly energy production (kWh/yr)	11,375	13,916	65,176	61,830
Yearly energy consumption (kWh/yr)	5,225	5,681	29,828	32,128
Unmet load (kWh/yr)	426	0	2,300	0
Unmet load (%)	7.54%	0%	7.16%	0%
PV production (kWh/year)	11,375	12,782	65,176	56,371
Genset production (kWh/year)	/	1,134	/	5,459
Energy from batteries (kWh/year)	4,447	3,668	18,329	16,577
Autonomy (hours)	31	32	22	19
Solar fraction	100%	92%	100%	91%

4.1.4 Case 3

A 200W SHS can meet the community requirements, providing power for lighting and recharge of portable devices, such as smartphones, speakers or radio, and small TV, decoder and DVD players. It is important to provide high quality system to guarantee the longevity and avoid to decrease the trust of the client in small photo voltaic products.

The cost of a SHS ranges between 200 and 600 USD. It can be donated by a public entity or a donor or sold to the community members through dedicated business models. Pay-as-You-Go solutions allows to reduce the upfront cost, relying on digital finance platforms. The user pays a monthly fee for the rental of the product or only pays for the amount of energy used.

Assuming a price of 300 USD per product, the Ar Wa Karr community would only require an investment 7,500 USD, which is much lower than the capital cost of a mini-grid. Nevertheless, the service would be limited to domestic consumption and it would not improve productive use of energy and the household incomes.

4.2 Economic Assessment

The economic assessment of a potential mini-grid project is crucial for evaluating the long term sustainability. Private companies and investors should carefully study project-related capital costs, O&M costs and revenues in order to understand whether to invest on it or not. Different economic parameters can help to predict the cash flows throughout the system lifetime. In particular, computing the Levelized Cost of Electricity (LCOE) allows to estimate which electricity tariff would make the project viable and profitable and to compare different strategies and business models.

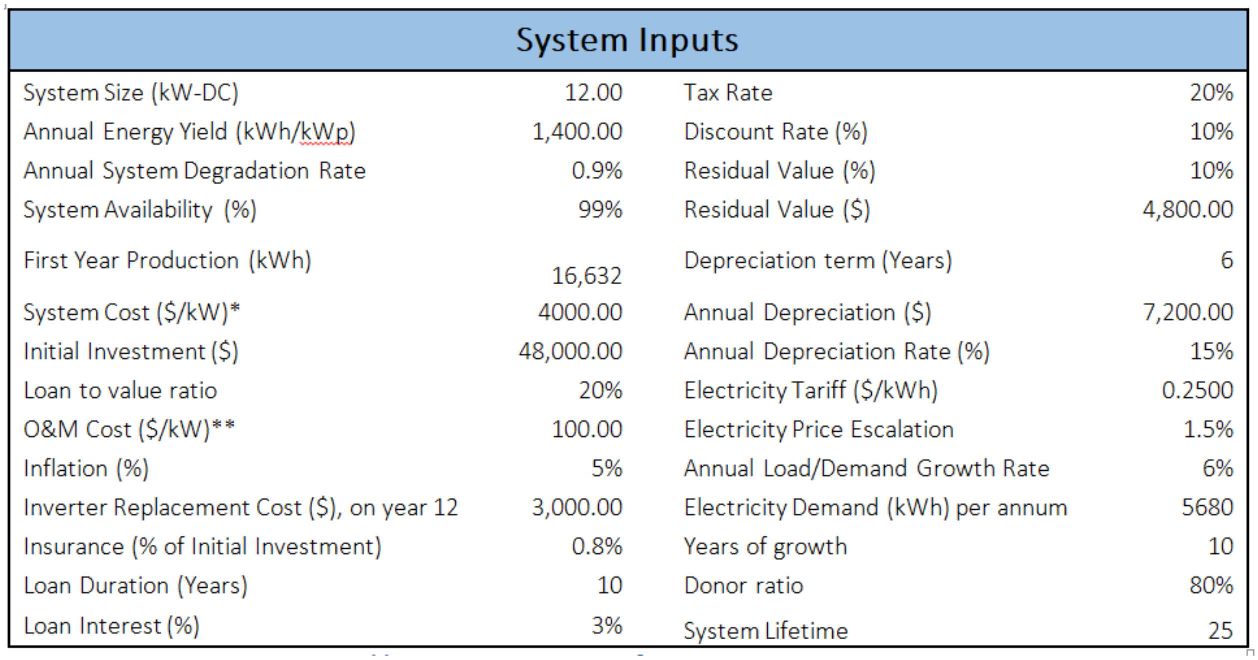
In this section, three different scenarios have been taken into consideration and simulated:

- Mini-grid, private-owned with equity loan;
- Mini-grid, 80% sponsored by international funding, 20% managed by a private company;
- Mini-grid, 100% sponsored by international funding, community managed.

4.2.1 Methodology

The village load profile has been assumed equal to the current load profile resulted from the preliminary study. The optimal system configuration given by Homer simulations consists in 8 kW PV system with electrochemical storage and backup diesel generator. Considering a demand growth rate of 6% for 10 years, the cumulative annual electricity demand will raise from 5,680 kWh/year to 10,172 kWh/year. To face this increasing request, the system size has been expanded to 12 kW.

Table 5 - Input parameters for economic assessment



System Inputs			
System Size (kW-DC)	12.00	Tax Rate	20%
Annual Energy Yield (kWh/kWp)	1,400.00	Discount Rate (%)	10%
Annual System Degradation Rate	0.9%	Residual Value (%)	10%
System Availability (%)	99%	Residual Value ($)	4,800.00
First Year Production (kWh)	16,632	Depreciation term (Years)	6
System Cost ($/kW)*	4000.00	Annual Depreciation ($)	7,200.00
Initial Investment ($)	48,000.00	Annual Depreciation Rate (%)	15%
Loan to value ratio	20%	Electricity Tariff ($/kWh)	0.2500
O&M Cost ($/kW)**	100.00	Electricity Price Escalation	1.5%
Inflation (%)	5%	Annual Load/Demand Growth Rate	6%
Inverter Replacement Cost ($), on year 12	3,000.00	Electricity Demand (kWh) per annum	5680
Insurance (% of Initial Investment)	0.8%	Years of growth	10
Loan Duration (Years)	10	Donor ratio	80%
Loan Interest (%)	3%	System Lifetime	25

A spreadsheet has been created to simplify and automatize the calculations. Table 5 shows the spreadsheet inputs to compute critical economic parameters. System costs have been assumed considering capital investments of existing projects installed by Sunlabob. These costs include T&D lines installation expenses. Tax and interests rates have also been assumed according to existing Sunlabob's projects. Annex 10 – LCOE Calculations for Private-owned mini-grid shows the yearly values and results for private-owned Mini-grid case.

Annual O&M costs are computed with equation 1.

$$c_n = Annual\ O\&M\ Cost[USD]_n = O\&M\ Cost\left[\frac{USD}{kW}\right]_{n-1} \cdot (1 + Inflation\ Rate) \tag{1}$$

Electricity price increases each year according to the electricity price escalation rate and it is calculated with equation 2. The community electricity demand is also growing annually, following equation 3.

$$Electricity\ price_n\left[\frac{USD}{kWh}\right] = Electricity\ Price_{n-1}\left[\frac{USD}{kWh}\right] \cdot (1 + Electricity\ Price\ Escalation) \tag{2}$$

$$Electricity\ Demand_n[kWh] = Electricity\ Demand_{n-1}[kWh] \cdot (1 + Demand\ Growth\ Rate) \tag{3}$$

Annual revenues come from the sale of electricity to the community members. Therefore, they depend on the annual electricity demand, as shown in equation 4.

$$S_n = Annual\ Revenues_n[USD] = Electricity\ price_n\left[\frac{USD}{kWh}\right] \cdot Electricity\ Demand_n[kWh] \tag{4}$$

The cost of the insurance is calculated as a percentage of the initial capital investment I and it is affected each year by the inflation rate (see equation 5 and equation 6).

$$Insurance\ [USD] = Insurance\ [\%] \cdot I\ [USD] \tag{5}$$

$$Insurance_n\ [USD] = Insurance_{n-1}\ [USD] \cdot (1 + Inflation\ Rate) \tag{6}$$

The annual discount factor is computed with equation 7.

$$DF_n = Discount\ Factor_n = \frac{1}{(1 + Discount\ Rate)^n} \tag{7}$$

Furthermore, depreciation refers to the decrease in value of the mini-grid during the asset lifetime. It is a method of reallocating the cost of a tangible asset over its useful life span of it being in motion. Businesses depreciate assets for tax purposes. Equation 8, equation 9, equation 10 and equation 11 describe how depreciation has been included in the economic assessment.

$$R = Residual\ Value\ [USD] = Residual\ Value\ [\%] \cdot I[USD] \tag{8}$$

$$Depreciation\ [\frac{USD}{year}] = \frac{I[USD] - Residual\ Value\ [USD]}{Depreciation\ term\ [years]} \tag{9}$$

$$Annual\ Depreciation\ Rate\ [\%] = \frac{Depreciation\ \left[\frac{USD}{year}\right]}{C\ [USD]} \tag{10}$$

$$D_n = Depreciation\ Tax\ Shield_n\ [USD] = Depreciation[USD] \cdot Tax\ rate \tag{11}$$

Moreover, the commercial loan refund is accounted in the annual expenses according to equation 12.

$$L_n = Loan_n = \frac{I[USD] \cdot Loan\ ratio}{Loan\ ratio} + \left(I[USD] \cdot Loan\ ratio - \frac{I[USD] \cdot Loan\ ratio \cdot n}{Loan\ ratio} \right) \cdot Interest\ ratio \cdot (1 - Tax\ rate) \qquad (12)$$

Besides O&M costs, annual variable costs include also replacement cost and insurance, as shown in equation 13.

$$C_n = Variable\ costs[USD] = (c_n[USD] + Replacement\ cost_n[USD] + Insurance_n\ [USD])(1 - Tax\ rate) \qquad (13)$$

To measure the difference between annual cash inflows and outflows, the Net Cash Flow is computed (see equation 14). This economic parameter is used to discern the short-term financial viability of a business, which is considered to be its ability to generate cash. If a company is consistently generating positive net cash flow over a long period of time, this is the best indicator of its viability. Conversely, continuing negative net cash flow is the prime indicator of any number of operational or financing problems.

$$Net\ Cash\ Flow_n = I_0[USD] + c_n[USD] + Insurance_n[USD] + L_n[USD] + Replacement\ cost_n[USD] \qquad (14)$$

Finally, the discounted values have been computed multiplying the annual values by the corresponding annual discount factor.

The Internal Rate of Return (IRR) has been computed using the excel function "IRR", inputting the annual cash flow cells. The Net Present Value (NPV) corresponds to the cumulative discounted cash flow at the system end-of-life. The payback time (PBT) is computed with the excel function "COUNTIF", counting the number of year with a negative cumulative cash flow summed with the remaining fraction of the year when the cumulative discounted cash flow turns positive. The Levelized Cost of Electricity has been computed with equation 15.

$$LCOE\ \left[\frac{USD}{kWh}\right] = \frac{Total\ Life\ Cycle\ Cost}{Total\ Lifetime\ Energy\ Production} = \frac{I_0 + C + L + S}{E} \qquad (15)$$

Where C, L and S are respectively the sum throughout the system lifetime of discounted annual operation costs, discounted annual loan payment and discounted annual revenues.

4.2.2 Results

Case 1

Case 1 simulates a private-owned mini-grid where a private investor pays to install, operates and maintains the system. Companies usually access debt capital to cover the capital cost. In this case, the commercial loan has been assumed covering 80% of the initial investment, 10 years to pay it back and 3% of interest. The electricity tariff has been set to 0.25 USD/kWh (387MMK/kWh), which is a quite high price for Myanmar. Table 6 shows the results of the calculations.

Table 6 - Economic assessment results, case 1

Results	
IRR	N.A.
NPV (25 years)	$ - 32,819
PBT (years)	N.A.
LCOE (25 years)	$ 0.71304

It can be noticed that the project is not viable with the parameters taken. The NPV is negative, consequently IRR and PBT cannot be calculated. The LCOE value shows that the electricity tariff should be higher than 0.713 USD/kWh to be economically sustainable. Nevertheless, such price is not affordable for the community. Figure 27 displays the predicted cumulative net cash-flow throughout the lifetime of the project.

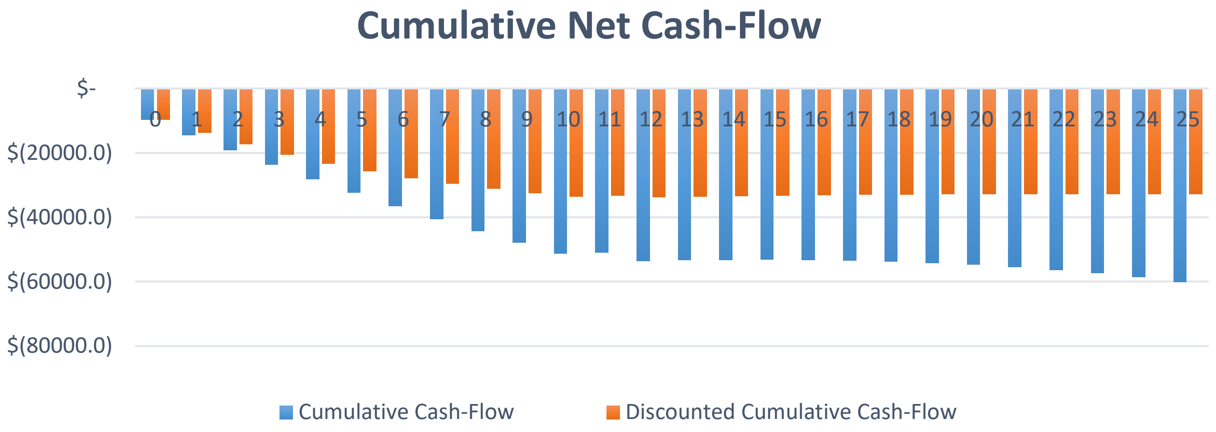


Figure 27 - Cumulative Net Cash Flow, Case 1

Case 2

Case 2 simulates a private-owned mini-grid with incentives covering 80% of the upfront costs. The company pays only 20% of the CAPEX to install the system, relying on a commercial loan to cover it. The loan conditions are, like in Case 1, 10 years to pay it back and 3% of interests. The system is owned, operated and maintained by the private actor. The electricity tariff has been set to 0.25 USD/kWh (387MMK/kWh), which is a quite high price for Myanmar. Table 7 shows the results of the computations.

Table 7 - Economic assessment results, case 2

Results	
IRR	N.A.
NPV (25 years)	$ - 10,537
PBT (years)	N.A.
LCOE (25 years)	$ 0.42149

It can be noticed that the project is not viable with the parameters taken. The NPV is negative, consequently IRR and PBT cannot be calculated. The LCOE value shows that the electricity tariff should be higher than 0.42 USD/kWh to be economically sustainable. Nevertheless, such price is not affordable for the community. Figure 28 displays the predicted cumulative net cash-flow throughout the lifetime of the project.

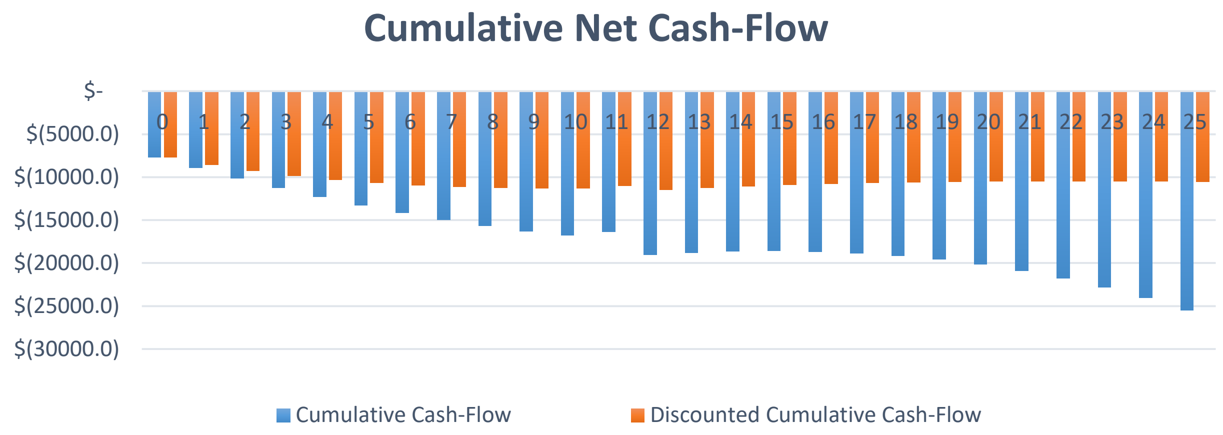


Figure 28 - Cumulative Net Cash Flow, Case 2

Case 3

Case 3 simulates a community-owned mini-grid fully donated by a public entity or a donor, providing grants or financial assistance to an outside organization which design and install the system. The local community takes care of tariff collection and operation and maintenance. The revenues from the electricity sold should cover all the O&M expenses in order to be autonomous and sustainable. The electricity tariff has been set to 0.32 USD/kWh (496MMK/kWh), which is a very high price for Myanmar. Table 8 shows the results of the calculations.

Table 8 - Economic assessment results, case 3

Results		
IRR		3%
NPV (25 years)	$	2,951
PBT (25 years)		17.08
LCOE (25 years)	$	0.32602

The project is viable. The IRR and NPV result respectively 3% and 2,951 USD. The community can sustain the mini-grid that has been provided with. Nevertheless, the tariff set is high for the community and may lead people to avoid consumptions, turning the project to unsustainable. Figure 29 displays the predicted cumulative net cash-flow throughout the lifetime of the project.

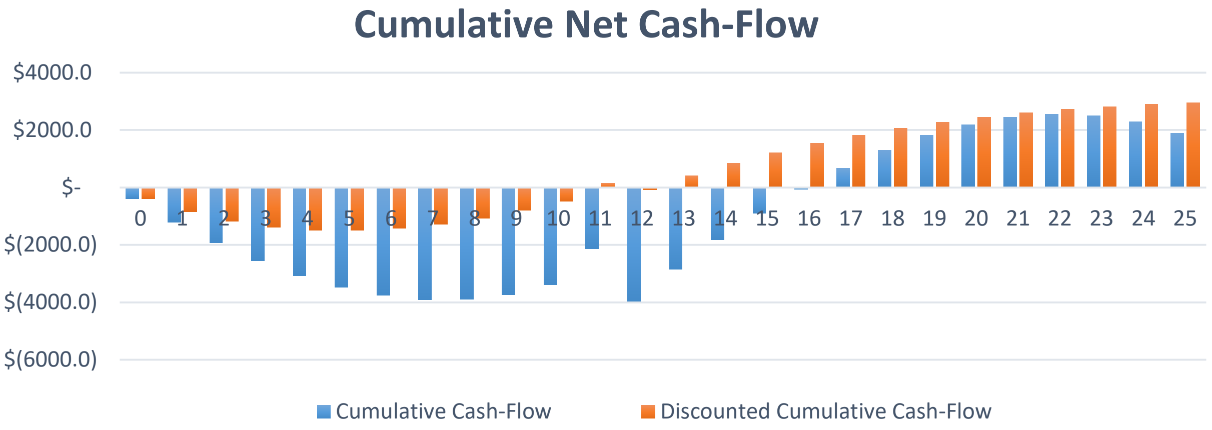


Figure 29 - Cumulative Net Cash Flow, Case 3

5. Conclusions

Community participatory strategies successfully achieved a more inclusive and participatory approach to community energy design and planning, gaining a better and more holistic understanding of the local context and energy needs in the community. This approach was well-received by the community, project partners and is well suited for high levels of community engagement. In particular, during The Minigrid Game sessions the participants show enthusiastic engagement and an increased understanding of the different power ratings of appliances and their impact on the monthly electricity bill, that allow them to converge to a more realistic willingness to pay.

The Ar Wa Karr community has a poor and unreliable access to electricity and it would benefit greatly from improved energy services. However, there are several unique issues to consider that need a further consultation and study of the community. Strong cooperation and agreement from the community will be required to relocate the members to only one general area, reducing seasonal migration. Furthermore, low energy demand and low purchase power complicate the sustainability of the mini-grids, discouraging private investors. This issue is highlighted in the economic assessments in chapter 4. The results of the computations show that the investment would be unsuccessful for a private company, also in case of access to a commercial loan. The results slightly improve if the capital cost of the system is partially covered by incentives. Nevertheless, the LCOE is still too high and the tariffs settings to reach the sustainability would be too high for the users. The best scenario is represented by a mini-grid fully donated by a public entity or a donor. In this case, the community would be able to sustain the cost of operation, maintenance and replacement, although paying an electricity tariff higher than usual Myanmar's prices. Creating and forming community electricity cooperatives or other local organizations to manage and operate the system may lower the O&M costs, reducing consequently the LCOE and the electricity tariffs.

As future steps, in order to afford new energy services, community members must not only increase their livelihoods, but also obtain more regular income throughout the year to pay for monthly services. Additional support is needed to facilitate the creation of new enterprises and income-generating opportunities within the village. This could take the form of attracting investment and businesses to set up processing and production of seafood products on Pyinsalu Island, or developing small-scale processing by villagers and enabling access to outside markets. Any enterprise creation will require energy services, which also benefits the community by creating additional energy demand.

In conclusion, it would be beneficial to deploy The Minigrid Game several more times to converge on other mini-grid design-related parameters, continue community engagement and gain further community acceptance of the difference configurations, and collaboratively put in place a long-term community management plan. Multiple sessions would also enable larger numbers of community members to participate. This would all help ensure substantive community engagement throughout the entire project lifecycle.

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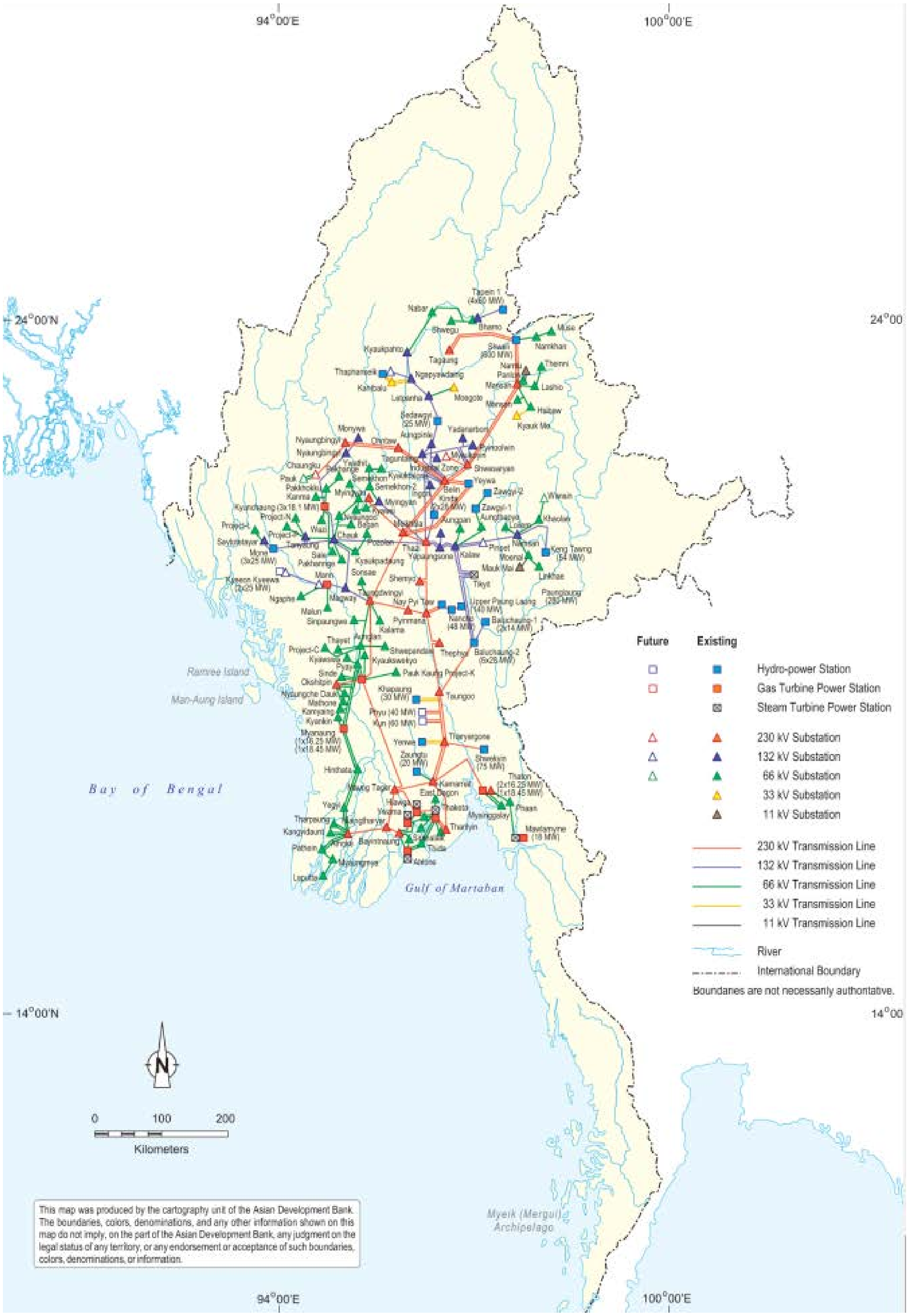
Annex

Annex 1 – Myanmar Transmission and Distribution Lines



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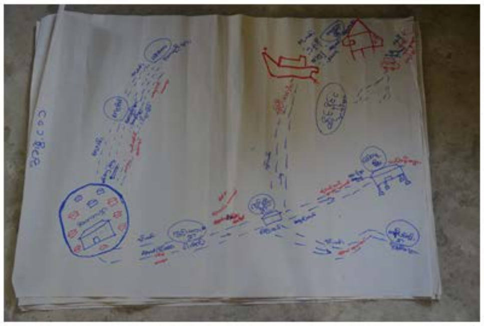
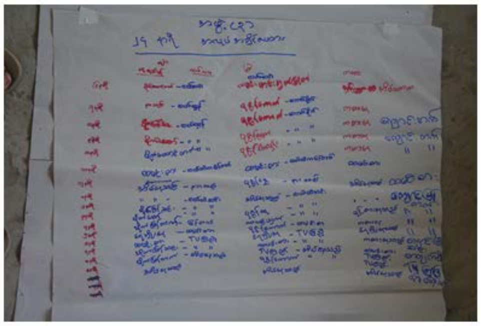
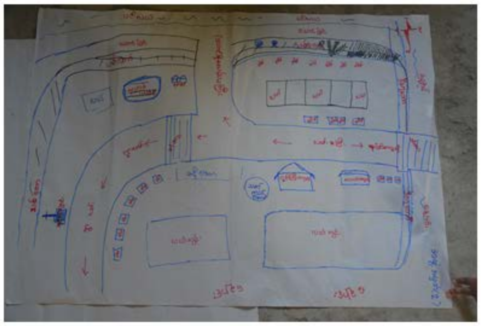
Annex 2 – Set of talking points used to guide semi-structured interviews

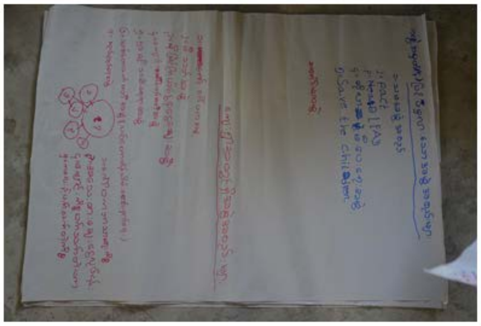
- Community size
- Household size
- Income source (how much?)
- Existing energy
- Energy use (current and future appliances)
- Current energy expenditure
- Willingness to pay
- Expectation of reliability
- Perception of existing options (for electrification), eg national grid
- Governance structure
- Shared resources in village (if any)

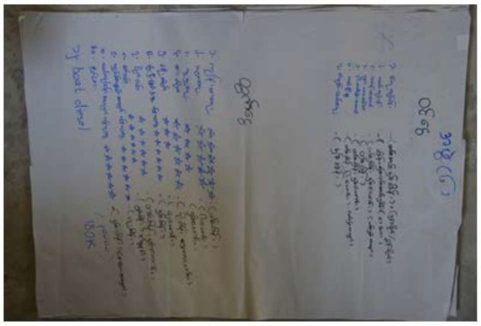
Annex 3 – Mapping Activity's Posters











Annex 4 – The Minigrid Game process [42]

Introduction	• Introduce workshop facilitators • Brief participants with game's objectives and flow of the workshop
Game initialization and test play	• Participants go through a brief tutorial of how to play a game-round • Participants familiarize themselves with the game's mechanics and are given time to test the user interface to see what they can do with the game • Game and household parameters are entered into the game • Individual households purchase appliances that they would like to use in their houses
Game-rounds	• Participants draw surprise event cards both at household and community levels. These event cards affect their budgets or community funds. • Participants play game-rounds by turning on and off appliances according to a game clock. • Participants pay for their household bills at the end of a game-round. Payments are collected by the system operator and enter a community fund. • The operator pays for the system's energy bill using the community fund.
Discussions in between game-rounds	• Collectively view the current system load profile and compare it with previous rounds. • Identify and discuss the peaks and lows, if the system capacity has gone over the set capacity. • Review household bills and discuss willingness and ability to pay. • Review community fund and discuss if payment system is acceptable (eg prepaid vs energy-based tariffs, which is more convenient based on community values) • Determine if system capacity is sufficient and any load management options needed.
Changing game settings in between rounds, based on discussions	The following settings can be changed based on discussions and collective agreement by the community: • System capacity and costs • Tariff rates and payment systems (ie prepaid, flat-rate or energy-based tariffs) • Households' monthly incomes • Micro-hydro or solar generation
Conclusion and feedback	• Evaluation of participants' understanding and a final discussion

Annex 5 - The Minigrid Game's appliance settings

Appliance	Price (MMK)	Ratings (kW)
Incandescent light	1,000	0.1
LED light	1,500	0.015
CFL light	1,200	0.03
Radio	5,000	0.003
TV	80,000	0.18
Phone charger	3,000	0.003
Computer	700,000	0.07
Refrigerator	300,000	0.15
Washing machine	300,000	0.28
Kettle	10,000	1
Rice cooker	40,000	0.7
Iron	12,000	1
DVD player	15,000	0.02
Fan	15,000	0.03

Annex 6 - Initial household cashbox amounts and salaries for Minigrid Game

Household	Cashbox amount (MMK)	Salary (MMK)
H0	500,000	60,000
H1	600,000	60,000
H2	800,000	60,000
H3	800,000	80,000
H4	500,000	100,000
H5	790,000	100,000
H6	750,000	125,000
H7	1,000,000	150,000
H8	1,000,000	125,000
H9	1,000,000	125,000

Annex 7 – Semi-structured interviews results

#	Members	Source of income	Income	Loan	Existing energy	Estimated expense	Wished appliances	Willingness to pay	Seasonal	Notes
1	2	Dry season: Fishery Rainy season: nothing	Average: 200 000 MMK Min 50 000 Max 500 000	Yes	Oil lamp, Head lamp with batteries, no phones	1700 MMK Lamp, 3 batteries that last 2 night, each battery cost 100 MMK	Better light to separate the fish, freezer	10 000 MMK	No	They lost 5 children in the storm of 2010, Very poor, quite low energy expectations
2	3	Dry season: Fishery Rainy season: Small shrimps and crabs	Average: 100 000 MMK Min 50 000 Max 150 000	Yes	LED light with batteries, candles, fan, radio, old phone	He charges the battery in the village for free	Freezer	10 000 MMK	Yes	He was a taxi driver before. He stopped when everybody could afford a motorbike.
3	3	Dry season: Fishery Rainy season: nothing	Average: 200 000 MMK Min 50 000 Max 500 000	Yes	Torch, light bulb with batteries	Charge in the village for 500 MMK. It last around 8 hours.	Freezer, rice cooker, steam cooker	2 000 MMK, only for lighting but charcing batteries sometime can cost 15 000 MMK.	Yes	He would rather have a solar system on his own. A little skeptical about a centralized system, not reliable. His boat got stolen, so he got 10 Lakhs loan to buy a new one.
4	4	Dry season: Fishery Rainy season: Reap the rice	Average: 200 000 MMK Min 200 000 Max 250 000	Yes	LED light with batteries	200 kyats per charge, 1 charge per day. 6000 MMK per month	Rice cooker, steam cooker, iron, television	13 000 MMK	No	They got a 700 000 MMK laon last year from a microfinance NGO with a very low interest. Borrowed 150 000 MMK this year from his boss.
5	5	Dry season: Fishery Rainy season: Crabs	Average: 700 000 MMK Min 200 000 Max 1 000 000	Yes	TV, small pv and batteries, 4 lighting bulbs	PV+battery+inverte costed 400 000 MMK (they paid themselves), TV+satellite costed 150 000 MMK.	Rice cooker, steam cooker, iron, grinder for fish paste	10 000 MMK	No	They have a hired worker: 100 000 MMK. The boss borrowed 2 milions, interest was 10% and now it has been reduced to 6%. 400 000 MMK debt. Share the solar energy with the community free of charge.
6	3	Dry season: Fishery, Sell food Rainy season: Sell food	Average: 45 000 MMK Min 40 000 Max 60 000	No	2 torches with batteries	250 MMK per battery	Rice cooker, steam cooker	8000 - 9000 MMK	No	Electric tools would not be needed for work. For the market manual processing is enough.
7	6	Dry season: Fishery Rainy season: nothing	Average: 250 000 MMK Min 100 000 Max 300 000	Yes	Small PV panel, lighting, small battery	Small battery costs 4500 MMK, bigger battery costs 14 000 MMK	Rice cooker	6000 - 7000 MMK	No	Bad experience with solar energy in another village
8	4	Dry season: Fishery Rainy season: nothing	Average: 400 000 MMK Min 200 000 Max 500 000	Yes	Small PV panel, battery, lights, television, DVD player			8 000 MMK	No	Panels Gookooma
9	6	Dry season: Crabs and small shrimps Rainy season: Farming	Average: 200 000 MMK Min n.a. Max n.a.	Yes	Small PV panel, battery, lights, laptop, speakers		TV, cooking tools	5000 MMK	No	The land is borrowed but they run it on their own. Rough salaries: 250k throwing seeds, 250k reaping the rice
10	6	Dry season: Fishery Rainy season: nothing	Average: 200 000 MMK Min 100 000 Max 300 000	No	Torch, batteries			6 000 MMK	No	The husband lives in Thailand. She was not very participative.
11	4	Dry season: Fishery Rainy season: nothing	Average: 150 000 MMK Min 100 000 Max 200 000	Yes	Small PV panel, battery, lights, television			5000 to 10 000 MMK	No	Planning to increase the amount of nets from 5 to 11. The son is in Yangon working.
12	3	Dry season: Fishery Rainy season: Fishery (in the river with only 1 net)	Average: 400 000 MMK Min 200 000 Max 600 000	Yes	Small generator , PV panel for lighting, batteries	Generator: 1 liter/time, 800 MMK/liter, 3 or 4 times per week.	TV, cooking tools, fish grinder	10 000 MMK	No	Small generator used for TV twice a week.
13	4	Dry season: Shop keeper Rainy season: Shop keeper and Farmer	Average: 500 000 MMK Min 300 000 Max 600 000	Yes	Small generator, batteries, lights, TV, DVD player, speakers	3 bottles of diesel/day, 500 MMK/bottle, 45 000 MMK/month	Cooking tools, freezer	30 000 MMK	No	The shop covers the daily expenses of the household. 2.5 milions MMK per year. 10 acres of land. 5 lakh per season to employee
14	2	Dry season: Fishery Rainy season: Catch prawns to dry	Average: 200 000 MMK Min n.a. Max n.a.	Yes	Small PV panel, battery, lights, phone	67 000 MKK for the energy system. They cook with wood that they collect	Cooking tools	5 000 MMK	No	Does not have a boat. Borrow it if there is one available. Charged for the fuel.
15	7	Dry season: Fishery, crabs and prawns Rainy season: nothing	Average: 200 000 MMK Min n.a. Max n.a.	Yes	Battery, TV, DVD player, speakers, lights, smartphone	Battery costed 120 000 MMK	Fridge, TV, washing machine	2 000 MMK	Yes	Monthly interest 20-30%.

#	Members	Source of income	Income	Loan	Existing energy	Estimated expense	Wished appliances	Willingness to pay	Seasonal	Notes
16	3	Dry season: Fishery Rainy season: Crabs	Average: 280 000.MMK Min 200 000 Max 300 000	Yes	Battery, lighting		Cooking tools, better lighting	5 000 MMK	No	Boss sold the crab trap for 3.5 Lakhs
17	7	Dry season:Casual labour (carpenter, making fishing nets) Rainy season: Same	Average:200 000MMK Min n.a. Max n.a.	Yes	Motorcycle battery, lights, radio	Motorcycle battery costs 5 000 MMK and charges for free, lights 1 500 MMK		5 000 MMK	No	
18	5	Dry season: Small fishery, casual works Rainy season: Same	Average: 100 000 MMK Min 60 000 MMK Max 150 000 MMK	No	Light with AA batteries,	1 battery costs 100 MMK, it lasts 3 days	Lighting	3 000 - 5 000 MMK	No	
19	6	Dry season: Livestock, paddy field, crabs Rainy season: Same	Average: n.a.60 000 MMK Min n.a. Max n.a.	Yes	Small PV panel, battery, lights, phone	Solar costed 52 000 MMK	Better lights, phone	5 000 - 10 000	No	
20	5	Dry season: Casual labour, selling snacks Rainy season: Casual labour	Average: 80 000.MMK Min n.a. Max n.a.	No	Small PV panel, battery, lights, phone	Battery+solar charger+DVD player costed 70 000 MMK	Cooking tools, better lighting	5 000 MMK	No	Casual labours: make crab traps, make fishing nets. They buy livestock with the savings.
21	2	Dry season: Casual labour (Fishing, crabs and shrimp farming Rainy season: Same	Average: 150 000 MMK Min n.a. Max n.a.	No	Battery, LED lights	Charge the battery for free at the neighbours'	Cooking tools, better lighting	3 000 MMK	No	Estimated net yearly savings: 1.5 lakhs
22	3	Dry season: Fishery Rainy season: River fishery	Average: 325 000 MMK Min n.a. Max n.a.	Yes	Small generator, batteries, lights, TV, DVD player, radio, smartphone	4 500 MMK per month for Diesel, Generator+dyanmo costed 3 Lakhs	Better lighting, more TV, fan	8 000 MMK	Yes	An annual tax of 12 000 MMK is paid to the government to obtain the permission to fish in a particular place of the river. 30 Lakhs fishing in the ocean, 9 Lakhs in the river. 5% interest per month Use generator as boat engine backup.
1	3	Dry season: Sell prawns, shop Rainy season: Same	Average: 200 000 MMK Min 150 000 Max 300 000	No	Small PV panel, battery, lights, TV, fan, speakers		Cooking tools, freezer, kettle, iron	5 000 - 6 000 MMK	No	Casual labour workers collect the small prawns and sell them to her. She has an inland fishing pond. She asks 200 MMK per phone charge to the neighbours. With a grid, she could sell ice and popcicles.
2	7	Dry season: Fishery Rainy season: nothing	Average: 300 000 MMK Min n.a. Max n.a.	Yes	Small PV panel, battery, lights, phone	PV system bought 2 years ago for 28 000 MMK	Better lighting	10 000 - 15 000 MMK	No	Get 2 Lakhs loan from the ngo LEAD. 1st cycle is ended. Now they are in the 2nd cycle. 2% interests. They spend 20-25K mmk for boat fuel.
3	6	Dry season: Fishery Rainy season: Crab traps and fish traps	Average: 190 000 MMK Min n.a. Max n.a.	Yes	Battery, lights, phone	Battery costed 12 000 MMK	Electric stove	5 000 MMK	No	Got 4 Lakhs and 2 Lakhs loan respectively from PACT (2.5% interest) and LEAD (2% interest). Loan used to buy a motorbike, buy livestock and make traps. 1 pig = 2 Lakhs. Monthly expenditure is 1.5 Lakhs.

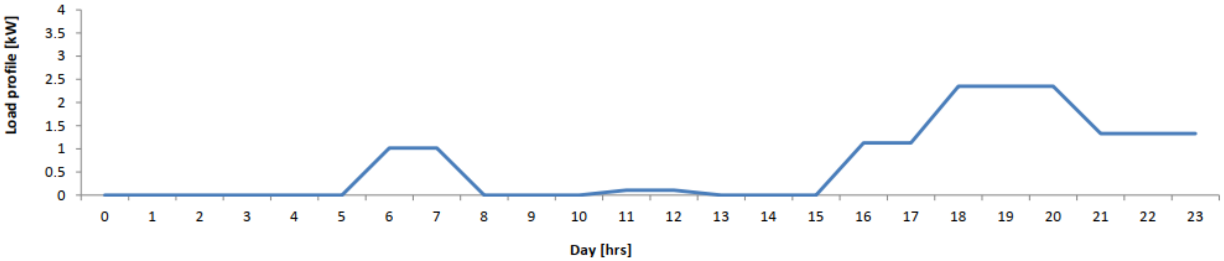
Annex 8 – Load Profiles

Current load profile

Appliances	Pow [W]	Households	Ks	TotPow[kW]	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
4 x LED lights	40	10	0.9	0.36																			0.36	0.36	0.36	0.36	0.36	0.36
4 x CFL bulbs	72	15	0.9	0.972																			0.972	0.972	0.972	0.972	0.972	0.972
TV	100	7	1	0.7							0.7	0.7									0.7	0.7	0.7	0.7	0.7			
DVD player	40	4	0.8	0.128							0.128	0.128									0.128	0.128	0.128	0.128	0.128			
Fan	60	2	0.9	0.108												0.108	0.108				0.108	0.108						
Radio	80	3	0.8	0.192							0.192	0.192									0.192	0.192	0.192	0.192	0.192			

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Hourly total power [W]	0	0	0	0	0	0	1.02	1.02	0	0	0	0.108	0.108	0	0	0	1.128	1.128	2.352	2.352	2.352	1.332	1.332	1.332

Peak Power[kW]	2.352
Approximated daily energy demand [kWh]	15.564

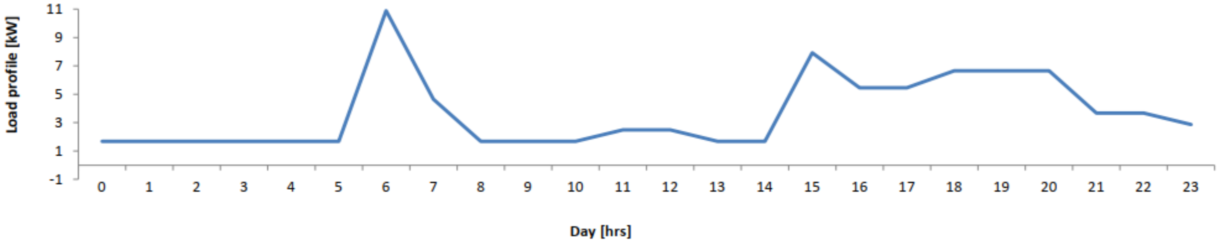


Potential load profile

Appliances	Pow [W]	Households	Ks	TotPow[kW]	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
4 x LED lights	40	15	0.9	0.54																			0.54	0.54	0.54	0.54	0.54	0.54
4 x CFL bulbs	72	10	0.9	0.648																			0.648	0.648	0.648	0.648	0.648	0.648
TV	100	15	1	1.5							1.5	1.5									1.5	1.5	1.5	1.5	1.5			
DVD player	40	10	0.8	0.32							0.32	0.32									0.32	0.32	0.32	0.32	0.32			
Fan	60	15	0.9	0.81												0.81	0.81				0.81	0.81	0.81	0.81	0.81	0.81	0.81	
Rice cooker	600	13	0.8	6.24							6.24									6.24								
Fridge	400	7	0.6	1.68	1.68	1.68	1.68	1.68	1.68	1.68	1.68	1.68	1.68	1.68	1.68	1.68	1.68	1.68	1.68	1.68	1.68	1.68	1.68	1.68	1.68	1.68	1.68	1.68
Radio	80	18	0.8	1.152							1.152	1.152									1.152	1.152	1.152	1.152	1.152			

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Hourly total power [W]	1.68	1.68	1.68	1.68	1.68	1.68	10.89	4.652	1.68	1.68	1.68	2.49	2.49	1.68	1.68	7.92	5.462	5.462	6.65	6.65	6.65	3.678	3.678	2.868

Peak Power[kW]	10.892
Approximated daily energy demand [kWh]	88.022



Annex 9 – Community Daily Routine

Time		6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Male	Fishing	Set up trap					Lunch	Rest			Retrieve Trap		Shower	Dinner	Check Nets	Fix Nets
	Farming	Work on paddy field						Lunch	Rest	Work on paddy field			dinner	Watch TV	sleep	
Female	Fishing	Cook	Pick Prawns		Boil Prawn	Dry Prawn	Lunch	Mix Prawn	Rest	Crush Prawn	Cook	Pick Prawn	Shower	Dinner	Watch TV	Pick Prawn
	Farming	Cook	Work on paddy field				Lunch	Rest	Work on paddy field			Dinner	Watch TV		Sleep	
Children	Under 5	Play					Lunch	Sleep		Shower	Play	Watch TV	dinner	Watch TV		Sleep
	5 to 16	Prepare			School							Study		Dinner	Watch TV	

Annex 10 – LCOE Calculations for Private-owned mini-grid

Case 1

System Inputs	
System Size (kW-DC)	12
Annual Energy Production (kWh/kWp)	1400
Annual System Degradation Rate	0.009
System Availability (%)	0.99
First Year Production (kWh)	16632
System Cost ($/kW)*	4000
Initial Investment ($)	48000
Loan to value ratio	0.8
O&M Cost ($/kW)**	100
Inflation (%)	0.05
Inverter Replacement Cost ($), on year 12	3000
Insurance (% of Initial Investment)	0.008
Loan Duration (Years)	10
Loan Interest (%)	0.03
Tax Rate	0.2
Discount Rate (%)	0.1
Residual Value (%)	0.1
Residual Value ($)	4800
Depreciation term (Years)	6
Annual Depreciation ($)	7200
Annual Depreciation Rate (%)	0.15
Price of Electricity ($/kWh) (Tariff paid by client)	0.25
Electricity Price Escalation	0.015
Annual Load/Demand Growth Rate	0.06
Current Community Electricity demand (kWh/yr)	5680
Years of growth	10
Donor percentage	0

* Include T&D lines
** Include fuel expenses

				Discounted Values								
Year	Annual Energy Production (kWh)	Capex ($)	Discounted Factor	Depreciation Tax Shield ($)	Annual Operation ($)	Residual Value ($)	Loan Payment ($)	Annual Revenues ($)	Energy Production (demand)	Net cash-flow	Cumulative Net Cash-flow	Cash-Flow Fraction
0		$ (9,600)	1	0	0	0	0	0	0	-9600	-9600	-2.3461
1	16,632		0.9090909	1309.09091	-1152.0000	0	-4328.72727	1388.8891	5473.4545	-4091.8382	-13691.8382	-3.8031
2	16,482		0.8264463	1190.08264	-1099.6364	0	-3859.04132	1358.4598	5274.4198	-3600.2179	-17292.0561	-5.4723
3	16,334		0.7513148	1081.89331	-1049.6529	0	-3438.97821	1328.6972	5082.6227	-3159.9339	-20451.9900	-7.3947
4	16,187		0.6830135	983.53938	-1001.9414	0	-3063.39731	1299.5866	4897.8001	-2765.7521	-23217.7421	-9.6221
5	16,041		0.6209213	894.12671	-956.3986	0	-2727.68254	1271.1139	4719.6983	-2412.9673	-25630.7094	-12.2205
6	15,897		0.5644739	812.84246	-912.9259		-2427.68948	1243.2649	4548.0729	-2097.3505	-27728.0599	-15.2763
7	15,754		0.5131581	0	-871.4293	0	-2159.69778	1216.0261	4382.6884	-1815.1010	-29543.1608	-18.9040
8	15,612		0.4665074	0	-831.8189	0	-1920.36830	1189.3841	4223.3179	-1562.8031	-31105.9639	-23.2587
9	15,472		0.4240976	0	-794.0089	0	-1706.70453	1163.3258	4069.7427	-1337.3877	-32443.3516	-28.5568
10	15,332		0.3855433	0	-757.9176	0	-1516.01790	1137.8384	3921.7521	-1136.0972	-33579.4488	102.8632
11	15,194		0.3504939	0	-723.4668	0	0	1049.9145	3565.2292	326.4477	-33253.0012	-68.3499
12	15,058		0.3186308	0	-1455.2959	0	0	968.7847	3241.1174	-486.5112	-33739.5124	143.7362
13	14,922		0.2896644	0	-659.1919	0	0	893.9241	2946.4704	234.7322	-33504.7802	171.2752
14	14,788		0.2633313	0	-629.2286	0	0	824.8481	2678.6094	195.6195	-33309.1606	207.5563
15	14,655		0.2393920	0	-600.6273	0	0	761.1099	2435.0995	160.4826	-33148.6781	257.0247
16	14,523		0.2176291	0	-573.3261	0	0	702.2968	2213.7268	128.9708	-33019.7073	327.6979
17	14,392		0.1978447	0	-547.2658	0	0	648.0284	2012.4789	100.7627	-32918.9446	435.6464
18	14,263		0.1798588	0	-522.3901	0	0	597.9535	1829.5263	75.5634	-32843.3812	618.4851
19	14,134		0.1635080	0	-498.6451	0	0	551.7480	1663.2057	53.1029	-32790.2783	989.6395
20	14,007		0.1486436	0	-475.9794	0	0	509.1129	1512.0052	33.1336	-32757.1447	2123.1664
21	13,881		0.1351306	0	-454.3440	0	0	469.7724	1374.5502	15.4284	-32741.7163	-148720.2804
22	13,756		0.1228460	0	-433.6920	0	0	433.4718	1249.5911	-0.2202	-32741.9364	-2338.3032
23	13,632		0.1116782	0	-413.9787	0	0	399.9763	1135.9919	-14.0024	-32755.9388	-1255.3787
24	13,509		0.1015256	0	-395.1615	0	0	369.0690	1032.7199	-26.0925	-32782.0313	-894.4727
25	13,388		0.0922960	0	-377.1996	443.02079	0	340.5500	938.8363	-36.6496	-32818.6809	
Total	**373,844.39**	**$ (9,600)**		**6271.575407**	**-18187.5226**	**443.021**	**-27148.3046**	**22117.14632**	**76422.7278**	**-32818.6809**	**-32818.6809**	

Results	
IRR	N.A.
NPV (25 years)	-32818.6809
PBT (years)	N.A.
Discounted PBT (years)	N.A.
Basic LCOE (25 years)	-0.71304