SCALING SOLAR HYBRID MINIGRIDS: AN INDUSTRY ROADMAP

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The following organizations participated in the development of the roadmap. Their inclusion below is not an endorsement of the contents herein:

- Africa Minigrid Developers Association (AMDA)
- Duke University Energy Access Project
- IIT – Universidad Pontificia Comillas
- Integration Consulting Group
- International Energy Agency (IEA)
- International Renewable Energy Agency (IRENA)
- Minigrid Innovation Lab/Crossboundary Energy Access (CBEA)
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- Rochester Technology Institute (RTI)
- Rocky Mountain Institute (RMI)
- SEforALL
- USAID/Power Africa
- World Bank
- World Resource Institute (WRI)

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INTRODUCTION

Minigrids: the path to SDG7 and net-zero rural growth

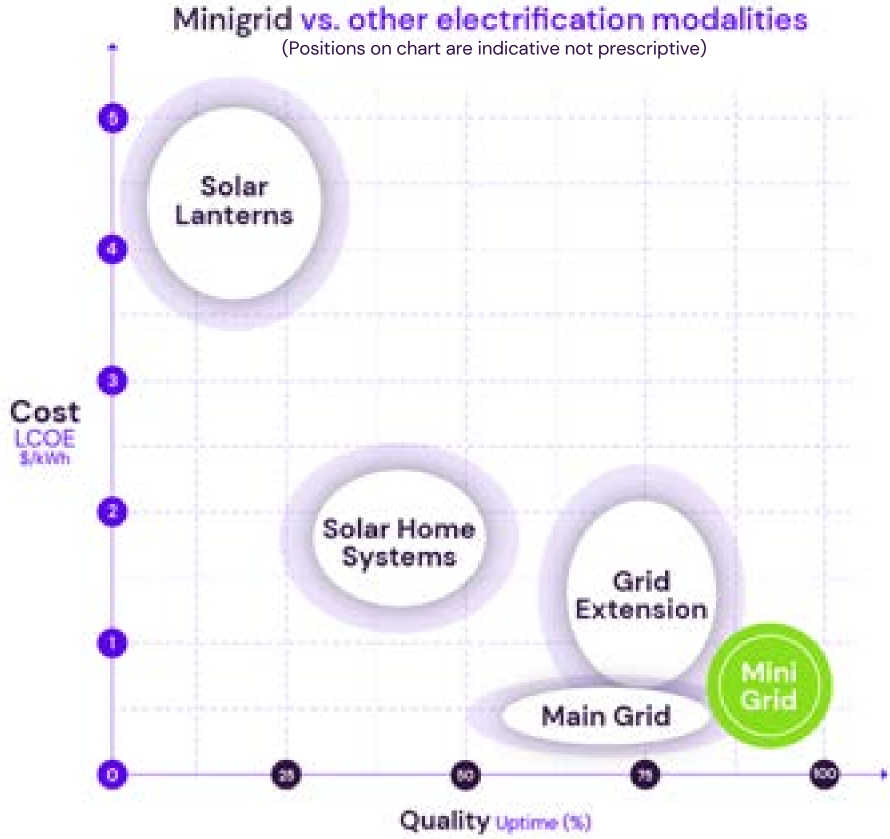
Energy is key to both economic and social development. Although the United Nations has acknowledged the importance of clean, modern and affordable energy in its Sustainable Development Goals (SDGs) with Goal 7, energy is in fact pivotal to at least 9 of the 17 SDGs. Affordable energy is required to fight poverty, provide a modern education, ensure health and safety, provide clean water and sanitation, build infrastructure (energy is infrastructure), create jobs, and economically produce and deliver food. We need to do all this in a way that also supports the fight against climate change.

It is now widely accepted by development banks, national governments and multilateral agencies[1] alike that providing this clean and affordable energy universally can only happen on a reasonable time scale by scaling solar minigrids. More than 700 million people still have zero access to electricity, while up to 3 billion more only have access to unreliable power. Energy access is not only a basic human right, it can help reduce civil unrest, unemployment and migration and increase climate resilience. Most importantly, scaling minigrids can also power rural economic growth for nearly half a billion people.

While 2010-2020 saw success in providing basic levels of electricity from small-scale solar for lighting and phone charging, 2020-2030 must be about providing productive levels of energy that can catalyze better livelihoods, what is often referred to as “modern energy”. This is energy that can power the food value chain (irrigation, agro-processing, cold storage) and rural industry, help achieve better healthcare and education outcomes, and enable access to clean drinking water, the digital economy and much more. Centralized power utilities have failed for decades to fulfill this role and continue to be mired under poor management and heavy debt[2]. Diesel generators, which have filled the gap left by grid failure[3], are also no longer an affordable option, either economically or environmentally. The most cost-effective, sustainable solution is the solar minigrid.

The chart below clearly demonstrates the advantage of minigrids compared to rooftop solar and the grid, based on Levelized Cost of Electricity (LCOE) vs. availability. Small-scale solutions like solar lanterns and solar home systems (SHS) are great innovations to bring clean energy to non-electrified communities, but are both relatively expensive and unable to provide the levels of energy needed to enable development.

1 See data from World Bank, IEA, European Commission
2 World Bank, only 2 of 39 Sub-Saharan African (SSA) countries have profitable utilities
3 Wood Mackenzie, 17 SSA countries produce more power from diesel generation than the grid



State-owned utilities on the other hand are more affordable (thanks to subsidy) and have decent quality of power. But decades of experience have shown that they are also unable to provide reliable service, especially in hard-to-reach areas. They are designed purely to sell electricity, whereas mature minigrid developers excel at service provision and working with communities to foster greater economic activity, including through the financing of energy efficient appliances and productive machinery.

Minigrids are part of a global trend towards distributed energy resources (DER). This is community-based energy, where locating the generation of energy close to the end-customer results in a more robust, reliable, resilient and lower-cost energy system. With scale, DER can achieve costs similar to the main grid, deliver 24/7 renewable electricity to households, small businesses and factories, and most importantly help communities develop demand through encouragement of productive uses of electricity. This last point is critical, as DER, including minigrids, can provide the building blocks for self-sufficient community development. Productive use of energy is what will kick-start rural economies in a way that lifts people out of poverty.

Despite the urgency of scaling minigrids to achieve SDG7, the nascent industry is still struggling. After more than a decade of effort there is still no profitable minigrid developer. Some investors have withdrawn from the sector citing the “lack of a viable business model”. If capital flows into the minigrid industry decline, SDG7 will surely fail. What is missing is a clearly defined pathway for minigrid developers to get to sustainability and scale. Other industries have benefited from roadmaps that set forth such a path, with clear and specific metrics and timelines for achieving those metrics.

ROADMAP OBJECTIVES

As such, this roadmap is an attempt to identify the key characteristics for sustainability and scale for the minigrid industry, and to select the appropriate metrics and timelines to achieve them. Although this effort has received input from investors, private developers, think tanks, researchers, and industry associations, this is not intended to be a definitive roadmap. New industries are always changing, and this roadmap will no doubt evolve with the industry. It is important, therefore, to clearly outline the objectives of the roadmap.

What this roadmap does

- Defines barriers to industry sustainability and scale: outlines the key areas for private sector developers to address for the industry to become profitable and to scale.

- Decodes what success looks like through specific and measurable KPIs: frames what actions the industry must take and provides the means to measure success.

- Provides targets: sets clear goals for investors, donors, and private sector R&D that will drive investment to solve the industry's most pressing challenges.

- Raises the level of ambition for the industry: the industry is still walking and needs to run if the international community is to meet SDG7 by 2030.

- Reframes the discussion on metrics such as cost: the industry has to date measured Cost Per Connection. We recommend instead basing that measurement on Levelized Cost of Energy (LCOE), the standard energy industry metric for cost.

- Redefines market type: instead of defining markets by country, we suggest defining markets by community type, which considers key socio-economic factors at the local, not the national level. This is an important new framework for thinking about market development, and a key consideration in the viability of minigrid business models.

What this roadmap does not do

- Attempt to directly resolve issues the industry cannot control: Energy is a highly regulated industry, with many important issues decided by government. This roadmap focuses on actions and outcomes that are within the control of the private sector. Government-controlled issues are highlighted to show their impact and to stimulate healthy discussion, but no specific policy recommendations are made.

- Make recommendations on subsidy: there are different opinions within the industry on the appropriate role of subsidy in the minigrid sector. As such this roadmap attempts to highlight and clarify the issue but does not seek to determine what is the correct solution.

- Define market readiness: Different countries and different communities within those countries are at different levels of development, which determines whether operating minigrids is more or less economically viable. This roadmap attempts to clarify these issues, but does not define readiness of any particular region or country.

BACKGROUND

Barriers to Sustainability and Scale

Despite a crystal-clear value proposition, sustainability and scale for the minigrid industry have been elusive. The key reason is lack of a business model that is sustainable and replicable. Without a successful business model, it is very difficult, maybe impossible, to attract the necessary capital to scale.

Lack of a Working Business Model. The industry needs a business model that is profitable, not just at the minigrid site level itself, but which also provides enough margin to cover administrative overhead. It is this viable business model that will unlock the $127 billion in capital which the industry needs to scale. The three major components to achieving a working business model — cost, service, and demand — have been broken out separately to bring more detail to the solutions needed.

1. Costs are too high: Unlike the grid, which is heavily subsidized and does not charge cost-reflective tariffs, minigrid developers receive little, or at best inconsistent, operational subsidy. In addition, at this stage of the industry's development, minigrid developers are typically too small to achieve significant economies of scale. As a result, costs remain high and minigrid energy is not affordable for many people living below the poverty line unless subsidized like the main grid.

2. Service must be better than the grid: Not all minigrid developers achieve the needed uptime, customer service response times and quality of power (3 phase AC with good voltage and frequency control) to meet customer needs. National grids often provide poor-quality power. Minigrids must meet the quality needs to both justify the cost and meet the demands of productive use loads.

3. Demand is too low: Minigrid developers must put considerable effort into generating demand. However, many companies continue to act like traditional utilities and focus only on generation. Lack of sufficient demand has led to many unprofitable minigrid companies, which makes it impossible for them to scale.

Inability to Scale Fast Enough. Once the above business model challenges are met, the work is not done. The rate of deployment must also increase 10 times. As many as 200,000 newly built minigrids are required by 2030 to end energy poverty. Today there are 20,000.

With the industry building less than 1,000 minigrids per year it will take well over a century to reach the 2030 goal. With a forecast of more than 100 years versus an SDG target of 8 years, the industry needs at least 10 companies building minigrids at 10 times the current pace to meet the need.

Subsidies for Scale vs. Subsidies for Cost: most often we hear the case for subsidization revolving around off-setting costs (subsidies are discussed in more detail later). Clearly it is more expensive to electrify the hard-to-reach communities which live off-grid. But whereas cost subsidies make sense in many cases, an even stronger case might be made for incentives to drive scale. If the world wants to see an order of magnitude increase in deployment rate, it might make sense to provide a subsidy that is higher than just the amount needed to marginally reduce the cost (i.e. a higher than market rate return), and thereby incentivize even more rapid scaling. This technique was used very successfully in Germany to promote a world-leading rate of solar deployment. By offering a lucrative FiT (feed-in-tariff), the private market brought all the technology, capital and resources needed to build clean renewable energy at an incredible pace.

Building on Previous Roadmaps

For the industry to overcome these challenges, the entire ecosystem needs to have clarity on what is needed and how to get there. To achieve such clarity, other industries have relied on industry roadmaps. A roadmap provides an opportunity to develop consensus on goals, to provide the metrics to measure success, to drive the needed innovation, and to steer investment towards achieving the needed technical and market milestones. In an extraordinary success story, the semiconductor industry put forward a technology roadmap that guided both public and private sector R&D for decades. Over a hundred billion dollars was guided by the roadmap. The milestones were not only achieved but exceeded and led to a revolution in the way the world works.

The World Bank has created a similar framework for the minigrid sector (shown to the right). This was an important step forward, as it defined key barriers to growth, and provided detailed metrics and timelines. However, these metrics are more generally applicable, for use by government and investors, as well as minigrid developers. A more developer-centric roadmap would be beneficial by providing minigrid companies with clear metrics that are within their control.

Objective/Indicator	2018 Baseline	Target 2020	Target 2025	Target 2030
1 | Increase Pace of mini grid development				
Time from PO to commisioning (weeks)	6-12	7	6	5
Time from goods arriving on site to commisioning (weeks)	6-12	5	4	3
Mini grids per portfolio per year	10-50	>100	>250	>750
2 | Provide superior-quality service				
Develop industry-wide standard for minimum technical specifications	Under preparation	For solar HMGs	For solar & hydro HMGs	For all RE minigrids
Industry-wide reliability - uptime	90-97%	97% part-time	97%-24/7	99%-24/7
Customer satisfaction	83-84%	85%	88%	90%
Average industry load factor	22%	25%	35%	45%
3 | Establish enabling mini grid business environment in key access deficit countries				
Average RISE score for minigrid framework*	59	60	70	80
Average Doing Business Score*	52	55	65	75
4 | Crowd in government and private-sector funding				
Ratio of government and private funding to donor funding	1.7 : 1	3 : 01	5 : 01	10 : 01
Ratio developer investment: donor funding	7 : 01	8 : 01	9 : 01	10 : 01
Billions of dollars invested	28	40	93	217
5 | Reduce cost of solar-hybrid energy				
Levelized cost of energy ($/kWh)	0.55	0.3	0.25	0.2

* refers to top 20 electricity access deficit countries

MINIGRID INDUSTRY ROADMAP:
A Path to Sustainability and Scale

Toward that end, the authors are proposing a new roadmap specifically for minigrid developers. Although it focuses on developers, it also highlights areas where governments and regulators influence the viability of the minigrid business model. It deviates from the World Bank roadmap in the following ways:

1. Categories that are outside the control of minigrid companies are limited and separated to allow for very developer-specific KPIs.

2. New categories such as "Demand" and "Viable Business Model" are added, as they are key to success for any developer.

3. In each section, metrics are added or adjusted to better reflect industry needs. Some metrics are removed due to over-specificity. Metrics, where possible, should measure outcomes, not "how" the outcome is achieved.

4. Lastly, a more aggressive timeline is envisioned. Minigrids are not being deployed at anywhere near the rate required to meet 2030 targets. The industry must accelerate both technical and business model innovation.

Sustainability and Scale

As the structure of the roadmap suggests, there are two over-arching industry goals: sustainability and scale. Cost, quality of service and demand are key drivers in determining the viability of an individual minigrid, sometimes in the industry referred to as unit economics. If an individual unit is not profitable, one cannot make it up in scale and there is no use in replicating the business model. Even then sustainability requires some level of scale locally so the profit from each unit is enough to cover corporate overhead. This local scale varies country to country but is important to assess ahead of time so the developer has a pathway to sustainability.

Achieving scale on an industry-wide basis in the desired timeframe is an entirely different issue. Achieving scale per the World Bank's goal is more about rate of deployment. At least 10 developers must deploy minigrids at 10 times today's fastest rate to achieve sector goals. This scaling is far beyond what is needed for sustainability.

Proposed Minigrid Industry Roadmap

	World Bank[1] or Industry[2] 2020	World Bank[1] or Industry[2] 2025	World Bank[1] or Industry[2] 2030	Proposed Roadmap 2025	Proposed Roadmap 2030
Sustainability					
Viable Business Model					
Local Scale (minigrids/country/developer)[7]	10	40	80	100	400
ROI[6]	-neg-	0%	5%	8%	12%
Cost - LCOE ($/kWh)	$0.30	$0.25	$0.20	$0.23	$0.17
Base CapEx ($/watt)	$2.90	$2.70	$2.50	$2.25	$2.00
OpEx ($/kWh)	$0.20	$0.18	$0.15	$0.15	$0.12
External Cost Factors[8]					
Cost of Doing Business ($/w)	$1.00	$0.75	$0.50	$0.50	$0.25
CapEx Subsidy ($/connection)[5]	$450	$325	$200	$200	$100
Quality (24/7)					
Uptime[3]	97% (pt-time)	97%	99%	95%	97%
Response Time (average)	6 hrs.	3 hrs.	2 hrs.	2 hrs.	1.5 hrs.
Demand					
ARPU (average revenue per user)	$6	$8	$10	$10	$12
Load Factor/CUF (capacity utilization factor)	25%	35%	45%	50%	65%
Scale					
Scale - Rate of Deployment					
Install Time (weeks)	7	6	5	4	2.5
Throughput (minigrids/year)[4]	100/yr.	250/yr.	750/yr.	600/yr.	1,800/yr.

Notes:

1. "Mini Grids for Half a Billion People", World Bank ESMAP.
2. Where the World Bank has not reported metrics, Husk has projected based on industry averages.
3. For Uptime, "97% pt" refers to part-time.
4. Throughput requires at least 10 companies achieving this rate per year to meet World Bank goals.
5. CapEx subsidy: many markets are not commercially viable and require subsidy. These numbers are for reference only, but project a trend away from subsidies over time.
6. Investor expectations vary widely vis-a-vis ROI. The intent of the roadmap is to achieve consensus on this.
7. Average number of minigrids per country per each developer.
8. These factors are outside developers' control, but often strongly influence cost and contribute to whether a viable business model is possible.

Sustainability

As mentioned above, sustainability requires both a viable business model at the individual minigrid site level and some degree of scale to cover overhead. The three components that drive the viability of the business model are cost, quality of service and demand.

Cost - LCOE

Cost may be the most important factor in the roadmap. Not only is it key to the viability of the business model, but it is also crucial to opening up the market. Energy demand is highly elastic. If electricity costs are more than $1.00/kWh, the minigrid market for rural communities is very small. Only wealthy individuals and small business owners could afford it. Alternatively, a cost of less than $0.20/kWh would put minigrids on par with many African utilities. Hundreds of millions of people with no access to energy could afford some level of service.

The internationally accepted measurement of electricity cost is Levelized Cost of Energy (LCOE). LCOE alone is sufficient to measure cost, but this roadmap has listed the key components of cost to better highlight the needed change. LCOE is the total cost to produce electricity over the life of the power plant (typically 25 years), divided by the total energy sold by the power plant during that timeframe. This definition is slightly different from some other power plant applications, because in most cases it is assumed that 100% of the energy output of a power plant will be sold or consumed. Minigrids are a unique solution in that for literally every installation the entire output of the power plant is NOT used. The unused power is a huge inefficiency in the industry and must be accounted for in the cost calculation.

A simplified formula for LCOE is shown below. It is used merely to demonstrate the importance of the capital expenditures (CapEx) and operating expenditures (OpEx) sub-KPIs used in the roadmap. The actual LCOE formula is quite complicated as it must include all costs over the life of the power plant and even include the cost of capital (or discount rate) over that timeframe. There are many sources for a detailed LCOE formula, including IEA, NREL, Stanford University and others.

$$\textbf{LCOE} (\$/kWh) = \frac{\text{Lifetime Costs including both CapEx + OpEx}}{\text{Lifetime Energy Sold (kWh)}}$$

CapEx

CapEx is the total cost to build a power plant. These costs are all-inclusive of land, labor, hardware, software, and engineering. Everything must be counted. CapEx is complicated by the fact that each country treats imports differently and can apply duties, taxes, and other costs which can potentially double the landed-at-port costs compared to the deployed-at-site costs. To further complicate the issue the government can also offer subsidies which effectively reduce the costs. So, there are potentially both positive and negative factors influencing the final CapEx, and the impact can be substantial. If the inherent CapEx, based on design and supply chain costs, is the base, the final costs can range from 0.5 times to 2.0 times the base.

These factors must be separated to develop usable KPIs for both developers and regulators. One metric is controlled by the minigrid developer and the other is controlled by the government and regulators within the country. Toward that end we are suggesting the following KPIs:

Base CapEx or CapEx

The Base CapEx, or simply CapEx in this roadmap, is the inherent cost of the system. It is determined by the minigrid developer and their ability to take advantage of innovative design and frugal engineering, and also to optimize supply chain and logistics.

External Cost Factors

Factors exist which are outside the control of developers. These can affect CapEx and must be added to the Base CapEx in the final LCOE calculation. There are both negative impacts (cost of doing business) and positive impacts (CapEx subsidy).

Cost of Doing Business - The Cost of Doing Business addition to CapEx is dependent on the country in which the minigrid developer operates. It is determined by taxes, duties, in-country transportation costs, and "supplemental costs of doing business" (including questionable payments) that are sometimes experienced in areas of operation. These costs are determined by national and sub-national authorities.

CapEx Subsidy – Subsidies are a complicated topic with technical, economic and political aspects. Subsidy can take many forms, including: temporary or permanent, CapEx oriented or OpEx oriented, and cost-reflective or policy-driven. In modern integrated planning, it is common knowledge that cross-subsidies (between different parts of an integrated distribution network) are almost unavoidable regardless of whether a minigrid is grid-connected or independent. Even so, what is appropriate in any given situation is beyond the scope of this paper. Our goal is to highlight the impact of subsidy and clarify where they might help or hinder the sustainability and scale of the minigrid sector.

OpEx

OpEx is the total cost to run the power plant for 25 years. As with CapEx these costs must be all-inclusive of any recurring cost in land, labor, hardware, software, engineering, maintenance, replacement parts, supplies, etc. Everything must be counted. The preferred metric for OpEx is similar to LCOE, $/kWh. It is the total of all operating costs divided by the total energy sold over the same period. In classical power plants this ranges from less than $0.01/kWh to over $0.10/kWh, with diesel generators usually on the high end and low maintenance solar or hydroelectric power on the low end.

Lifetime Energy Sold

With minigrids, the denominator of the LCOE equation, energy sold, is different from developed markets, where typically all of the energy produced by a power plant is sold. Therefore, for those markets, the calculation for the energy produced is 100% of the electricity a power plant can produce. However, in off-grid or weak-grid markets, demand is often weak and energy produced is often wasted. Measuring total capacity does not reflect the true cost of energy. One must measure the actual energy used by consumers, not theoretical production. This is referred to as Capacity Utilization Factor (CUF), which measures the percentage of energy sold compared to total possible production. To illustrate the gravity of this problem, the average minigrid CUF in Africa is about 30%. In other words, just one-third of a power plant’s generation is actually sold to customers. This obviously drives up the cost of energy.

Other Issues:

Cost Per Connection - one of the metrics frequently used in the energy access world is Cost Per Connection (CPC). It drives many of the minigrid subsidy programs in Africa. Nonetheless, CPC is a flawed cost metric. It can potentially lead to bad behavior as companies, taking advantage of CapEx subsidies, optimize for short-term cash, as opposed to long-term service. It turns out that CPC is an indirect measure of CapEx; the total CapEx divided by number of customers connected. As such, it incentivizes minigrid developers to connect as many customers as possible to get a big payout under results-based finance (RBF) schemes, regardless of demand or on-going support requirements. If these customers are not economically viable, they could be abandoned later. For sheer economics, it is far better for a minigrid developer to have one customer consuming 10,000 watts than having 100 customers each consuming 100 watts. Revenue is the same either way, but both the CapEx and OpEx are higher with 100 customers. It makes no sense to incentivize CPC without making sure the business model works long-term.

Capacity Utilization Factor – CUF could be included as a KPI in this cost section as it has a direct impact on cost, but is listed as a demand KPI instead. Although CUF has an impact on cost, it is primarily a measure of how much energy is used and therefore is a better fit as a demand KPI. In addition, the industry needs a strong and easily measurable metric for demand generation and CUF meets those criteria.

Quality

Quality of service is important for the off-grid market, but maybe even more important for weak grid markets where the grid only produces electricity for 4-8 hours per day. In these weak grid conditions, many of the benefits of energy access never materialize. Households might be willing to accept infrequent service, but businesses and factories are often very negatively impacted. As a result, revenue generation, job creation, and wealth accumulation are all limited. It is this economic activity, not lighting homes, that will lift communities out of poverty, as outlined by the Modern Energy Minimum (MEM) framework[4].

There are many measures of quality, including stable voltage, current and frequency. But to simplify, the new roadmap aligns with the World Bank benchmark around uptime and adds quality of service as well:

Uptime

Of all the metrics suggested by the World Bank, this is the only one where we recommend a less aggressive number: 97% as opposed to 99% for the final 2030 goal. Importantly, the shorter-term goal is even lower at 95% by 2025. These suggested changes are because cost and the resultant tariffs required for profitability are more important than the extra few percentage points of uptime. Unfortunately, uptime is directly related to cost and it is not a linear relationship. Achieving that last 2-4% of uptime would significantly increase LCOE and therefore customer tariffs. Paradoxically, higher uptime beyond 97% could actually impede the goal of eliminating energy poverty.

Response Time

A metric for response time is included to represent a level of customer support and satisfaction. State-owned utilities are typically abysmal at customer support and satisfaction, and this is an important area of differentiation for the minigrid industry. As it will be difficult (on an unsubsidized basis) to compete on tariffs in the near term with the heavily subsidized main grid, service and quality from minigrid developers must be excellent to guarantee a viable business model, whether the grid arrives in the future or not.

Also, in many cases it is likely that the main grid and minigrids will co-exist, either in competition or in collaboration. It is true today in India where minigrids and the main grid compete. The minigrid business model that survives does so through customer satisfaction.

Demand

Demand is perhaps the major Achilles' heel for the minigrid industry. Paradoxically, if people or businesses are not used to having reliable electricity or have no electricity at all, despite a huge pent up demand, it does not automatically translate into consumption. There are simply few if any appliances to consume electricity. Why would someone buy a TV if there is no power to run it? As a result, minigrid developers typically have to generate supply and demand if they want to be economically viable.

There is no commonly accepted method to measure demand, but the most important to a minigrid developer is the economic impact of that demand. To that end, the recommended metrics are Average Revenue Per User (ARPU) and Capacity Utilization Factor (CUF).

[4] Energy for Growth Hub

ARPU

The industry accepted metric for revenue is ARPU. Obviously, as demand goes up the revenue per user should go up and more of the power plant capacity will be used. The typical ARPU in Africa is around $6.00/user/month. This explains one of the challenges for a viable business model as the ARPU needed (depending on LCOE in that country) to break even might be closer to $9.00-$10.00. Increasing ARPU is easier said than done, but there are some success stories that show it is possible.

CUF

CUF is the quantity of electricity sold relative to the maximum produced; basically comparing supply to demand. In solar minigrids this maximum varies based on location and the amount of sunlight. This is a great metric to indicate how efficiently a minigrid operator is using the generating capacity. It is a function of appropriate sizing of the minigrid to begin with (don't build unneeded capacity) and then driving the demand curve to best match the supply curve. This is a challenge for solar-powered minigrids because the maximum production is during daytime and the maximum usage begins just as the sun is setting. Fundamental analysis indicates that anything less than 50% utilization is unlikely to result in a viable business model. This is a challenge for most developers because the industry average is about 30%.

LF vs. CUF

The World Bank uses Load Factor (LF) to measure effective use of electricity generating assets. LF is the average kWh delivered to customers divided by the peak load. This metric is commonly used in utility companies. In that case, LF is relevant, as typically all the electricity that is produced is used and generating assets are brought on-line or off-line to match supply to demand. It is a less effective metric with 100% renewable energy minigrids, where a substantial amount of electricity produced is not utilized and almost all the generating capacity varies based on the amount of solar irradiation. With solar minigrids the peak load might be only 50% of the minigrid capacity. The LF would not take into account the inefficiency of an oversized minigrid. The CUF includes non-utilized capacity and therefore better highlights the challenge of managing an off-grid minigrid. Although LF and CUF are similar and often track each other, the recommendation is to use CUF going forward for solar minigrid power plants.

To measure demand, ARPU and CUF are not perfect, but together they go a long way to describing the health of a minigrid business. These two along with LCOE are probably the top three metrics to determine if a developer has a viable business model.

Viable Business Model

This is a unique criterion for a roadmap, as it is financial as opposed to technology or market driven. It is included to draw attention to the fact that without a sustainable (profitable) business model the minigrid sector will fail. It is estimated by the World Bank that the sector needs to attract $127 billion in investment before the end of the decade to build out the required minigrid infrastructure. To do this, the industry needs the right kind of investors deploying the appropriate amount of capital. In any case, investors will need to see a return on investment (ROI). Much of what is required to generate an ROI is included in the above metrics of cost, quality and demand. Hitting the targets will ensure profitability at the minigrid site level. In addition, some scale is required at the local level to cover corporate overhead costs in the territory of operation. Therefore, there are two metrics for business viability: local scale and ROI.

Local Scale

Profitability at the minigrid site level is not sufficient. Every developer has overhead within a country, certainly for administration and probably for sales and marketing if they are driving demand as suggested. Covering this overhead is significant, as profit margins are typically slim at each site. It is estimated that at least 40-100 sites are required to cover overhead in most areas. This is very dependent on the specifics of the minigrid operator and the country in which they are operating, but rough guidelines are provided to create industry targets that move to total profitability at the corporate level.

Return on Investment

ROI is an output metric more than an input, as it measures how the final result of all the other metrics combined. A discussion with the investor community is required to establish the final ROI metrics. While a higher ROI is better for investors, it often requires minigrid operators to raise their tariffs, making energy less affordable for customers. Some investors actually want to see higher impact (more connections, therefore more customers) but others focus on profitability. With some investors these are dueling goals, often resulting in mixed signals and confusion among minigrid operators. One of the reasons to add this to the roadmap is to drive these discussions and achieve a consensus on the optimal ROI vs. impact scenario.

Note on specific ROI recommendations: the above scenario is already playing out for some minigrid developers. Based on a survey of different companies, ROI is as high 15%, yet the roadmap suggests 8% is appropriate for 2025. Developers with higher ROI could significantly increase the number of customers currently being served by lowering tariffs (i.e. offering more affordable electricity), but this would reduce ROI. More research is required, but ROI is likely to vary according to both market type and business model. Specifically, as developers expand into harder-to-reach communities, industry-wide ROI may be lower in 2025 than what industry leaders are achieving today.

Other Considerations Vis-a-Vis a Viable Business Model

There is a complication in regard to the minigrid business model. Throughout history electrification has been subsidized and this is particularly true of Africa today. Even with subsidies, almost all Sub-Saharan African utilities lose money. This is somewhat shocking considering that they have enormous scale (as compared to minigrids) and are typically supplying the more affluent and easy-to-reach urban communities. Rural Africa is less affluent and more expensive to reach. Therefore, it seems obvious that minigrids, which currently lack economies of scale, would have a hard time serving the hard-to-reach rural communities profitably. After a decade of hard work by minigrid developers, this has proven to be the case. There is currently no profitable minigrid company.

As a result, most industry experts have concluded that minigrid companies cannot succeed without subsidies. The authors do not 100% subscribe to this belief, but recognize that subsidies are required in many markets. To clarify this point, a market segmentation has been developed as part of the roadmap. Looking at per capita GDP, amount of economic activity driven by MSMEs and size of markets, we find three distinct market types:

1. Concessionary Markets: some communities are too poor to support a commercially viable minigrid market. Subsidies are required and it could be a perpetual requirement if the underlying poverty is not addressed.

2. Bridge Markets: some communities have good fundamentals, but electricity demand is still insufficient today. Concessionary capital is suggested to bridge the gap until ARPU and CUF rise to profitable levels. This period would last 3-5 years if this was a true transitional market. In this scenario, the concessionary financing becomes a bridge to viability as opposed to a permanent subsidy.

3. Commercially Viable Markets: these communities will support a profitable minigrid sector today. Not all developers have the cost structure or demand generating capability, but those are developer limitations. The technology is available, and the market is viable today.

Market Segmentation of Minigrid Industry in Africa

Concessionary Markets	Bridge Markets	Commercially Viable Markets

• Not viable without grants
• No roadmap to profitability
• Serving most difficult markets
• Focus on households
• Metrics used:
  ◦ $/connection and number of beneficiaries
	• Need grants for bridge period only, 3-5 years
	• Clear roadmap to profitability
	• Serving marginal markets
	• Focus on MSMEs & households
	• Metrics used:
	  ◦ commercially viable metrics
		• Grants not needed, but helpful for 18-24 month scaling period
		• Profitability at 40-80 sites/country
		• Serving stronger markets
		• Focus on MSMEs, factories, institutions & households
		• Metrics used:
		  ◦ LCOE < $0.30/kWh
		  ◦ ARPU > $10/customer
		  ◦ CFU > 50% utilization

"Perpetual grant model"	"Bridge to viability model"	"Working minigrid model"

Currently within the minigrid industry, companies and other stakeholders typically look at the above market types through a country lens, but in reality the markets are much more nuanced than that. Within every country there are pockets of wealth and poverty, and typically the more rural the community the less economically viable it is. As such, markets are best described as regions or communities rather than entire countries. This is an important new framework for addressing energy access at the country level, as all three market types are likely to exist within the same country, and therefore each will require different levels of subsidy. There is no one-size-fits all approach for each country.

Segmentation vs. Subsidies

This market segmentation may be useful when discussing appropriate subsidies. It is clear that the optimal subsidy strategy would differ between market segments. Some markets require subsidy and others do not. Also, the form of subsidy should probably also be adjusted. Whereas an RBF CapEx-oriented subsidy might be good for Bridge Markets, an on-going OpEx subsidy should be considered for Concessionary Markets.

The authors suggest the sector explore the use of OpEx subsidy for hard-to-reach markets. If the problem is low and slow to improve demand, this is a revenue vs. OpEx problem. Also, an OpEx subsidy would require continued support of customer connections (rather than a one-time payment for each connection), driving developers to focus on long-term customer satisfaction. The subsidy could even flow through the consumer, reducing the potential for developers to take advantage of CapEx subsidies (RBF) and providing support to those who will benefit most.

Scale

Rate of Deployment - Speed

Once most of the above sustainability targets have been reached, it is possible for the minigrid industry to achieve scale. It is impossible for the industry to attract the needed capital if its underlying business model is not sustainable: i.e. if the cost, quality, and demand metrics are not meeting expectations. Still, sustainability alone is not adequate to achieve meaningful scale.

To fully understand the rate of deployment challenge, it is insightful to examine the gap between current rates and what is needed. The average installation rate today by the top 10 companies is less than 100 per year each. The rate needed from each company by 2030 is almost 2,000 per year. Closing that gap, installing at a nearly 20 times higher rate, requires a complete change is how most minigrid companies organize and operate their businesses. In fact, of all the roadmap requirements, scale is the most daunting. At the current rate of minigrid deployment, it would take more than 100 years to meet the 2030 goal. This is not a 10% or 20% problem, but rather a 10X or 100X problem. There are two major KPIs to address this speed or rate of deployment challenge: throughput and install time.

Throughput

The key metric for rate of deployment is throughput, or how many minigrids per year should developers have the capacity to build. The throughput calculation was derived from the assumption that 10 companies would account for over 90% of the installations, as is common in most industries. In fact, the top three companies in most industries account for over 80% of market share. It is only an approximation, but good enough to identify the target installation rate for a successful minigrid developer. The other input into the calculation and goals was the desire to deploy 200,000 minigrids by 2030. If this goal is relaxed, the deployment rate could be reduced.

Installation Time

The second metric is installation time. This is equivalent to the World Bank's metric "Time from goods arriving on site to commissioning". The second World Bank metric, "Time from purchase order to commissioning" seems less relevant because as long as lead times are known, purchase orders can always be placed to achieve the desired throughput.

Unlike sustainability, where the roadmap breaks the problem into sub-categories of cost, quality and demand, the roadmap does not have sub-categories for scale. The authors have focused more on the unique minigrid-specific challenges of the business model and less on the more generic scaling issues such as logistics, operations, and supply chain management. Standard business "best practices" can be employed in most cases.

ROADMAP FRAMEWORK

The preceding set of categories and specific metrics are intended to provide a framework. After detailed discussion with industry influencers, experts, and practitioners it appears that this framework can be useful. Discussion is still required to establish specific targets vis-à-vis the timeline to achieve SDG7 goals.

Specific Targets

The roadmap shows both the current World Bank targets and new suggested targets. In general, it is clear that the industry needs to be more ambitious. As such, most of the 2030 goals have been moved up to 2025, with more ambitious targets set for 2030. Though aggressive, the authors believe that these targets are attainable, as internal data from leading developers show that several 2025 targets had already been met in 2021. Challenges remain, but there are also hopeful signs. Price declines in solar panels and batteries continue, and there are clearly innovation opportunities to reduce OpEx as well. But innovation is not limited to cost control.

The goal of the roadmap is to direct innovation into the needed areas of demand generation and scaling. There is considerable concessionary capital already going into developing productive uses in rural areas. This will increase demand and improve CUF as well. Furthermore, new business models have been developed to improve ARPU through both customer mix and added products and services. Innovation is not limited to technology.

Issues Outside the Roadmap's Scope

It was mentioned earlier that this roadmap is developer-oriented, leaving out some important factors that affect the viability of the minigrid industry. Husk is working with the Africa Minigrid Developers Association (AMDA) to expand on this roadmap to include the entire ecosystem including governments, regulators, donors and investors. In this work we have identified **8 critical success factors** for the minigrid industry. They include the 5 contained in this roadmap, plus 3 additional ones.

The 5 success factors covered in this roadmap are:

1. Viable Business Model: minigrid developers must survive;

2. LCOE: minigrid developers need to achieve LCOE of less than $0.20 by 2030;

3. Demand: minigrid development must include both supply and demand with more emphasis on demand as compared to mainstream utilities;

4. Quality/Service: minigrid power must be high-quality and reliable;

5. Scale: minigrid developers need to achieve at least 10X their current scaling capacity, achieving deployment rates of 1,800 minigrids/year by 2030;

The 3 success factors not covered are:

6. Subsidies: subsidies are required in most markets. Where needed, subsidies should range from permanent to multi-year bridge such that minigrid developers achieve a viable business model. In all cases, subsidies should at least match the direct and indirect subsidies given to existing national grids;

7. Supportive Regulatory Environment: regulations should promote not hamper minigrid development;

8. Capital Availability: in a capital-intensive sector like power provision, access to the appropriate forms of capital at the right time, the right quantity, and at the right price is crucial to sector success. The cost of capital impacts both LCOE and sustainability.

AMDA is taking up the challenge to address these last 3 success factors with specific recommendations and a roadmap of their own. The authors are integrally involved in this effort to create a sector-wide roadmap that covers all the important elements in the ecosystem.

SUMMARY

Energy is key to both economic and social development. Clean and affordable energy is not only the central theme of SDG7, it is pivotal to achieving at least 9 of the 17 SDGs; to fight poverty, to provide a modern education, to ensure health and safety, to provide clean water and sanitation, to build infrastructure (energy is infrastructure), to create decent work, to economically produce and deliver food, and last but not least, to support both climate mitigation and adaptation.

It is widely accepted that universal access to clean and affordable energy on a reasonable time scale can only happen by scaling solar minigrids. Centralized power utilities have failed for decades to achieve universal access, and continue to struggle with management challenges and heavy debt. Solar home systems are expensive and cannot provide 24/7 power for entire communities. Diesel generators are even more expensive and contribute to climate change. The most cost-effective, sustainable solution to achieve energy access is clearly the solar minigrid.

Yet, the minigrid sector has faced major challenges in achieving sustainability and scale. Costs are often too high to make energy affordable in many markets, and at the same time demand is often too low to result in a sustainable minigrid business model. Of course, with a weak business model it is difficult to raise the needed capital and resources to scale.

To bridge these gaps, this roadmap has been devised to highlight key areas for improvement. Specific metrics with a timetable have been identified to define a roadmap to success. This roadmap has both technology drivers (like CapEx) and business drivers (like ROI), as the solutions to scale require innovation in both technology and business model. Such innovation is possible and has occurred in other industries, but the effort must be focused. Private and public R&D, investor capital, and donor funding must be directed towards the right solutions. This roadmap is an attempt to provide such focus, not only for minigrid developers but for the entire minigrid ecosystem of governments, donors, investors, suppliers and regulators.

CONCLUSIONS

- Scale and sustainability are paramount — and possible — for industry viability: Scale and sustainable business models are the two pillars of industry success and are only possible if private sector developers address challenges around cost, demand and quality. Scale and sustainability lead to market maturity, and ultimately to achieving Sustainable Development Goal 7 (SDG7) — access to modern, clean, affordable, reliable energy for all.

- LCOE is the industry's north star: On the question of cost, the industry must align itself around Levelized Cost of Energy (LCOE). The current standard, Cost Per Connection, does not conform to standard energy industry practices and invites market distortion. Pegging industry development to LCOE will ensure that scale is possible and that tariffs are the most affordable they can be for unelectrified communities.

- Demand is at the crux of sustainability, economic growth and social impact: As ability to pay for energy is a major issue, developers need to drive productive uses which enhance the value of energy. More value means more ability to pay and higher ARPU. So, driving demand is not only essential for sustainability but leads to robust economic and social impacts. The industry must be hyper focused on ARPU and the quantitative measure of demand, CUF.

- Scale may be the most daunting challenge: The local scale needed for developers to achieve profitability is very small compared to what is needed to achieve universal energy access. In fact, 10 companies with 10X the current maximum rate of deployment are needed to achieve SDG7.

- Many market types co-exist in any country: The tendency for governments, funders and companies to view the minigrid market at the country level must shift to match the reality at ground level, as different market types (commercially viable, bridge and concessionary) are present in all countries. These markets will require different strategies and probably different business models. This has major implications not only on developers but on national policy and regulations.

APPENDIX

Methodology

This roadmap has been formulated primarily through internal business development processes at Husk Power Systems ("Husk"). Husk has been a category creator in the minigrid industry, having developed the first commercially viable biomass minigrid in 2008 and the first hybrid solar minigrid in 2017. Along the way, Husk also developed other technologies such as DC microgrids, smart metering and resilient IoT technologies. Husk has also pioneered business model innovations, experimenting with development only, build-own-and-operate, franchising, and combinations of all these.

From these experiences Husk has seen operationally what has worked and what has failed in building and operating minigrids. During this process Husk has employed a number of KPIs. Over the last decade certain KPIs have been discarded as counter-productive and others have gained in importance. The appropriate metrics have altered over time as the company scaled from single digit numbers of minigrids, to 10s of minigrids to finally the largest fleet of minigrids in Asia and Africa today at over 150 in operation.

This industry roadmap therefore is derived from Husk's internal roadmap, which has allowed Husk to become the industry's largest and fastest-growing minigrid company working across two continents. The following are the specific methods used to calculate each of the roadmap metrics.

LCOE - Levelized Cost of Energy is defined as the Net Present Value (NPV) of all the costs (using your cost of capital to get NPV) divided by the net present value of all the energy sold during the same period. This roadmap uses a 25 year lifetime for a minigrid asset. Costs consist of two major parts: initial CapEx (power generation, civil work, distribution network, smart meters, etc.) and annual OpEx (salaries, land lease, insurance, etc.). These are explained in more detail below.

For hybrid (solar-battery-diesel) minigrids, energy sold should be divided into daytime and night-time demand to understand and predict the use of diesel. The diesel expense needs to go into OpEx. Demand should be projected for the 25 year period. It is important to make sure that the demand does not exceed power generation capacity at any time.

Base CapEx - includes all capital expenditures incurred in building a fully commissioned minigrid. In addition to the obvious generation and storage CapEx, it must include costs for the distribution network, licensing costs, logistics, and project management costs. For capital costs, replacement CapEx must also be considered. For example, a lead acid battery bank needs to be replaced about every 4 years, and inverters about every 10 years. Actual replacement times and costs should be used for the specific minigrid components used.

OpEx – all direct expenses incurred to run and maintain a minigrid asset over its 25 year life. This should include salaries of electricians and technicians to operate and maintain the minigrid. In addition, it should include insurance costs of the asset, land rental, data costs, maintenance costs etc. It should also include corporate overhead costs that are dedicated to managing a group of minigrid assets. These costs should be amortized over the entire portfolio of minigrids assets. For example, corporate costs for a group of 20 minigrids would be allocated so that only 5% (1/20th) of costs are assigned to each individual minigrid.

Uptime – the average numbers of hours each customer had access to electricity on a daily basis divided by 24 hours. For example, 23 hours of access would result in 95.8% uptime (23 divided by 24).

Response Time – the time needed to address a service problem reported by a customer. The time starts the moment a customer contacts the service provider (by phone, voice or text message). The response time is determined by when the customer confirms that the issue was closed. Track 100% of events and calculate the average time of all events in the period being measured.

ARPU – the Average Revenue Per User per month in local currency. Use the current exchange rate to determine equivalent in US Dollars.

CUF – the Capacity Utilization Factor of the asset. This is the energy sold or used by customers (the demand) divided by the capacity the minigrid has to produce energy (the supply). The demand side should be straight-forward based on payments made or information coming from the smart-meter system. The supply side is more complicated. Most minigrids use solar PV as a primary source of power and this supply varies with the weather. The solar capacity can be estimated based on weather models. For example, one can run PVSyst (fed with the details of the minigrid asset) to determine the projected actual energy the minigrid asset is generating on a monthly/annual basis.

Due to solar variability, almost all minigrids have a back-up power supply, typically a diesel generator. That capacity must be included. Yet, since it is back-up only, it may not be fair to include the entire 24/7 diesel capacity. This roadmap only uses 1/3 that capacity or equivalent to 8 hours use per day as equating to 100% utilization. For example, using the 8 hours standard with a 40kW diesel genset would add 320kWh per day to the minigrid power generation capacity.

Local Scale – local scale is merely the number of minigrids needed in a specific country or territory to cover the overhead costs in that same country or territory. The size of the territory would be governed by the organizational structure of the minigrid developer. Typically, the territory would be a country, as each country usually requires accounting, HR, and other overhead functions. Each minigrid usually provides a small profit margin based on the business model and the unit economics. The minimum number of minigrids is simply the cost of the overhead divided by the average profit margin of a single minigrid.

ROI – Return On Investment is calculated using the free cash flow projections for a period of 25 years (include initial CapEx and replacement CapEx), using the long-term capital structure of minigrid portfolio, using cost equity and debt and projecting demand over the same period of time.

Install Time – is simply the time from the initiation of a minigrid install until it is physically completed and ready for activation. It does not include the site selection process or permitting or other regulatory approval processes.

Throughput – is the total capacity for an individual developer to install minigrids in one year. It is obviously related to install time but integrates the number of install teams working in each country and all the countries where minigrids are being installed by that developer.