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The Promise of Renewable Energy Microgrids for Rural Latin America

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The Promise of Renewable Energy Microgrids for Rural Latin America

Introduction and Summary of Findings

Since the adoption of the utility business model in the early 20th century, governments have relied on extending their national transmission grids to supply electricity to remote populations.[1] Many countries in Latin America have followed this model. In the few cases where grids were not extended, electrification has been achieved by installing local diesel generation. Yet, both grid expansion and diesel generation have significant drawbacks: transmission and distribution lines in remote areas can be unreliable;[2] logistics for diesel can be extremely complicated, leading to fuel shortages; and both methods can be very expensive. Both approaches can also cause serious environmental damage: diesel generation emits significant quantities of carbon dioxide and criteria air pollutant emissions, and grid expansion often requires constructing transmission and distribution lines through environmentally sensitive areas.

Recent developments in microgrid technology, as well as the falling costs of renewable energy technologies and energy storage, have made it possible to shift away from the traditional centralized paradigm towards a more distributed and renewable energy landscape. Indeed, for areas in which demand is low or spatially scattered, renewable energy-powered microgrids often offer a more cost-effective power solution than either grid expansion or diesel generation.[3] Moreover, when properly designed and maintained, technologies that use local renewable resources are less likely to suffer logistic or reliability problems. Given these benefits, renewable microgrids should be a favored mechanism for electrification in remote regions of Latin America.[4] Solar microgrids should be particularly attractive given the abundant solar radiation that much of the region receives.[5]

And yet, deployment of solar microgrids throughout Latin America has been slow. To understand the cause of this stagnation, the Guarini Center on Environmental, Energy & Land Use Law at New York University School of Law, together with SolarCity, convened an international workshop in October 2016 to examine barriers and opportunities to microgrid deployment in remote regions of Latin America.[6] The expert workshop brought together

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[1] *See, e.g.*, Carl Kitchens & Price Fishback, *Flip the Switch: The Impact of the Rural Electrification Administration 1935–1940.* 75 J. OF ECON. HISTORY 1161 (2015) (explaining that between 1935 and 1939, the U.S. Rural Electrification Administration spent close to 0.3% of its GDP on a massive rural electrification program to connect farms and ranches across the country through "subsidized loans to newly formed cooperative utilities and existing private utilities").

[2] *See e.g.* PETER H. LARSEN, ET AL., ASSESSING CHANGES IN THE RELIABILITY OF THE US ELECTRIC POWER SYSTEM. LAWRENCE BERKELEY NATIONAL LABORATORY (2015) (indicating that distribution areas with lower customer density have higher frequency of interruptions).

[3] Marianne Zeyringer, et al.., *Analyzing grid extension and stand-alone photovoltaic systems for the cost-effective electrification of Kenya.* ENERGY FOR SUSTAINABLE DEV. 25, 75–86. doi:10.1016/j.esd.2015.01.003.

[4] *See, e.g.*, Andrew Harrison Hubble & Taha Selim Ustun, *Scaling Renewable Energy Based Microgrids in Underserved Communities: Latin America, South Asia, and Sub-Saharan Africa*, 2016 IEEE PES Power Africa Conference 134, 138 (2016) (running microgrid simulations on 15 countries, including Argentina, Brazil, Ecuador, Paraguay, and Uruguay, and finding that economics generally favor microgrid development, particularly in countries with very high diesel prices, such as Argentina and Uruguay).

[5] *See* LATIN AMERICA PV PLAYBOOK, GTM RESEARCH (2016), https://www.greentechmedia.com/research/report/latin-america-pv-playbook (noting that due in part to its high solar insolation levels, Latin America is positioned to be one of the most attractive regions on the planet for solar development).

[6] This was the second annual international microgrids workshop held in collaboration with SolarCity; the first examined opportunities and obstacles to microgrid deployment in Small Island Developing States. For a summary of findings from that workshop *See* DANIELLE SPIEGEL-FELD, DEPLOYING SOLAR POWERED MICROGRIDS ON SMALL ISLAND DEVELOPING STATES: BREAKING THROUGH THE BARRIERS TO REALIZE THE BENEFITS (2015), *available at* http://guarinicenter.org/microgrids/.

government and utility representatives from Latin American countries (Argentina, Chile, Colombia, Guyana, Mexico, Panama and Uruguay) as well as development bank officials, private financiers, law firms, academics, renewable energy industry experts, and representatives of several inter-governmental and non-governmental organizations.

Over the course of the two-day workshop, participants reviewed a series of case studies examining potential renewable energy microgrid projects in remote regions of the participating countries. Each case study illustrated that solar powered microgrids offered a cost-effective alternative to diesel generation. Specifically, modelling indicated that installing a hybrid system in which photovoltaics provided a minimum of 66% of electricity consumed would lower the levelized cost of electricity in each community examined.

The remainder of this report is organized in two main parts: In Part 1, we present a summary of the case studies of potential new microgrid projects that were examined during the Workshop, including the assumptions that were made during the modelling exercises. In Part 2, we review the major barriers to microgrid deployment that participants identified, and possible strategies to overcome such obstacles that they suggested.

Part I – Case Studies

A. Overview

Participants at the workshop examined seven case studies of potential microgrid projects in rural regions of six countries in Latin America: Argentina, Colombia, Guyana, Mexico, Panama, and Uruguay.[7] Each case study explored the economics of installing a microgrid system, as well as potential barriers to implementation. SolarCity analysts and engineers performed all modelling for the case studies with source data provided by national energy experts.

Participants at the workshop examined case studies of two different categories of projects: diesel displacement projects and energy access projects. Case studies of diesel displacement projects explored the possibility of replacing existing diesel generation with photovoltaics (PV) and advanced battery energy storage. By contrast, case studies of potential energy access projects examined the potential for deploying microgrids in communities that currently lack access to electricity (or have only minimal, sporadic access). In these instances, the case studies compared the economics of expanding supply via new diesel generation as opposed to a hybrid PV and diesel system.

The technology used all case studies was the GridLogic system, developed by SolarCity. These systems combine a ground-mounted PV array, battery storage, and backup generators with a control system to provide a free-standing power system. The various components of a GridLogic system are represented in Figure 1.

[7] For some countries, engineers at SolarCity performed case studies of multiple potential projects. However, with the exception of Argentina, we only reviewed one case study per country during the workshop and will only describe this subset of case studies in this report.

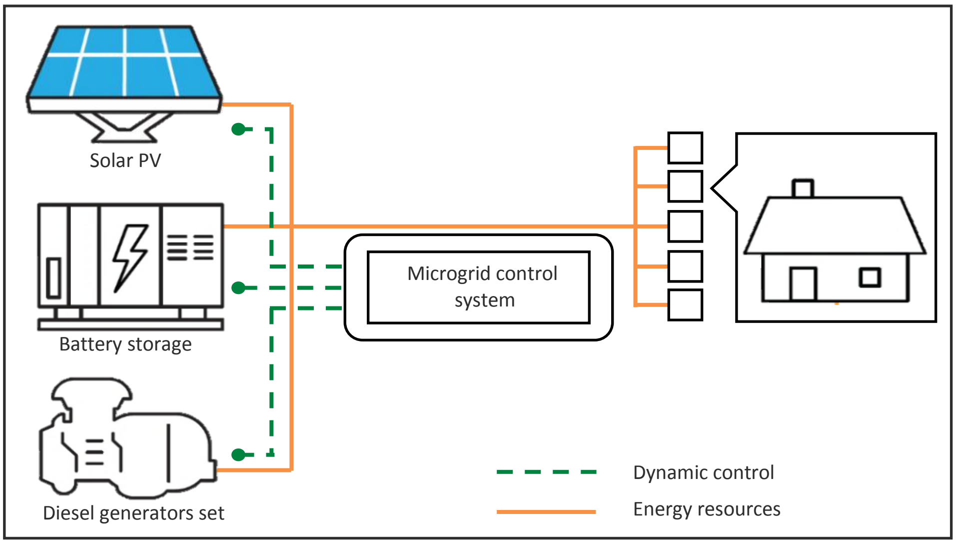

Figure 1

The overarching goal of the case studies was to determine whether the GridLogic system, as an example of a solar powered microgrid, could provide a cost-effective alternative to diesel generation in rural territories. As discussed below, all case studies provided evidence to support this proposition.

B. Assumptions

SolarCity used the following assumptions in the models created for the case studies:

Levelized Cost of Energy: The comparative economic benefits of renewable energy microgrids can be quantified using the internationally recognized metric known as the Levelized Cost of Energy (LCOE). Energy experts in industry and academia use this metric to compare the costs of energy generation across different types of technology.[8] This metric is especially useful when comparing renewable energy versus diesel based generation, as the two technologies have very different cost structures. Renewable technologies have high upfront capital costs and low operating costs, while diesel technologies have low upfront capital costs and high operating fuel costs.

In the modelling performed for these case studies, the LCOE was calculated as follows:

$$LCOE = \frac{NPV\ (CapEx + O\&M)}{TotGen}$$

where

- CapEx = Capital expenditure[9]
- O&M×NPV = Net present value of operating and maintenance expenditure (O&M) based on discount rate *r* and project life *T*, calculated as $O\&M \times NPV = \sum_{i=1}^{T} \frac{O\&M}{(1+r)^i}$
- TotGen = Total generation over project life *T*. For all calculations, the project life for renewable systems was considered to be T = 30 years.

[8] Govinda Timilsina, et al., *Solar Energy: Markets, Economics and Policies*, 16 RENEWABLE ENERGY REVIEWS 449, 453 (2012).
[9] Existing generator financing costs and O&M were omitted from calculations for diesel generators (a conservative assumption).

The relevant variables for diesel and renewable systems are:

Variable\Technology	Diesel	Renewable
CapEx	None*	Capital cost + financing costs
O&M expenditure	Fuel + generator replacement	Operation and maintenance + battery replacement
Discount rate	6%	6%

*Conservative assumption, assuming exiting diesel generation on-site can be integrated into the microgrid system.

Specific assumptions for each variable are described as follows:

Discount rate: All case studies used a standard discount rate of 6%.

Diesel fuel costs: In calculating the LCOE of diesel generation, case studies assumed site-specific fuel costs as reported immediately prior to the workshop on October 27th, 2016. Importantly, a barrel of Brent crude oil was trading at approximately $52 in late October 2016, which represents a decline of roughly 50% from peak prices recorded just two years earlier.[10] The comparative economic advantage for renewable generation versus opposed diesel generation would increase with increased oil prices.

Diesel fuel cost escalator: SolarCity assumed 6% per annum, which is reasonable relative to the latest WB forecasts.

Operations and Maintenance escalator: The case studies presumed a 3% annual escalation in O&M costs for renewable energy systems.

Storage: The case studies assumed use of a lithium-ion storage system produced by Tesla with a warrantied life of 10-years, which accounts for degradation.

Replacement of parts: Case studies assumed that diesel generators and solar inverters would be replaced after 15 years.

C. Findings

Engineers at SolarCity worked with country representatives to put together technical and economic modelling of the potential projects examined in each case study, which were then discussed at the workshop. The case studies were set in regions that differ widely in terms of geography, population density, current electricity prices, and load curves. To cite one metric that captures the variation, the fully burdened cost of diesel in the different communities was estimated to range from $2.21 per gallon (La Palma, Panama) to $5.64 per gallon (Villa Traful, Argentina). Yet, despite these differences, economic modelling indicated that installing a hybrid system in which PV provided at least 66% of electricity consumed would reduce the LCOE below that provided by diesel-only systems. The modelling results indicated that it would be

[10] In the summer of 2014, a barrel of Brent crude oil traded for approximately $100.00. This analysis does not consider the benefits of reduced exposure to fuel price volatility, which could be considerable given the possibility for rebound towards prior highs.

cost-effective for some communities to produce over 95% of electricity supplied via solar PV. Below, we summarize the seven case studies, which are presented in alphabetical order according to the country in which they are situated.

Notably, while the case studies described in this report assessed communities that differ significantly, it is important to acknowledge that they reflect a particular set of conditions, and that the conclusion that renewable energy microgrids are more cost-effective than diesel may not hold for all remote communities.

Argentina – Los Toldos and Villa Traful

Argentina has one of the highest electrification rates in Latin America, with 98% of the population having some access to electricity. Yet, representatives at the workshop indicated that over a million Argentinians are disconnected from the grid, with many relying on isolated diesel generation systems to provide electricity. There are 120 diesel powered microgrids throughout the country, including 25 systems that serve towns with more than 2,000 inhabitants.

Argentina currently produces 67% of its electricity from thermal generation and 30% from hydropower. The remainder derives from nuclear and renewable sources. The government has a mandate to produce at least 20% of the country's electricity from renewable resources by 2025, and has implemented a number of programs and fiscal incentives to support the development of utility scale and distributed renewable resources.[11]

Los Toldos, Province of Salta

Summary of Proposed Solution (Los Toldos)	
Solar Photovoltaic Capacity (kW DC)	1,000
Battery Energy Storage Capacity (kWh) (EOL)	4,000
RE Proportion	97%
Land Requirement (acres)	3
Diesel LCOE	$0.39
RE LCOE	$0.22
Blended Diesel & RE LCOE	$0.24

** Based on Current Diesel Fuel Cost

Los Toldos is a town of 2,225 people in the north of Argentina, near the border of Bolivia. The dominant economic activity in the area is agriculture, with a focus on sheep and corn. Electricity demand is expected to grow by roughly 10% per year.

Today, Los Toldos depends on diesel, which is imported from Bolivia, to meet its electricity needs. Peak load for the town is approximately 547 kW and it has 1,000 kW of installed capacity. Demand typically peaks in the evening hours, around 9pm. A gallon of diesel, including transportation expenses, costs $5.21, and the LCOE of the current diesel system is approximately $0.39. Bolivia also imposes a supply limit of 9,000 gallons per month, aggravating concerns about fuel shortages that are common to many remote communities.

[11] Law 27.191, Art 5, sets forth the 20% target through 2025. Additionally, Law 27.191, Art. 4, amended Law 26.190 by introducing several incentives to foster renewable sources of energy. Incentives include accelerated depreciation of assets, early return of paid Value Added Tax, and exemption from dividend tax, among others. On the program side, in 2016 Argentina launched Round 1 of the RenovAr Program, a competitive bidding process for the government's purchase of electric power from renewable sources; details on http://www.energia.gob.ar/contenidos/archivos/Reorganizacion/informacion_del_mercado/mercado_electrico/plan_renovar/RenovAr_Round_1_-_RfP_with_Annexes_(fv_07-25-2016)_(English_Version).pdf.

Notably, it is not possible to connect Los Toldos to the central grid because doing so would require installing transmission lines across a national park, which is prohibited by the country's environmental protection laws. The government therefore would like to transition the community towards local renewable generation.

With these objectives in mind, modelling performed by SolarCity indicated that the optimal solution for Los Toldos would be to install a microgrid system that includes 1,000 kW of solar photovoltaics and 4,000 kWh of storage. The proposed solution would be able to supply 97% of Los Toldos' electricity demand with solar energy. Capital costs for the new technology were estimated to be approximately $6.7 million and the LCOE of this hybrid system was estimated to be $0.24 kWh, which would represent a savings of 33% compared to the current diesel-only system. Notably, the Argentine government would need to navigate some complications in constructing the project due its remote location. In particular, the government may need to arrange for the project developer to be able to access the site via Bolivia.

Villa Traful, Province of Neuquén

Villa Traful is a small community of 500 people in the southwest of Argentina, near the Chilean border. The site is set on the edge of a picturesque lake in the Nahuel Haupi National Park. The primary industries in the area are tourism and agriculture.

Today, Villa Traful relies entirely on diesel generation for its electricity supply. The area has a peak load of approximately 500 kW and has 1,640 kW of installed capacity. Load growth is expected as the region anticipates increased tourism, including potential new hotels, but there is significant uncertainty as to the extent of the predicted growth. Demand is fairly uniform throughout the day but peaks slightly around 9pm.

Summary of Proposed Solution (Villa Traful)	
Solar Photovoltaic Capacity (kW DC)	2,500
Battery Energy Storage Capacity (kWh) (EOL)	6,000
RE Proportion	93%
Land Requirement (acres)	7.5 or 5*
Diesel LCOE	$0.54
RE LCOE	$0.25
Blended Diesel & RE LCOE	$0.30

LCOE Based on Current Diesel Fuel Cost
*5 acres needed if high efficiency modules are used

It is difficult to transport fuel to the remote Villa Traful, which leads to very high local fuel prices– the fully burdened cost of diesel was estimated to be $5.64 per gallon at the time of the workshop. It is not possible to connect the area to the central grid via transmission expansion due to the sensitive ecology of the surrounding areas; as is the case with Los Toldos, grid expansion would required installing transmission lines across a National Park. In addition, given the pristine local environment, which is the main attraction for the local tourism industry, the government would like to reduce the combustion of fossil fuels in the area. For all of these reasons, the government eagerly seeks to transition towards local renewable generation.

Two key constraints need to be accounted for in designing a potential solar microgrid project for the site. First, solar production varies considerably throughout the year, peaking in January and reaching a low in June. Second, due to restrictions on clearing land, there are only approximately five acres available on which to site new technology.

In light of these constraints, SolarCity's modelling assessment indicated that the optimal solution for Villa Traful from would be to install a system in which solar photovoltaics (PV) produced 93% of electricity supply over the course of a year. Specifically, the optimal solution was found to be to install 2,500 kW of PV and 6,000 kWh of battery storage. The LCOE for the proposed hybrid system was estimated to be $0.30 per kWh, which is approximately 45% less than the LCOE of the current diesel-only system.

Colombia – Santo Domingo, Cartagena del Chairá

Summary of Proposed Solution (Santo Domingo)	
Solar Photovoltaic Capacity (kW DC)	40
Battery Energy Storage Capacity (kWh) (EOL)	80
RE Proportion	89%
Land Requirement (acres)	<1
Diesel LCOE	$0.32
RE LCOE	$0.27
Blended Diesel & RE LCOE	$0.29

** Based on Current Diesel Fuel Cost

Electrification rates vary considerably throughout Colombia. Nationally, over 99% of the country's 47 million inhabitants have access to electricity. Yet, among rural populations, only approximately 87% of the population has access, and many of these communities have inadequate access. The small town of Santo Domingo in the southwest of the Colombia fits into this second category: The community's 96 ratepayers only have access to electricity 5 days of the week, which is supplied by diesel generation.

Santo Domingo's peak load is 40 kW and total installed capacity is 50 kW. As in many other communities, daily peak demand is in the evening hours, between 7 and 9pm. Given the proximity to the equator, solar production does not vary significantly throughout the year. The fully burdened cost of fuel at the site is $3.56 per gallon and the LCOE is approximately $0.32 per kWh.

The government is eager to expand electricity supply in the area and lower the cost of service. The government also wants to move towards renewable resources to avoid polluting the pristine local environment, and to contribute to its goal of supplying 20% of the country's electricity by renewable resources by 2030.

Modelling indicated that the least cost solution for the community would be to install 40 kW DC of solar PV capacity and 80 kWh of battery storage. The additional capacity provided by the system would allow the community to receive electricity 7 days a week, and 89% of the electricity supplied would be produced by the PV installation, leaving only 11% to be supplied by the diesel generation. The LCOE of new hybrid system was estimated to be $0.29 per kWh, which is nearly 10% below the current LCOE for diesel generated electricity.[12] Less than 1 acre of land would be required to implement the proposed solution.

Guyana – Lethem, Upper Takutu-Upper Essequibo

Twenty percent of Guyana's population lives in the Hinterlands, which relies almost exclusively on isolated diesel systems for electricity supply. Grid expansion is not a viable option for the area due to the challenging topography and large distances between villages. The country is also deeply committed to taking on a leadership role in climate change mitigation, including via the promotion of renewable energy resources.

Lethem is one of many Hinterland populations that currently rely on diesel generation. The village, which is located 422 kilometers from the country's capital, has 1,290 consumers. The primary industries in the area are agriculture and food processing. Peak load is 800 kW, but the

[12] Notably, however, this system was predicted to have a payback period of roughly 13 years, which was longer than the predicted payback period for systems examined in other case studies.

government expects load to grow by approximately 4% per year. Load peaks in the afternoons, between 11am and 4pm. The fully burdened local fuel cost is $2.45 per gallon and the government currently provides a subsidy of $500,000 per year to help defray operating costs. The LCOE for the existing system was estimated to be just under $0.24 per kWh. The government hopes to find a renewable energy solution for the Lethem site that would enable it to reduce the cost of electricity production, thereby allowing it to eliminate the current subsidy, and greenhouse gas emissions, while improving energy security and reliability.

In light of these project objectives, SolarCity's modelling suggested that the preferred solution would be to install a hybrid system in which solar PV provided 95% of the electricity supply. The proposed system would include 4,500 kW of solar PV capacity as well as 12,000 kWh of battery storage. The LCOE of the proposed hybrid system was estimated to be just over $0.20. The system would require approximately 15 acres of land, which workshop representatives indicated is available. Government representatives indicated that the main challenge they would face in attempting to implement the solution is the lack of local technical expertise regarding the design and operation of hybrid systems. They hope to receive assistance building local capacity.

Summary of Proposed Solution (Lethem)	
Solar Photovoltaic Capacity (kW DC)	4,500
Battery Energy Storage Capacity (kWh) (EOL)	12,000
RE Proportion	95%
Land Requirement (acres)	15
Diesel LCOE	$0.24
RE LCOE	$0.20
Blended Diesel & RE LCOE	$0.20

** Based on Current Diesel Fuel Cost

Notably, in calculating the economics of the project, engineers assumed that the government could secure a concessional loan at a rate of 2% and that it would be possible to finance 100% of the project. Government representatives hoped they would be able to secure such financing for this project from a multilateral development, which they viewed as a necessary pilot study, but indicated that the cost of capital for any subsequent projects would likely be higher.

Mexico – Delicias, Baja California

The Federal Electricity Commission of Mexico reports that 1.8 million residents of the country lack access to electricity.[13] In its efforts to expand electricity access throughout the country, the government established the "Fondo de Servicio Universal Eléctrico (FSUE or the "fund") as part of its electric industry reforms of 2014.[14] FSUE has three chief objectives: electrify rural populations; distribute energy efficient lamps; and subsidize residential users in extreme poverty. Wherever possible, the fund is committed to using renewable technologies to achieve its aims.

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[13] http://www.gob.mx/sener/galerias/fondo-de-servicio-universal-electrico?idiom=es Mexico recently approved a comprehensive energy reform. Pursuant to these reforms, generation and retail supply are now subject to a competitive market regime, while the state is in charge of transmission and distribution, as well as planning and control of the government run National Electric System. Notably, however, the National Energy Control Center is authorized to enter into partnership with private firms to help carry out its transmission and distribution responsibilities.

[14] The fund raises revenue through a number of sources, including fines that are levied on the electric industry and donations received from third parties. *See* Ley de la Industria Eléctrica [LIE], Diario Oficial de la Federación [DOF] 11-08-2014, Art 114, *available at* http://www.dof.gob.mx/nota_detalle.php?codigo=5355986&fecha=11/08/2014; Bases del Mercado Eléctrico [BME], *and* Diario Oficial de la Federación [DOF] 8-09-2015, Bases 17.8.2 and 17.8.3, *available at* http://www.cenace.gob.mx/Docs/MarcoRegulatorio/BasesMercado/Bases%20del%20Mercado%20El%C3%A9ctrico%20Acdo%20Sener%20DOF%202015%2009%2008.pdf.

Summary of Proposed Solution (Delicias)	
Solar Photovoltaic Capacity (kW DC)	74
Battery Energy Storage Capacity (kWh) (EOL)	190
RE Proportion	92%
Land Requirement (acres)	<1
Diesel LCOE	$0.31
RE LCOE	$0.22
Blended Diesel & RE LCOE	$0.24

** Based on Current Diesel Fuel Cost

The village of Delicias, which is located in Baja California, is home to 80 people. At present, the community only has access to electricity 2 hours per day and annual electricity consumption is 25 MWh. The electricity that is available is produced by diesel generation. The fully burdened cost of fuel in the area is $3.97 per gallon and the LCOE of electricity from the system is approximately $0.31 per kWh.

The government would like to increase electricity supply in the community, without needing to resort to transmission expansion, which is thought to be uneconomic given the community's remote location and the small number of ratepayers. In keeping with the fund's priorities, the government also prefers to implement a renewable power solution for the community.

A major challenge in designing a power solution for this population is forecasting what the community's load profile will look like. Having such limited access to electricity today, engineers cannot look to historical consumption patterns to predict when, and how much, electricity the community would use if supply were available 24 hours a day, seven days a week.

After consultation with Mexican authorities, SolarCity's engineers decided to assume the population would require three times the current supply and that the supply should be available on a 24/7 basis. With these parameters in mind, they determined that the most cost-effective solution would be to install a hybrid system in which solar PV provided 92% of electricity delivered. The proposed system would incorporate 75 kW of solar PV capacity as well as 190 kWh of battery storage. The LCO of electricity from the hybrid system was estimated to be approximately $0.24 per kWh, which represents savings of 23% compared to the current diesel-only system.

Panama – La Palma, Darién

Summary of Proposed Solution (La Palma)	
Solar Photovoltaic Capacity (kW DC)	2,500
Battery Energy Storage Capacity (kWh) (EOL)	6,000
RE Proportion	66%
Land Requirement (acres)	7.5
Diesel LCOE	$0.22
RE LCOE	$0.15
Blended Diesel & RE LCOE	$0.18

** Based on Current Diesel Fuel Cost

There are 16 isolated systems throughout Panama today, which collectively have an installed capacity of 32 MW. At least two more systems are expected to come online next year. The transmission utility ETESA conducts a competitive bidding process for generation in the isolated regions in accordance with protocols set by the regulatory authority (ASEP), and the utility ENSA concludes Power Purchase Agreements with the winning bidders. While the Panamanian government maintains several incentive programs to support renewable energy development, at present, all isolated systems rely on fossil generation.

La Palma is one of the many isolated

communities that currently relies on fossil generation. There are 4,200 inhabitants of the town, which is located on the southwest coast of Panama. The primary economic activity in the area is subsistence farming, and, more recently, tourism.

La Palma sits on the banks of a river in the center of a very dense jungle. Pursuant to a regulatory mandate, Panama's distribution companies are currently carrying out infrastructure projects to integrate La Palma and other similarly situated off-grid systems into the central grid, and have not ruled out extending transmission lines to connect the areas. But proceeding along this path could cause significant damage to the ecologically sensitive surrounding areas.

Peak load in La Palma is 800 KW and total annual consumption is 4,527 MWh. The current installed capacity is 3,159 kW and expected load growth is 2%. There are two small peaks in demand during a typical day, in the early afternoon and early evenings, however, the load profile is generally quite flat. The local cost of fuel is $2.21[15]. The utility that is in charge of providing service to the area, ENSA, hopes to add renewable energy to the local generation mix. Their primary objective is to implement the most cost-effective approach for the area and to develop sustainable energy solutions that would make integration to the central grid unnecessary.

SolarCity's modelling indicated that costs would be minimized by installing a hybrid system in which solar PV generates 66% of the local electricity supply. The proposed installation would incorporate 2,500 kW of solar PV as well as 6,000 kWh of battery storage. The LCOE from the hybrid system would be approximately $0.18 per kWh, which is almost 20% less than the current LCOE, which was estimated to be $0.22 per kWh. As one workshop participant noted, the percentage of renewable energy in the system could be increased to over 90% while still conferring cost advantages to the ratepayers.

<u>Uruguay – Minuano, Colonia</u>

Uruguay is among the most developed nations in Latin America and has achieved nearly 100% electrification. Yet, there remain several small population centers in the country that have not been connected to the grid and rely on isolated diesel systems. To further its environmental objectives, as well as reduce the cost of electricity in these areas, the government would like to transition these communities towards renewable resources, and is particularly interested in exploring the possibility of off-grid renewable systems so as to avoid the expense and environmental damage associated with transmission expansion. To that end, the government piloted a hybrid solar, battery and diesel system in the small village of Cerros de Vera, which entered into service in February of 2015. The government has been pleased with the new system, which has substantially lowered the LCOE in the village. It hopes to launch a second pilot project to serve the village of Minuano, for which SolarCity conducted a case study.

Summary of Proposed Solution (Minuano)	
Solar Photovoltaic Capacity (kW DC)	35
Battery Energy Storage Capacity (kWh) (EOL)	70
RE Proportion	87%
Land Requirement (acres)	< 1
Diesel LCOE	$0.36
RE LCOE	$0.27
Blended Diesel & RE LCOE	$0.29

** Based on Current Diesel Fuel Cost

[15] Fuel costs in La Palma are considerably lower than in other isolated areas that are harder to access, where the fully-burdened cost can be two or three times greater.

Minuano is a small community consisting of approximately 15 houses and a school in central Uruguay. The community is 25 miles from the nearest village, which itself has only 500 inhabitants. There is little economic activity in the area and no public transportation.

Today, there is no public electrical infrastructure in Minuano (some homes self-generate with diesel or solar home systems, but these systems are quite unreliable and there is no public data as to the quantity of electricity produced by the systems.) As such, SolarCity's engineers, working in concert with representatives of the Uruguayan government, developed an assumed load profile based on consumption patterns of similar communities. They modelled a peak demand of 8 kW and assumed a daily peak between 7 and 8pm. The fully burdened cost of fuel in the area is $4.85 per gallon and the estimated LCOE from a diesel system was estimated to be $0.36 per kWh.

Modelling performed by SolarCity indicated that the optimal solution for Minuano from a cost perspective was to install a hybrid system in which solar PV would provide approximately 87% of supplied electricity. Specifically, the system would include 35 kW of solar PV capacity and 70 kWh of battery storage as well as an 8 kW diesel generator. The LCOE from the hybrid system was estimated to be $0.29 per kWh, which represents a savings of just under 20% compared to diesel generation alone.

Summary of Economic Findings

To summarize, each case study found that installing a hybrid system that incorporated solar PV, battery storage, and modest quantities of diesel generation was more cost-effective than relying on diesel generation alone. A summary of table of the comparative economics of the two types of systems is presented below.

Community	Current/Modelled Diesel LCOE	Blended RE & Diesel LCOE of Hybrid Microgrid	Percent Saved
Argentina - Los Toldos	$0.39	$0.26	33.3%
Argentina - Villa Traful	$0.54	$0.30	44.4%
Colombia - Santo Domingo	$0.32	$0.29	9.4%
Guyana - Lethem	$0.24	$0.20	16.7%
Mexico - Delicias	$0.31	$0.24	22.6%
Panama - La Palma	$0.22	$0.18	18.2%
Uruguay - Minuano	$0.36	$0.29	19.4%

Part II – Deployment Challenges and Proposed Strategies for Overcoming Them

The case studies examined at the workshop provided strong evidence that solar powered microgrids could help lower the cost of electricity service in isolated regions of Latin America. However, participants also identified a number of challenges that could complicate efforts to deploy these systems. Broadly speaking, the workshop revealed two categories of challenges: First, there are "project development barriers," which are difficulties parties face when they attempt to build stakeholder support and secure financing for a project. Second, there are the "implementation and maintenance barriers," which are problems parties encounter during the ongoing operation of microgrids to ensure that they remain financially and technologically sustainable.

Importantly, the challenges identified during the workshop were quite similar to those that surfaced in a previous workshop concerning opportunities and obstacles for microgrid deployment in Small Island Developing States.[16] This suggests that the same barriers may also emerge in other regions. As such, efforts to devise solutions to overcome deployment barriers in isolated regions in Latin America may have applications to markets with similar social, regulatory, and/or economic structures as well.

Project Development Barriers

Many of the development phase challenges that workshop participants highlighted were similar from country to country. The most commonly experienced challenges described by participants include difficulty aligning various government stakeholders, designing regulatory reforms, and, above all else, securing financing.

Challenge #1: Aligning Governments Actors

Numerous government actors must coordinate to facilitate microgrid deployment. For instance, while energy ministries generally develop renewable energy targets and related policies, the permits and funds for the renewable energy projects that are needed to meet those targets often come from environment and finance ministries, and/or energy regulators. Tax authorities may also play a role because their policies may alter the incentives for renewable energy development. Without close coordination between all of these institutions it is exceedingly difficult to bring renewable energy microgrid projects to fruition. Yet, too often, workshop participants noted, the various government bodies operate independently and fail to develop coordinated policy objectives. For example, a government representative explained that part of the reason that renewable energy growth in his country had failed to meet expectations is that the tax authorities responsible for administering fiscal incentives, such as the elimination of Value Added Tax on renewable technologies, are not well versed in the technologies involved in renewable energy systems.

To forge greater policy coherence, participants suggested that the energy ministries in each country engage representatives of other relevant government bodies in discussions about renewable energy and electrification goals at their earliest stages. Investing in this sort of policy coordination should also help governments to secure funding for projects as several development bank representatives noted that their organizations are reluctant to fund projects that do not appear to have a broad support from the recipient government. The same individuals indicated that they look particularly carefully at whether a country's finance ministry supports a venture.

Challenge #2: Considering Off-Grid Solutions and Grid Expansion on Equal Footing

Workshop participants indicated that their countries often neglect to examine alternatives to grid expansion in domestic transmission and distribution planning processes. For instance, one official observed that his government had not evaluated the option of constructing a microgrid as alternative to building an underwater transmission line to connect a small, isolated island population to the central grid. Participants also repeatedly noted that their countries have not developed regulatory tools, models, and metrics that allow them to perform effective cost-benefit analysis of grid expansion as compared to off-grid solutions. Moreover, some of the benefits of off-grid systems such as hedging against fuel price volatility and shortages are hard to

[16] The earlier workshop identified the following list of barriers: Aligning governments and utilities; securing development bank support; engaging the private sector; building scale; acquiring sufficient land; procuring insurance; integrating pre-existing distributed generation; training specialized workforces; managing construction logistics; and, allocating predicted savings. *See* Spiegel-Feld, *supra* note 6, at 13-15.

quantify. The failure to rigorously evaluate off-grid alternatives may cause regulators to invest unnecessary capital in grid infrastructure, while undermining the pursuit of public policy objectives including environmental protection and increased reliability.

To ameliorate the situation, Latin American countries could require regulators to compare the costs and benefits of off-grid and on-grid solutions during transmission planning and permitting. There is international precedent for such a policy. For example, the U.S. Federal Energy Regulatory Commission (FERC) has directed transmission planning authorities to give "comparable consideration" to alternatives other than transmission expansion during the planning process.[17] The goal of this policy was to protect ratepayers from "charges that are excessive relative to less costly and equally or more effective alternatives."[18] Although industry practice in the U.S. has fallen short of FERC's ambitions,[19] at a minimum these rules lay the groundwork for a more efficient allocation of resources in the electricity sector. If regulators in Latin America were to include a similar requirement for cost-benefit analysis in their own planning processes, they should consider how to avoid the pitfalls that have limited the efficacy of FERC's regulations and how to integrate it into their own rural electrification programs.[20]

Challenge #3: Establishing Customized Regulatory Frameworks

Developing customized regulatory frameworks for renewable microgrids that match their particular economic and operational features can make them both more cost-effective and more sustainable. Like most renewable energy resources, solar microgrids produce variable quantities of electricity depending on seasonal patterns and the time of day. Dynamic pricing schemes can manage this variability by shifting demand towards the solar peak and encouraging users to curtail consumption when solar energy is less abundant. At present, however, most Latin American governments lack experience crafting these kinds of flexible tariffs, such as time-of-use rates or real time pricing, and their utilities often lack the communication infrastructure needed to facilitate dynamic pricing schemes. Similarly, several workshop participants noted that countries have not developed tailored-made regulatory frameworks to incentivize and monitor microgrids, and lamented that they are subject to the same standards regarding third party access as grid-connected systems.

To address these barriers, governments should work with technical experts from development banks and elsewhere to introduce tariff schemes and regulatory frameworks that are tailored for microgrids. These efforts should also include educational programs for the community to empower them to make economic decisions when responding to dynamic price signals. It will also be important for regulators to maintain an active dialogue with their counterparts in other

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17 *See* FERC Order 890, Preventing Undue Discrimination and Preference in Transmission Service, 72 Fed. Reg. 12, 266 (March 15, 2007); FERC Order 1000, Transmission Planning and Cost Allocation by Transmission Owning and Operating Public Utilities, 76 Fed. Reg. 49,842 (Aug. 11, 2011).

18 Scott Hempling, *'Non-Transmission Alternatives': FERC's 'Comparable Consideration' Needs Correction*, ELECTRICITY POLICY 2 (May 2013), *available at* http://www.scotthemplinglaw.com/files/pdf/ppr_nta_comparable_consideration_0513.pdf.

19 For a description of the shortcomings of Orders 1000 and 890, and suggestions as to how they can be improved upon to ensure more thorough consideration of non-transmission alternatives, *see* Shelley Welton, Non-Transmission Alternatives, 39 HARV. ENVT'L L. REV. 457 (2015). *See also* Hempling, *supra* note 18. The Bonneville Power Authority, which operates the transmission network in the Pacific Northwest, is often cited as a best practice example for the consideration of non-transmission alternatives. For review, *see* CHRIS NEME & RICH SEDANO, REGULATORY ASSISTANCE PROJECT, US EXPERIENCE WITH EFFICIENCY AS A TRANSMISSION AND DISTRIBUTION SYSTEM RESOURCE (2012).

20 Notably, effective implementation of this policy in rural Latin America would also require enhanced coordination between resource planning and rural electrification programs at the national and local level. The FERC policy is not intended specifically for rural electrification, but more broadly for power system expansion.

Latin American countries and beyond so that they can exchange best practices and lessons learned.

Challenge #4: Engaging Beneficiary Communities

Many rural communities are skeptical[21] of both renewable energy and off-grid systems. For example, a representative noted that isolated communities had previously exhibited a preference for grid-connected and/or fossil generation because of concerns about the reliability of microgrids. To overcome this opposition, developers should engage community representatives as the project is being designed, including during the modelling assessments, so that they become more familiar with the new technology. The relevant authorities should also be careful to maintain an open dialogue with communities after the microgrids have been installed to address concerns as they arise.

An additional reason to enroll the community from early stages is for them to develop a sense of ownership of the project, particularly through the provision of basic preventative and corrective maintenance (see also Challenge #8). In the absence of remote monitoring, the community members are usually trained to perform maintenance and operation activities for their microgrids.[22] This can enhance the uptime and overall reliability of the system considering that technicians face long lead times for visits after equipment outages in such remote areas. It can also help reduce operating costs.

Challenge #5 Securing Development Bank Support

Development banks are a critical source of low-cost financing for microgrid projects and their support is often essential to assembling a bankable project. These banks offer a range of financing instruments including grants, soft loans and loan guarantees. They can also provide critical technical assistance, including advice about contract development and regulatory reforms.

Yet, development banks are cautious when selecting projects, and government representatives should be careful to understand their preferences before seeking support. Representatives at the workshop highlighted several criteria they find particularly important when assessing whether to fund a given project, including, but not limited to:

1) The government's commitment to the project;
2) The country's capacity to implement and maintain the system; and
3) The extent to which the project furthers environmental objectives.

With respect to the government's commitment, some institutions, including the World Bank, prefer the Ministry of Finance to be the project proponent and direct point of contact. Other funders, including the United Arab Emirates, are more flexible as to who the project proponent is, but still insist that the relevant offices demonstrate that they are committed to the project and that they have coordinated with other agencies. In terms of local capacity, various funders indicated a preference for engaging existing local businesses and workers where possible, as opposed to training a completely new workforce. Finally, funders consider carbon reduction and biodiversity preservation goals[23] and may prefer microgrids over grid expansions in

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[21] Gayarthi Vaidyanath, Activist Say Solar Can Power India, But Politics and Economics of Coal Win Out, E&E News (October 19, 2015), *available at* http://www.eenews.net/stories/1060026477.
[22] *See e.g.* DANIEL SCHNITZER et al., MICROGRIDS FOR RURAL ELECTRIFICATION: A CRITICAL REVIEW OF BEST PRACTICES BASED ON SEVEN CASE STUDIES*,* UNITED NATIONS FOUNDATION (2014).
[23] For more details on World Bank Environmental and Social Safeguards, *See* WORLD BANK, ENVIRONMENTAL AND SOCIAL FRAMEWORK, SETTING ENVIRONMENTAL AND SOCIAL STANDARDS FOR INVESTMENT PROJECT

circumstances where transmission line extensions through sensitive habitat would otherwise be required. Development bank representatives at the workshop also indicated that they would no longer support deployment of new diesel generation as a means of rural electrification.

Workshop participants noted that governments frequently misunderstand both the role development banks play and their funding criteria, which hinders their ability to secure support. To overcome this potential obstacle, development bank representatives encouraged governments to approach them from the earliest stages of project development. This can help parties to structure a project that aligns with the banks' priorities and more effectively leverage their expertise.

Challenge #6: Project Scale

The small scale of off-grid projects may make them unattractive to private sector investors and may dissuade some public funders as well. Private financiers at the workshop noted that the fixed costs of due diligence for projects of this sort can be considerable and can easily exceed the potential financial gains if projects are not reasonably large. Public financiers also indicated that it can be difficult to provide loans of less than $5,000,000, given the associated administrative costs. This could be a significant obstacle to securing financing because several of the projects examined at the workshop had capital costs of less than $5,000,000.

To overcome this obstacle, government and utilities should attempt to bundle projects.[24] In countries where multiple utilities operate, bundling may also require that utilities are willing to collaborate on applications for funding. Participants noted that it would be difficult to bundle projects between different countries due to discordant regulatory frameworks and pricing.

Challenge #7: Engaging the Private Sector

Participants at the workshop generally agreed that to reach the required volume of microgrid deployment, private financiers will need to be engaged. As was repeatedly noted throughout the meeting, public sector oriented lending institutions such as the World Bank and Inter-American Development Bank can help catalyze the initial deployment of microgrids in a given country. However, the industry will ultimately need to channel private capital to grow and become financially sustainable.

Participants noted that falling technology costs have created valuable investment opportunities for private sector institutions. And yet, many private institutions are reticent to commit capital to Latin American microgrid projects because of the perceived riskiness of the investments, and the fact that few institutions have experience with these types of projects.

Participants highlighted a number of steps that Latin American countries and their utilities can take to reduce the risk associated with microgrid investment. For instance, one participant noted that several countries had started issuing Power Purchase Agreements (PPAs) that were denominated in U.S. dollars, which he felt was a major step forward because it reduced the currency risk associated with the investments. However, many countries need to improve the contract terms offered in PPAs. For example, several participants observed that some PPAs are

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FINANCING (Aug. 2016), *available at* http://consultations.worldbank.org/Data/hub/files/consultation-template/review-and-update-world-bank-safeguard-policies/en/materials/the_esf_clean_final_for_public_disclosure_post_board_august_4.pdf.

[24] Development bank representatives at the workshop noted that Panama's competitive bidding process, which bundles thirteen projects, provides an example of an effective way to build scale.

not designed with duration that is long enough to allow them to match available financing packages or to give sufficient time to pay back the investment. Greater regulatory certainty – and transparency – would help as well, as most of these are long-term capital intensive asset investments. In particular, governments must clearly define the roles for utilities and microgrid developers in their electricity sector, and fulfill their commitments even if microgrids compete with their own utilities. Countries that lack Net Energy Metering or Feed in Tariffs for grid-connected solar should also clarify what the tariff structure would be for an isolated microgrid if it were eventually connected to the central grid.

Implementation Challenges

Implementation challenges relate to the deployment, operation and maintenance of a project, including ensuring its financial stability.[25] The most common implementation challenges reported during the workshop were securing human capital for the construction, operation, and maintenance of the microgrids systems, as well as designing tariffs and subsidies that provide for cost-recovery without unduly burdening the local population. We describe these issues below.

Challenge #8: Training Specialized Workforce

Isolated regions in Latin America typically lack a work force with the skills required to operate and maintain solar powered microgrids. And while national governments, and even development banks, may have personnel with the required skills and expertise, it can be difficult for them to provide sustained, readily available support to remote populations to maintain solar microgrids. To mitigate this problem, national governments, development banks, and project developers should invest in building local capacity through comprehensive training programs. Development bank representatives at the workshop noted that they strongly encourage applicants to incorporate plans for local capacity-building in any application for support. Particularly in competitive generation markets, this type of planning may be a prerequisite for project approval. As a regulator at the workshop stated: "We have to understand who will have the knowledge to operate the new system before we can approve it."

One way to effectively build a local workforce is to train the employees of a nearby company to conduct microgrid maintenance. For instance, one representative at the workshop noted that local telephone company employees could be enlisted to help with maintenance of microgrids. The same representative also highlighted that, in her estimation, the overwhelming majority of preventive maintenance could be carried out by low-skill workers. SolarCity representatives also noted that they endeavor to engage the local workforce in the construction of a microgrid so that they develop a deep understanding of the technology and are prepared to maintain it. Finally, various participants suggested that if a country is able to bundle projects in a given region, it might be able to realize economies of scale by training a single, mobile local workforce.

Challenge #9: Maintaining Liquidity for Battery and other Infrastructure Replacement

Solar powered microgrids are composed of two distinct technologies – PV panels and batteries – that have different useful lives. For the transition towards renewable energy systems to be successful, the entities responsible for their operation will need to maintain sufficient liquidity to

[25] For review of common operational and commercial practices that impact the sustainability of microgrids, *see* Schnitzer et al, *supra* note 22.

replace batteries and other infrastructure as the system ages.[26] Investors should consider implementing safeguards to ensure that the relevant entities – be they public or private – maintain the required liquidity during the financing stage. For example, investors could require developers to tie up capital in trusts for the exclusive purpose of battery replacement. Governments could also condition any required permits on the existence of a guarantee with the same purpose. If depreciation is built into the tariff scheme, a specific fund can be created and maintained through revenue collection. Critically, however, one development bank representative noted that due to falling technology costs, his institution was becoming less concerned about grantees' ability to pay for battery replacements.

Challenge #10: Calibrating Tariffs and Subsidies

Communities in isolated regions of Latin America are typically quite poor and have limited ability to pay for electricity service. As such, governments generally subsidize electricity service for these users.[27] However, workshop participants noted that, while subsidization may be necessary, it is also critical that communities have a meaningful financial stake in the technology, meaning that they pay for some portion of the electricity it provides, in order to invest in its maintenance. Regulators will need to balance the need to supply affordable power with community investment and cost-reflective tariffs in setting both capital and O&M subsidy levels. Notably, academic literature provides support for the idea that local investment is essential to creating sustainable off-grid projects; for instance, the authors of a literature review of efforts to improve rural electrification in South Asia observed that in all the countries studied, "local participation helped in reducing theft and distribution losses, improved billing and revenue collection efficiency and more importantly ensured stable delivery of electricity."[28]

Part III – Concluding Reflections

This workshop provided strong evidence that solar powered microgrids can effectively help Latin American countries to bring cost-effective electricity to isolated communities, while simultaneously advancing their climate policy objectives. Some of these countries have a substantial share of renewable sources in their energy mix but have yet to realize their full potential, particularly with respect to rural electrification. By implementing selective regulatory reforms, and forging partnership with development and financing institutions, Latin American countries should be able to take advantage of the many benefits renewable energy powered microgrids offer, and provide electricity to millions in the region that still lack access to sufficient, reliable supply. In so doing, they can also serve as a laboratory for new technology, testing systems, methods, regulatory frameworks, and processes. These valuable empirical lessons may encourage the proliferation of off-grid renewable technologies in Africa and Asia, where improved access to electricity is greatly needed.

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[26] The useful life of renewable energy assets installed in a microgrid typically exceeds the useful life of batteries used in the system. *See* Eric Hittinger et al., *Evaluating the Value of Batteries in Microgrid Electricity Systems Using an Improved System Model*, 89 ENERGY CONVERS. MANAG. 458 (2015).

[27] Subsidies can take many forms, but the most common are direct case-by-case subsidies for each specific microgrid or socialization of costs under microgrid tariff regulation.

[28] Debajit Palit, Akanksha Chaurey, *Off-grid Rural Electrification Experiences from South Asia: Status and Best Practices*, ENERGY FOR SUSTAINABLE DEVELOPMENT 15 (2011) 266-276, 271.

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