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Technical Guide: Energy Systems

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Technical Guide: Energy systems

Sustainable Development Goal (SDG) 7 is to ensure access to affordable, reliable, sustainable and modern energy for all. While significant progress has been made towards universal electrification in recent years, there is still much work that needs to be done, especially in sub-Saharan Africa where approximately 600 million people do not have access to electricity. In sub-Saharan Africa virtually all national electrification strategies recommend a two-track approach to expanding electrification – with a centralised track, undertaken by national government, being focused on grid extension, and a decentralised track, generally undertaken by nongovernmental entities and private entrepreneurs, being focused on the development of off-grid solutions (e.g. mini-grids).

As each of these tracks progresses, so too will national grids and off-grid systems increasingly be required to interconnect. While mini-grid developers and operators generally view ‘grid arrival’ as being a threat to the viability of their operations, interconnection can have significant benefits for national grids and the goal of universal electrification, however, given favourable regulatory environments and the technical ability, interconnection can also provide a solution to many of the demand-side related problems experienced by mini-grids.

As mini-grid developers tend to develop operations at great distances from national grids (to avoid actual/perceived issues bought about by grid arrival), grid interconnection is a relatively rare phenomenon in Africa, however it is sure to become increasingly commonplace. By providing an overview of i) on and off-grid energy systems, ii) the regulatory environment to which they are subjected, iii) interconnected grids and the regulatory and technical environment required for successful grid interconnection, and iv) examples of successfully interconnected grids in the developing world, this guide aims to provide the reader with preliminary insight into a complex field that will become increasingly important in achieving universal electrification. Useful references are cited at the end of the document should the reader require further information.

What is an energy system?

An energy system can be described as the set of production, transformation, transport and distribution processes of energy sources. While there are important differences between on and off-grid energy systems, the two can interconnect and the integration of small power producers (SPPs) and mini-grids with national grids is viewed as key means of widely delivering electrification and renewable energy in Africa.

On-grid energy systems

Grid systems are made up of individual generators (or power plants), transmission lines, a distribution network and a 'load'.

In Africa, grid electricity is predominantly generated by fossil fuels (coal, gas, diesel) or hydro (especially in East, Central and West Africa). However, in certain countries such as South Africa and Kenya, independent power producers (IPPs) provide much of the new generation capacity through large, grid-connected photovoltaic and wind farm installations. Different types of generators produce power at different voltages, for example a typical 500MW coal fired turbine will produce electricity at 20,000 volts and a large wind turbine will produce electricity at 600 volts.

The safe and effective transmission of electricity over long distances (via transmission lines) requires low current in order to reduce losses, which in turn requires high voltage (pressure) to transmit the electricity. No matter the power source, voltage is thus transformed before it is transmitted at between 132,000 and 765,000 volts. Ideally, transmission lines are interconnected systems that reduce redundancy and increase reliability of supply, however in most African countries this is not the case, resulting, in part, in unreliable grid networks.

Distribution lines pick up electricity from transmission lines and transform it down for local distribution, usually to 11,000 volts at a large substation, and then further according to need, for example to 220/240 volts for domestic use which is transformed via small, pole-based transformers.

On-grid load management

Electric load is the portion of the system that consumes electric power such as appliances and machinery. Power utilities are required to balance the electricity produced by generators with load consumed and typically entrust this role to a System Operator. Pricing (tariff) strategies are employed for shaping general demand profiles (high tariffs at peak demand times reduce consumption and low tariffs at low demand times increase consumption) however a range of methods are employed to control short term fluctuations, including using gas and diesel driven turbines that can quickly be turned on and off (unlike coal fired power stations). As renewable power sources (especially wind and solar, which are typically intermittent) are increasingly added to national grids, load balancing becomes increasingly challenging and the implementation of smart grids – through which loads can more accurately be managed via digital communication – becomes necessary.

On-grid regulatory environment

As Figure 1 depicts, many SSA countries still operate under a vertically-integrated state-owned monopoly with limited private participation allowed in the generation and distribution.

This monopolistic approach disincentivises privatisation as governments view electricity generation and distribution as a basic service with social and political implications that make it better suited to being provided through public entities; privatisation is thus viewed as opening up a critical service to exploitation.

Ideally, national independent energy regulators would play a key role in allowing the integration of government owned on and privately owned off-grid systems so as to accelerate electrification efforts. However, while almost all African countries have the legislative frameworks that call for or envisage independent regulators, in reality measures for ensuring independence are either not in place or are weakly enforced, resulting in regulators being subject to political influence and the entrenchment of state-owned electricity monopolies.

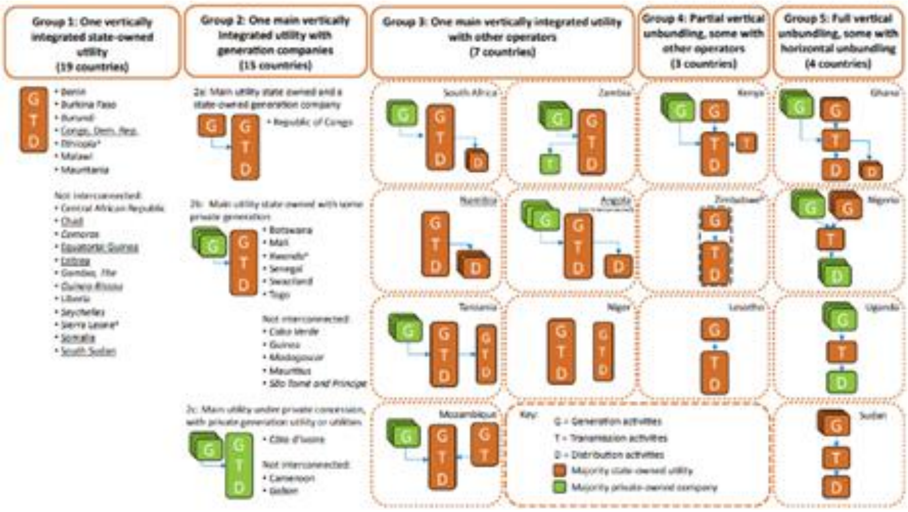

Figure 1. Demonstrating the vertically integrated nature of electricity generation and distribution in many African countries, Source: World Bank, 2016.

Off-grid energy systems

Off-grid energy systems come in two forms, mini-grids or standalone systems; traditionally, both operate independently of national grids and are thus known as 'off-grid systems'.

Stand-alone systems do not connect to distribution systems and provide electricity directly to individual appliances (e.g. a solar water pump, or water heating system), homes, or small productive uses such as a small business (e.g. agricultural milling machines). While usually powered by solar systems, biomass, small wind and small hydro generators are also widely used. Specialised DC equipment is commonly used in such systems; however, inverters can also be used to generate low voltage AC for standard appliances. Storage systems, usually in the form of battery banks, can be used to extend time of use.

Mini-grids, also referred to as micro-grids or isolated grids, are either interconnected single or distributed energy resources (DERs) plus load within a clearly defined boundary. They generally provide between 10kW and 10MW for a limited number of customers via a distribution grid (note transmission networks are absent in mini-grids) that can operate in isolation from national electricity transmission networks, and they are typically found in rural locations that are off the main grid, or in grid connected areas that suffer from unreliable national grids. Clean mini-grids utilise renewable energy to produce electricity and batteries and/or diesel generators provide back-up power.

Understanding off-grid energy demand

In communities where electricity is not available, lighting is often provided by kerosene or oil lamps which has social and environmental issues from the air pollution. At the most basic level, electrification in developing countries is crucial for the provision of lighting and powering electronics such as radios, mobile phones or televisions for these populations to be connected to the rest of the world. These types of applications are typically low demand and can be met with small, solar home systems (SHS).

Electrification of other activities such as cooking and heating (which again commonly use oil-based fuels or biomass in the absence of electricity) require greater power and energy supply due to the magnitude of the demand. Understanding the applications and activities (the demands) that the off-grid energy system will be supplying is crucial for correctly sizing the energy system. If the demand is greater than what the energy system can supply (undersizing), there will be power cuts and poor quality of supply. Similarly, if the energy demand is overestimated and the supply oversized, the upfront cost of the energy system will be excessive and the revenue or benefit from the provided electricity may not cover the cost of the system.

Off-grid load management

The loads listed above can be classified as baseloads, deferrable loads, daily cycle loads and interruptible loads. A baseload is electricity demand that is relatively consistent and continuous throughout the day and night, such as refrigeration and communications equipment. A deferrable load refers to demand that can be shifted temporally, as required, and includes appliances such as washing machines, pumps, and electronic devices. Daily cycle loads are those that are used at certain times of the day or night on a predictable basis, such as lighting in the early morning and night, and televisions or cooking appliances in the evening. Finally, interruptible loads are those which can reliably reduce their demand for a fixed capacity upon request by the energy supplier to ensure there is sufficient power and supply throughout the day and night.

Understanding user demand profiles prior to sizing and installing a mini-grid, and entering into upfront agreements with certain users to negotiate interruptible and deferrable loads, is thus an important mechanism for balancing supply and demand in the mini-grid design stage. However, as the needs of electricity users change, and as mini-grids expand, supply/demand imbalances will persist, the ongoing management of the energy system demand profile is crucial to ensuring security of supply and maximising the profitability for energy providers.

Supply/demand imbalances generally fall into one of the below five categories:

- Peak demand higher than peak supply;
- Peak supply higher than peak demand;
- Demand peaks do not coincide with supply;
- Overall demand higher than supply; and,
- Overall supply higher than demand.

In response to these imbalances, there are five respective management interventions:

- Peak clipping, where consumption is restricted/reduced at peak demand times;
- Valley filling, where demand is stimulated at low demand times;
- Load shifting, where demand is shifted to peak generation periods;
- Demand reduction, where overall demand is reduced to within generation capacity; and,
- Demand stimulation, where demand is increased to match generation.

Strategies employed for implementing these management interventions include:

- Selling new energy efficient appliances to household customers;
- Selling appliances to business customers to stimulate daytime demand (peak supply hours on solar mini-grids);
- Replacing old appliances with new energy efficient appliances;
- Scheduling commercial loads to match generation time;
- Limiting power consumption;
- Developing energy consuming businesses to create demand;
- Educating customers on electricity benefits to stimulate demand;
- Custom tariffs to increase, shift or reduce demand as required.

The last of the above-listed strategies, customising tariffs, is frequently employed by mini-grid operators. Figure 2 below illustrates a demand-side management incentive profile for an off-grid energy system using solar PV with battery backup. During the 'Normal' periods, demand is generally low and constant (baseload) however there is no irradiation and so the batteries will be discharging. There will typically not be a tariff penalty (increase) or incentive at these times. During the 'Restriction' periods the batteries are either in need of recharging (the morning period) or there is a demand surge (evening period), both of which require the demand on the energy system to be curtailed. The tariffs will typically be increased during these periods and interruption agreements implemented to ensure security of supply and dissuade usage at this time. Finally, the 'Bonus' period is characterised by abundant energy supply, fully charged batteries and a manageable power and energy demand. As such, the tariffs are generally lowered to encourage demand in this period and deferrable loads shifted to this period.

Off-grid regulatory and policy environment

National policies and regulatory frameworks play a significant role in determining opportunities for mini-grid development. A wide array of such policies and frameworks are to be found in Africa; some African regions/countries, such as Francophone Africa, tend to take a centralised and often burdensome approach to licencing procedures, while others, including some East African countries, take bottom up, decentralised and less burdensome approach. However, across the board, the most impactful policies for determining opportunities for mini-grid development are: licencing; concessions; subsidies; tariff setting, and; grid arrival:

Licencing:

While some countries allow mini-grids to be built and operated in a largely deregulated manner, the majority require for licences to be obtained. However, amongst those that require licencing, a wide variety of licencing approaches are taken. For example, some countries require separate licences for generation, distribution and the sale of electricity, while others issue single licences for each of these elements. Further, some countries issue a single licence that allows for multiple mini-grid developments, while others requirement for a single licence per a mini-grid. Capacity thresholds, below which licences are not required for new mini-grids, are also a common feature amongst countries. Further, licencing exemptions are sometimes granted where mini-grids are developed in close proximity to national grids, or where all power produced is used by the entity that owns the project. Throughout Africa, licences are typically granted for 15 – 25 years, allowing for project assets to be amortised.

Concessions:

Some national regulators have looked to attract private sector participation in the mini-grid market through organising concessions that give developers exclusive rights to operate and maintain distribution and generation assets within specific localities for specified periods of time, after which mini-grids are transferred to public ownership. Concession sizes vary widely and can either prioritise mini-grids are a mix of systems that are deemed appropriate by the developer.

Subsidies:

Being relatively nascent, the mini-grid sector will be reliant on subsidies until the market takes off on a commercial financing basis. Upfront capex subsidies, results-based financing (RBF) and tax incentives provide the main types of support that have driven mini-grid development. Upfront capex subsidies typically provide grants or concessional loans to cover upfront costs associated with technical assistance, distribution, generation and metering equipment, while RBF involves the payment of pre-agreed sums when projects reach defined milestones. RBF programmes are increasingly popular, especially in countries with relatively decentralised regulatory frameworks. Lastly, the waiving of taxes on types of renewables equipment in many countries also serves to increase the attractiveness of mini-grid investments.

Grid arrival:

The arrival of a national grid at a mini-grid site is generally viewed as a threat to the viability of the mini-grid; this stems from the expectation that mini-grids would be required to connect to the main grid which could result in the expropriation of mini-grid assets with little compensation, or from the increased competition introduced by a national grid. Developers thus tend to site mini-grids in remote regions that are far away from the national grid, resulting in few cases of grid arrival having yet been experienced. However, for the most part, countries have not set up clear rules regarding grid arrival and are thus ill-prepared for the phenomenon. Solutions mooted, and sometimes implemented, include: governments compensation mini-grid operators through a variety of models; conversion to a small IPP or distributor, where power is sold to the national grid operator, or; operating alongside the grid and offering a superior service to that of the national grid which results in the retention of customers, despite the likely tariff differential.

Tariff setting:

In most instances, tariffs needed to fully recover the costs of a mini-grid (cost-reflective tariffs) are significantly higher than retail rates available on national grids, which are generally subsidized. The issue for mini-grid developers in SSA is that many of the countries in SSA do not have cost-reflective tariffs, as depicted in Figure 2. Only 19 out of the 39 countries assessed in SSA had cost-reflective national tariffs which meant that the state-owned utilities were requiring subsidies to be able to sell the electricity at those tariffs. The viability of off-grid projects in countries that have adopted a national tariff scheme and subsidise the electricity tariffs are severely limited and the returns are in most cases too low to attract investors.

At the other extreme, deregulated, cost-reflective tariffs are often higher than the national utility tariffs in SSA but are still more competitive than diesel, kerosene and oil energy sources that are used in the absence of renewable off-grid electricity. Cost-reflective tariffs more effectively attract micro-grid investment by providing a viable means for developers to recover costs and earn returns, and can thus increase the overall speed of off-grid renewable energy deployment. That said, there may be issues of discontent from users that are paying higher tariffs than their grid-connected peers.

In reality, the tariff scheme may be somewhere in between these extremes either through concessions made by the regulator or government to sell electricity at higher tariffs or through subsidies to the off-grid developer, or through an approvals system whereby the regulator or utility enacts a ‘cost-plus’ tariff system which allows the developer to recover capital costs and operating expenses plus a return on the investment that is agreed and included in the tariff. Further, the affordability of electricity is also a critical factor in determining whether cost-reflective tariffs can be charged or not. Resultantly, tariff related subsidies are generally required in order for operators to recoup capital and operational related expenditure which, in many cases, are provided by national governments or institutional donors.

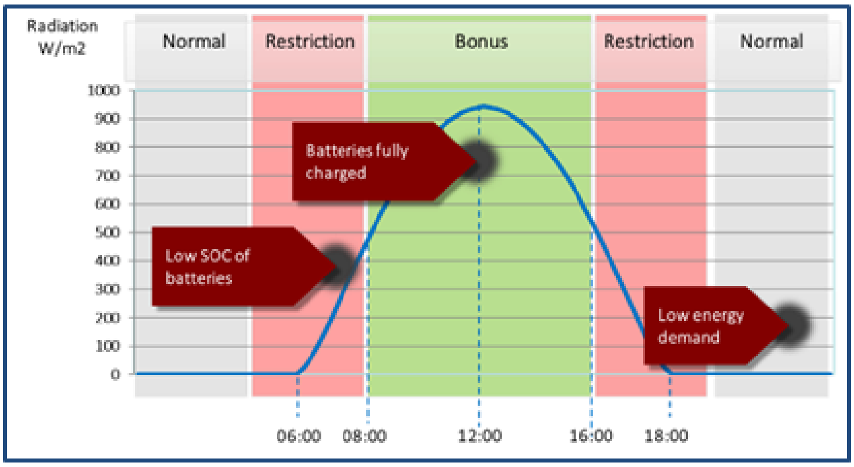

Figure 2. A demand-side management incentive profile for an off-grid energy system using solar PV with battery backup

Interconnected grids

Despite grid arrival often being viewed as a threat to the viability of mini-grids, grid interconnection will provide an increasingly important strategy for achieving universal electrification. This is especially so in sub-Saharan Africa where virtually all national electrification strategies recommend a two-track approach to providing greater access to grid-based electrification – with a centralised track, undertaken by national government, being focused on grid extension, and a decentralised track, generally undertaken by nongovernmental entities and private entrepreneurs, being focused on the development of off-grid solutions. As these tracks progress, grid arrival, and resulting interconnection, will become an increasingly common phenomenon.

Grid interconnection provides distinct advantages for national grids, namely:

- *Exchange of peak loads*: where the peak load of power generators can be exchanged, i.e. if peak demand is greater than the rated capacity of a plant, excess load can be shared by other generating stations interconnected with it.
- *Use of older plants:* where short duration peak load requirements can be met by older plants that would not be able to supply constant long-term generation.
- *Economical operation*: interconnection allows for more efficient generating stations to work year-round, while less efficient generating stations work for peak hours only.
- *Increased diversity factor*: interconnected systems result in maximum demand on the overall system being reduced as load curves of individual stations are generally different.
- *Reduced plant reserve capacity*: reserve capacities of individual generating stations that are interconnected can be much lower than what is required by standalone systems.
- *Increased reliability of supply*: interconnected systems provide a much more reliable electricity supply as continuity of supply can be provided if one station breaks down.

Despite grid arrival often being viewed as a threat by mini-grid developers, in many cases, mini-grids can maintain a competitive advantage post grid arrival for the following reasons:

- Mini-grids, and the non-subsidised cost of mini-grid electricity, can be less expensive than grid extension due to lower capital costs and lower operating costs realised by transmission and distribution loss avoidance.
- The inherent need for mini-grids to strongly pursue demand side management also results in keeping capital costs of generation equipment low relative to demand.
- Mini-grids often provide a more reliable source of power than national grids (especially in Africa, where many national grids are notoriously unreliable) .
- Mini-grid developers can often access development focused finance which is generally not available to utility scale developers.
- Mini-grids can be installed faster than traditional utility grid extension projects can be delivered, and can therefore electrify areas faster than grid extensions can.
- Development and operation of mini-grids creates more local long-term jobs than grid extensions do as generation is embedded within the community.

Additionally, given a favourable regulatory environment and the ability to overcome technical barriers to interconnection, the ability to interconnect mini-grids and national grids can work to address many of the mini-grid demand/supply imbalances previously described, whilst maintaining a loyal off-grid customer base and profitable operation. The potential for grid interconnections that serve the interests of both a national grid and mini-grids, and which work to accelerate the realisation of universal electrification, thus becomes clear.

Regulatory and policy requirements for successful grid interconnections

The World Bank's 'From the Bottom Up – How Small Power Producers and Mini-Grids Can Deliver Electrification and Renewable Energy in Africa' report (referenced below) identifies the following regulatory elements as being key to delivering successfully interconnected grid systems:

- Feed-in tariffs (FITs), referring to the price that a small power producer (SPP, which includes mini-grids) will receive for the wholesale power that it sells to a national utility, is the most important of these elements; FITs need to at least allow for mini-grid operators to cover costs;
- Guaranteed interconnection to the grid with prespecified rules for assigning responsibility for the costs of the interconnection;
- Standardized interconnection and operation procedures;
- Guaranteed purchase of power whenever it is produced by the SPP;
- Physical capability of the purchasing entity to receive the power;
- A fixed, prespecified pricing formula for the purchase of the SPP's power with a clearly defined adjustment mechanism for the life of the contract;
- A regulatory mechanism through which the utility buyer can recover the costs of wholesale purchases from an SPP; this is usually done through an automatic pass-through of these costs to the buyer's retail customers;
- A standardized power-purchase agreement (SPPA) with a duration at least as long as the prespecified FIT pricing formula
- Guaranteed sale of backup power by the utility to the SPP when needed because of planned or unplanned outages.

Technical requirements for successful grid interconnections

Mini-grids generally produce power at between 400 and 3,300 volts, this being much lower than voltages produced by large on-grid generators. When connecting to main grids, voltages thus need to be increased, generally to between 11,000 and 110,000 volts, depending on regional or in-country

requirements. The mini-grids last switch or circuit break is referred to as the point of interconnection (POI), beyond which all technical matters become the responsibility of the main grid operator or

utility. The meter that measures sales to the utility is located at the point of supply (POS), which usually sits adjacent to the POI.

In order to ensure efficient and technically reliable and safe interconnections, it is increasingly an expectation that utilities standardise the application process and technical specifications for grid connections; many utilities have developed a grid code and a distribution code for this purpose. Grid interconnections should incorporate standard protection facilities for preventing damage from overvoltage, under-voltage and over-current. Additionally, voltage thresholds, frequency (hertz), harmonic distortion, and power factor need to be synchronised in the interconnection process.

Generally, mini-grid operators or SPP's would be required to pay for the interconnection. Utilities will either require that operators pay for a 'shallow connection', which includes only the section of line and other equipment from the generator up to the POI, or a 'deep connection' which includes 'shallow section' infrastructure plus upgrades to the upstream network that need to be made to accommodate the additional grid capacity.

There are a number of other highly technical complicating factors that need to be accounted for when connecting mini-grids to main grids, especially if there is a need to keep the mini-grid operating whilst the main grid is down – as would be the case if the abovementioned competitive advantages of a mini-grid are to be realised. For a deeper understanding of these factors, refer to the World Bank's 'From the Bottom Up' report previously mentioned.

Interconnected energy system case studies

Table 1. Interconnection models and their attributes in 4 developing countries

Country	Interconnection Model	Customers served	Interconnected Capacity (MW)	Tariffs (USD per KWh)
Tanzania	Small power producers (SPP) (direct to end-user)	2,200	6.4	$0.13
Cambodia	Small power distributor (SPD)	1,000,000	6-50	$0.12-0.20
Sri Lanka	SPPs (wholesale to grid)	~200	0.08	$0.12
Indonesia	SPPs, SDPs and side-by-side	~2,000	~1.8	$0.037

To date, grid extension has been the predominant focus for providing access to electricity; however, the cost of electricity and speed of deploying solar, hydro and/or biomass mini-grids is competing with grid extensions, particularly in the more remote regions. For remote, unelectrified communities, stand-alone mini-grids have become the most cost-effective means to provide basic electrification as the cost of grid-extension to these areas is uneconomical and the low-levels of demand mean that the revenues do not justify or cover the cost to connect these users to the national grid. That said, for areas where there are mini-grids in place that are soon to be reachable (economically) from the national grid and areas where economic activity is advancing to a level that the electricity demand is outgrowing the ability of a mini-grid to supply, the role of an interconnected energy system in meeting these energy needs will become apparent. In sub-Saharan Africa, for example, mini-grids and the national grids, being AC systems, will electrify over 150 million households by 2030 and integrating these systems into an energy system that is better able to supply reliable electricity to meet rising demand will be required.

There are concerns from mini-grid developers on what happens to their investment once the grid arrives in their locations due to many mini-grids being abandoned when the national grid arrives. There are a few countries where there are regulations and policies in place to ensure the investors investment in the mini-grid is protected with the arrival of the national grid, including Cambodia, India, Indonesia, Nepal, Nigeria, Rwanda, Sierra Leone, Sri Lanka and Tanzania. The arrangements that are adopted when the grid arrives and an interconnected energy system is created vary by country and are largely dependent on the regulatory and policy environments.

Tanzania

In Tanzania, private developers have managed to interconnect their mini-grids to the national utility (TANESCO) via the country's small power producers (SPP) framework. Under the SPP framework, private mini-grids between 100 KW and 10 MW are able to feed-in electricity to the national grid and receive a wholesale electricity tariff from TANESCO for this electricity which it then on-sells to end-users. The mini-grids can also purchase electricity at wholesale tariffs from the utility for resale through the mini-grid infrastructure. One such example of this is the Mwenga 4 MW mini-grid which was developed in 2012 by the Rift Valley Corporation and has been expanded to include a 2.4 MW wind farm. The mini-grid supplies 2,200 consumers in 17 villages and a tea and coffee factory with electricity and then selling excess electricity to TANESCO. TANESCO benefits by having additional generation capacity to sell on to their existing customer base, while the mini-grid developer receives security of demand knowing the excess electricity, not consumed by the tea and coffee factory or the residential consumers, will be sold at an agreed tariff and ensuring utilisation (and revenue) is maximised. The mini-grid can also purchase electricity from the grid during periods where their demand exceeds the mini-grids supply capacity. The tariffs charged to residential customers were equivalent to the national utilities residential tariff ($0.13/KWh) which reduced political opposition to the mini-grid6.

The major issues with this interconnected energy system were that TANESCO's retail tariffs, which it charged end-users using electricity from this mini-grid, were not fully cost reflective and as a result the utility has incurred financial troubles which has affected its ability to meet financial obligations – thus negatively impacting the bottom line of both TANESCO and the mini-grid developers. Additionally, during periods of grid instability, the mini-grid developer would disconnect their system from the grid to avoid triggering their safety mechanisms and protect their equipment; however, to reconnect the mini-grid with the national utility, the developer would have to pay exorbitant (TANESCO peak demand tariffs and 75% of the maximum demand over the previous 3 months) penalties stipulated in the interconnection agreement6.

Cambodia

Another arrangement that has been seen in Cambodia is where the mini-grid converts into a small power distributor (SPD) that purchases all of the electricity that it on-sells from the utility and then distributes the electricity via the infrastructure established when operating as a stand-alone system. As of 2018, over 250 mini-grids in Cambodia have been interconnected to the national grid and are the electricity distributors for 1 million customers. Prior to the regulations being implemented in 2016, these mini-grids were free to determine their own tariffs which would vary based on the cost of the electricity supply.

The Cambodian regulations then enforced standardised tariffs across all interconnected mini-grids and provided subsidies for mini-grids that had higher operating costs than the standardised tariffs. The regulated tariffs were formulated to cover the cost of the fixed capital, the wholesale purchase of grid electricity and to allow a profit margin for the developers. The mini-grid developers were required to invest in infrastructure improvements to ensure the grid power could be distributed effectively through these mini-grids but provided zero-interest loans to assist with these investment requirements. Since the regulations were implemented, these developers have expanded their reach to incorporate more customers and some small mini-grids have consolidated to achieve greater economies of scale.

Sri Lanka

The arrival of the national grid via the Ceylon Electricity Board (CEB) in Sri Lanka did not see the same level of success for private developers as in Cambodia. Sri Lanka had an abundance of community operated micro-grids generating hydroelectricity with an installed capacity of 7.5 KW and serving 27 customers on average. Cumulatively, these micro-grids electrified 10,000 households and had an installed capacity of 4 MW10.

Due to their typically small size and customer base, transforming into SPDs was not economically viable and the arrival of the grid with lower, though not cost reflective, tariffs and a higher quality of electricity meant that over 100 of these micro-grids were abandoned. Only a handful of these community-owned micro-grids managed to convert their operations into SPPs, although not in the same arrangement as in Tanzania. The Sri Lankan SPPs were not allowed to provide electricity directly to end-users and instead could sell electricity wholesale to the CEB for the utility to on-sell to the end-users. The end-users that were connected to the micro-grids previously were required to disconnect and connect to the national grid, most were willing to do so due to the lower cost of electricity from the grid and the removal of supply limitations which enabled them to power more appliances than the micro-grid could handle.

The micro-grid developers had to finance the interconnection upgrades and had to pay for government approvals, which is a major factor in many being abandoned as these community-owned organisations lacked the financial resources to make these necessary payments.

Indonesia

Indonesia has seen the emergence of multiple energy systems resulting from the arrival of the national grid in areas previously electrified by mini- and micro-grids. Small hydroelectric grids were developed with government and international support since the 1990s which resulted in more than 1,300 independent micro-grids being developed across the country. The regulatory environment was not conducive initially for mini-grids to become interconnected energy systems with the national grid as law did not permit government-funded micro-grids to connect to the national grid under an SPP or SPD arrangement until 2017. The issue was that the vast majority (80%) of the micro-grids in operation were government-funded10.

As a result, only 6% of the micro-grids in Indonesia remained in operation after the arrival of the national grid and the customers served by the defunct micro-grids were then supplied by the national utility.

Of those that have remained operational, 9 have adopted a SPP arrangement whereby the micro-grid sells electricity at wholesale to the national utility (Perusahaan Listrik Negara (PLN)) at government-agreed tariffs, similar to the Sri Lankan experience. 4 projects continued selling their electricity directly to end-users while also selling electricity, at wholesale, to PLN in a similar fashion to the Tanzanian model10.

Lastly, there are up to 50 micro-grids in Indonesia that are operating side-by-side to the national grid but which are not interconnected creating a unique parallel electrification system whereby some customers are serviced by the national grid and some by the micro-grid that was present before the national grid arrived. The reason for this unique arrangement is that the tariffs from the micro-grid (being hydro-powered projects) were often lower than the national utility’s tariffs or the connection fee charged by the national utility was excessive and unaffordable for these households which resulted in them maintaining their connection with the micro-grid operator.

It is thus evident that while the arrival of the national grid can pose a threat to the survival of private mini-grids, there are mechanisms that have been proven effective in marrying the two into an interconnected energy system to the benefit of the end-users through reliable and consistent electricity supply, the mini-grid developers through expanded supply and improved utilisation rates, and the national grid by leveraging private capital deployed into distribution infrastructure and additional electricity supply capacity.

Industry Associations

- **GOGLA**: GOGLA is the global association for the off-grid solar energy industry. Established in 2012, GOGLA now represents over 170 members as a neutral, independent, not-for-profit industry association. Its mission is to help its members build sustainable markets, delivering quality, affordable products and services to as many households, businesses and communities as possible across the developing world.
- **The Alliance for Rural Electrification (ARE):** ARE is an international business association that promotes a sustainable decentralised renewable energy industry for the 21st century, activating markets for affordable energy services, and creating local jobs and inclusive economies. ARE operates across 50 countries, 3 continents and has 150 members.
- **African Minigrid Developers Association (AMDA):** AMDA is Africa's first trade association dedicated exclusively to the mini-grid industry, and is composed of developers operating AC mini-grids that ensure power reliability of at least 20 hours per day. The association also works closely with a variety of solution providers, including EPCs, hardware and software vendors and integrators.
- **African Association for Rural Electrification (CLUB-ER):** The objective of Club-ER is to accelerate the development of access to electrical energy services in the rural areas of the African continent, by creating relevant conditions and by systematising the beneficial pooling of experiences and resourcing among domestic agencies and structures in charge of rural electrification.

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Please contact your Client Relationship Manager if you want help with introductions to specific individuals with these institutions