Global Green Growth Institute

Solutions for the Missing Middle

The Case for Large-Scale Mini-Grid Development

Insight Brief 2 / September 2017

Courtesy of Bryan Derballa

Acknowledgements

This Insight Brief was prepared under the guidance and leadership of Mahua Acharya, Assistant Director-General of the Investment and Policy Solutions Division at GGGI.

This Insight Brief benefited considerably from the review and input of GGGI experts, including Lasse Ringius, Dereje Senshaw, Carol Litwin, Vikalp Sabhlok, and Katerina Syngellakis.

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GGGI Insight Brief: Insight Brief 1 / November 2016: Mind the Gap: Bridging the Climate Financing Gap with Innovative Financial Mechanisms
Insight Brief 2 / September 2017: Solutions for the Missing Middle: The Case for Large-Scale Mini-Grid Development

Cover photo: A man carries a basket in Nilkanta Rayan Gaddi village outside of Surapur, India on October 8th, 2015. A solar PV mini-grid system developed by Selco Solar provides electricity to the community via a distribution network. Courtesy of Bryan Derballa.

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Insight Briefs are based on GGGI's experience and analysis. GGGI will produce additional Insight Briefs from new insights gained while working to find ways to finance green growth.

Executive Summary

More than one billion people lack access to electricity, 80% of whom live in remote areas and small islands.[1] For these populations, extending centralized electricity grids is not financially viable.[2] Moreover, small off-grid electricity solutions, such as solar home systems (SHS), are unable to scale quickly enough to meet projected electricity demand. Therefore, to ensure affordable universal energy access by 2030 – one of the United Nation's Sustainable Development Goals (SDG) – there is an urgent need to scale investment in mini grids, the "missing middle" between central grid extensions and small off-grid systems.[3]

Technological advancements in solar photovoltaics (PV) have reduced costs by roughly 80% since 2009, while energy storage systems (ESS) have made similar progress in the past few years.[4] Using a combination of GGGI project data and publicly available data, this Insight Brief demonstrates that solar PV plus ESS mini grids are now cost competitive with diesel mini grids, often more affordable than grid extensions, and offer significant bankable investment opportunities in the technology switching and energy access markets.

GGGI estimates that the global market for technology switching – converting existing diesel mini-grid electrification systems to solar PV-diesel hybrid systems – is USD 550 billion and could reduce up to 470 million metric tons of carbon dioxide (CO_2) emissions annually, equivalent to Brazil's annual CO_2 emissions from all sectors.[5] With relatively low upfront capital requirements, this market can quickly attract private investment, provided that safeguards, such as clear offtake structures and bankable power purchase agreements, are in place.

Building on the technical expertise and economies of scale gained through technology switching, project developers, utilities, and investors can develop the larger energy access market. Critical barriers to investment include high upfront capital expenditure, credit risk of remote communities, and the lack of enabling regulations. Public and private sector stakeholders can overcome these barriers by identifying "anchor clients" with predictable energy demand and access to capital, creating new business models that reduce upfront and transaction costs, and developing supportive regulatory frameworks and incentives, among other potential solutions.[6]

With proven technology, a clear economic case, and two potential markets, solar PV plus ESS mini grids are poised to scale rapidly to reduce emissions and achieve affordable universal energy access. To do so, governments and utilities must support their development through national energy planning that recognizes decentralized off-grid renewable energy generation as a viable alternative to grid extension, as well as policies and regulations that mobilize investment in the sector.

1. Global Electrification Challenges

The global economy has reached a critical turning point. From 2014 to 2016, total annual greenhouse gas (GHG) emissions from the energy sector remained steady, even as the global economy grew.[7] The decoupling of economic growth from GHG emissions is an encouraging milestone, yet it is far from sufficient. Global energy systems must rapidly decarbonize while meeting new energy demand.

According to the International Energy Agency (IEA), electricity generation in developing countries will increase by 2.5% per year until 2040 – roughly a doubling of annual electricity demand in less than three decades.[8] Whether this new generation comes from fossil fuels or renewable energy sources will play a crucial role in determining the outcome of global decarbonization efforts.

Looking at the challenge from a societal standpoint, one billion people in developing countries lack access to electricity and the opportunities and quality of life improvements it provides. One of the United Nation's Sustainable Development Goals is to provide 100% energy access globally by 2030.[9] The question is how.

Approximately 80% of this population do not live near a centralized electricity grid. In most areas, grid expansion through new transmission and distribution lines is cost-prohibitive. Additionally, traditional off-grid diesel generation systems are carbon-intensive and subject to fuel price fluctuations. Solar home systems (SHS) also offer only a partial solution, as they typically provide limited, intermittent power supply and are difficult to scale.

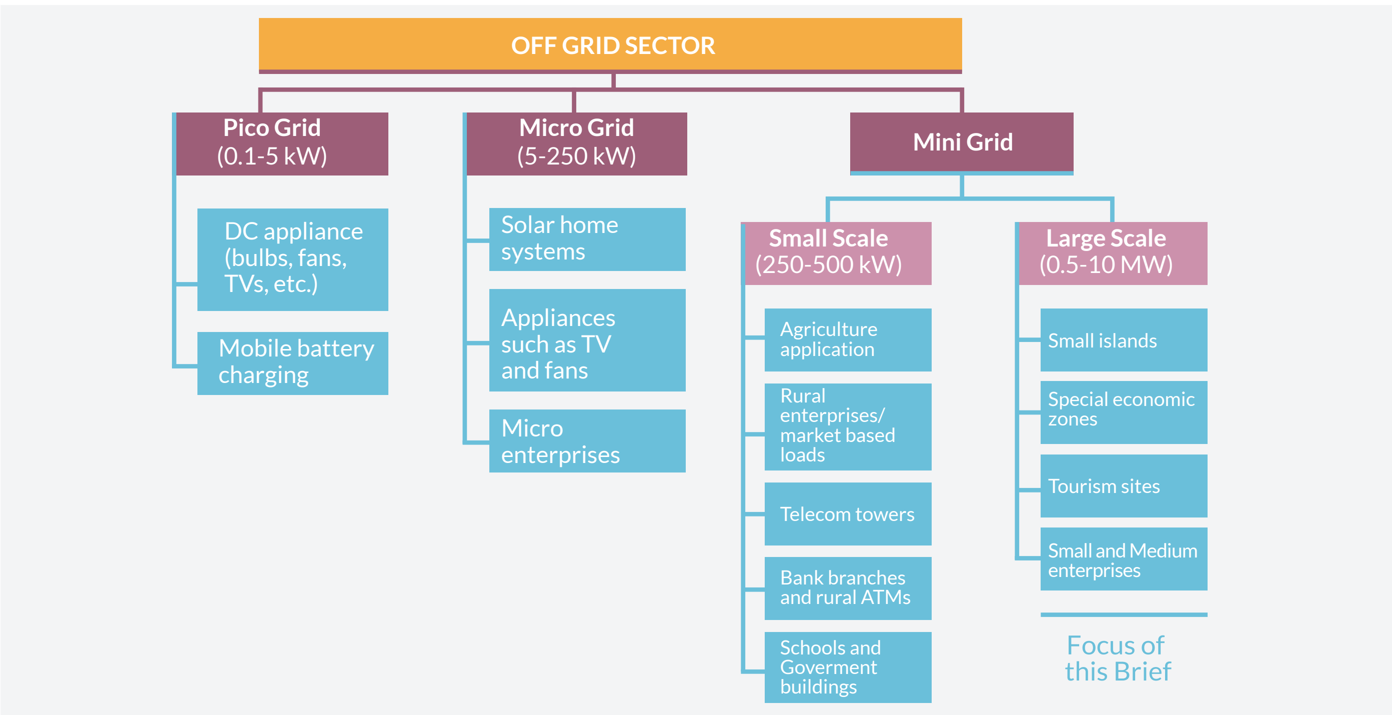
However, there is an off-grid alternative that sits between centralized grids and individual home systems – the "missing middle" that this Brief focuses on. This "missing middle" can be captured commercially through mini grids powered by renewable energy. Due to technological advances, mini grids with solar photovoltaics (PV) and energy storage systems (ESS) provide reliable, low-carbon electricity, often at a lower levelized cost of electricity (LCOE) than fossil fuel-based systems. Remote areas and small islands now have an opportunity to "leapfrog" the carbon-intensive central grid model in favor of low-carbon, decentralized electricity generation.

The primary aims of this Insight Brief are to (1) make an economic case for the deployment of large-scale mini grids powered by renewable energy and (2) identify and categorize the potential markets, stages of development needed, and barriers to overcome to achieve market maturity.

2. Classification of the Off-Grid Sector

The off-grid sector is classified into three groups based on size (see Figure 1): pico grid, micro grid, and mini grid.

Figure 1: Categorization of the off-grid energy sector based on the size and application of the grid



Pico grids are 0.1-5.0 kW in size. They have minimal load applications, such as lightbulbs, DC fans, and mobile battery charging.

Micro grids are 5-250 kW in size. They can be used for SHS and larger AC appliances, such as TVs, basic lighting, and fans. With higher loads than pico grids, micro grids can meet the electricity needs of some microenterprises.

Small-scale mini grids are 250-500 kW in size and are used for agriculture applications, rural enterprises with small machinery, telecom towers, schools, and government buildings. **Large-scale mini grids** are 0.5–10 MW in size. They provide electricity to rural communities, remote tourism sites, special economic zones, small and medium enterprises, and small islands and other regions currently unserved by traditional grids. They offer the affordability and flexibility of smaller grids and the energy services and system reliability of central grids – hence, the "missing middle."

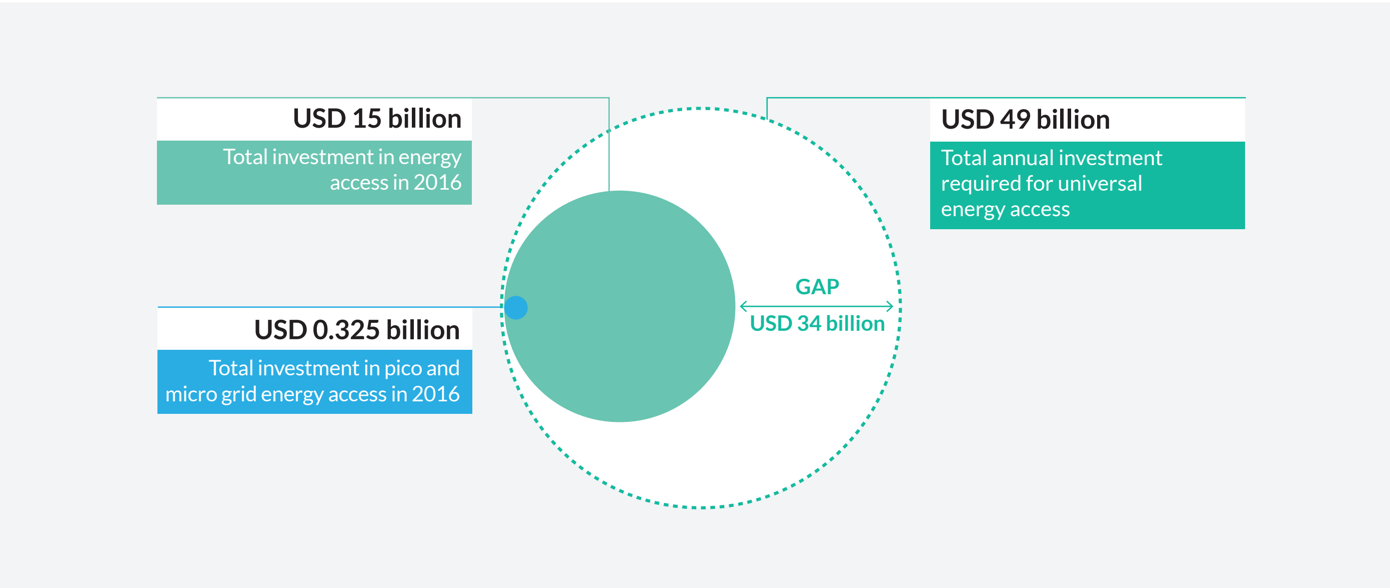
3. Investments for Energy Access

The Energy Access Financing Gap

According to GGGI's Mind the Gap Insight Brief, the total climate finance needed in non-OECD countries is USD 2.5-4.8 trillion over the next 15 years.[10] In line with this estimate, IEA projects that almost USD one trillion is required for universal energy access by 2030 – roughly USD 49 billion per year.[11]

As Figure 2 demonstrates, in 2016, annual investment for all centralized and decentralized energy access was only USD 15 billion. Of the USD 34 billion shortfall, the IEA estimates that almost USD 20 billion needs to be invested in pico, micro, and mini grids to achieve 100% decentralized energy access by 2030.[12]

Figure 2: Universal Energy Access Investment Flows and Financing Required



Pico and Micro Grids Lack Investment

In 2016, investment in pico and micro grids was a paltry USD 325 million (see Figure 2).[13] These smaller off-grid technologies have failed to attract the investment needed to scale for several reasons. First, logistical constraints make it costly and difficult for businesses to reach potential customers in remote areas and small islands. Second, in these areas, regulatory frameworks are often weak or nonexistent. Third, lenders perceive small-scale off-grid projects as high risk due to the lack of creditworthiness of SMEs and other energy end-users. Fourth, the small investment size of individual projects deters private investment.

Large-Scale Diesel Mini Grids Have Dominated the Energy Access Market

Historically, diesel mini-grid systems have been the most prevalent and least cost solution for energy access in remote areas and small islands. They account for 400 GW installed capacity globally. By comparison, that is equal to roughly one quarter of the total installed capacity of China.[14] Using conservative estimates, existing diesel mini grids emit roughly 750 million metric tons of carbon dioxide (CO_2) per year, roughly equivalent to Germany's annual CO_2 emissions.[15]

Replacement of diesel generation assets with solar PV-diesel hybrid systems is referred to as technology switching. Up to 250 GW of the 400 GW of total installed diesel mini-grid capacity, mostly in sub-Saharan Africa and Asia, has the irradiation potential for technology switching to solar PV-diesel hybrid systems. Technology switching could produce CO_2 emissions savings of up to 470 million metric tons annually, equivalent to Brazil's annual CO_2 emissions from all sectors.[16] This untapped market represents a strong investment opportunity, particularly for climate finance (see Sections 4 and 5 below).

Large-Scale Solar PV plus ESS Mini Grids

To close the significant energy access financing gap by 2030, new energy developments must scale more rapidly than pico and micro grids, yet avoid the negative climate impacts of diesel mini grids. Large-scale solar PV plus ESS mini grids accomplish both. These systems reduce or avoid many of the logistical constraints and regulatory challenges that pico and micro grids face, as project developers and utilities benefit from the regulatory frameworks and infrastructure already in place for existing mini grids. Moreover, the large installation size of solar PV plus ESS mini grids often attracts more creditworthy energy end-users, which reduces credit risk for investors. Finally, as covered in Section 4, there is already a robust economic case for solar PV plus ESS mini grids, as well as technology switching to solar PV-diesel hybrid mini grids.

4. The Economic Case for Solar PV with ESS Mini Grids

Amid technological advances and fierce competition, solar PV prices continue to fall rapidly.[17] However, to attract the almost USD 20 billion in annual investment capital needed to supplant diesel mini grids and power the energy access market, solar PV plus ESS mini grids must be cost competitive and provide equivalent energy services. Using data from rural electrification projects in GGGI's portfolio and publicly available data, GGGI has compared the advantages, risks, and LCOE for five off-grid electrification options in Table 1 and Figure 3.

Box 1: GGGI Portfolio

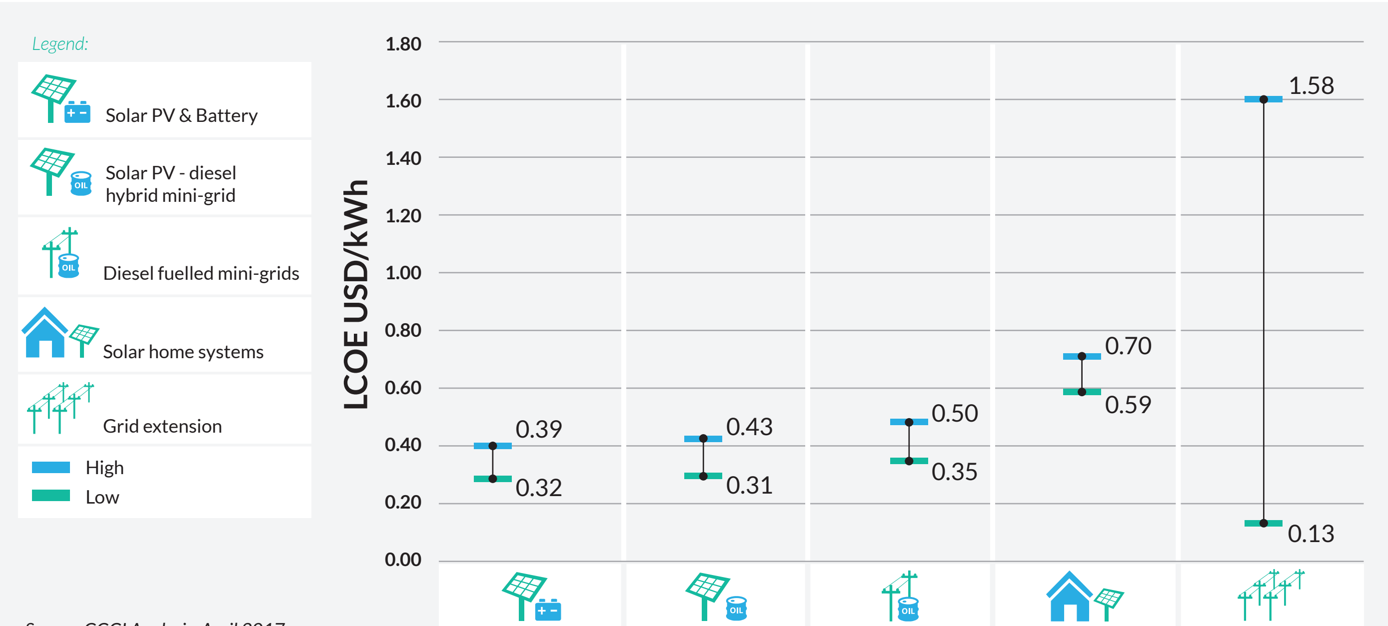
GGGI'S PORTFOLIO • **ISLAND SOLUTIONS**

INDONESIA	**INDONESIA**	**FIJI**	**VANUATU**
Development of aggregate 15 MW solar PV project on eight islands in Nusa Tenggara Timur (NTT) Province.	Design and development of 10 MW solar PV project for the Mandalika Special Economic Zone (SEZ).	Development of solar PV to achieve 65% renewable electricity generation for the island of Taveuni.	GGGI - UNDP partnership is accelerating rural electricity access through solar PV project development.

Table 1: Comparison of Off-Grid Electrification Options

	Solar PV plus ESS Mini Grid	Solar PV-Diesel Hybrid Mini Grid	Diesel Mini Grid	Solar Home System	Grid Extension
Advantages	High reliability Green generation Lowest cost of generation for rural locations and small islands	Least capital investment and fastest implementation as base infrastructure for technology switching is existent on diesel fueled mini grid Existing experience of solar PV installation on central grid can be used for solar PV-diesel hybrid on isolated mini grid	Proven technology Existing infrastructure and developer experience is available	Low barrier to entry, as startup cost is low Useful for scarcely populated regions with low load requirements	Economical if close to the central grid and existing generation can meet load requirement Can manage large load fluctuations
Risks	High initial investment Investments would be jeopardized in the event of central grid extension, which is largely influenced by local political factors	Due to low quality grid infrastructure, renewable energy penetration on such grids is restricted Dependent on diesel price fluctuations and transportation infrastructure	Highest GHG emissions At low electricity demand, diesel mini grids can be inefficient (<15%) and expensive Dependent on diesel price fluctuations and transportation infrastructure	Difficult to scale, as the market is fragmented Limited power supply and intermittency Requires the most customer interaction Logistical issues with rural regions is a hindrance	Most expensive since 80% people without energy access do not live close to centralized grid
Total LCOE (USD/kWh)	0.28-0.35	0.31-0.43	0.35-0.50	0.59-0.70	0.13-1.58

Figure 3: LCOE for Off-Grid Electrification Options



Source: GGGI Analysis, April 2017

Solar PV plus ESS is Already Cost Competitive

Looking first at the three mini-grid options, solar PV plus ESS mini grids provide equally reliable energy service with lower risks compared to the two diesel-based solutions. Their upper and lower limit LCOE are also cost competitive.

Compared with smaller off-grid solutions, such as SHS operating on pico or micro grids, solar PV plus ESS mini grids are more affordable. Although the base technology for providing energy access is the same, solar PV plus ESS mini grids benefit from greater economies of scale. Moreover, although SHS have gained momentum in the past few years, they can only at best provide a partial solution to consumers, as they provide limited power supply and are difficult to scale quickly.

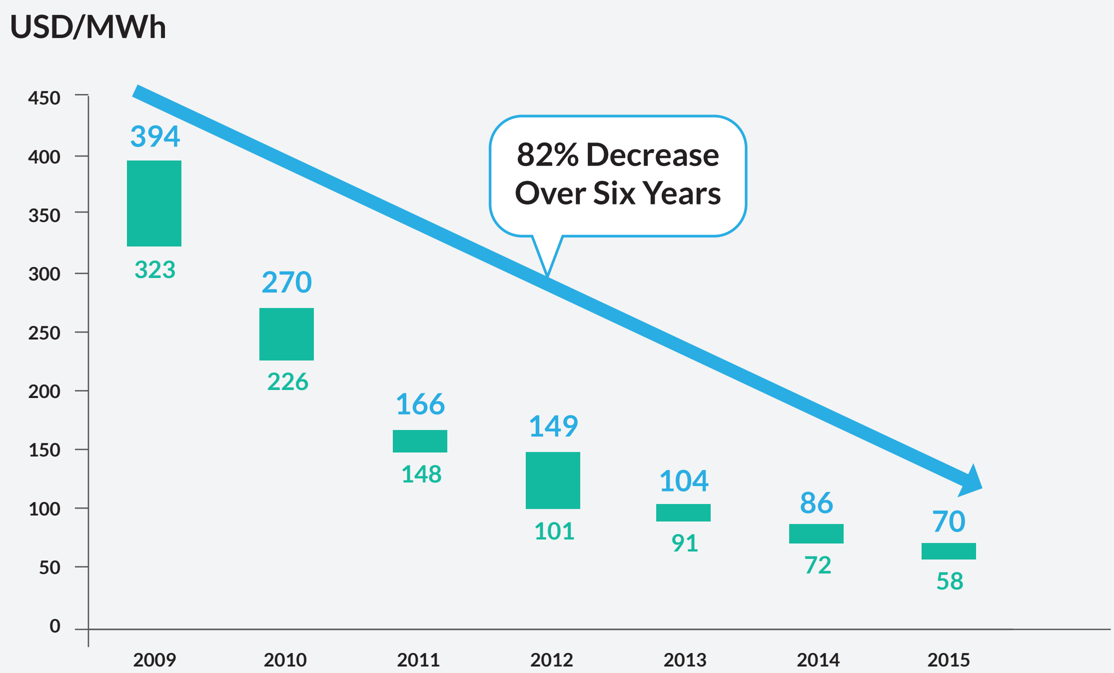
Grid extensions are a special case because the LCOE varies considerably depending on the distance from the grid, local geographic features, and the demand density in remote areas, among other variables. Since most people without energy access do not live near a centralized grid, solar PV plus ESS mini grids will usually be the less expensive option.
In cases where electricity demand is located near the grid, it may still make economic sense to extend the grid, as retail tariffs on the central grids are highly subsidized. The possibility of future grid extension into remote areas and small islands poses a risk for private sector investors looking to invest in solar PV plus ESS mini grids, which they can mitigate by signing standardized, long-term power offtake agreements with the local utilities.

Solar PV plus ESS Costs are Still Falling

To further substantiate the case for solar PV plus ESS mini grids, it is important to consider the downward trend in LCOE for solar PV, the base renewable technology. Figure 4 represents the upper and lower limit LCOE for utility-scale solar PV from 2009 to 2015 in the United States.

There has been a roughly 80% reduction in solar PV module prices since 2009.[18] A Deutsche Bank report indicates that the total module costs of leading Chinese solar companies decreased from around USD 1.31/W in 2011 to around USD 0.50/W in 2014, representing a fall of 60% in just three years.[19] The economic case for solar PV plus ESS mini grids will continue to improve as solar PV prices decline further.

Figure 4: Decrease in the LCOE for Utility-Scale Solar in the U.S. from 2009 – 2015



Source: Lazard's Levelized Cost of Energy Analysis – version 9.0

5. Mini Grid Market Development

Considering all the options on a cost and risk basis, there is a strong business case for choosing solar PV plus ESS mini grids for technology switching and for new mini-grid development for energy access. Investors looking to enter these two markets must decide where to invest based on the associated advantages, risks, initial investment needed, LCOE for each, and climate change and energy access priorities.

Technology Switching to Solar PV-Diesel Hybrid Mini Grids

The most promising initial opportunity for solar PV mini grids is technology switching. GGGI estimates that the 250 GW diesel mini-grid market represents a USD 550 billion investment opportunity – approximately USD 34 billion annually between 2017-2030.[20] See Table 2.

Table 2: Technology Switching to Solar PV-Diesel Hybrid Mini Grids

KEY OUTCOMES OF THE STAGE	
· Standardized and bankable power purchase agreements developed for mini grids · Fuel switching from diesel or other fossil fuels to solar PV · Mini grids controlled by the utility (e.g., grid management, demand management, tariff design structure).	
Advantages	**Disadvantages**
· Proven technology and business model · Least upfront investment · Fastest implementation · Least complicated design · Attractive for developers	· No back-up / existing grid-dependent · For sizing, renewable energy generation must consider stability of the grid

For project developers, utilities, and investors, technology switching offers the following benefits:

- Reduced upfront investment and transaction costs, as much of the infrastructure is already in place;
- Known generation capacity based on the energy usage patterns of current energy end-users;
- Lower logistical and transportation costs than diesel;
- Long-term power purchase agreements with the local utility; and
- Experience working with solar PV plus ESS that they can apply to the energy access market.[21]

However, technology switching faces several constraints and challenges. Remote areas and small islands often have limited transportation networks, supply chains, and skilled workforces. In addition, underdeveloped off-grid markets may lack standardized or reliable power offtake agreements, in-country experience to design and maintain solar PV projects and manage intermittency on the grid, and private sector capacity to manage the complexities of tariff design, demand management, and revenue collection. Utilities and installers can address many of these challenges by developing initial solar PV-ESS mini-grid demonstration projects.

Incorporating ESS into Solar PV-Diesel Hybrid Mini Grids

For the relatively large energy end-users that constitute most of the diesel mini-grid market, reliability is as important as cost. Therefore, the logical next step for industrial facilities, mines, ecotourism sites, special economic zones, and other commercial enterprises is to integrate ESS into solar PV-diesel hybrid mini grids. See table 3.

By storing excess electricity, ESS better matches the solar PV generation profile to demand, allowing for higher utilization of solar PV and reduced fluctuations and spikes in the power supply. In such systems, solar PV plus ESS account for 40-50% of grid utilization, while diesel generators cover the remainder.[22]

Table 3: Incorporating ESS into Solar PV-Diesel Hybrid Mini Grids

<table>
<tr><th colspan="2">KEY OUTCOMES OF THE STAGE</th></tr>
<tr><td colspan="2">· Utilities will start using solar PV plus ESS mini grids and will have more buy-in as this solution will address the issue of older existing mini-grids
· Developers will build the technical capacity for solar PV plus ESS systems
· High reliability with energy storage will cater to demands from SMEs and industrial plants in the region</td></tr>
<tr><th>Advantages</th><th>Disadvantages</th></tr>
<tr><td>· Grid has more clean energy
· Modular energy source that can be scaled as per the energy demand increase
· Energy storage integration technology rapidly advancing</td><td>· High capital cost
· Energy storage may require temperature / humidity controls</td></tr>
</table>

An added advantage of ESS is that it optimizes the runtime of the diesel generator by catering to small loads, which reduces inefficiency and unnecessary GHG emissions.

Energy Access for All through New Mini Grids

While technology switching is a quick win to reduce GHG emissions, solar PV plus ESS mini grids provide even greater societal benefits when used to increase energy access in remote areas and small islands. However, building and managing a new solar PV plus ESS mini grid with at least 0.5 MW capacity is a complex undertaking. It requires high upfront capital, an enabling regulatory framework (e.g., licensing, procurement framework, safety standards), resource planning, and technical expertise, among other considerations.[23]

New mini-grid development for energy access benefits from having an "anchor client," such as a mine, tourism site, special economic zone, or other commercial enterprise with measurable and predictable energy consumption patterns, as well as land, capital, and political support to advance the project. Predictable demand from a creditworthy client reduces investment risk for project developers and utilities, making the project more economically viable. Communities and smaller enterprises located near the anchor client also benefit from being able to connect to the mini grid, commonly referred to as the "excess power business model."[24]

Even without an anchor client, solar PV plus ESS mini grids often make economic sense for communities in remote areas and small islands that are already paying higher rates for lower quality, limited energy services from kerosene lamps or pooled diesel generators. The challenge, then, is not whether there is consumer willingness to pay, but, rather, whether consumers have sufficient capital to cover the upfront costs of installing solar PV plus ESS mini grids. Private sector investors, government incentives, and new business models can enable this market to develop, provided that governments can create a reliable regulatory system and appropriate incentives.

Project developers in developing countries have experience with project preparation and system design. However, they often lack much-needed expertise in more traditional utility functions that are vital to the success of mini grids, such as demand management, tariff design, revenue collection, and operation and maintenance (O&M) management. For solar PV plus ESS mini-grid demonstration projects, GGGI recommends that project developers focus on electricity generation and rely on utilities for distribution and customer interaction.

6. Conclusion

Roughly one in seven people on earth lacks access to electricity. For decades, utilities in developing countries have relied on grid extension and off-grid diesel generation to provide electrification to remote areas and small islands. However, solar PV plus ESS mini grids are disrupting that strategy, as rapidly falling costs, new business models, and grid management technologies enable project developers and rural communities to influence traditional utility energy planning through decentralized, customer-driven electricity generation.

Mini grids powered by renewable energy can also play a critical role in the world's efforts to achieve the goals of the Paris Agreement to decarbonize. Technology switching existing diesel mini-grid systems to solar PV-diesel hybrids could displace as much as 470 million metric tons of CO_2 emissions each year. However, to achieve these outcomes by 2030 as part of the U.N.'s SDGs, governments and utilities must adjust to and support the sea change that is underway.

Going forward, governments and utilities must integrate decentralized renewable energy into the design of national energy systems. They must also engage project developers, investors, and other private sector stakeholders to mobilize investment in solar PV plus ESS through policies and incentives, such as feed-in tariffs, auctions, capacity quotas, and net metering.

In other words, they must occupy the "missing middle" by recognizing large-scale solar PV plus ESS mini grids as a viable, low-cost, low-carbon solution for technology switching and energy access.

Annex 1: Modelling Assumptions for Solar PV

Indonesia				
No	Item	Unit	Value	Source
1	Capital Cost	USD/kW	1,136	Sum of Capital costs: · EPC · Capital Costs - Non-EPC · Interest during construction
2	Invertor Replacement Cost (in year 15)	USD/kW	85	The USA price (assumptions for USA plus 10% shipping costs and no tax), as renewable Energy Generation is provided with tax exemption from import duty on the import of Capital Goods[25]
3	Fixed O&M	USD/kW-yr.	20	Sustainable Energy in Remote Indonesian Grids: Accelerating Project Development[26]
4	O&M escalation per year	%	1.23	Based on average forecast US Consumer Price Index (2011 – 2020)[27]
5	Capacity Factor (average)	%	17	GGGI designed projects in Indonesia[28]
6	Corporate Income Tax	%	25	Indonesia Investment website[29]

United States of America				
No	Item	Unit	Value	Source
1	Capital Cost	USD/kW	1,273	U.S. Photovoltaic Prices and Cost Breakdowns: Q1 2015 Benchmarks for Residential, Commercial, and Utility-Scale Systems[30]
2	Invertor Replacement Cost (in year 15)	USD/kW	77	
3	Fixed O&M	USD/kW-yr.	10	Lazard levelized cost of energy analysis version 9.0[31]
4	O&M escalation per year	%	1.23	Based on average forecast US Consumer Price Index (2011 – 2020)[32]
5	Capacity Factor (average)	%	21	Lazard levelized cost of energy analysis version 9.0[33]
6	Corporate Income Tax	USD/kW-yr.	10	Trading Economics 2016[34]

India				
No	Item	Unit	Value	Source
1	Capital Cost	USD/kW	643	Sum of Capital costs: · EPC · Capital Costs - Non-EPC · Interest during construction
2	Invertor Replacement Cost (in year 15)	USD/kW	42	Private developer input
3	Fixed O&M	USD/kW-yr.	7	
4	O&M escalation per year	%	4.0	
5	Capacity Factor (average)	%	18	
6	Corporate Income Tax	%	34.6%	Trading Economics 2016[35]

Germany				
No	Item	Unit	Value	Source
1	Total Capital Cost	USD/kW	1,150	Sum of Capital costs: · EPC · Capital Costs - Non-EPC · Interest during construction
2	Invertor Replacement Cost (in year 15)	USD/kW	147	Fraunhofer Levelized Cost of Electricity Renewable Energy Technologies 2013
3	Fixed O&M	USD/kW-yr.	42	World Energy Perspective[36]
4	O&M escalation per year	%	1.23	Based on average forecast US Consumer Price Index (2011 – 2020)[37]
5	Capacity Factor (average)	%	9	World Energy Perspective[38]
6	Corporate Income Tax	%	30	Trading Economics 2015[39]

Assumptions

Common Assumptions for All Countries

System size: 1 MW
For all EPC costs, the difference between Crystalline and Thin Film in Utility Solar PV is immaterial[40]
Panel Degradation per year: 0.3%
Expected Economic Life: 25 years
Proportion of Debt: 70%
Proportion of Equity:30%
Cost of Debt (pre-tax): 9%
Cost of Equity: 12%

Energy Storage Systems (ESS)

Capital Cost: USD 500/kWh (Cost includes the land and civil works, labor, security, engineering costs, finance fee and contingencies for end of life service delivery requirement.
Battery Degradation per year: 1.5%
Total capital for solar PV – ESS is considered at ~ USD 3,200/ kW

Grid Extension[41]

- Grid extension: USD 22,000/km (for transmission line only)
- Distribution grid of 2km at a fixed cost of USD 18,000/km
- 100 connections, each consuming an average of 50kWh/month for the grid extension.
- Grid extension: 1KM (=100 connections per km) USD 580/connection – Low
- Grid extension: 1KM (=3 connections per km) USD 6,960/connection – High

Solar Home Systems (SHS)

Low vs high price (developed vs undeveloped SHS market) for a 40Wp system

Diesel Mini Grids

System Size: 0.5 MW
Load conditions assumed: 75%
Fuel Usage liters/hour for a 500 KVA generator: 80[42]
Cost components: Cost of High Speed Diesel (HSD), considered as on 27th March 2017 with no subsidy, O&M costs account for lubricant requirement and general maintenance for diesel generator (major break downs are not accounted for the calculation). For small island nations and Sub Saharan African countries, logistics cost is 30% of the fuel cost and for India and China logistics cost is 10% of the fuel cost.

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[5] GGGI calculation for CO_2 emissions for diesel system assumes 0.5 MW rated capacity of each installation and 75% operating capacity, an optimum condition to achieve operation efficiency. Potential for technology switching is 250 GW. CapEx/MW for solar PV-ESS is estimated at USD 3.5 million for 2018. A yearly 10% reduction in CapEx (in account of technology advancements) is assumed until 2030. For total market sizing, the price of USD 2.2 million/ MW is considered to arrive at technology switching market, an opportunity of USD 550 billion. Time value of money is not considered for this calculation.

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[15] GGGI calculation assumes 0.5 MW rated capacity of each installation and 75% operating capacity, which is an optimum condition to achieve operation efficiency.

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[17] Lazard 2015.

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[20] The potential for technology switching is 250 GW. CapEx/MW for solar PV-ESS is estimated at USD 3.5 million for 2018. A yearly 10% reduction in CapEx (in account of technology advancements) is assumed until 2030. For total market sizing price of USD 2.2 million/ MW is considered to arrive at technology switching market, an opportunity of USD 550 billion." Time value of money is not considered for this calculation.

[21] PwC 2016.

[22] Data taken from GGGI projects in Indonesia.

[23] PwC 2016.

[24] PwC 2016

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[31] Lazard 2015.

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