International Renewable Energy Agency

RENEWABLE ENERGY FOR REMOTE COMMUNITIES

A guidebook for off-grid projects

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The International Renewable Energy Agency (IRENA) is an intergovernmental organisation that supports countries in their transition to a sustainable energy future, and serves as the principal platform for international co-operation, a centre of excellence, and a repository of policy, technology, resource and financial knowledge on renewable energy. IRENA promotes the widespread adoption and sustainable use of all forms of renewable energy, including bioenergy, geothermal, hydropower, ocean, solar and wind energy, in the pursuit of sustainable development, energy access, energy security and low-carbon economic growth and prosperity.

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ABBREVIATIONS

AC	alternating current
Ah	ampere hour
Capex	capital expenditure
CERRC	Clean Energy for Rural and Remote Communities (Canada)
CO_2eq	carbon dioxide equivalent
COMET	Community Engagement Toolkit
DC	direct current
DG	diesel generator
DRE	decentralised renewable energy
ESMAP	Energy Sector Management Assistance Programme
FGD	focused group discussion
GEF	Global Environment Fund
GIS	geographic information system
HKH	Hindu Kush Himalaya
HOMER	Hybrid Optimisation of Multiple Energy Resources
HPNet	Hydro Power Network
HRES	hybrid renewable energy source
IDP	internally displaced people
IPP	independent power producer
IREC	International Renewable Energy Certificate
IRENA	International Renewable Energy Agency
KII	key informant interview
km	kilometre
kVA	kilovolt ampere
kWh	kilowatt hour
kWp	kilowatt peak
LCOE	levelised cost of electricity
LED	light emitting diode
LORESS	locally owned renewable energy projects that are small scale
MW	megawatt
MWh	megawatt hour
NDC	nationally determined contribution
O&M	operations and maintenance
PEC	Photovoltaic Electrification Committee (Mexico)
PPA	power purchase agreement
PPP	public-private partnership
PUE	power usage effectiveness
PV	photovoltaic
RET	renewable energy technology
2G-SHS	second-generation solar home system
SARES	Sarawak Alternative Rural Electrification Scheme
SDG	Sustainable Development Goal
SHS	solar home system
SIDS	small island developing states
3G-SHS	third-generation solar home system
UN	United Nations
UNDP	United Nations Development Programme
UNHCR	United Nations High Commissioner for Refugees
URA	Utility Regulatory Authority (Vanuatu)
USD	United States dollar
V	volt
W	watt
WCMC	World Conservation Monitoring Center
Wh	watt hour
Wp	watt peak

INTRODUCTION

ELECTRICITY ACCESS DISPARITIES

People living in both urban and rural locations need access to reliable, efficient and modern amenities. However, groups living in rural areas, especially in low-income and developing countries, experience a large disparity in access to an essential amenity – electricity – when compared to those living in urban areas. The 2023 edition of the *Tracking SDG7* report (IEA *et al.*, 2023) found that electricity access was available to 98% of urban residents in contrast to only 85% of their rural counterparts. The situation is worse in the least developed countries,[1] where in 2021 there was an average access rate[2] of just 56%. This left about 481 million people without electricity out of a global figure of 675 million as of 2021. If additional measures are not taken, 660-560 million people in sub-Saharan Africa and 70 million people in developing Asia will still lack access to electricity by 2030, given the trend of increasing population numbers in these regions (IEA *et al.*, 2023).

RATIONALE FOR EXTENDING ACCESS

The 2030 Agenda for Sustainable Development, adopted by all United Nations (UN) member states in 2015, is driven by 17 sustainable development goals (SDGs). Of these, SDG 7 recognises energy's catalytic role in development and its ability to overcome deprivation and enhance services. The SDG 7 goal strives to ensure access to affordable, reliable, sustainable and modern energy for all.

To achieve universal energy access, electricity must reach the communities living on all areas of the planet, including on high mountains and remote islands. Access must be extended also to those who have only a remote chance of grid extension, such as communities displaced from their homeland due to conflict or civil strife and some Indigenous and tribal groups that have limited exposure to modern energy options. This is known as last mile access. The UN's High-Level Dialogue on Energy made a high-priority recommendation in the *Theme Report on Energy Access*, emphasising that "the *last mile* of energy access must become the *first mile* to be tackled" (United Nations, 2021). To make this happen, electricity access rates must improve significantly and reach the most remote, poorest and most vulnerable population segments, including displacement-affected communities. In addition, the access solutions need to be context-sensitive to meet the specific needs and situations of vulnerable populations (United Nations, 2021).

Extending electricity access to these remote communities for basic services (Tier 1+ services; see Table 4) alone is not sufficient. Energy is an enabler and can have a direct impact on community livelihoods. Through energy access programmes, electricity provision can power rural productive uses in addition to household needs. Using electricity for production maximises its benefits for such communities, helping to alleviate poverty and provide better standards of living. In addition, improved community and social services – such as powering health facilities, schools and training centres, and water supply and sanitation – highlights how by achieving the objectives of SDG 7, other SDG targets can also be realised.

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[1] *The UN defines least developed countries as "low-income countries confronting severe structural impediments to sustainable development. They are highly vulnerable to economic and environmental shocks and have low levels of human assets" (UNDESA, n.d.).*

[2] *Access (to electricity) rate (or "electrification rate") refers to the share of the population with access to electricity out of the total population in the specified time period or geographic area. Household access is predominantly based on the multi-tier framework where the minimum provision of access to electricity service is the equivalent of Tier 1 and above Tier 1 (Bhatia and Angelou, 2015).*

Photo: Mini-grid O&M hub lit using solar PV in Zanzan villages, Cote d'Ivoire (© AZIMUT 360 SCCL).

GRID EXTENSION *vs.* OFF-GRID SOLUTIONS

Grid extension is achieved by building new power transmission and distribution lines, transformers, and other infrastructure to connect remote and underserved users to the main grid. In densely populated urban areas, it is financially viable for utility companies to extend grid lines because the demand for electricity is high and there is varied use of electrical appliances and a large number of connections. The scale and usage reduces the cost of building new infrastructure. In remote areas and communities that have low electricity demand, on the other hand, the grid extension approach tends to be expensive and unviable. Furthermore, investment costs are unmet due to low tariffs set for their electricity provision.

Off-grid energy systems (mini-grid or stand-alone), which operate independently of the main power grid, offer an opportunity to provide energy to remote and unserved communities. The systems typically use fossil fuels, such as in diesel generators (DGs); however, they can also be powered by renewable energy technologies (RETs) such as solar, wind, biomass or hybrid. Such systems can be customised and designed to meet consumers' specific and low electricity needs. Choosing to adopt sustainable, reliable and clean energy using RETs means communities can reduce their reliance on the costly fossil fuel options that are commonly used to meet their electricity needs.

Grid extension is the traditional approach that government programmes and funding agencies tend to take up in extending electricity access to settlements. Yet, grid extension requires large amounts of capital investments and time, both of which slow efforts and pace. The main grid distribution lines must be extended over long distances to reach scattered settlements and, most often, to provide for low power demands. For example, providing a rural household connection through grid expansion costs USD 1100 (United States dollars) in Viet Nam and USD 2 300 in Tanzania. The costs are almost half this in urban areas, where it costs USD 570 and USD 600-USD 1100, respectively, in the same countries (Ehrhardt *et al.*, 2019)

Added to the costs incurred, upfront investments would need to be extensively subsidised, or grant driven given the low monthly tariffs for end-consumers living in rural and remote areas. Analysis of cost-reflective tariffs across 39 utilities in Sub-Saharan Africa shows that 25% of the utilities require a cost-reflective tariff of USD 0.40 per kilowatt hour (kWh). For about half the utilities, it is in the range of USD 0.20 to USD 0.40/kWh, with the balance, 25%, of the utilities requiring less than USD 0.20/kWh. The implication is that, oftentimes, extending access is cheaper using mini-grids than by extending the grid (ESMAP, 2022).

Evidence-based studies show that off-grid renewable-based solutions need lower investments compared to grid-connected ones for extending full electricity access. The forecast scenario shows a 30% reduction for low-demand estimations and 5% reduction for high-demand estimations in comparison to the costs of extending the grid (Blechinger *et al.*, 2019). Mini-grids powered by solar, hydro and biogas technologies provided electricity access to 11 million people as of 2021. Solar mini-grids serve about a third of the population that is supplied by mini-grids providing electricity. Solar has proven to be the least-cost option, in addition to its ease of deployment and scalability (IEA *et al.*, 2023).

SCOPE OF THE GUIDEBOOK

This guidebook explores methods of electricity provision, through renewables, using stand-alone systems and mini-grids. It describes the key elements that help design and operate projects for electricity provision. Its content provides project providers, community leaders, private enterprises and government agencies with an understanding of what is required to extend electricity access to the last mile.

The findings of nine case studies in which electricity provision was extended to remote communities and those unserved by the grid are detailed (see Annex I). Each case study – unique in its location and approach of delivery mechanism – illustrates the success factors that provide for smooth and sustained operations.

The case study projects chosen for this study meet a broad set of criteria:

- They have regional representation.
- They belong to the “remote” category defined in the study.
- They showcase the use of different RETs.
- They exhibit delivery mechanisms designed for the local context in electricity supply.
- They showcase smooth supply operations since project inception.

The guiding principles based on the findings in this report have been further validated using focused group discussions (FGDs) and key informant interviews (KIIs) with project principals, key stakeholders and subject experts.

Table 1 lists the nine case studies, a brief description of each study and the reference project title used in this guidebook.

Table 1 List of the case studies surveyed and analysed

Project title	Brief description	Referred to as
Indigenous community of Old Crow, Yukon, Canada	A 940 kW solar photovoltaic (PV) mini-grid system in the remote northern community of Old Crow, Yukon, reduces the community’s reliance on diesel for electricity generation. Yukon government legislation and policies, as well as a power purchase agreement (PPA) with the local utility, ensure that the community benefits from the project. **Ongoing since 2016**	Old Crow community, Canada
Refugee settlements of Dollo Ado, Bokolmayo Woredas, Somali region, Ethiopia	Five refugee camps in Dollo Ado get electricity access from solar PV mini-grids and water supplied using off-grid solar pumps. Solar co-operatives run by the members of the refugee and host community (in its fringes) operate the systems to meet household and agriculture-related electricity needs. **Ongoing since 2019**	Dollo Ado & Bokolmayo camps, Ethiopia

Project title	Brief description	Referred to as
Remote settlements in Zanzan region, Côte d'Ivoire	Seven remote villages in Côte d'Ivoire use an innovative delivery model combining private sector expertise, public capital and strong community ownership through an overarching Mini-Grid Federation and Technicians Associations. There is strong ownership from the mini-grid users of the rural households, ensuring long-term sustainability. **Ongoing since 2012**	Zanzan villages, Côte d'Ivoire
Remote village of Totota, Liberia	In the remote village of Totota, mini-grid users form an electric co-operative to become the first-ever micro-utility in Liberia. The co-operative, set up in partnership with NRECA International, showcases the tremendous potential of community-owned co-operatives, impacting more than 20 000 people through a sustainable community-driven decentralised renewable energy (DRE) delivery model. **Ongoing since 2017**	Totota Village, Liberia
High-altitude, scattered settlements in Oaxaca, Mexico	Under the Luz en Casa, Oaxaca (Light at Home) programme, household settlements in high-altitude terrain get electricity access from third-generation solar home systems (SHSs). Innovative financing comes from public-financing establishments as well as equity ownership by the SHS users, made possible in part through micro-loans granted via a crowdfunding platform. The solution has an impact on a large geographical area. **Ongoing since 2012**	Oaxaca households, Mexico
Rural hills community of Okhaldunga, Nepal	A local community from the rural hills in Nepal has successfully set up a solar PV mini-grid through a private enterprise. The villagers are trained to operate and manage the renewable energy system. Revenue earned from the electricity supply is given out as micro-loans that in turn spur economic activity, ensuring the sustainability of the project. **Ongoing since 2020**	Okhaldunga rural hills, Nepal
Remote island community, Isle of Eigg, Scotland, United Kingdom	Located in the west of Scotland, the Isle of Eigg community of 45 households chose a hybrid renewable energy solution to help reduce its reliance on diesel fuel. The project's notable features include a usage cap as well as a remarkable "traffic-light" system that helps align consumption to manage demand *vs.* supply, ensuring sustained operations. **Ongoing since 2008**	Isle of Eigg, Scotland
Remote rural villages of Sarawak state, Malaysia	Under the Sarawak Alternative Rural Electrification Scheme (SARES), the utility, Sarawak Energy, provides electricity access to very remote villages using off-grid solar PV-based solutions as an approach to achieve total electrification by 2025. **Ongoing since 2016**	Sarawak Energy, Malaysia
Remote island community of Loltong Village, Vanuatu	The hybrid DRE solution of pico-hydro and solar PV systems in meeting the local community's power needs showcases a proven model to be replicated by other such communities for energy self-sufficiency and reducing use of diesel fuel. **Ongoing since 2021**	Loltong remote island, Vanuatu

1 REMOTE COMMUNITIES: SCOPE FOR EXTENDING ELECTRICITY ACCESS

DEFINING REMOTENESS

Remote communities with no grid access typically have low population density (and therefore low electricity demand), low incomes, difficult terrains and poor transportation infrastructure.

Remote communities included in the scope of this study are defined as those with remoteness from the power grid for three reasons:

- They are geographically remote from the mainland and challenged by difficult to access terrains, such as rural settings; mountain regions; small, isolated islands; and deep forest settlements.
- They have a remote chance of gaining grid access, such as refugee communities displaced due to conflict, internal strife and natural calamities.
- They fully rely on off-grid energy sources and have very low demand profiles, such as some tribal and Indigenous communities.

The three settlement types overlap with respect to their demand profile (low electricity needs), being in economic and energy poverty, and having a remote chance of attaining grid-based electricity supply.

REMOTE COMMUNITIES ACROSS REGIONS

The following sections examine most of the remote communities across regions, as defined by the study. Although only fragmented data on electricity access to such settlements are available, the effort is to showcase the size, spread and locations of these settlements. In doing so, it is possible to determine the amount of effort required to establish replicable working models for electricity provision and their potential to reach these unserved settlements.

Mountain populations

As of 2015, an estimated 1 050 million people lived in mountain areas included in the World Conservation Monitoring Center (WCMC) definition.[3] Over the 1975 to 2015 period, the share of mountain population to total world population remained constant at 14%. Population densities are high at low altitudes and very low at higher altitudes. One-third of mountain populations lives in cities, one-third in towns and semi-dense

[3] *The WCMC classification covers mountain regions that include both hills and mountains. A total of 22% of the world's land, or 29 million square kilometre (km²), is classified as mountain region, of which about half is below 1 000 metres (m). Rugged land is considered mountain region if it is at least 300 m above sea level, but plateaus and broad valleys running through the mountains below 2 500 m are not considered mountain regions. All land above 2 500 m is classified as mountain, including plateaus. This accounts for 20% of the total. (Blyth et al., 2002)*

areas, and the remaining one-third in rural areas. Regional trends in urbanisation and population growth show increased population growth in the mountain ranges of western Asia (with the exception of Anatolia, Türkiye) and southern Asia, low or declining population growth in the ranges in eastern Asia and Europe, and moderate population growth matched with high urbanisation in the Latin American ranges (Ehrlich *et al.*, 2021).

These settlements' primary energy needs tend to be for cooking, and space and water heating. The fuel consumption patterns in the Hindu Kush Himalaya (HKH) region are taken as representative of mountain settlements. Here, there is a strong reliance on biomass, which is abundantly available, while liquid petroleum is used for processes in small industries and for running commercial enterprises (see Box 1).

Box 1 Energy consumption in the Hindu Kush Himalaya region

The population living in the mountain areas of the eight Asian countries* that form the HKH region comprise about 9% of its collective total. A total of 52.4% of the rural populations of the HKH countries (World Bank, n.d.) live without access to electricity (the populations with the least access are in Myanmar, followed by Pakistan), with people living in the mountains making up a large share of those without access to electricity. Households in the region need energy for cooking and space heating as a priority. To meet this need, households rely heavily on biomass. Its excessive use has resulted in forest degradation, indoor pollution that triggers health issues, social deprivation associated with collecting wood, and scarcity during winter months.

Biomass is an abundant primary energy resource for the HKH region, which comprises forests (20%), shrublands (15%) and grasslands (39%). Other forms of renewable sources include hydro, solar and wind, whose potentials have yet to be quantified. Patterns of usage in countries like Bhutan and Nepal (countries largely located in the region) are studied to determine the fuel composition that helps to meet the energy needs of key sectors in the region. The largest shares of household energy needs are for cooking (61%) and space heating (14%), possibly from traditional fuels such as biomass. Electricity supplied to the residential sector in Nepal is met through grid supply, the power from which is supplied from domestic hydropower plants. Unmet demand is complemented by diesel and imported power. Common cottage industries of the HKH region, such as agro-processing, blacksmiths, potteries, sawmills and bakeries, need process heat. This is provided using coal, traditional biomass, petroleum products and electricity. The main commercial sectors in the HKH region are local businesses, hotels and restaurants, because tourism is a key sector for the region. The sector's energy demands have to be met with liquid petroleum fuel and electricity.

The agricultural sector in Nepal uses 9.9% of the total petroleum product consumption and 2.2% of total electricity consumption. Energy is needed for tillage (52%), irrigation (32%) and threshing (13%) to serve the demands of large-scale, commercial farming. For farming communities located off the grid, DRE solutions would help to mechanise farming processes. Mechanisation can increase productivity and strengthen market linkages, leading to higher earnings. IRENA, in partnership with ICIMOD and SELCO Foundation, has assessed the energy needs of food value chains in Nepal (buckwheat and gundruk) and Bhutan (potatoes and yak milk) in a bid to understand the possible energy nodal points of these food value chains. Based on the findings, the study has provided decentralised solar PV-based solutions for on-farm and post-harvest processes. These solutions are a step towards building resilient livelihoods for small and marginal farmers in mountainous regions around the world.

Source: Dhakal *et al.* (2019); World Bank (n.d.); IRENA, ICIMOD and SELCO Foundation (2022).
Note: * The HKH region spans eight countries: Afghanistan, Bangladesh, Bhutan, China, India, Myanmar, Nepal and Pakistan.

Small Islands populations

Under the UN charter on small island developing states (SIDS), 57 island states are members and associates of the UN regional commissions. The total population of SIDS is estimated at 65 million. These are people who, given their remote geography, are exposed to unique social, economic and environmental challenges. The SIDS nations are making the shift towards renewable energy sources to access utility-scale electricity and choosing decentralised off-grid systems (see Box 2).

Box 2 Choice of renewable energy for extending electricity access in small island developing states

At utility scale, a large number of SIDS plan to integrate renewable energy sources as part of their mix of primary fuel sources. Factors that influence the choice of renewable energy include:

- the high costs of producing electricity using DGs that run on imported fuels
- the abundant resource potential available of renewable energy resources
- the well-understood environmental and societal benefits of renewable energy use
- the existence of political support and strategic planning to develop a sustainable energy supply that in turn aids international efforts on climate change mitigation through nationally determined contributions (NDCs) (IRENA, 2019a).

The small island nations of Papua New Guinea and Solomon Islands rely on off-grid solutions using renewable energy sources for connecting homes in remote islands. In Papua New Guinea, home to 600 small islands, the National Electricity Authority has as its primary task the provision of access to 70% of all households by 2030 and to 100% of households by 2050. The World Bank is supporting the authority in data collection on the number of unserved households, their electricity demand and the least-cost power options available to them (including hybrid forms of solar and hydro). IRENA helps the authority with data relevant to its NDCs, providing training on greenhouse gas emissions calculations (IRENA, 2022a). The National Electricity Authority is pursuing various models of off-grid implementation through public-private engagement, wholly private sector participation or through local governments using grants. The departments of health, fisheries and other sectors for which energy is an enabler manage small renewable energy-sourced power plants (such as hydro) to provide their services.

Solomon Islands is an island country made up of six major islands and 900 small islands in Oceania. Of the nation's estimated population of 700 000, 76% has access to electricity. The share of renewables in its total energy supply is 44%, primarily from bioenergy. Households almost fully consume the energy produced (97%), with other sectors using 3%. In the provision of access to scattered and remote communities, the government is exploring the rural energy service company model, in which provision of power is enhanced with value added service by the provider. In such a public-private partnership (PPP) model, there is strong engagement from the communities benefitting from the decentralised projects. In testing the pilot programme, the government is shoring up community organisations, registering them as co-operatives and, through capacity building programmes, helping them administer community consolidated funds and establish their own investments. Revenue is earned from the community land lent to the provider, who has a PPA signed for 30 years to supply electricity and services to the community.

A key aspect to consider in providing access to small islands and their communities is the diversity of cultures, including languages. This in turn influences their demand profiles (limited mechanisation, types of livelihoods, *etc.*) and therefore needs to be understood while designing DRE projects.

Source: IRENA (2019a, 2022a, 2023).

Indigenous populations

An estimated 476 million Indigenous[4] people (Oxford Learner's Dictionaries, 2023) are located across 90 countries. Accounting for 6% of the population, Indigenous peoples practice at least 5 000 different cultural traditions and speak more than 7 000 languages (The World Bank, 2020). Despite their large numbers and vast cultural capital, this population accounts for an estimated 18% of the world's poorest people (IFAD, n.d.). Very little consistent data are available to decipher the energy access available to these communities. The poor development index indicators of the Indigenous groups in specific regions are evidence of the many essential deprivations they face, making them even more vulnerable to impacts of climate change and natural hazards. Information collated from various sources shows that energy poverty is distinctly higher in many Indigenous groups of a nation, for both developed and developing nations (Figure 1).

Figure 1 Energy poverty in indigenous communities across developed and developing countries

Australia	Low-income large-family households most exposed to energy poverty comprised the greatest proportion of households in indigenous communities (KPMG 2017).
Bolivia and Guatemala	The gap between indigenous and non-indigenous households that have access to electricity ranges between 18-25% (World Bank 2003).
Canada	Of the 292 remote Canadian communities that are not connected to the electricity grid or natural gas network, over half (170) are indigenous (AANDC and NRCan 2011).
Lao PDR	Ethnic minority groups other than majority Lao-Tai have a higher incidence of poverty which is attributable to a number of factors including access to electricity (World Bank 2017b).
Mexico	96.6% of the population has access to electricity but 3.5 million people remain without access; 60% of those without electricity access are indigenous peoples (World Bank 2017c).
United States	14% of households on Native American reservations had no access to electricity, compared to 1.4% of households nationally (EIA 2000).

Source: Carino and Sriskanthan (2018); KPMG (2017); AANDC and NRCan (2011); World Bank (2013, 2017a, 2017b); EIA (2000).

Displaced populations

The number of refugees and internally displaced people (IDP) is constantly increasing worldwide. According to United Nations High Commissioner for Refugees (UNHCR) data, at the end of December 2021, the UNHCR was safeguarding and protecting a total population[5] of 94.7 million. A major share of people assisted and under the UN agency's protection is made up of refugees and internally displaced persons (IDPs) due to conflict and internal strife. Refugee settlements are considered temporary, even though there are cases in which such camps have existed for over 30 years, making way for more permanent arrangements. Displaced populations live on foreign donated land, have limited resources and options for economic development, and have the bare minimum in basic amenities.

[4] *The Oxford Learner's dictionary defines the word Indigenous as "(of people and their culture) coming from a particular place and having lived there for a long time before other people came there".*

[5] *Categories under which populations of concern are assisted by UNHCR are: refugees, people in refugee-like situations, asylum seekers, returned refugees, IDPs of concern to UNHCR, returned IDPs, stateless persons and others of concern to UNHCR.*

2 REACHING THE LAST MILE: POWERING REMOTE COMMUNITIES

> *"Thanks to Luz en Casa, I can see my little home with light*
>
> Paula, 89-year-old female user in the Mixe mountains
>
> *Case Study V – High altitude, scattered settlements in Oaxaca, Mexico*

KEY PRINCIPLES OF OFF-GRID PROJECTS

When an off-grid project is conceptualised for electricity provision, fundamental design principles[6] must be considered (Table 2). One-off successful projects can achieve scale and replication through a country-level programmatic approach by fostering the right kinds of partnerships. Appropriate policies, regulations and financing also aid the transition from grant-based projects to commercial-scale projects that involve private stakeholders.

Photo: Installing a solar home system for a household in Oaxaca, Mexico (© acciona.org).

[6] *This is not a comprehensive list. It shows the main design principles that influenced and were studied for electricity provision to the nine remote communities in the case studies detailed in this guidebook.*

Table 2 Design principles for off-grid electricity provision projects

Key principles	Description
The conception, design and implementation approach need to be consistent with the overall rural electrification plan for the area.	Projects should not be driven by one-time donated hardware, local commercial interests or political pressures.
The choice of RETs must be based on practical considerations.	Technology maturity, resource potential and its yearlong adequacy, ease of O&M (including the availability of skilled workers), uninterrupted feedstock availability, and easy access to spare parts and service are needed.
Data-driven decisions will guide technology design and system sizing.	Data on energy consumption and projected loads, including power usage effectiveness, incomes, and willingness to pay across various sectors of the community are essential.
Early stage community involvement is vital for sustained and successful operations.	Community engagement and consultation beginning at the project assessment stage and continuing in each step of development engender ownership and support from members.
The private provider's role in electricity provision needs to be fully comprehended.	Depending on the business model, the role of the private enterprise and its capabilities and engagement with the community need to be in place.
Light-handed regulatory measures that simplify provision for private players while adequately protecting consumer interests are recommended.	Technical standards should be set and quality equipment supplied to end users. Tariff rates should be regulated to match the cost of service and to incentivise provision. Policies and regulations to promote private sector involvement through incentives, subsidies or viability gap funds should be introduced.
Options for the use of power in productive and institutional services complementing domestic needs should be maximised.	Improved livelihoods from additional revenue generation and anchor loads increase capacity utilisation of the off-grid systems and help ensure that they sustain and scale operations over time.

Based on: World Bank (2008).

The following section looks at the success factors based on the nine case studies. The factors are in line with the principles listed in Table 2 for the success and sustained operations of the off-grid renewable energy access projects.

COMMUNITY ENGAGEMENT

Electricity access projects for remote communities are carried out for three key reasons:

1) In response to the community's demand. This demand could be guided by local entrepreneurs or champions or from the community learning about the benefits of electricity provision from nearby regions where such projects have impacted the local population.
2) When private developers tap into market potential and operate mini-grids or stand-alone systems as a paid service.
3) In response to a government or development agency promotion, in provision of energy access under its programme.

Independent of the purpose that drives the access project for electricity provision, the case studies show that keeping the community informed and engaged – beginning with the initiation period and following through to subsequent operations and further scaling up – is key to maintaining a project's sustainability. Dialogues with the benefitting community can take place using a participatory approach in which the input of individual users is taken into account. Community heads, governing bodies, local non-governmental organisations and social champions who have built-in trust with the community can also be good candidates for mobilising community engagement and feedback. In addition, adopting progressive methods, such as using digital tools for illustrations and simulations, can help to explain project elements to communities that may be unfamiliar with new energy technology and provision processes. Using these methods can also assist in collecting primary data and user responses, which are key to designing systems and planning for electricity provision (Box 3).

The case studies reveal that individuals engage in electricity access projects in myriad ways; while some forms of engagement are common to all approaches, others are unique to the context and delivery modes of the provision of access.

These engagements include:

- Defining the community's needs to help assess the household demand profile, aspirational loads, potential productive loads and electricity required for essential services.
- Engaging with the promoter or developer in setting up the institutional body (that may use existing traditional structures for governance) and designing one to use local skilled workers for technical and operational tasks.
- Providing a strong in-kind contribution with provision of land and labour, sourcing local materials (sand, bricks, water *etc.*), and transporting hardware through inaccessible terrain during the construction and installation of the systems.
- Training and employing youth and women in the operation of the renewable energy system, tariff collection, account maintenance, engagement with individual users, and service and sales support.
- Serving as advocates and agents of change in the community to publicise the benefits of further replication and scale-up.

Community involvement also enhances the sustainability of longstanding operations. Examining electricity provision projects for remote communities, carried out by the private sector over different time periods, helps to reveal how this involvement works.

- The community is able to set its own norms and develop rules based on its capacities (including perceived financial capacity limitations) and needs if it is allowed to directly influence decisions from the very early stages of the project.
- Higher levels of community inclusion allow for community views and needs to be reflected. This can be achieved through co-designing projects, setting realistic tariffs, identifying and providing land for infrastructure, providing construction labour, being actively involved in setting up and running the management structure, and overseeing the operations and maintenance (O&M) of mini-grids.
- Gender equity can be achieved by enabling women's active participation in the governance processes.
- Community ownership is created when socio-cultural contexts are taken into consideration. Understanding these contexts helps in the design of more resilient projects.
- Community engagement will reveal members' existing and short-term capacities as well as their willingness to engage with the project. Activities can then be built into the project design to strengthen member's capacities and raise external stakeholder support for the required time period (Katre *et al.*, 2019)

Box 3 Digital tools enabling community participation

Digital tools such as the Community Engagement Toolkit (COMET) have been effective in helping communities to understand operative loads, express their demand needs, and understand the costs that would be incurred under different RET scenarios and their hybrid versions. Simulating mini-grid operations under different scenarios and showcasing their output helps the community understand technical aspects (*e.g.* load management, how best to use for additional productive loads) as well as their revenue-related benefits. Through thematic workshops, targeted groups of the community engage with a facilitator to understand these features. The understanding leads to improved capacity utilisation of the mini-grid systems and a willingness to pay for their operations by end users.

The advantage of such digital tools is their ability to collectively engage with community groups. The use of graphics and images throughout the simulation process educates all beneficiaries in a village. The toolkit is designed to adapt to local contexts by using local currencies and languages. Workshop facilitators provide troubleshooting options in the overall mini-grid operations including overloading, defaults in payments and other issues that arise.

Source: Interview with A. Abdullah of Energy Action Partners.

MEETING ELECTRICITY NEEDS AND MANAGING SUPPLY

Electrical appliances assessed as loads can be classified on the basis of the services they provide and range from very low power to very high power equipment. Table 3 distinguishes typical household appliances according to the Energy Sector Management Assistance Program (ESMAP) technical report (Bhatia and Angelou, 2015)

Table 3 Operating power range of typical household appliances

Appliances – power range						
		Very low power	**Low power**	**Medium power**	**High power**	**Very high power**
Services provided	Lighting	Task lighting	Multi-point lighting			
	Communication and entertainment	Mobile phone (charging), radio	Television, computer, printer			
	Space heating and cooling		Fan	Air cooler		Air conditioner, space heater
	Refrigeration			Refrigerator, freezer		
	Mechanical loads			Food processor, water pump	Washing machine	Vacuum cleaner
	Product heating				Iron, hair dryer	Water heater
	Cooking			Rice cooker	Toaster, microwave	Electric cooker, oven

Source: Bhatia and Angelou (2015).

The case studies show that the electricity demand profile of remote communities is related to several aspects, including location, culture, awareness, affordability and willingness to pay for the use of electricity for everyday needs. Unserved households that are very impoverished need basic Tier 1 loads (see Table 4 for tier definitions) to be met for lighting and to replace their conventional use of candles, battery cells, oil lamps and kerosene or diesel for other loads. Remote communities in developed economies, on the other hand, operate a diverse array of electrical appliances requiring a 24-hour supply. These groups rely heavily on diesel. Powering their homes would require a large capacity of renewable energy-based (mostly hybrid) solutions (Tier 4 and Tier 5). A snapshot of the load profile and demand needs met across the nine case studies is shown in Table 5.

Table 4 Multi-tier electricity access to household services

	Tier 0	Tier 1	Tier 2	Tier 3	Tier 4	Tier 5
Power capacity rating In watts or daily watt hours		3 W	50 W	200 W	800 W	2 000 W
		12 Wh	200 Wh	1.0 kWh	3.4 kWh	8.2 kWh
Tier criteria	Not applicable	Lighting and phone charging	General lighting, television, fan	Tier 2 + any medium-power appliances	Tier 3 + any high-power appliances	Tier 4 + any very high-power appliances

Source: Bhatia and Angelou (2015).
Note: W = watt; Wh = watt hour; kWh = kilowatt hour.

Survey-based studies engaging with community members at project inception have helped to determine the loads and category-based electricity needs in the communities. In designing system capacities and load management, different methods help in optimising supply.

The different household electricity consumption plans include:

- Monthly tier service plans that define the appliances a household can connect (Dolo Ado and Bokolmayo refugee camps, Ethiopia).
- Level-of-use package plans that place an upper limit on the number of units (see Table 5) a household can consume in a month (Zanzan villages, Côte d'Ivoire).
- Prepaid credits managed through automated metering that is set up for each household.

Table 5 User package plans with an upper limit on electricity consumed

Usage plans	kWh/month	Max power (W)	% of users
Basic	8.4	500	6
Medium	16.7	500	57
Comfort	33.4	500	24
Great comfort	58.5	1 000	12
Shop	58.5	2 000	1

Note: W = watt; kWh = kilowatt hour.

Photos: Solar PV mini-grid providing electricity access to one of the 550 off-grid villages under the SARES programme in Malaysia (© Sarawak Energy Berhad).

Another approach places a cap on the operative loads that can be used. In the case of the Isle of Eigg, Scotland, a cap of 5 kW for households[7] and 10 kW for businesses is prescribed. An intelligent "tariff-light" system for load management helps match consumption with the units generated by the integrated renewable energy mini-grid. Solar PV mini-grids use battery storage to operate night loads, and some have DGs to supplement supply when it is limited.

Under government-driven programmes, as in Malaysia, where the provincial utility provides last-mile connectivity, the prescribed daily or monthly units allocated to households form the basis (along with the number households to be served) to arrive at system capacities of the mini-grid for a village (Sarawak Energy, Malaysia).

Crucial to demand management for all these approaches is the active participation of informed consumers who know how to manage their electricity demand and operate appliances to allow for allocated electricity supply among all users.

BUILDING CAPACITIES IN THE COMMUNITY

In most of the nine case studies, the delivery model and the operations and maintenance (O&M) structure include the training of individuals in the community. The training could relate to carrying out day-to-day O&M of the systems, being in charge of revenue collection, keeping inventory, performing administrative tasks, and engaging with external stakeholders, including government agencies. Tapping into local entrepreneurship skills, members can be trained to operate machinery for productive uses (Okhaldunga rural hills, Nepal) or to set up local micro-franchises for sales of direct current (DC) appliances, spares and service provision (Oaxaca households, Mexico). Capacity building, upskilling and on-the-job training need to be part of the project design, initiated from the project planning stage, and involve youth, women and marginalised groups of the community.

Service providers, as part of the supply chain, hire local people and train them to undertake basic troubleshooting and maintenance, providing service as first line of response. Local champions bring awareness of the benefits of the system and its proper use and communicate to the groups on operating mini-grid matters (*e.g.* scaling up installed capacities, demand stimulation, *etc.*).

The case studies describe job roles for local people in small utility services including micro utilities (Old Crow community, Canada), electric co-operatives (Totota Village, Liberia), accounts and managerial roles, and those where operators are also skilled in managing productive use loads: brick making, oil pressing units, *etc.* (Loltong remote islands, Vanuatu). The case of mini-grids operating in remote villages in Zanzan villages, Côte d'Ivoire, showcases what kinds of job roles are created in managing operations (see Box 4).

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[7] *Each resident is given an OWL energy monitor that helps households to stay within their allocated load limits.*

Table 6 Load profiles and operative loads met through renewable energy solutions in the nine case studies

Case study	Load profile	Renewable energy system solutions	Demand met – Categories and loads
Old Crow Solar Project, Canada	Total annual consumption is 2 389 megawatt hours (MWh) /year; split between residential and commercial (45%) and public services (55%).	Solar PV micro-grid system of 940 kW 350 kWh of battery storage for one-hour autonomy with micro-grid controller as balance of system	Project meets 20% of the community's annual loads, supplementing diesel. Partially covers the domestic loads of about 150 households and 15 commercial enterprises.
Refugee communities in Dollo Ado and Bokolmayo Woredas, Ethiopia	16 megawatts (MW) of electricity across five refugee camps serves agro-processing units, furniture production centres, charcoal pellets and briquette production. Humanitarian relief includes health clinics, schools, and domestic and community loads.	Six solar PV mini-grids of 120 kilowatt peak (kWp) across five refugee camps Two battery storage options (0.72 kWh and 1.44 kWh) for night use	Project serves the domestic loads of 1 299 households (most of the households have an average load of 10-15 W, with six to eight average working hours per day. A few households have an average load of 70-150 W and six to eight average working hours per day). Supplies 259 solar streetlights across five refugee camps.
	1.1 MW for irrigation and water pumping.	Off-grid solar PV system of 56.32 kWp operates two surface pumps totalling 30 kW and a vacuum pump of 2.2 kW for irrigation purposes	Provides irrigation for 45 hectares of land, benefiting over 90 local farmers.
Remote villages of Zanzan region, Côte d'Ivoire	A total of 17 MWh/month provides access to seven remote villages under the project intervention, including household loads, equipment for productive uses and public services.	A 214 kWp solar PV system along with battery storage of 1 771 kWh	Project serves the domestic loads of 311 households, 64 commercial enterprises and 29 public services (schools, health clinics).
Totota Village, Liberia	The village's 369 metered household units have an average monthly consumption of 30 kWh.	72 kWp solar PV system with a 120 kWh lithium-ion battery, 80 kilovolt ampere (kVA) diesel backup generator managed by a smart micro-grid controller	Project meets the domestic loads of 369 households 24 hours a day, seven days a week, and serves three commercial units for cold storage of vegetables.
Luz en Casa Oaxaca, Mexico	Each household has a minimum requirement of 0.6 kWh/day for lighting only and 1.2 kWh/day to use additional media devices such as DC TVs or music players.	SHS for two capacity sets: 120 Wp-150 Wp or 240 Wp-300 Wp with lithium iron battery of 23 Ampere hours (Ah) or 50 Ah	SHS sets are purchased based on household affordability. Basic domestic loads (Tier 1+) are met for 8 600 households. In addition, productive uses handled include agro processing, tortilla making and lighting of small commercial kiosks.

Case study	Load profile	Renewable energy system solutions	Demand met – Categories and loads
Rural hills of Ohkaldunga Nepal	A total of 160 kWh/day is needed to power 246 village households and operate low-power tasks such as welding and tool repairs.	50 kWp solar PV mini-grid with a 345 kWh storage battery	Project meets the domestic loads of 246 households, two cold storage units and seven home stays for tourism. Grinding mills are in the pipeline for agro processing.
Isle of Eigg, Scotland, United Kingdom	Power is needed to serve the domestic loads of 45 households with a cap of 5 kW per household and commercial loads with an upper limit of 10 kW.	Three hydro-electric generators, one 100 kW and two 5 kW, on the west and east side of the island Four 6 kW wind turbines, offshore in the south A solar PV mini-grid of 50 kW on the main island Battery storage where power is banked to provide for the entire island for 24 hours Two 70 kW DGs, used only to match the variable and seasonal output of the renewable energy sources to meet demand	The total installed capacity of 357 kW with a 11 kilometre (km) long underground, high-voltage micro-grid system for distribution provides for the domestic loads of 45 households and the commercial loads of 20 businesses including hotels, restaurants, cafes, guesthouses, medical clinics and convenience stores.
Remote villages, Sarawak, Malaysia	The SARES is required to provide: • energy totalling 3 kWh/day/household • battery storage with sufficient capacity to provide at least 2 days of autonomy • energy to meet a load demand of 1 000 W for each household.	The size of the solar PV systems depends on the size of the community and the number of households served in each of the 550 villages selected under the programme.	Access to basic electricity has been provided to 550 villages in Sarawak State. It helps to power lights, fans, TVs, phone chargers, speakers, laptops, small rice cookers and low-wattage washing machines. Low-wattage power tools can be used for crafts. A total capacity of 14 MW of solar PV systems has been installed to date under SARES.
Loltong Village, Vanuatu	Energy is needed to serve the domestic loads of 75 households, commercial loads of 11 businesses and institutional loads of 11 public services.	A hybrid system of 7 kW of pico-hydro and solar PV arrays of 2.6 kWp Battery storage of 33 kWh and a battery inverter of 15 kVA	The pico-hydro system generates a total of 68 kWh/day to meet the daily demand of operative loads. The solar PV arrays serve as backup when demand goes beyond the average threshold and to supplement supply during dry seasons, when the water flow rate drops. The average consumption per user accounting for all categories is 12.39 kWh/month.

Source: Original compilation for this report, 2023.

Box 4 "Homes of Energy": Mini-grids O&M hub

The provision of electricity to seven remote villages served to meet one of the prime outcomes – technical demonstration and building of awareness and capacities to its end users – of the UNIDO and EU-Akwaba partnership project in the Zanzan region of Côte d'Ivoire.

"Homes of Energy" built in each of the seven villages accommodate solar panel arrays. Their dimensions are based on the installed system capacities. In addition to three separate areas for housing hardware (batteries, inverters and miscellaneous items such as backup generators), a separate room is available for the committees managing the solar mini-grid operations to meet and discuss.

The villagers, as the end beneficiaries, are fully responsible for the technical, social and financial management of running the mini-grids in their villages.

The local users' committee in each village comprises ten members with equal representation of all village groups. The members include a chairperson, a vice chairperson, a secretary, a treasurer, the supervisor, the deputy, women, men, youth and a business representative. The committee is responsible for performing administrative duties, managing user contracts and carrying out fee collection tasks.

The technical maintenance of the mini-grids involves three levels:

1. basic and daily maintenance managed by a trained village supervisor
2. preventive maintenance managed by local technicians grouped under an association for technicians for all the seven mini-grids
3. specialised maintenance carried out by local expert technicians or an external technician contracted under the project.

The Monitoring Committee (made up of the chairpersons of the seven local associations, a representative of Akwaba, a representative of the business/workers, two representatives of the local authorities and a village official) monitors and evaluates the functioning of the installed mini-grids.

The local users and the Monitoring Committee are also responsible for the financial management of the mini-grids. Funds saved in a blocked account are used to meet the costs of spare parts replacement and more expensive maintenance projects. Funds saved in an open bank account are used to meet the system's day-to-day operational expenses.

The project has created jobs to manage the mini grids through skills training. At least 34 local jobs (including 11 installers, 2 federally posted managers and technical directors, 7 mini-network supervisors, and 14 productive use managers) have been created. After the project, at least 100 local jobs were created indirectly.

Source: UNIDO (2016); azimut360 (2017).

Choice of RETs

Technical and cost factors are key considerations when RETs are evaluated for off-grid solutions. Site-specific feasibility studies help in choosing the technology for the remote location and include:

- land availability, its access and suitability for installations
- techno-economic assessments that help determine the renewable energy resource potential through the year
- comparative costs of electricity generation (*e.g.* the levelised cost of electricity, or levelised cost of electricity [LCOE])
- user demand profiles and categories
- availability of hardware, transportation to the remote site and local raw materials.

Six of the nine case studies have deployed solar PV-based mini-grids under the current study. All solar-based solutions have storage as backup to provide for night and, to some extent, for day autonomy when the solar irradiation is low. The community's perspective on the mini-grids, based on the primary data collected for the study, is positive. The ease of its installation, subsequent use and operations – and the community's confidence in it being a proven technology – influence its social acceptance and adoption. The rural populations of Oaxaca who live in remote, scattered settlements could get Tier 2+ services by using solar home systems (SHSs). The evolution of these stand-alone systems has improved technical and cost features (see Box 5).

Box 5 Technology evolution of solar home systems (SHSs)

Innovations in SHS technology have resulted in the introduction of third-generation solar home systems (3G-SHSs), which are proving to be more efficient, smaller and lighter, easier to install, more economical, and easier to use than earlier generations of SHSs. The reduced cost of and efforts to perform O&M, and proven durability, are attractive benefits for providing off-grid systems for remote settlements that are sparse and scattered. Based on the use and services offered by second-generation solar home systems (2G-SHSs) and 3G-SHSs, the table below compares both types of SHS product on their technical, costs and operating features.

Component	Description	2G-SHS	3G-SHS
Solar panel	Technology Capacity (Wp) Supply (Wh)	Mono or poly crystalline 50-80 200-250	Mono or poly crystalline 20-50 100
Lighting	Technology Capacity (W)	Fluorescent lamps 7 -11	LEDs 3
Battery	Technology Capacity (Ah)	Lead-acid 100-120	Lithium-ion 6 -10
Regulator		External solid-state power electronics	Microelectronics integrated into the battery box
Connection		Splices	Plug and play
Weight (kilogrammes)		3-50	6
Cost/kW (USD)		1 000	350-650

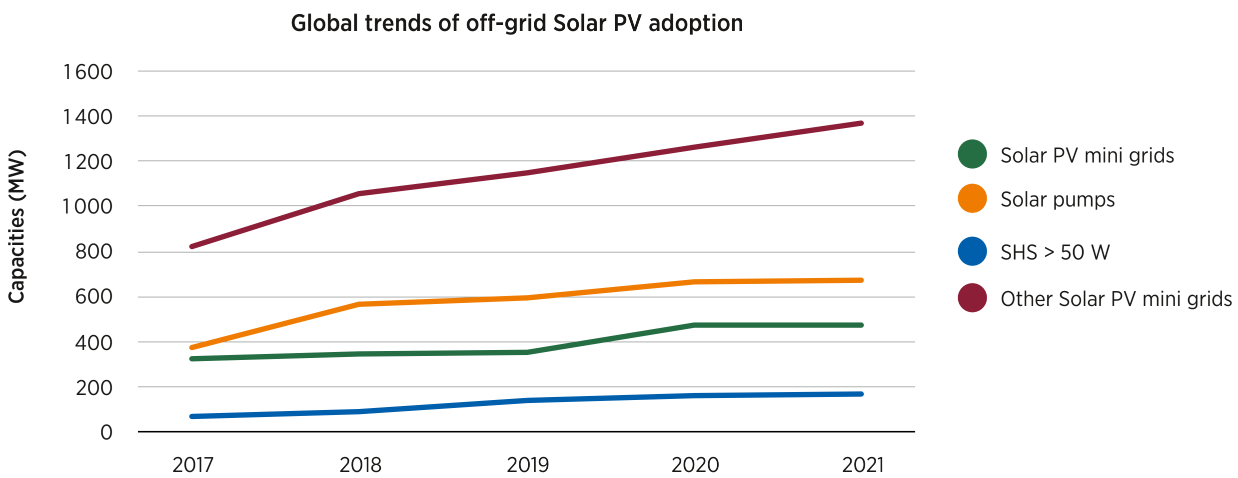
The internal micro-electronics in the 3G-SHS model work as a charge regulator for the batteries and allow for online services (*e.g.* pay-as-you-go model) and remote monitoring using a global positioning system. The model's operational and technical simplicity comes from the plug-and-play system. This ensures simple and faster installation of solar equipment and that end users can install their equipment themselves. In the Oaxaca project, Mexico, micro-franchises sell DC appliances that can be operated using the 3G-SHS model. Productive use equipment has also been designed (with relatively high costs) that is compatible with new-generation stand-alone systems.

Source: Eras-Almeida *et al.* (2019).
Note: LED = light emitting diode.

Given solar PV technology's modular and distributed nature, it has seen high uptake for off-grid solutions across regions where the solar resource potential is abundant. The global trend in its deployment for residential and productive uses in the 2017-2021 period is positive, as seen in Figure 2 (IRENA, 2022).

The technology can be used as a stand-alone system or to power mini-grids, meeting the electricity needs of residential, commercial and productive (agro) sectors.

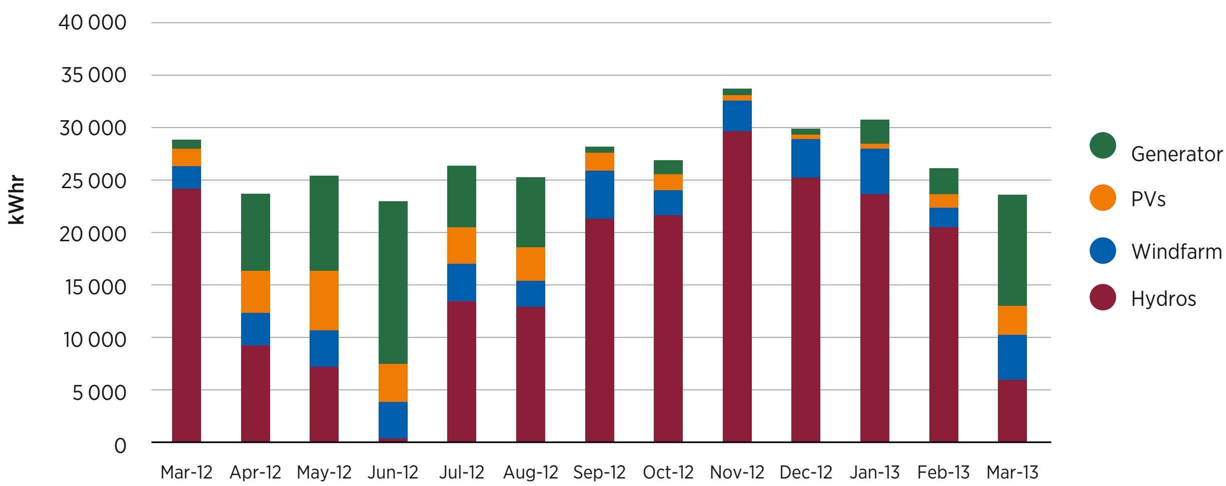
Figure 2 Solar PV deployment shows a positive trend, 2017-2021



Source: IRENA (2022).

Other field projects showcase the use of hybrid renewable energy sources (HRES), as in the Isle of Eigg, Scotland (Figure 3) and Loltong remote islands, Vanuatu. HRES is integrated with renewables as the primary source, along with batteries and DGs as backup. Given the intermittent and variable nature of renewable energy sources, hybridisation ensures a reliable and continuous supply allowing for variable electricity generation. In addition, it helps to reduce overall generation costs, optimise system capacities and thereby reduce operations costs.

Figure 3 The Isle of Eigg project: Monthly hybrid power generation, March 2012-March 2013



Source: Zbigniew and Bhattacharyya (2015).

Modelling studies on the existing hybrid systems in operations at Isle of Eigg, Scotland using Hybrid Optimisation of Multiple Energy Resources (HOMER) show that overdesigning with higher capacity generators to ensure higher reliability, in this case a 180 kW diesel generator (DG), can be avoided by replacing it with a number of small gen-sets (80 kW) that can be operated as required. Alternating current (AC) loads can be directly fed with power from AC sources (wind and hydro in this case), reducing the battery and inverter capacities. Optimising system capacities in tandem with smart demand management has cost implications, bringing down the mini-grid's capital and operations costs (Zbigniew and Bhattacharyya, 2015).

The sizing and use of storage batteries can be optimised to a large extent by operating loads on off-grid solar PV during peak sunshine hours. Simple load management practises, such as operating a bakery or an oil pressing mill at night, can improve the capacity utilisation of installed systems, bearing in mind that loads operated at night match the storage capacity of the systems (as in the case of solar PV). Such practises are further incentivised by time-of-day tariffs, discounted connection fees and attractive prices for energy-efficient end-use equipment.

Renewable resource management

Managing the renewable energy resource strengthens community involvement. For instance, biomass-based systems create a need and additional revenue-earning potential for the farmers growing timber to provide the biomass fuel. To sustain hydro mini-grid operations, the community may engage in watershed restoration and management activities. Perceived as a nature-based solution, renewable energy encourages agroecological cultivation and related livelihoods. Also, since water is a common resource, using it as an energy resource involves the entire community and requires a need for consensus on all related activities and benefits derived from it. Micro-hydro projects can provide additional benefits, as they are located in pristine forest areas that attract ecotourism, *e.g.* hotels and restaurants. Carbon credits and trading are examples of other incentives for such settlements to preserve their forest areas. Water conservation and its related activities are seen to strengthen cultivation, enabling food security and improving local economies and resilience.[8]

In addition to the resource potential of the renewable source and the maturity and cost of the technology influencing the choice of a RET or the hybrid system, there are other influencing factors given the remoteness of the sites that need to be factored in.

- It is essential to localise the supply chain as much as possible to ensure that spare parts and replacements are available from the most proximal location. Spare hardware may become unavailable over the entire operating phase of the mini-grids. Vendor support or technical expertise is needed to help communities source alternatives, given that the operating period of systems can be over 15 years.
- Requisite and sufficient local expertise should be available in construction, and installation of systems should be conditional on the climate and terrain of the region. For example, for the Old Crow community, Canada project, local knowledge was needed to build on fragile permafrost. Other expertise was sought to lay an ungrounded electrical distribution system, which is typical in remote grid installation.
- Knowledge of local extreme weather conditions and the collateral damage they can cause to the mini-grid systems is required.

[8] *KII with Dipti Vaghela, Hydro Power Network (HPNet)*

The advantages of different RETs for remote community access are shown in the comparative table in Annex II. Each of the RETs have advantages that need to correspond to the local context and demand profile.

ENABLING POLICIES TO IMPROVE ELECTRICITY ACCESS TO REMOTE COMMUNITIES

Government policies play a key role in accelerating electricity access rates, helping develop publicly funded programmes and incentivising the private sector by creating the needed enabling markets.

Guidance to frame sound policy that can influence the improvement of electricity access provision to remote and unserved communities is composed of three key elements:

1) Government strategies

- Clear and ambitious targets are needed as part of the government's long-term energy planning in provision of universal access or in reducing diesel fuel dependency.
- Funding for capital costs, rebate schemes for end users and incentives for private players need to go hand-in-hand with easy access to finance for targets to be achieved through clean energy and energy efficiency projects.
- Focused policy approaches that assure continued government engagement are necessary. These should provide for tribal, Indigenous, and other marginalised communities to help determine their energy needs and to further improve their socio-economic development, thereby building resilience.

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2) Regulatory and procurement policies

- Thresholds for tariff rates must consider affordability for consumers. In turn, power purchase agreements (PPAs) must match the cost of electricity generation and supply, and account for O&M, depending on the contractual agreement with the provider.
- Community owned and managed renewable energy projects should be allowed to sell power to micro-utilities using independent power producer (IPP) policies. As a result of power purchase obligations, utilities then source their power from local, clean energy generation units (*e.g.* Old Crow community project in Yukon, Canada and the provincial Locally Owned renewable energy projects that are Small Scale [LORESS] in New Brunswick, Canada; see Box 6).

3) Cross-sector policies that enable increased scale of operations

- Policies dedicated to improving the socio-economic development of remote communities and the provision of continued, effective community services where electricity is an enabler are well defined. This influences the upscaling and replication of existing community-led clean energy projects.

Box 6 Provincial projects help Indigenous communities tap into their renewable energy resources

The New Brunswick provincial project LORESS (Locally Owned renewable energy projects that are Small Scale) allows for the utility, New Brunswick Power, to purchase up to 40 MW of renewable energy power from two of the First Nations (*i.e.* Indigenous communities) and another 40 MW from municipalities or local entities. LORESS has resulted in the Wocawson Energy Project – a partnership of independent renewable energy power producer Natural Forces (49% ownership) and the Tobique First Nation (51% ownership) – to install and operate a five-turbine wind farm in Sussex, New Brunswick. In addition to offsetting the electricity needs of the community, the sale of the 20 MW of electricity generation that the wind farm can produce enables the community to build more houses, improve infrastructure and invest in higher education.

The long-term surety of economic gain and the understanding of wind energy plants have resulted in the Tobique First Nation entering into a new partnership with the renewable energy power producer to install and operate a ten-turbine wind farm, the Burchill Wind Project, near Saint John, New Brunswick.

Such partnerships, and the involvement of Indigenous communities in renewable energy power production, have added momentum to Canada's climate action. Indigenous leaders are well suited to navigate these actions, having long-standing ties with their native lands and a tradition of protecting their natural environments.

Source: Energy Council of Canada (2022).

Around the world, an escalating number of refugee populations are becoming a semi-permanent presence in their host countries. Calls are increasingly being made for focused planning and policies to ensure electricity provision and optimise its use for camp-based settlements, replacing the inefficient, oversized DG sets that these settlements are often equipped with. Pilot projects realised through PPPs have showcased the use of off-grid solutions for refugee and host communities (*e.g.* the case of Dolo Ado and Bokolmayo camps, Ethiopia and the Renewable Energy for Refugees [RE4R], Moving Energy Initiative). Such projects are driven by grants and need to be scaled up to address the size and energy needs of the displaced populations.

Energy assessments of refugee settlements in different phases and locations of establishment have been led by IRENA in partnership with UNHCR. These assessments have led to several overarching strategy recommendations to provide energy solutions that are contextual and meet the needs of refugee settlements, their host communities and the attending agencies (see Box 7).

Box 7 Enhancing energy supply for refugee settlements with renewable energy options

IRENA, in its collaboration with UNHCR, has contributed to the UN agency's new Global Strategy for Sustainable Energy 2019-2024. One of the main objectives of this new strategy is to increase the use of renewable energy sources to provide for access to the refugee settlements, giving displaced communities opportunities for improved socio-economic conditions. To understand the current and expected energy needs of refugees, host communities and other stakeholders, detailed energy assessments were conducted of four selected refugee settlements, two in Iraq and another two in Ethiopia. The settlements' energy needs were extrapolated based on their establishment phase. The settlements in Iraq were in the post-emergency or early development phase, while those in Ethiopia were in the development or protracted situation stage at the time of the scoping study.

In addition to the DRE solutions suggested based on the findings, key recommendations were given for energy planning and provision to refugee settlements:

1) Regular and methodical energy data collection by the humanitarian agencies is needed to support decision making on energy infrastructure and to respond to energy-related queries. This includes data of energy requirements and operations at the offices of humanitarian agencies in the field. Support agencies rely heavily on DGs. Their use could be optimised to help avoid installing machines with oversized capacities, as observed by the study.

2) In understanding the income vulnerability or capacity of the refugee household, suitable models of energy delivery could be deployed. Meter-based electricity supply, as suggested for the Iraq settlements, would ensure a quality power supply; whereas in Ethiopia, data on household incomes would help develop market-based cash assistance that in turn could scale-up the supply of energy for refugees.

Source: IRENA (2019b).

FINANCING CAPITAL EXPENDITURE AND SHORTFALLS IN WORKING CAPITAL

The case studies and discussions with stakeholders show that almost all remote communities' access projects have a large grant component used to meet upfront costs. While a large percentage of these grants is spent on equipment, budget is also allocated for project design, feasibility studies, community engagement, an initial training programme and the establishment of an institutional structure for operating the renewable energy systems.

Working capital is usually met through tariffs collected from end users. Tariffs are earned through different modalities: monthly prepaid cards purchased from the serving utility, flat tariffs paid monthly for the load packages opted for by the user, or metered tariffs collected based on monthly readings. Pay-as-you-go or fee-for-maintenance rates come into play when off-grid solutions such as individual SHSs are used to provide access.

Tariffs that are set based on developers discussions and community consensus are usually equivalent to the amount users were paying for conventional fuels (*e.g.* candles, kerosene or diesel) prior to the clean energy provision. Alternatively, in the case of power usage effectiveness (PUE), tariffs may reflect the project's expected commercial benefit. Metered tariffs are set by the governing co-operative and approved by the regulator in compliance with the rates set by the state regulatory body. The rates are at best in lieu of the generation costs from the mini-grid systems. Projects driven by government programmes or those that are donor funded may be, over the short term, largely subsidised or have upper limits in tariff rates. The promoter meets the operation costs or the balance unmet by the subsidised tariffs.

In almost all cases studies, the revenue earned provides for day-to-day operations, meeting the salary costs of the working personnel and the costs of basic repairs. Capital may need to raised or grants sought when spare parts or batteries (in the case of solar PV) need to be replaced or to pay for the repair of components, such as those of a micro-hydro system. The inability to raise funds to meet recurring capital expenses is a key factor in systems being shut down or disused.

REPLICATION AND SCALING-UP

The nine case study projects have had positive impacts on their communities, and these delivery models can be replicated in suitable locations. Project responses[9] citing the reasons for project success and the potential for replication included:

- The government, community, utility and donors work in tandem. Where applicable, the distribution utility was involved at the inception and during the planning of the project.
- Political, economic and social stability allows for smooth operations over the medium and long term.
- The supply chain is strong and localised, and local companies and a skilled task force are present to provide repair and maintenance services.
- The consumer population is mixed, and varied electrical loads serve residential, commercial, industrial and productive uses.
- Financing for capital construction is long-term (patient[10]) and apolitical.
- Clarity on short- and long-term electrification plans influences the sites and communities selected for access projects.
- Where the community's domestic needs only are served, the project must equal a minimum base load for it to be viable.

Scalability is a direct response to the increase in community demand to operate more loads. This demand could be from the use of additional home appliances; the mechanisation of productive loads; or the addition of an anchor load from a commercial entity, such as a mini-grid, even over an extended period of operating the mini-grid. Electricity needs are for water pumping or improved public service. Productive use loads are minimal where farming and livelihoods are for sustenance and local consumption alone.[11] The scaling up of system capacities can be complemented with the use of efficient equipment and progressive load management techniques.

[9] *Project responses from the nine case studies that answered questions about enabling conditions that allow for replication.*
[10] *"Patient" capital prioritises innovations in addressing poverty, is highly risk tolerant and allows extended time horizons to return capital.*
[11] *Focus group discussion with Gram Oorja Solutions Pvt. Ltd.*

3 DELIVERY MECHANISMS FOR ELECTRICITY PROVISION

> *The reason why people join the cooperative is because light is life. Light brings success. Because of light in Totota today … we have success in the community*
>
> Joseph Scott, the co-op's board president and a small-business owner
>
> *Case Study IV – Remote village of Totota, Liberia*

COMMUNITY CENTRIC

Community-centric models have been shown to be sustainable across regions and to positively impact project beneficiaries. These models engage community stakeholders from the very beginning of an energy project and extend to its governance, with members charting out project roles and responsibilities. This involvement strengthens institutional, financial and technical capabilities, which are key to any model's long-term sustainability. Community engagement also ensures user satisfaction with electricity access and alignment with user needs, helping to assure regular payments and leading to economic sustainability.

The social and environmental benefits of moving away from existing polluting fuels and the enabling feature of improved public services in health and education remain strong drivers to replicate community-centric models.

Community ownership entails the provision of reliable electricity supply through a local institutional arrangement that manages day-to-day technical and financial operations. The asset ownership of the mini-grid systems across models belongs to the prime financier (promoter) or can be wholly transferred to the community itself. The most common financing approach sees a project's upfront costs (including capital expenditure [Capex]) being met by a large share of grants, and in some cases a small share of equity from the end users, as connection costs. The recurring O&M costs are met through a fee-for-service model (metered or flat monthly fees) by the consumers.

The case studies highlight some of the organisational structures involving the community for the governance and day-to-day operations of mini-grids.

Solar co-operatives

The co-operative comprises members from the host or refugee communities who provide energy-as-a-service to fringe neighbourhood host households and to the displaced settlements. The members of the co-operative manage the day-to-day operations of the solar mini-grid. The entity is responsible for reliable electricity supply and oversees all technical matters (*e.g.* Dollo Ado and Bokolmayo camps, Ethiopia).

Village federation and technician associations

Clusters of villages are managed by a central federation, whose governance also helps to increase synergies and provide for common services (such as managerial guidance, inventory purchases, maintenance *etc.*). Made up of representatives from each of the villages, the federation serves as a representative for political and advocacy dialogue with local, regional and national authorities.

An individual technician association in each village takes care of the respective mini-grid systems and is responsible for all technical matters. The staff are encouraged to operate productive uses, such as flour mills, cold storage and other forms of mechanisation, to meet community needs and help to maximise capacity utilisation (*e.g.* Zanzan villages, Côte d'Ivoire).

Electric co-operatives

All end users of electric co-operatives are its registered members and elect their board of directors to oversee governance. The co-operative wholly owns the assets for both the generation and distribution network. It is authorised to pay for additional inventory, including meters, and to extend distribution using operating funds. The tariffs are set by the governing body, accounting for the O&M costs, while complying with the national regulatory tariffs advised. Electric co-operatives in remote settings are best suited to settlements with less than 1 000 consumers whose load profile requires system capacities of around 100 kW to 250 kW, supplied using low-voltage supply lines (*e.g.* Totota Village, Liberia).

PV electrification committees

Suited to off-grid solutions (as in SHSs), PV electrification committees (or individuals) serve as representatives of their small groups. They provide for the initial tasks of assessing household electricity demand, are trained in SHS installation and maintenance, and collect and deposit the fee for service from end users. They are complemented by the local micro-franchising entities – local technicians trained to repair, replace and (through their retail service) sell spare parts and other DC appliances to households (*e.g.* Oaxaca households, Mexico).

Village energy committees

Village energy committees are local elected bodies that take over the operations and financial management of the mini-grid. They work best when the village community is enabled to develop its own governance structure and the body comes into existence soon after the renewable energy system is fully operational (*e.g.* Okhaldunga rural hills, Nepal).

Micro-utility

The micro-utility is a registered subsidiary of a governing entity, such as a heritage trust of a remote island. It provides generation and distribution of electricity to its consumers (*e.g.* Isle of Eigg, Scotland, United Kingdom).

Utility supported by community

This organisational structure sees the state distribution entity that is mandated to extend access use DRE solutions in areas where grid extension over an interim period of time is not viable. Community members support the utility in overseeing basic operations. Contracted maintenance operators under the programme train the community to perform basic maintenance and troubleshooting, as well as provide periodical support, including repairs (*e.g.* Sarawak Energy, Malaysia).

ROLE OF THE PRIVATE PROVIDER

Private developers can be involved through both the development model and the enterprise (commercial) model.

- Developers are contracted through government schemes or donor-driven projects and are mandated to provide the services over a defined time period on the basis of the contractual agreement. Their payments come mostly from the government as fees for service, conditional on the units generated and supplied to the beneficiaries.
- Developers can provide electricity as a commercial activity – energy-as-service or along with value-added service – whose revenue earnings are based on the tariff settlement with their consumers.
- Local, community-based entrepreneurs who get involved in providing access often have a better understanding of their groups' electricity needs and development aspirations. The added social dividend of enhanced impacts on health, extended hours for education and women's safety remains a strong driver for social enterprises to install and operate renewable mini-grids in remote community settlements.

Private providers are involved at various levels in sustaining the projects, but their primary role is to design, install and commission the renewable energy systems deployed. They may train and build a local taskforce and transfer O&M soon after systems are fully functional or over a period of time, depending on the contract.

In delivery models where the operator goes beyond providing energy-as-a-service in adding value chains by strengthening ecosystems, including market linkages, the prime objective is to enhance productive uses and create livelihoods. Demand profiles and increased energy consumption for productive uses are contextual to the livelihoods practised and can remain low over a time period (Katre *et al.*, 2019). The engagement with the community in such models happens over extended periods of time.

Photo: Lighting at night, adds to the safety of the remote communities and households in Oaxaca, Mexico (© acciona.org).

Box 8 Enterprise innovation – Emerging roles of private providers

There are models in countries where entrepreneurs nurtured in the community and understanding the local energy needs have, as a **family occupation**, taken up the provision of energy services. Projects tap into local finances, not having received external or donor money. Such models have showcased sustained operations and been replicated in countries such as Myanmar and Afghanistan.

A progressive model in Nepal has seen the community bring in a **productive use expert** who helps the community run the renewable energy systems, maximising the capacity utilisation. By bringing in commercial interests, the experts (different from the developer) help increase the use of electricity for productive purposes, supporting the community in demand management and operating such loads at different times of the day (KII with HPNet [Hydro Power Network]).

Creating the environment needed for community users to engage in productive uses is a double win for the developer. It improves capacity utilisation of the mini-grid system and provides economic growth from improved incomes. The developer serves as an **ecosystem integrator**. By mapping the local livelihoods that use diesel, working with operators using agro-machinery (such as hulling, milling and threshing machines) to make the shift away from diesel and improving the ergonomics of the machinery, the ecosystem integrator helps the community to be more energy efficient. There are also opportunities to increase gender awareness (by reducing the height of installations, adding mobile features and user-friendly components, as in plug and play) and for communities to obtain affordable financing by engaging with local village banks and agricultural finance institutions from the beginning through to the final phase of market linkages (FGD with HamaraGrid Pvt. Ltd.).

Technology and tourism help to translate high-altitude treks to life-fulfilling experiences, bringing light to the lives of the mountain communities. Expedition fees cover the costs of nano/pico solar grids installed in the homes of remote mountain communities. Travelers (many who finance their trips through crowd funding) help in carrying the panels, and on reaching the village help in installing and experiencing firsthand the transformational lighting up of village homes and faces. The enterprise engineers make trips prior to the expedition to ready the site for installations. Many foreign travelers have been inspired to replicate this model for people living in high altitudes in their own countries. The enterprise now helps to create livelihoods among these communities by setting up homestays as part of the access provision, turning some of the remotest villages into destination getaways! (KII with HPNet; FGD with Great Himalayan Expedition Pvt. Ltd.).

GOVERNMENT PROGRAMMES FOR THE PROVISION OF ELECTRICITY TO REMOTE COMMUNITIES

Electricity provision, when taken up through government programmes, addresses areas serving large, remote populations in getting connections and power supply, or in helping communities that are heavily reliant on diesel to transition to clean sources. The following tables chart three such supported programmes for remote communities in Brazil, Malaysia and Canada.

Table 7 Brazil: Luz para Todos (Light for All) government programme

BRAZIL	
The Luz para Todos (Light for All) programme addresses the provision of electricity to remote areas of the country.	
INSTITUTIONAL STRUCTURE	The Ministry of Mines and Energy is the programme co-ordinator and has the final decision on project approvals. The ministry's national and regional committees, regulation agencies, electrical concessionaires and state governments assist in the selection of priority communities. As the regulatory body, the National Electrical Energy Agency fixes the O&M tariff threshold, oversees commissioning protocols and audits performance reports. The state-owned company ELECTROBAS is mandated to perform programme operations. It evaluates techno-economic viability, approves funding releases and performs inspections on commissioning. The Regional Utility Concessionaire, made up of private distribution companies and rural electrification co-operatives, is responsible for day-to-day O&M activities and organising all connections under its concession.
TOOLS & DRE SOLUTIONS	Geographic information system (GIS)-based data tools, referred to as Sistema de Informação Georreferenciada do Programa Luz para Todos (SIGFI), help to identify areas that lack access to electricity, as in the remote areas. Models, as in Modelo de Integração de Geração Distribuída (MIGDI), help to integrate distributed generation sources and provide electricity using micro/mini-grids. Solar PV is the prevalent choice as the DRE technology.
LOAD PROFILES	The residential, community and commercial needs are met within a window of 13 kWh to 80 kWh per month for lighting, cooling and communications. Monthly average electricity supply of 45 kWh is being provided per consumption unit.
FINANCING	The government provides the Regional Utility Concessionaire with an economic subsidy ranging from 80% to 100% of the direct investment costs. O&M costs are financed through tariffs collected from end users. A social tariff is given to select categories of end users where the discount subsidy is based on monthly units consumed (65% for 0 kWh-30 kWh, 40% for 30 kWh-100 kWh and 10% for 101 kWh-220 kWh). For Indigenous communities, supply is fully subsidised with a provision of 50 kWh/month.

Table 8 Malaysia: Sarawak Alternative Rural Electrification Scheme (SARES) government programme

MALAYSIA	
The Sarawak Alternative Rural Electrification Scheme (SARES) provides last-mile connectivity through the decentralised solutions executed by the government utility.	
INSTITUTIONAL STRUCTURE	The Malaysian federal and the Sarawak state governments have signed agreements with Sarawak Energy, the sole utility provider in Sarawak, for the implementation of the SARES. The utility appoints solar contractors to build solar PV-based solutions (either stand-alone or mini-grids, based on the community size). Sarawak Energy is also mandated through a separate agreement with the Sarawak state government to maintain these systems. Local companies are contracted for technical maintenance and support that includes regular refresher training courses for the community and replacement of parts when required. End users of the community are trained by the companies and are responsible for their system's day-to-day operations, including efficient utilisation (without overloading), cleaning panels and reporting any major faults for rectification to the utility. Communities are encouraged to use existing village governance structures to oversee the operation of installed SARES systems.
TOOLS & DRE SOLUTIONS	A total of 550 rural villages have been identified that are distant from the existing utility grid (ranging from 5 km to more than 200 km). Villages with challenging accessibility, such as those that can only be reached by earth roads, logging roads or river transportation, are also included in the scheme. Solar-PV technology is used through stand-alone systems or centralised mini-grids.
LOAD PROFILES	Under the scheme, the average electricity usage of a rural household is met. Capacity design is based on the provision of 3 kWh/day for a household in the community. It provides light with five units of LED lighting and four power sockets to operate fans, a television, an electric rice cooker and a small refrigerator.
FINANCING	The direct investments to meet the upfront costs for the infrastructure and DRE systems is taken up by the utility, Sarawak Energy, which is subsequently reimbursed through payments from the federal and state government budgets on project completion. The O&M costs are met through budgets outlined by the Sarawak state government. The utility helps in the preparation of the annual budget based on operating SARES projects in the region. The end users are exempted from any service fees or tariffs for the electricity supplied. The community (as a form of equity/in-kind support) provides land and local labour for the project and subsequent operations.

Table 9 Canada: Clean Energy for Rural and Remote Communities (CERRC) government programme

CANADA	
The Clean Energy for Rural and Remote Communities (CERRC) programme enables rural, remote and indigenous communities to transition away from costly diesel-powered electricity to renewables.	
INSTITUTIONAL STRUCTURE	The Clean Energy for Rural and Remote Communities programme (CERRC) is the main federal programme that supports renewable energy capacity building, large capital projects, innovation projects, and bioheat projects in rural, remote and Indigenous communities (NRCan, 2023). Managed by the Department of Natural Resources Canada, the programme also collaborates with other federal programmes and initiatives that support the clean energy transition. In addition, provinces and territories have their own clean energy programmes and policies within their jurisdictions. Communities and project proponents may choose to collaborate or partner with for profit or non-profit companies and organisations, including Indigenous organisations, for project planning, technical expertise, installation, operation and maintenance, as well as subsequent training and services. When assessing projects for funding, the CERRC programme emphasises the importance of community involvement in project ownership, planning and implementation, and overall community benefits derived from renewable energy projects.
TOOLS & DRE SOLUTIONS	Each project chooses RETs based on site-specific considerations, including community benefits and technical and economic feasibility. The program is able to fund projects that deploy a variety of renewable energy technologies, including solar PV, hydro, wind, biomass-based and hybrid solutions.
LOAD PROFILES	The project design and capacities installed are based on technical and economic feasibility, taking into account the demand profiles of the community to ensure reliable and affordable supply that meets community needs. Local serving utilities are often involved from the onset of the project planning phase to ensure adequate amount of grid penetration without disrupting grid reliability.
FINANCING	Depending on the project context, the programme can cover a range of costs, including feasibility studies cost and upfront Capex. Local serving utilities and regulatory bodies are responsible for regulating fees or tariffs. As such, communities typically sign Power purchase agreements (PPAs) with their local utility. Project revenues both ensure sustainable project operations and provide an income that the community can invest in other priority areas.

4 FINANCING STRATEGIES TO REACH REMOTE COMMUNITIES

> *The installation of this mini-grid has given us the light of hope in our respective lives*
>
> Community member of the village
>
> *Case Study VI – Rural hills community of Okhaldunga, Nepal*

CURRENT CONTEXT: GRANT-BASED PROJECTS

Projects to extend electricity access to remote communities are generally financed by governmental or donor-driven grants and subsidies. In the nine case studies analysed in this guidebook, the equity contribution from the beneficiaries (end users) is small, ranging from 1% to 3%. Equity contributions are also made through in-kind support, such as leasing community-owned land for the project site and supplying labour to help in the installation and commissioning of the renewable energy systems. Most such programmes are centrally controlled, with budgets that provide only for lower tier-level services (*e.g.* Tier 2+ services to operate small domestic appliances, lighting and mobile charging). The inability to meet increasing demand, drive productive end-uses or provide for essential public services hampers the long-term operations and sustainability of these projects. In addition, donor funds are often budgeted only for initial capital costs. Additional funds are required for demand stimulation (to provide PUE) to help in system augmentation and for the huge expenses incurred in carrying out repairs and replacing original machinery with spare parts.

INVESTING FOR IMPACT

To scale up and provide for enhanced tier services to remote communities, a shift to market-based solutions is needed, along with a reliance on private capital in addition to aid money.

Impact investors learning from the field have identified some general principles to consider when participating in hard-to-reach markets.

Equity investments help create markets and influence the creation of financially sustainable companies with strong governance structures and proven delivery mechanisms.

Access entry points made with products that match demand (*e.g.* SHS for a low-demand case) and proven business models that help end users afford and pay for the product (*e.g.* pay as you go) allow for larger uptake, thereby building scale.

Established companies with a proven track record of penetrating remote markets are more likely to have success due to their record in similar regions where markets were non-existent or underdeveloped. These companies have experience with the due diligence process, sufficient equity to showcase financial stability and a demonstrated record of their models.

To encourage the private sector to participate in projects perceived as risky, innovative financing mechanisms are called for. These could include blended grant-debt capital, in which the grant capital is essential to mitigate the perceived risks, which otherwise would discourage investors from participating (Acumen Energy Investments, 2022).

Another innovative investment strategy is patient capital (both debt and equity), which falls under the umbrella of impact investment but prioritises impact differently from traditional methods. Falling somewhere between pure philanthropy and market-based solutions, the patient capital strategy focuses on investing in innovations that address poverty. Its key features are high risk tolerance and an extended time horizon for capital return.

Investments can also be made through issues of International Renewable Energy Certificates (IRECs), which certify the environmental attribute of 1 MWh of renewable energy generated and consumed. An IREC is issued for every 1 MWh of renewable energy power that is produced or consumed. The certificate can be traded and sold as a commodity. IREC buyers range from corporate entities to non-profit organisations and individuals trying to attain their carbon-transiting targets.

IRENA is supporting remote and unserved communities by helping them move away from being pure aid recipients to being participants in more market-based projects. Working with countries under the **Global Initiative on Transitioning Remote Communities to Renewables,** IRENA aims to strengthen its work with countries where the potential and need to serve remote communities is high, helping them to develop detailed, country-level programmes for off-grid renewables electrification. This guidance will provide pathways for implementing projects at speed and with scale to achieve universal electricity access.

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ANNEX I: CASE STUDIES

OLD CROW COMMUNITY, CANADA

Community	**Remote northern community of Old Crow, Yukon, Canada, home of the Vuntut Gwich'in First Nation** To reduce Old Crow's reliance on diesel, the Vuntut Gwich'in First Nation installed a solar PV micro-grid system. Yukon government legislation and policies, as well as a PPA with the local utility, ensure that the community benefits from the project.
DRE solution	A total of 2 160 single-sided mono-crystalline solar panels are aligned in an east-west direction. The 940 kW (AC) solar PV system has 616 kWh of battery storage. Power is supplied to the community using a micro-grid network.
Context	Old Crow is a remote Indigenous community located in the Artic Circle, 350 km away from the territorial grid. Its annual electricity consumption of 2 389 MWh was being fully met by diesel. The annual diesel requirement was 700 000 litres, delivered by planes, making the community of 250 people vulnerable to fuel pricing and lack of availability and resulting in ecological damage.
Delivery mechanism	The Vuntut Gwich'in First Nation owns the solar facility and has entered into a first-of-its-kind electricity purchase agreement with ATCO Yukon, the local utility, to sell its power for 25 years. The utility owns the micro controller, storage battery and distribution networks. The plant helps meet 24% of the community's annual consumption. During summer's long hours of sunshine, the plant helps to keep diesel generation turned off.
Financial viability	The Old Crow project was fully financed by grants from the federal and Yukon territorial governments under their programmes to achieve climate targets, enable Indigenous participation in the energy sector and encourage economic development in northern regions. Yukon ratepayers pay similar rates for electricity across the Yukon, regardless of the location and cost of local generation. This territory-wide ratepayer cross-subsidy utility model allows for reduced costs in places where thermal generation is expensive (remote/isolated communities). Ratepayers in locations where electricity generation is cheaper (with hydropower) help cover the increased costs for locations where generation costs more. The price of electricity for solar power paid by ATCO Yukon to Vuntut Gwich'in First Nation is based on avoided costs from the utility (diesel fuel + deferred maintenance). The rate is USD 0.51/kWh.
Emissions reduction	The annual carbon dioxide equivalent (CO_2eq) emissions reduced is estimated to be 680 tonnes.

DOLLO ADO AND BOKOLMAYO WOREDAS, SOMALI REGION, ETHIOPIA

Community	**Refugee settlements of Dollo Ado and Bokolmayo Woredas, Somali region, Ethiopia** Five refugee camps in Dollo Ado access electricity from solar PV mini-grids and water supplied using off-grid solar pumps. Solar co-operatives hosted and driven by the members of the refugee and host community (in its fringes) supply both household and agro-related electricity needs.
DRE solution	Six commercial solar PV mini-grids with 120 kWp of total capacity have been installed across the five refugee camps and are operated and maintained by their solar co-operatives. In total, electricity is sold to more than 1 200 households from both host and refugee communities and implementing partner offices. Storage provision is with 6 V, 200 Ah and 12 V, 102 Ah batteries that provide for night-time loads. An off-grid solar water pump (a pilot surface water pumping structure) has been designed to irrigate 45 hectares of arable land that is being cultivated by both host and refugee communities. Operating under the Melkadida irrigation scheme-1, the off-grid solar water pumping system is a consolidated system consisting of two main pumps with a capacity of 30 kW, a single vacuum pump with a capacity of 2.2 kW and a total solar PV capacity of 56.32 kWp.
Context	In Ethiopia, Somali refugees are in a protracted asylum situation with limited prospects for durable solutions, such as voluntary repatriation, local integration or resettlement to a third country. Somali refugees arrived in Ethiopia in three main phases: in the late 1980s and early 1990s for reasons related to the fall of the Siad Barre regime, in 2008/2009 related to the outbreak of new violence and in 2011 due to drought. Renewable energy projects in the location look beyond basic Tier 1 electricity supply, to act as an enabler for other sectors such as health, education and livelihoods. In providing energy to both the refugee and the host communities, the projects build harmony, provide improved public services and create revenue-earning opportunities.
Delivery mechanism	The business model is broadly positioned as energy-for-service. In each of the five camps, the solar energy co-operative is part of a larger management structure.[12] The co-operatives are organised to provide reliable electricity supply to the 1 250 connected households and one implementing partner office.
Financial viability	The upfront costs of installing the solar PV systems and distribution grids have been met through grants from philanthropic organisations. Financial viability is attained through a fee-for-service model in which the consumer pays a flat fee based on the household's connected load (*e.g.* the number and type of electrical appliances in use). Tariffs are set in consultation with the concerned parties, taking into account the purchasing power of the community and the revenue required to meet O&M costs. The co-operatives are encouraged to use their surplus earnings to provide free electricity[13] to vulnerable households that cannot afford to pay.
Emissions reduction	The amount of CO_2eq emissions reduced is estimated to be 141 tonnes.

[12] *The whole structure is a sum of committees: a management committee that sets the strategic direction of the larger co-operative, a market and business committee that engages in specific aspects of the overall marketing strategy, a technical committee that reviews technical elements of its activities, and a control and audit committee that oversees the financial reporting and disclosure process.*

[13] *Supply to power a single light bulb (15 W) for two consecutive years. Since the COVID pandemic struck, the co-operative has helped power the health centres to respond to emergencies. The solar units generated are also used to power quarantine centres, UNHCR's food distribution centre and the reception centre for newly arrived refugees in Dollo Ado.*

ZANZAN REGION, CÔTE D'IVOIRE

Community	**Remote settlements in Zanzan region, Côte d'Ivoire** Seven remote villages in Côte d'Ivoire use an innovative delivery model combining private sector expertise, public capital and strong community ownership through an overarching Mini-Grid Federation and Technicians Association. With sizeable equity from the mini-grid users of the rural households in financing the project, there is strong ownership of the project, ensuring long-term sustainability.
DRE solution	Solar PV mini-grids with a total capacity of 214 kW along with battery storage of 1 771 kWh. Back-up power is for night-time use and provides autonomy of 2.5 days of non-sunshine hours.
Context	The Zanzan region, located to in the northeast Côte d'Ivoire, is the most under-utilised and had the lowest electrification rate in 2009. The likelihood of attaining grid extension for the seven villages selected for mini-grid implementation was poor. The objective of the mini-grid installations was provide inhabitants with a decentralised and sustainable electricity infrastructure that met household needs and those of vital community uses: education, health, information and public lighting in all seven villages.
Delivery mechanism	Each of the solar PV mini-grids belongs to the village (including people connected and not connected to the mini-grid). The local associations (created in the frame of the project) manage the mini-grid systems, including the productive uses of energy (community fridges, freezers and mills) that were encouraged. The Gbreko Kanian Federation centrally manages the financial and technical tasks. Energy used by the mini-grids is exclusively used to power the association members' loads (households), local association productive activities (fridges, freezers, mills) and community uses (school, health centre and street lighting).
Financial viability	Grants, equity and in-kind support involving seven different stakeholders (including consumers) contributed to the upfront costs. Fee-for-service is from a prepaid mode of tariffs set for five different consumer energy bundles. Monthly contributions were calculated to ensure financial balance. They include individual electricity services (50%), amortisation of batteries (40%) and community service consumption (10%). The tariffs for power consumed by health centres/public lighting/energy house/association house are met by the mini-grid users. The tariffs for power consumed by schools are met by parents of the attending students.
Emissions reduction	The amount of CO_2eq emissions reduced is estimated to be 271 tonnes.

TOTOTA, LIBERIA

Community	**Remote village of Totota, Liberia** In the remote village of Totota, mini-grid users form an electric co-operative to become the first-ever micro-utility in Liberia. The co-operative, set up in partnership with the United States non-profit association NRECA International, showcases the tremendous potential of community-owned co-operatives, impacting more than 20 000 people through a sustainable community-driven DRE delivery model.
DRE solution	A solar/battery/diesel hybrid system supplies nearly 24-hour power to the community. The renewable power source consists of 72 kW of fixed-tilt solar PV panels, a 120 kWh lithium-ion battery with smart micro-grid controller, and an 80 kVA backup generator. Power is delivered over a network consisting of 7 km of three-phase 50 square millimetres of aerial bundled cable 240 V/415 V low-voltage line.
Context	Totota is a rural community located approximately 128 km northeast of Monrovia in Bong County along the main access road from Monrovia to Cote d'Ivoire. It is an important regional trade centre. Totota was selected because of the commercial and industrial potential along the main highway through town among other such towns through a prioritisation process conducted with the Rural and Renewable Energy Agency of Liberia.
Delivery mechanism	NRECA International constructed the hybrid system and has transferred ownership to the electric co-operative, which owns 100% of the generation system and the distribution network. The electric co-operative has since invested in additional meters, and an additional generator, using retained operating funds. Its members are simultaneously owners and consumers. The electric co-operative provides metered electricity supply on regulated tariffs set by its board of directors based on financial modelling and as stipulated by LERC, the Liberia national electricity regulator.
Financial viability	The tariff rates in the Totota Electric Co-operative are designed to cover all operating costs, including all fuel costs (for the diesel power plant), commercialisation expenses, staff salaries, spare parts needed to support generation and distribution operations, and other costs. The board controls the tariff to meet the cash-flow obligations of the co-operative. All usage is controlled by automated prepaid meters to which consumers do not have access. They can buy additional credit by phone from Totota Electric Co-operative. The schools and clinics have the same tariff as residential consumers, and their consumption is modest. They buy credit directly from the co-operative. The services they provide are partially subsidised by the government (if the clinic is public) or paid by the population in case they are private.
Emissions reduction	The amount of CO_2eq emissions reduced is estimated to be 35 tonnes in the period from 2018 to 2022.

"The reason why people join the co-operative is because light is life. Light brings success, Because of light in Totota today ... we have success in the community

Joseph Scott, the co-op board president and a small-business owner

OAXACA, MEXICO

Community	**High-altitude, scattered settlements in Oaxaca, Mexico** Under the Luz en Casa, Oaxaca (Light at Home) programme, household settlements in high-altitude terrain get electricity access from third-generation SHSs using a modern and innovative financing structure. Financing is from funding through public-financing establishments as well as equity ownership by the SHS users, made possible in part through micro-loans granted via a crowdfunding platform. The solution has an impact on a large geographical area.
DRE solution	The 3G-SHSs have a 120 watt peak (Wp)-150 Wp panel and a 23 Ah (12 V) battery or a 240 Wp-300 Wp panel and a 50 Ah (12 V) battery.
Context	The most remote Oaxaca rural communities live in poverty. Their remoteness complicates the access to basic services and contributes to their isolation and inequality of opportunities for development. These end users were the populations targeted by the Luz en Casa Oaxaca programme. The settlements are far from towns, scattered over steep topography and have no road access.
Delivery mechanism	Users get access through a fee-for-maintenance model, co-funded through a PPP. Users learn through training sessions the details of the SHS equipment, and its use, maintenance and actions in case of failure. The training teaches the users to install the equipment in their homes by themselves after having chosen the most suitable arrangement for their needs. In Oaxaca, there are six micro-franchises that operate to solve equipment failures and sell high-efficiency electrical appliances compatible with SHSs. Municipalities and PV electrification committees (PECs) participate in project management as service suppliers and communicational channels. PECs are also in charge of fee collection.
Financial viability	The first phases of Luz en Casa Oaxaca provided the 3G-SHS (5.9 Ah and 9.5 Ah) through a subsidised sale where users paid 50% of the cost of the 3G-SHS, which meant approximately USD 150. The fee-for-maintenance model has been established to cover repairs, replacement of equipment and customer service of the Centro Luz en Casa technician. To make the fee affordable, customers had access to the microfinance programme in co-operation with KIVA International Organisation (a crowd-lending, non-profit organisation). This gave them the chance to reduce their monthly fees for a one-year period. Payments were lower than the alternative energy costs (batteries, candles, kerosene, *etc.*) would have incurred. The fee depends on the size of the SHS and is paid every 60 days, individually or collected by the PEC, in the corresponding Centro Luz en Casa.
Emissions reduction	The amount of CO_2eq emissions reduced is estimated to be 1810 tonnes annually.

> ***Thanks to Luz en Casa, I can see my little home with light***
>
> Paula, 89-year-old female user in the Mixe mountains

OKHALDUNGA, NEPAL

Community	**Rural hills community of Okhaldunga, Nepal** A local community from the rural hills of Nepal successfully set up a solar PV mini-grid, co-ordinating with a private enterprise. Installed with upfront grants from a development bank, the villagers are trained to operate and manage the renewable energy system. Revenue earned from electricity supply is given out as microfinance loans that in turn spur economic activity and ensure the sustainability of the project.
DRE solution	The 50 kWp solar PV mini-grid is accompanied by 345 kWh of battery storage.
Context	The Mane Bhanjyang Village is located in mountainous terrain, with limited access to basic facilities, including roadways and transportation. Poverty presents an obstacle to getting essential services such as health and education, and the village inhabitants are a marginalised community earning less than USD 1.90/day.
Delivery mechanism	The mini-grid is community owned and operated. A user group formed by the end users act as a built-in governing body to manage and sustain the system operations.
Financial viability	The user group committee is tasked with reading the energy meters and collecting the electricity tariff at a fixed rate (USD 0.11 per unit). The pool of money collected is then lent out to members of the user group as needed. The payment recollection is done by the user group. The cash reserve serves as microfinance, providing financial support to the local people and paying the grid employees. These loans are expected to spur further consumption and socio-economic development, creating a virtuous cycle and increasing the user group's available money. The collected amount can be used to partially fund subsequent scaling-up plans.
Emissions reduction	The amount of CO_2eq emissions reduced is estimated to be 192 tonnes annually.

> ***"The installation of this mini-grid has given us the light of hope in our respective lives***
>
> Community member of the village


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ISLE OF EIGG, SCOTLAND, UNITED KINGDOM

Community	**Remote island community, Isle of Eigg, Scotland** Located in western Scotland, the Isle of Eigg community of 45 households chose a hybrid renewable energy solution to gain energy independence from the mainland and reduce its strong reliance on diesel fuel. The project is financed for its upfront costs through a partnership of local government agencies, non-governmental institutions and the local population. The project's notable features include a usage cap as well as a remarkable "traffic-light" system that helps reduce consumption to manage demand *vs.* supply, ensuring sustained operations.
DRE solution	An integrated hybrid renewable energy system of hydro, wind and solar provides the decentralised generation (a 100 kW hydro plant supported by two smaller 5 kW plants, four small wind turbines of 6 kW and a solar PV mini-grid of 50 kW). The output of all the renewable energy generation sources is brought together, controlled and distributed to households and businesses on the island using an island-wide high-voltage grid approximately 11 km in length. Transformers, located in close proximity to clusters of properties, convert the grid voltage to domestic voltage for household supply. To cover occasions when renewable generation is low, the integrated renewable energy system is supported by a pair of 70 kW DGs, which act alternately as backup and reserve. The DGs sets can be switched into the system automatically as a part of the control strategy.
Context	Eigg is part of the Hebridean Islands on an island located 12 km west of mainland Scotland.
Delivery mechanism	Eigg Electric is a micro-utility that is fully community owned and operated as a business enterprise. It is registered as a subsidiary of Isle of Eigg Heritage Trust, which owns Eigg. Consumers pay for the electricity supply through pre-paid cards worth USD 12.25 or USD 24.50.
Financial viability	Upfront costs have been financed through several players, including local government and non-government agencies. The sale of pre-paid packages provides for the daily operations and maintenance of the systems. Expenses from any major repairs and replacement of spare parts must be met by the mainland departments of Scotland's government.
Emissions reduction	CO_2eq per household is evaluated to be 20% lower than the United Kingdom average.

SARAWAK STATE, MALAYSIA

Community	**Remote rural villages of Sarawak State, Malaysia** In a state programme-driven model, the Sarawak Alternative Rural Electrification Scheme (SARES), the utility Sarawak Energy provides electricity access to very remote villages using off-grid solar PV-based solutions to achieve total electrification by 2025.
DRE solution	The SARES considers two types of solar PV options, SHS or solar PV-based mini-grids. One centralised system is provided for each community. The capacity of the mini-grid is linked to the size of the village and the number of its households. The system capacity allows for: • energy of 3 kWh/day for every family • battery storage with sufficient capacity to allow for at least two days of autonomy • a load demand of of 1 000 W per family. The solution also includes establishing a low-voltage distribution network and providing internal wiring and setting up electrical connections for each of the households.
Context	Sarawak is the largest state in Malaysia, with a total area of nearly 124,500 km^2. A total of 45% of the population of Sarawak lives in rural areas. In 2016, energy access coverage for rural areas of Sarawak was 87%. The Sarawak government intends to fast-track the rural electrification effort and achieve 100% electricity coverage by 2025. Its approach involves extending the grid or providing off-grid solutions to rural communities that are not in reach of the utility grid. Overall, 550 villages have been identified for SARES off-grid solar implementation. The SARES implementation will be completed in six stages and will be funded by Sarawak State and the federal government.
Delivery mechanism	Under the SARES, once the mini-grid has been installed and commissioned, the communities are responsible for the operations and basic maintenance of the systems. Relevant stakeholders, which include Sarawak Energy and the state government, have shared objectives and stay involved. Sarawak Energy-appointed maintenance contractors are responsible for corrective and periodic maintenance. They also train the community on basic operations and plan for battery replacements and grid transitions.
Financial viability	The SARES is executed under an overall long-term rural electrification programme to provide universal energy access. The Capex spent by Sarawak Energy is reimbursed by the government ministry. The operating expenditure budget is allocated through maintenance contracts. Sarawak Energy works closely with the Sarawak government to plan and estimate the budget needed to cover the maintenance of SARES stations across rural Sarawak. Under the scheme there is no income from electricity bill collection. The end-user contribution is that of providing suitable land for the project without any monetary compensation. Each community is responsible for basic day-to-day O&M.
Emissions reduction	The amount of emissions reduced is not available.

LOLTONG VILLAGE, VANUATU

Community	**Remote island community of Loltong Village, Vanuatu** The hybrid DRE solution of pico-hydro and solar PV systems in meeting the local community's power needs showcases a proven model that can be replicated by similar communities to attain energy self-sufficiency and reduce the use of diesel fuel.
DRE solution	Based on the feasibility study, the DRE solution is a pico-hydro solar PV hybrid mini-grid system. The integrated renewable energy system is made up of a 7 kW hydro system, a 2.6 kWp solar PV array, a 15 kVA battery inverter and a 33 kWh storage battery. The solar PV system acts as a supplement to the hydro system when consumption increases and more power is needed to meet demand. In total, the PV and hydroelectric system delivers a combined generation capacity of 8.8 kW of DC and 8 kW of AC power.
Context	Loltong Village is located in the north of the island of Pentecost, which is one of the 83 islands that make up the South Pacific nation of Vanuatu. The BRANTV programme of the Global Environment Fund (GEF) and the United Nations Development Programme (UNDP), implemented by the Ministry of Climate Change and the Department of Energy Vanuatu, chose the Loltong project site. The decision was based on baseline information of an existing 3 kW capacity pico-hydropower system built by the community and funded by the New Zealand government. The existing system was not operating due to poor design. GEF/UNDP funds were used to install new and incremental features to the existing system to meet the load demand and provide a constant, sustainable and quality supply of electricity to the community.
Delivery mechanism	The community of Loltong Village manages the mini-grid. The Vanuatu government retains ownership of the assets. The Hydro Committee, which has two appointed officers – a local technician and client relations officer – is responsible for collecting tariff billing and paying for O&M costs. The mini-grid is regulated by the Utility Regulatory Authority (URA), which is responsible for managing end-user complaints, reviewing the tariff and monitoring the quality of the services provided. The URA was set to review the community management model after one year of operations, which commenced in July 2022. The tariff rates' effective period has been extended by URA until May 2024. The Loltong Hydro Committee reports to the BRANTV Project, the Department of Energy and the URA on both a weekly and a monthly basis about the mini-grid's production.
Financial viability	The tariff model adopted for households, USD 0.71/kWh, is regulated by the URA and deployed as a prepaid service. The revenue earnings help to meet the O&M costs of the system and the two officers' wages. An additional means of earning revenue from productive uses has been introduced by setting up a block-making machine for bricks that is operated by the technician or leased to other users.
Emissions reduction	The amount of CO_2eq emissions reduced is estimated to be 160 tonnes annually.

ANNEX II: ADVANTAGES OF DIFFERENT RENEWABLE ENERGY TECHNOLOGIES FOR REMOTE COMMUNITY ACCESS

	Micro/mini hydro	Solar-battery	Solar-battery + diesel	Biomass gasifier (solid fuel)	Wind-battery	Diesel
Range of investment cost USD/kW (generation, distribution)	**500 - 10 000**	**4 000 - 7 000**	**3 000 – 6 000** Slightly cheaper than solar-battery	**1 500 - 10 000** Including gasifier, cleaning system, heat exchanger, gas genset, and grid	**4 500-13 000**	**300-800**
Pure O&M cost (assuming overall system lifetime of about 20 years; without depreciation) as % of investment (depends on equipment quality; battery and diesel genset replacement to be included)	**2-5 %**	**10-15%** Considering replacement of battery	**10-20%** Battery replacement and generator maintenance	**min 10%** Without fuel cost; daily maintenance required	**5-15%** Turbine replacement every 20 years Annual servicing Highest O&M cost among renewables	
Range of cost (LCOE) in US Cent per kWh	**5-30**	**30-100**	**50-100**	**5-50** Including the cost of biomass cost	**30-100**	**35-120** Often subsidised fuel price and transport

	Micro/mini hydro	Solar-battery	Solar-battery + diesel	Biomass gasifier (solid fuel)	Wind-battery	Diesel
Percentage of local contribution (equipment and installation)	**40-70%**	**5%**	**5%**	**30%-95%**	**20-40%** in community **40-60%** in country Depends on country; parts like charge controller, batteries, inverters etc. are often imported	**5%**
Local availability of spare parts	+++	-	-	++	+ Depending on country (normally all spare parts can be sourced locally except magnets)	++
Resource assessment	Measure water level (min 1 year) and flow	Data from solar radiation databases; worldwide available	Data from solar radiation databases; worldwide available; (see also diesel systems)	Collect data on agro residues for at least 3 years (supply chain); make forecast Seasonality important to consider	Measure wind speed (minimum 1 year)	Accessibility for diesel transport and affordability of diesel
Typical cost driver	Low head – high flow (more expensive than reverse) Complicated civil works (difficult terrain) Distance between the hydro site & supply area	Battery component: high investment of about 600-700 USD/ kWh every 6-8 years	Battery + cost for diesel fuel	Biomass fuel price Gas cleaning system Quality of gasifier (insulation etc.) Level of automatisation	Required battery capacity depending on volatility of wind resource	Local price of diesel fuel

	Micro/mini hydro	Solar-battery	Solar-battery + diesel	Biomass gasifier (solid fuel)	Wind-battery	Diesel
System design in view of scalability / modularity	Design based on available flow and (future) community demand Identify sufficient/big consumers (productive use) to increase load factor over 24 hour Investment cost nonlinear to system size	Design for maximum harvest of kWh to reduce investment cost; especially private developers tend to undersize system to reduce investment risk; later extension (+/-linear cost increase)		Good modularity (often several units from beginning to allow for maintenance)	Often expanded with PV (better modularity); investment cost nonlinear to system size	Capacity cannot be increased without new purchase Oversizing has very negative impact on efficiency and fuel consumption
General advantages	If flow is sufficient, no storage required Low cost per kW and per kWh Local added value; can become cash cow in case of later grid connection Possibility of direct drive	Abundant resource in particular in dry climates (Africa) Scalability of PV modules but not of batteries	Flexibility through diesel back-up	Easy storage (biomass or gas can be stored, allows to operate at optimum efficiency) Possible additional benefit for biomass vendors Less emission of particulate matter compared to other solid fuels	Local manufacturing of wind turbines (also leads to lower O&M cost) Complementary source to solar PV or diesel	Independent of availability of renewable energy resources

	Micro/mini hydro	Solar-battery	Solar-battery + diesel	Biomass gasifier (solid fuel)	Wind-battery	Diesel
General limitations	Lack or seasonality of flow Access to funds for high initial investment	Lack of irradiation access to funds for high initial investment Limited scalability of batteries (parallel lead-acid batteries) Environmental impact of batteries	Access to funds for high initial investment Access for diesel supply High operational cost for diesel	Technology less mature than others (early commercial stage) Thorough resource assessment required supply chain for biomass competition with food, dung etc. Natural biomass not pollutant, but: Deficient operation leads to generation of tar from cleaning system; can be problem	High spatial and temporal variability of the resource High maintenance requirements Due to high variability of wind, unreliability of wind turbines and drop in PV prices, wind becomes a complementary source to save fuel or generate electricity at night or during winter/ rainy season	CO_2 emission and environmental impact Long term price increase of fuel
Productive end use	Direct drive *e.g.* of agro processing machines possible Lower LCOE attractive for end use	Due to resource peak in dry season, very appropriate for irrigation		Heat (or cold) and electricity can be used Agro enterprises that produce the biomass resource Used for various mills and local industry		

Source: (HPNET and SKAT, 2020).

Note: Local availability of spare parts: "+" (plus sign) is indicative of the availability of the spares locally. An increasing number of plus signs shows increased market availability of spare parts.

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