NYU LAW

Clean and Resilient Power for Caribbean States

A Report on Barriers and Opportunity to Deploying Renewable Energy Microgrids in the Caribbean

Danielle Spiegel-Feld
Nathan A. Bishop
Peter Simpson Ross
Bryce Rudyk
Andrew G. Wood

January 2018

Guarini Center
Frank J. Guarini Center on Environmental, Energy, and Land Use Law
at NYU School of Law

Guarini Center on Environmental, Energy and Land Use Law
New York University School of Law
139 MacDougal Street, 3rd Floor
New York, NY 10012
212-998-6164

fgcelul@law.nyu.edu | guarinicenter.org

Danielle Spiegel-Feld is Executive Director of the Guarini Center on Environmental, Energy and Land Use Law at NYU School of Law ("Guarini Center"), **Nathan A. Bishop** is a Juris Doctor candidate at NYU School of Law, **Peter Simpson Ross** is an Energy Law Fellow at the Guarini Center, **Bryce Rudyk** the Climate Programs Director at the Guarini Center, and **Andrew G. Wood** is a Juris Doctor candidate at NYU School of Law.

Clean and Resilient Power for Caribbean States: A Workshop on Opportunities and Obstacles to Expanding Renewable Energy Microgrids

Introduction and Summary of Findings

The Caribbean hurricanes of 2017 made clear that many of the islands' power systems are woefully unprepared to withstand the increasingly severe weather events that climate change is generating.[1] Perhaps no island exemplified this inadequacy better than Puerto Rico; one month after hurricane Maria barreled into the island, approximately eighty percent of its population was still in the dark.[2] Two months after the storm hit, more than half of Puerto Rico remained without power and the island's transmission system lay in tatters.[3]

Renewable energy-powered microgrids could significantly enhance the region's resiliency. Microgrids generate electricity close to where it is consumed and can operate independently of the main generation and transmission system. As such, microgrids can keep communities' lights on even when the central grid fails. And because modern-day microgrids often incorporate a mix of renewable energy resources and battery storage, they can keep functioning even in the face of fossil fuel shortages, which often occur in the aftermath of severe storms.[4] By replacing fossil fuel generation with renewable energy, microgrids help advance climate goals as well.

In several respects, the Caribbean states are ideal candidates to lead the transition towards renewable energy microgrids. The recent loss of infrastructure, while devastating, provides an opportunity to rebuild the grid in a more sensible manner and creates a strong impetus to improve resiliency. Moreover, many Caribbean states have traditionally relied on imported fossil fuels for their electricity supply, which has caused them to endure unusually high power prices. As described herein, renewable energy powered microgrids can help lower power prices, thus boosting the region's economic competitiveness.[5] Finally, the islands' small size can make their bureaucracies more nimble and help facilitate more rapid, systemic change.

And yet, relatively few renewable energy-powered microgrids have been deployed in the Caribbean region to date. To understand the cause of the stagnation, on October 31, 2017 the Guarini Center on Environmental, Energy, and Land Use Law at New York University School of Law ("Guarini Center") held a workshop in collaboration with Tesla, Inc. and the United Arab Emirates Ministry of Foreign

---

[1] The 2017 hurricane season was unusually active and included 6 storms that were category three or above. PHILIP J. KLOTZBACH & MICHAEL M. BELL, SUMMARY OF 2017 ATLANTIC TROPICAL CYCLONE ACTIVITY AND VERIFICATION OF AUTHORS' SEASONAL AND TWO-WEEK FORECASTS 9 (2017), *available at* https://tropical.colostate.edu/media/sites/111/2017/11/2017-11.pdf. Two category five hurricanes – Irma and Maria – made landfall Caribbean islands. *Id* at 10-11. These storms were extremely powerful. For example, Irma maintained wind speeds of 160 knots for thirty-seven hours, which is the longest time any cyclone around the globe has maintained that intensity on record and Maria intensified more quickly (sixty knots in eighteen hours) than all but two other storms on record. *Id*.

[2] *Puerto Rico Still Without Power, One Month After Hurricane*, VOA NEWS (Oct. 20, 2017), *available at* https://www.voanews.com/a/puerto-rico-without-power-one-month-after-hurricane/4079858.html.

[3] Larry Greenemeier, *Repair or Rennovate? Puerto Rico Faces Stark Power Grid Options*, SCIENTIFIC AMERICAN (Nov. 13, 2017), *available at* https://www.scientificamerican.com/article/repair-or-renovate-puerto-rico-faces-stark-power-grid-options/ (last visited December 7, 2017).

[4] *See, e.g., Relief Effort Drags, Fuel Shortages Are Monumental*, NAT'L PUB. RADIO (Sept. 28, 2017), *available at* https://www.npr.org/2017/09/28/554157372/relief-effort-in-puerto-rico-drags-fuel-shortages-are-monumental.

[5] ARNOLD MCINTYRE ET AL., IMF WORKING PAPER 16/53, CARIBBEAN ENERGY: MACRO RELATED CHALLENGES 7 (2016), *available at* https://www.imf.org/external/pubs/ft/wp/2016/wp1653.pdf (noting that high power prices have persistently hindered economic competitiveness in the Caribbean region).

Affairs and International Cooperation to examine what obstacles have stifled microgrid deployment to date and how can we overcome these obstacles. The workshop was attended by a diverse group of experts from the development community, the renewable energy industry, the diplomatic community, non-governmental organizations, academia, as well as the utilities and energy ministries of four Caribbean states (Belize, Dominican Republic, Grenada, and Suriname).

The workshop provided strong evidence that renewable energy powered microgrids could lower the cost of electricity production in the participating states. In fact, case studies of potential new microgrid projects in remote regions of Belize, Grenada, Suriname, and the Dominican Republic indicated that the local utilities could minimize costs by installing microgrids in which renewable energy supplied at least 70 percent of the electricity consumed. And, critically, the modeling performed for these case studies did not assign any monetary value to many of the benefits microgrids provide, including: enhanced resiliency, reduced exposure to volatile fuel prices, local health benefits from cleaner air quality, and increased flexibility in complying with future climate obligations. If these benefits had been monetized, the economic case for transitioning towards renewable energy would likely have been even stronger.

The remainder of this report is organized as follows: Part I provides an overview of the case studies of potential microgrid projects that were examined during the workshop, including a description of the assumptions that were used in the modeling. Part II then reviews the key obstacles to microgrid deployment that were identified throughout the workshop and suggests strategies for overcoming these obstacles. Part III concludes.

Part I – Case Studies

Workshop participants examined five potential microgrid projects in four Caribbean countries: Grenada, Suriname, Belize, and the Dominican Republic. For each proposal, Tesla engineers worked with national energy experts from the participating countries to gather data about the project sites and then developed a model that considered, among other variables, technology and fuel costs, the load profile of the community, solar availability, and generator specifications. Where available, Tesla took into account load profile data (*i.e.*, the amount of electricity use and how it varied over the course of the day and the year) at the project's planned location. When this data was unavailable, which was the case several with unelectrified villages in Belize and the Dominican Republic, Tesla looked to load profiles from similar regions to create a reasonable estimate.

The projects showcased the wide range of microgrid solutions and how they can be tailored to fit the unique needs of individual sites. For example, the large town of Nickerie, Suriname, with a peak load of 13 MW, can install more substantial battery storage systems than communities in remote, unelectrified areas of the Dominican Republic without jeopardizing the project's economics. Areas with high diesel costs, such as Belize's Pueblo Viejo, can afford a higher level of renewable penetration than communities where diesel costs are lower. And islands such as Petite Martinique in Grenada, where land is at a premium, can install high-efficiency solar panels to minimize the system's footprint, which may be deemed too expensive in areas where land is abundant. Taken together, the projects demonstrate how customization can make projects more viable.

The common thread throughout the case studies was that, for each project, a solar photovoltaic microgrid with some form of battery storage yielded savings when compared to diesel generation alone.[6] Achieving

---

[6] Note that the case study of the project in the Dominican Republic, which explored the potential of electrifying a community that currently lacks any access to electricity, did not compare the economics of electrifying the community with diesel as opposed to solar plus battery storage solutions. Instead, only the economics of solar plus storage was considered.

the lowest levelized cost of energy often resulted in less than 100% renewable penetration, as keeping a small amount of backup diesel generation for some projects proved more cost-effective than relying solely on solar power and batteries. However, the percentage of diesel that was recommended to be retained was always very small – ranging from 29 percent to 1 percent – and, overall, the projects presented a convincing economic case for investing in renewable energy-powered microgrids in the Caribbean.

A. Assumptions

The following assumptions were used in models created for the case studies:

Levelized cost of energy (LCOE): The comparative costs of energy generation across different technologies can be quantified using an internationally recognized metric known as the Levelized Cost of Energy (LCOE). This metric is used by energy experts in industry and academia to compare the costs of energy generation across different technology types.[7] This metric is especially useful when comparing renewables versus diesel, 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 modelling performed for these case studies, the LCOE was calculated as follows:

LCOE = Capital Expenditure + Net Present Value of Operating Expenditure / Total Generation Over Project Life. The relevant equations for diesel and renewable systems were therefore:

- Diesel LCOE ($/kWh) = Net Present Cost (Fuel Cost + Generator Replacement) / Total Generation Over Project Life[8]
- Renewable LCOE ($/kWh) = Net Present Cost (Capital Cost + Financing Costs + Operating & Maintenance + Battery Replacement Cost) / Total Generation Over Project Life[9]

Discount rate: A discount rate of 6% was used for all case studies.

Diesel costs: In calculating the LCOE of diesel generation, case studies assumed local fuel costs as of Q4 2017.

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

Fuel cost escalator: The case studies presume a 3% escalation in fuel costs for diesel generation systems. This is a fairly conservative estimate; just a few days before the workshop, the World Bank forecast that oil prices would rise nearly 6% in 2018.[10]

Storage: The case studies assumed use of a lithium ion storage system produced by Tesla with a useable life of 10 years without accounting for degradation.

---

[7] For further details on the derivation of this formula, *see* Govinda Timilsina, Lado Kurdgelashvili & Patrick A. Narbel, *Solar Energy: Markets, Economics and Policies*, *in* 16 RENEWABLE ENERGY REVIEWS 449, 453 (2012).

[8] Existing generator financing costs and O&M were omitted from calculations (a conservative assumption).

[9] The project life for renewable systems was set to 30 years.

[10] Press Release, World Bank, Commodity Prices Likely to Rise Further in 2018 (Oct. 27, 2017), *available at* http://www.worldbank.org/en/news/press-release/2017/10/26/commodity-prices-likely-to-rise-further-in-2018-world-bank.

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

B. Findings

The case studies presented at the workshop examined two distinct types of projects: diesel displacement projects and energy access projects. Case studies of diesel displacement projects considered the feasibility of replacing existing diesel generation with renewable energy and storage. By contrast, case studies of energy access projects examined the potential to use renewable energy and storage systems to provide electricity to communities that currently lack it. In the section below, we begin by reviewing diesel displacement case studies in Grenada and Suriname, and then examine energy access case studies in Belize and the Dominican Republic.

Grenada

Grenada consists of several islands located 516 miles northeast of Venezuela, which occupy an area of approximately 167 square miles and support a population of 106,669 people. Grenada has an electrification rate of greater than 99.5%, but an estimated 2% of the population cannot afford the available electricity. Grenada Electricity Services Ltd (GRENLEC), which transitioned from a government-run, vertically integrated monopoly to private ownership in August 2016, owns 97% of Grenada's energy infrastructure.

Workshop participants examined case studies of projects on two of Grenada's islands: Petite Martinique and Carriacou.

Petite Martinique: Petite Martinique is a 586-acre island approximately 35 miles northeast of Grenada. At present, 300 people live in Petite Martinique. Boat building and fishing are the two main industries on the island.

Annual energy usage on Petite Martinique is 358,860 kWh and the peak power load is 170 kW. The island has an installed capacity of 364 kW. Demand peaks during the early evening hours when people return from work and turn on appliances and lighting. Seasonally, the island sees a higher load in the winter months when tourism increases. Electricity on the islands is currently produced by an entirely diesel-based system.

Summary of Proposed Solutions (Petite Martiniqu, Grenada)	
Solar Photovoltaic Capacity (kW DC)	400
Battery Energy Storage Capacity (kWh)	1,260
RE Proportion	96%
Expected Load Growth (per year)	2%
Land Requirement (acres)	1.5
Diesel LCOE	$0.65
Blended Diesel & RE LCOE	$0.48

** Based on Current Diesel Fuel Cost

Diesel costs on the island are quite high; at the time of the workshop, the fully burdened cost of fuel on the island was estimated to be $4.25 USD/gallon ($1.12 USD/liter) and Tesla's modelling indicated that the LCOE of the existing system to be $0.65/kWh. The government was eager to transition towards renewable energy in order to reduce costs and increase resiliency.

Modelling presented at the workshop indicated that the optimal solution for Petite Martinique from a cost perspective would be to install a renewable microgrid system in which solar photovoltaics (PV) supplied 96% of the island's electricity. The remaining 4% would be supplied from existing diesel generators.

The proposed solution would require Petite Martinique to install 400 kW of solar PV and 1,260 kWh of battery storage. During high production periods in the summer, the system would run entirely on renewables (through direct PV delivery and PV delivered via battery). In winter's low production periods, the island's diesel generators would come online in the early morning hours from midnight through 9:00 am.

The LCOE for the proposed system was estimated to be $0.48/kWh, which is 24% less than for the current diesel generation. This system would require a capital expenditure of $1,946,000, which was predicted to pay for itself in roughly 10 years by virtue of reduced diesel costs. After 20 years, the system was expected to generate $4,012,000 in savings and after 30 years it was expected to yield $7,834,000 in savings. Notably, a workshop participant expressed optimism that the initial capital cost would be fundable from a combination of grants or soft loans given the project's low capital requirements.

Carriacou: Carriacou is a 7,680-acre island dependency of Grenada supporting a population of 6,081 people. Fishing and agriculture are the main industries on the island. Carriacou experiences high diesel costs[11] (although not as high as Petite Martinique) and, as with Petite Martinique, the government seeks to increase renewable energy penetration in order to reduce costs and improve resiliency.

Annual energy use in Carriacou is 5.9 GWh and peak power load on the island is 1,300 kW. Like Petite Martinique, Carriacou's energy use peaks in the evening hours, however the island experiences less seasonal variation in demand than Petite Martinique. Electricity on the island is currently generated by a diesel-based system, which was estimated to have an LCOE of roughly $0.48/kWh.

Summary of Proposed Solutions (Carriacou, Grenada)	
Solar Photovoltaic Capacity (kW DC)	6,000
Battery Energy Storage Capacity (kWh)	16,800
RE Proportion	~100%
Expected Load Growth (per year)	2%
Land Requirement (acres)	21
Diesel LCOE	$0.48
Blended Diesel & RE LCOE	$0.38

** Based on Current Diesel Fuel Cost

Tesla's modelling indicated that Carriacou could minimize costs by replacing virtually all of the island's diesel generation with solar PV. To do so, the island would need to install 6,000 kW of solar PV capacity as well as 16.8MWh of battery storage. With this amount of PV and storage capacity, the island would be able to depend on renewable energy to satisfy its power demand during both high and low production months.

The LCOE of energy for the proposed system was estimated to be roughly $0.40/kWh, 17% less than it is currently. Due to its size, this system would require significantly more capital expenditure than that which was proposed for Petite Martinique. Specifically, the proposed microgrid system for Carriacou would require initial capital expenditure of $25,900,000. Notably, however, modelling indicated that it would take only 8.5 years to pay back this investment, due to avoided diesel costs, and the system was predicted to generate savings of $49,800,000 over 20 years. Over 30 years, the system was expected to produce $95,500,000 in savings.

Suriname

The Republic of Suriname is a state on South America's northeastern coast. Its population of 558,368 is mostly concentrated in the capital of Paramaribo, with much of the remainder of the country being heavily forested and sparsely populated.

---

[11] Fuel costs (fully burdened) on the island are $3.5 USD/Gal ($0.93 USD/L).

Suriname has an electrification rate of roughly 90% and receives approximately 40% of its electricity from hydropower; most of the rest of its electricity produced via heavy fuel oil and diesel generation. A representative from Suriname stated that oil is gaining market share as a domestic source of energy as load grows.

Suriname's electricity market is largely controlled by Energiebedrijven Suriname (EBS), a state-owned utility that owns 41% of the country's generation and all of the country's transmission and distribution. Remaining generation is owned by the state oil company Staatsolie and a private mining company, Suralco.[12] Many of the villages in Suriname's remote regions depend on standalone diesel generators for their electricity supply.

Suriname's government seeks to expand renewable energy development in the country. However, retail electricity prices are heavily subsidized throughout the country – the average retail rate is $0.04/kWh – which poses a barrier to increased renewable energy development.[13] Suriname's government is aware of this problem and is endeavoring to reduce the subsidies and create a more favorable environment for renewable energy investment.[14] For instance, the Electricity Act of 2016 creates purchase guarantees for renewable generation facilities. It also introduces net metering tariffs so that retail customers who install rooftop solar PV can be compensated for selling excess energy into the grid.

Nickerie: Nickerie is a remote district along Suriname's northwest coast with an estimated population of 36,639. Nickerie currently receives power from a combination of heavy fuel oil and diesel. As in Grenada, the local utility would like to increase renewable energy penetration in order to drive down costs and improve resiliency. The annual energy use in Nickerie is 77 GWh and peak power load in the district is 13 MW. Nickerie's energy use peaks slightly in the evening hours and the district experiences higher load during the fall and spring. Tesla's modelling determined that the current LCOE of in the district is approximately $0.32/kWh.

Summary of Proposed Solutions (Nickerie, Suriname)	
Solar Photovoltaic Capacity (kW DC)	40,000
Wind Capacity (kW)	3,600
Battery Energy Storage Capacity (kWh)	52,200
RE Proportion	71%
Expected Load Growth (per year)	2%
Land Requirement (acres)	NA
Diesel LCOE	$0.32
Blended Diesel and RE LCOE	$0.26

** Based on Current Diesel Fuel Cost

Tesla's modelling suggests that the optimal solution for Nickerie from a cost perspective would be to install a microgrid system in which wind and solar supply 71% of the community's electricity; the remaining energy would be supplied via diesel generation. During high production days, renewables would provide energy from 9:00AM through 1:00AM, with diesel contributing power during the early morning hours. During low production periods, diesel generators supply the bulk of electricity throughout the day. Under this proposed solution, Nickerie would have 40 MW of solar PV, 3.6 MW of wind, and 52.2 MWh of battery storage installed.

The LCOE for the proposed hybrid system was estimated to be $0.26/kWh, which is 19% less than the present diesel-only system. The proposed system would require capital expenditure of $135,000,000. A participant at the workshop indicated that this project might encounter difficulty securing all the required financing in a single phase, and instead recommend a pilot project in the short term to familiarize Suriname with integrating renewable generation and storage. Once constructed, the proposed system was expected to generate $299,000,000 in savings over 20 years and $555,000,000 in savings over 30 years.

---

[12] *Country: Suriname*, CLIMATESCOPE 2017, http://global-climatescope.org/en/country/suriname/#/financing-investments (last visited Nov. 30, 2017).

[13] *Id.*

[14] *Id.*

Belize

The state of Belize is a part of both Central America and the Caribbean region. Belize currently generates roughly 60% of its electricity from renewable sources, with 37.7% of total generation coming from hydro, 19.12% from biomass and only 0.09% from solar. The balance of domestic generation comes from diesel, crude oil, and natural gas. Additionally, Belize imports 35.39% of its electricity generation from Mexico.

Belize has committed to a Sustainable Energy Roadmap to 2030 built on five pillars: Energy Efficiency, Renewable Energy, Clean Production, Governance, and Infrastructure. Using these pillars, it plans to increase renewable energy to 80% of its electricity mix by 2020, and 97% by 2030. Belize also plans to improve its electrification rate to over 95% by 2020, and to over 98% by 2030.

Belize has begun to experiment with renewable energy microgrids already. In fact, in May of 2017, the government launched the pilot phase of a hybrid microgrid system in La Gracia, which is a community that previously lacked any access to electricity. A 25 kW hybrid system was installed, which uses 96 polycrystalline solar panels, an LPG generator and lead acid storage.

Summary of Proposed Solutions (Pueblo Viejo, Belize)	
Solar Photovoltaic Capacity (kW DC)	600
Battery Energy Storage Capacity (kWh)	1,680
RE Proportion	~99%
Expected Load Growth (per year)	2%
Land Requirement (acres)	1.5
Diesel LCOE	$0.87
Blended Diesel and RE LCOE	$0.67

** Based on Current Diesel Fuel Cost

Government officials report that the microgrid is quite popular with the community and that it has encouraged the construction of new homes in the area. However, figuring out the proper rate to charge for electricity produced by the microgrid has been challenging. At present, customers prepay for electricity using magnetic cards and power meters at a rate of 0.60 BZE/kWh. This rate was set to be affordable for the community but, at this price, the microgrid is operating at a loss. The local utility is expected to eventually take ownership of the project, becoming responsible for maintenance and operation, and also providing the investment to scale up the system. When it does, a new payment system, or at least a new rate, will likely need to be established.

Pueblo Viejo: During the workshop, participants examined a proposal to develop a new microgrid in a village known as Pueblo Viejo, which is located in the south of Belize, near the border with Guatemala. Pueblo Viejo is an agricultural village with approximately 600 inhabitants. Transport costs to the Pueblo Viejo are high, as is the cost of diesel. Fully burdened, the local cost of diesel is $5.75 USD/gallon.

The community currently lacks access to electricity, but working with government officials, Tesla forecast that initial annual energy demand in Pueblo Viejo would be 580 MWh/year if a microgrid were installed. Peak demand was forecast to be 140 kW.

Tesla’s modelling indicated that the optimal solution for Pueblo Viejo from a cost perspective would be to install a microgrid in which solar energy provides almost 99% of the community’s energy. The remaining 1% would be supplied by diesel. During high production days in August, renewables would provide all of the community’s energy. During low production days in the fall, diesel could be required from 7:00 pm to midnight. The proposed solution would require 600 kW of solar PV and 1,680 kWh of battery storage.

The LCOE for the proposed hybrid system was estimated to be $0.66/kWh, whereas a diesel-only system was estimated to have an LCOE of $0.86/kWh. This system would require capital expenditure of $3,220,000 for the solar and battery system, an estimated $250,000 for a diesel generator and 1.5 acres of land. As the community has never had access to electricity, additional infrastructure would also be required, including poles, wiring, metering and collection, to connect homes and building to the hybrid micro-grid. A participant at the workshop indicated that these costs could be as high as $1,000 per connection, and may require a separate source of funding.

Summary of Economic Findings

To review, each of the above case studies indicated that it would be more cost-effective for the community in question to generate most, if not all, of its electricity from renewable energy than to rely on diesel generation. The comparative economics are summarized below.

Community	Current/Modelled Diesel LCOE	Blended RE & Diesel LCOE of Hybrid Microgrid	Percent Saved
Petite Martinique	$0.65	$0.48	26.2%
Carriacou	$0.48	$0.38	20.8%
Nickerie	$0.32	$0.26	18.8%
Pueblo Viejo	$0.87	$0.67	23.0%

Dominican Republic

The final case study examined at the workshop considered the potential to use a combination solar PV and battery storage to provide electricity to a series of very small communities in a remote region of the Dominican Republic. Due to the very small size of these communities, as well as the government's renewable energy goals, the case study did not compare the economics of electrifying the area with diesel as opposed to solar and storage systems and instead looked only at the feasibility of installing the renewable energy systems.

The Dominican Republic is a country on the Caribbean island of Hispaniola, which the country shares with Haiti. The Dominican Republic is committed to renewable energy expansion and has mandated that 25% of electricity come from renewable energy sources by 2025. Experts at the workshop stated that the lack of available financial resources was the major barrier to achieving this goal.

A 2013 study by the Centro de Estudios Sociales y Demográfico found that 97.8% of Dominicans had access to electricity, leaving an estimated 112,000 households (412,000 people) without such access. Many of these households are in provinces bordering Haiti. Since 2013, the Dominican Republic's National Energy Commission (CNE) has developed six projects with total installed capacity of 515 kW to increase electrification. These projects have benefitted 509 families at a cost of roughly $408,000 USD.

Los Gajitos: Los Gajitos is a remote section of the San Juan Province, 217 km from the Dominican Republic's capital, Santo Domingo. Los Gajitos is made up of 4 communities, representing 124 households and 409 people, and includes one community center, two schools and three churches. There is currently no access to electricity in Los Gajitos, although 13 households are believed to have single solar panels with capacity of 12 watts. Lighting is provided primarily by candles and the households use wood to cook.

Tesla forecast that annual energy usage in these communities would be low if electricity access were provided, with a peak load below 10 kW per community. Energy consumption, under this scenario, would be used primarily for lighting, phone charging, and potentially refrigeration. However, as the communities become more accustomed to electrification, demand tends to increase. To accommodate this situation, where load is forecast to begin very low but grow over time, Tesla recommended using a standardized "kitted" solution for each community within Los Gajitos. The modular design of the system allows for incremental increases in production capacity should demand increase in the future. This contrasts with the other case studies examined at the workshop for which Tesla recommended custom-tailored solutions with industrial equipment.

Each standard kit includes 5kW of solar PV and 5 kW/ 10 kWh of battery storage (no diesel). The systems deliver an average of 14 kWh/day, which is enough to provide 10 households with 1.4 kWh/day. If more power is needed in the future, the system can be easily scaled up by adding more kits. Adding a second kit to the system, for example, would increase the power to 10 households to 2.8 kWh/day.

Summary of Proposed Solutions (Los Gajitos, Dominican Republic)	
Solar Photovoltaic Capacity (kW DC)	5
Battery Energy Storage Capacity (kWh)	5 kW/10kWh
RE Proportion	100%
Average Energy Delivery (kWh/day)	14
Expected Load Growth	n/a
Capital costs	n/a

These types of small, standardized solutions are often substantially more cost-effective for energy access projects than customized solutions. To begin with, the smaller equipment is easier to transport to remote sites like Los Gajitos, which helps keep transportation costs down.[15] Standardized solutions also incorporate less significant design costs than customized solutions. Finally, because standardized solutions use the same kits many times, utilities may be able to take advantage of economies of scale when buying multiple kits, which can lower the purchase price per unit.

Part II — Deployment Challenges and Proposed Challenges for Overcoming Them

The case studies examined at the workshop provided compelling evidence that renewable energy microgrids could effectively help lower the cost of power in the Caribbean and expand energy access. Despite these benefits, workshop participants observed that many challenges have hindered the deployment of this technology to date. In the paragraphs below, we review the "top ten" such challenges that were identified throughout the workshop and propose potential strategies to overcome them. The challenges are listed in an order that roughly corresponds to the frequency with which they were mentioned at the workshop.

#1 Building Capacity

Each country that participated in the workshop emphasized that limited local capacity was a hindrance to project deployment. As one development bank official with experience in the microgrid sector explained, "we can set up programs with fixed timelines, and halfway through have nothing to show for it because of capacity issues." Another representative of a Caribbean energy ministry noted that the lack of local technical capacity should be expected at this point in time because many Caribbean countries are only just starting to develop renewable energy projects with storage. With time, as local officials gain familiarity with these systems, local technical skills should increase.

In the meantime, Caribbean governments and development officials can help build capacity by moving towards a regional approach that engages organizations like the Caribbean Development Bank to provide training through technical assistance grants and other means. They can also increase local capacity through more regular dialogue with one and other and exchange ideas on best practices and lessons

---

[15] By way of comparison, Tesla's Powerpacks typically weigh 5500 lbs., whereas the smaller batteries envisioned in this case study weigh only 200 lbs.

learned. As one official noted, this type of investment in regional cooperation could pay dividends in other areas as well by promoting Caribbean unity.

#2 Expanding Access to Low Cost Capital/Reducing High Financing Costs

Renewable energy microgrids tend to have higher upfront capital costs than conventional generation resources, which makes accessing low-cost capital essential.[16] Unfortunately, however, Caribbean governments and utilities often encounter significant difficulty in accessing low-cost capital for renewable energy projects, and this puts renewable energy investments at a disadvantage when compared with conventional energy. The problem is not limited to the Caribbean; the UNDP Global Environmental Finance Unit has observed that cost of equity for renewable energy projects is a major barrier to project development in low and middle-income countries around the world.

Looking specifically at the Caribbean, there are a number of reasons why it is hard to find low-cost capital for renewable energy projects in the region. For one, there are few indigenous Caribbean banks. In Barbados, to take one example, most banks are Canadian and are controlled by financiers who lack familiarity with the Caribbean and its business culture. This lack of familiarity can create a certain reluctance to invest in the region, which translates into an elevated cost of capital. As for the few local banks that do exist, they are often unfamiliar with renewable energy technologies and therefore request unreasonable financing terms. For example, one expert noted that when a hotel in his home country tried to obtain a loan for a new solar installation the local bank requested 200 percent liquidity to securitize the loan. Concerns about currency risk, perceived regulatory risks (including inconsistent policy frameworks), power market dynamics (including volatility in prices), and developer risks (including the quality of the management of the project developer) all increase the cost of capital further.

Development banks and donor countries have a critical role to play in helping to reduce the cost of capital for these projects and are taking steps to do so. For instance, the Caribbean Development Bank's Special Development Fund offers concessional loans that can be used for microgrid projects. These loans offer longer maturity and grace periods as well as lower rates than CDB typically provides. The Green Climate Fund (GCF), which was established under the auspices of the United Nations Framework Convention on Climate Change to reduce greenhouse gas emissions in developing countries, also has a number of promising financing instruments that can be used for renewable energy projects in the Caribbean.[17] Bilateral donors are a critical source of low-cost financing for the region as well. Of particular note, the United Arab Emirates Ministry of Foreign Affairs and International Cooperation (UAE) launched a $50 million grant fund in 2017 that specifically targets renewable energy development in the Caribbean.[18] At the time of this writing, the UAE was actively seeking projects to support.

#3 Forging Collaboration between Governments and Utilities

Deploying substantial quantities of renewable energy requires the support of the local government and utility. But forging this collaboration can be difficult, particularly given that utilities may have certain disincentives to make new investments in renewable energy infrastructure.

---

[16] For instance, IRENA has estimated that the LCOE on a wind farm project is approximately 60% higher when the cost of capital is 14.5% rather than 5.5%. *See* IRENA, GENERATION COSTS: SUMMARY FOR POLICYMAKERS 7 (2012) *available at* http://www.irena.org/documentdownloads/publications/renewable_power_generation_costs.pdf.

[17] For example, at the time of this writing, the GCF had committed $190 million to a "Sustainability Energy Facility" in the eastern Caribbean. *See Project FP020*, GREEN CLIMATE FUND (Sept. 20, 2017), http://www.greenclimate.fund/-/sustainable-energy-facility-for-the-eastern-caribbean.

[18] More information on the UAE grant fund is available here: http://www.masdar.ae/en/media/detail/uae-launches-us50-million-renewable-energy-fund-for-the-caribbean.

Utilities tend to be risk adverse, which is understandable given that they are responsible for ensuring reliability of supply, and may therefore be skeptical of transitioning towards new forms of generation. They may also be more interested in maintaining legacy assets with a guaranteed rate of return than investing in new assets – particularly off-grid assets – which could complicate efforts to recoup their investment in existing generation resources.

To overcome these challenges, funders, project developers, and technical advisors should discuss project goals and logistics with utility representatives from the earliest possible stages. As one workshop participant put it, “Having everyone at the table, including the government and the utility, ensures everyone is buying in, which is critical to a project’s success.” Government officials can also help to bring local utilities on board by clearly communicating to the public how renewable energy can help lower prices, which is what consumers care most about; if the utilities’ customers start actively supporting renewable energy expansion, utilities themselves may come to see an economic interest in supporting the transition towards new generation resources.

#4 Building Economies of Scale

One of the universal challenges facing Caribbean nations as they seek to expand renewable energy resources is the difficulty of building scale, which is critical to containing per kilowatt-hour costs. One Caribbean utility official observed that his company wrestles with establishing economies of scale on every project they contemplate. Another expert from the development community echoed this comment, noting that “economies of scale within one country are virtually non-existent in the Caribbean.” Not only do small projects tend to have a higher cost per kilowatt-hour produced, but, particularly given the transaction costs associated with developing projects in a new market, many developers are unwilling to pursue projects in the Caribbean that do not entail a minimum amount of capital investment. Indeed, several of the projects that were explored at the workshop and in preparatory discussions appeared too small to meet this minimum size threshold.

Critically, however, there are measures that governments and utilities can implement to help build economies of scale. In particular, officials in different countries can collaborate with one and other to synchronize projects across different islands. By grouping together projects across countries, according to one expert, officials can generate very significant cost reductions.

#5 Aligning Peak Demand and Peak Production

At nearly every case study site we examined, peak demand was in the evening hours but peak production from renewable energy resources was in the mid-afternoon. Storing solar energy in batteries can help address this imbalance between supply and demand, but it comes with a cost; the more batteries one installs, the more expensive the microgrid system becomes. Thus, the more energy that is consumed mid-day when the solar array is operating at high capacity, the less batteries are needed to meet electricity demand, and the lower the microgrid system costs become.

Load shifting through smart tariff design could help align demand with supply. Charging customers more for using electricity during peak demand times can incentivize usage of electricity at other times of the day. Suriname, which has an abundance of hydropower, is experimenting with tariff design and load shifting for industrial and commercial consumers to reduce the cost of generation. Belize’s La Gracia photovoltaic system set daytime limits for electricity use that were double those for nighttime usage. This encouraged residential and commercial customers to use more electricity during the daytime hours when solar energy was plentiful, and reduced the need for batteries, which lowered the overall cost of the microgrid system. Implementing policies like this that serve to shift demand can play a key role in facilitating the adoption of clean energy microgrids.

#6 Navigating Land Constraints

Solar photovoltaic arrays require substantial land, which can pose a challenge for smaller islands where space is at a premium. If land constraints are serious, it is often economically advantageous to use high efficiency monocrystalline photovoltaic modules rather the more commonly used polycrystalline versions. Monocrystalline modules are more expensive, but leave a smaller infrastructure footprint on the island. For instance, the Tesla proposal for Petite Martinique in Grenada, an island with 586 acres, made use of high efficiency monocrystalline modules which require only 1.5 acres of space.

Locating solar microgrids on utility-owned land is often the easiest route politically. However, if the utility lacks the land required to site the solar arrays, it could opt to lease the land from a farmer or private landowner. Land with solar arrays can be used in conjunction with other economic purposes such as raising livestock. Grazing animals such as sheep or goats, have the additional benefit of controlling the growth of shading vegetation, which can decrease the modules' performance over time.

#7 Conducting a Comprehensive Cost-Benefit Analysis to Compare Renewable Energy against Fossil Generation

A number of the benefits renewable energy offers are difficult to monetize and are not accounted for in a traditional LCOE calculation. For instance, switching from diesel to renewable energy resources improves local air quality and reduces greenhouse gas emissions but neither of these environmental benefits are recognized in a typical LCOE calculation. LCOE calculations also ignore the value of enhanced resiliency that distributed renewable energy systems offer and they neglect to account for the fact that renewable energy systems help insulate governments from volatile fuel prices. The failure to account for these benefits makes it challenging for governments to properly assess the merits of transitioning towards renewable energy resources and may give an undue advantage to conventional generation.

There are some measures that governments and utilities can take to supplement a basic LCOE analysis as they evaluate renewable energy investments so they can conduct a more holistic assessment. For instance, some governments outside of the Caribbean, including the American state of Minnesota, have begun requiring utilities to incorporate a Social Cost of Carbon into their evaluation of new generation resources.[19] Caribbean governments could require their utilities to take a similar approach. There is less of a clear model as to how to best incorporate the value of enhanced resiliency or reduced exposure to volatile fuel prices[20] but both of these issues are clearly of great value to Caribbean states[21] and should be included in any comprehensive cost-benefit analysis.

---

[19] *See, e.g.,* Gavin Bade, *Minnesota Regulators Boost Carbon Cost Estimates for Utility Planning*, UTILITY DIVE (July 28, 2017), *available at* https://www.utilitydive.com/news/minnesota-regulators-boost-carbon-cost-estimates-for-utility-planning/448175/ (last visited Dec. 6, 2017).

[20] One idea for valuing the benefits of reduced volatility might be to incorporate the price of a hedge against oil futures in the LCOE equation. For more on how renewable energy projects can reduce exposure to fuel price volatility, *see* COMMISSION FOR ENVIRONMENTAL COOPERATION, RENEWABLE ENERGY AS HEDGE AGAINST FUEL PRICE FLUCTUATION (2008), *available at* http://www.cec.org/islandora/en/item/2360-renewable-energy-hedge-against-fuel-price-fluctuation-en.pdf.

[21] Oil price shocks can have severe economic consequences for Caribbean nations given their heavy dependence on imported fossil fuels. *See* ARNOLD MCINTYRE ET AL., IMF WORKING PAPER, CARIBBEAN ENERGY: MACRO-RELATED CHALLENGES 12 (2016), *available at* https://www.imf.org/external/pubs/ft/wp/2016/wp1653.pdf (last visited Dec. 6, 2017).

#8 Developing Stable Regulatory Frameworks and Aligning Utility Incentives

Not surprisingly, the countries that are able to attract the most foreign investment are the ones who create the most stable and predictable regulatory environments. This general rule holds true for renewable energy investments; investor confidence is necessary to attract private capital for renewable energy projects. There are many types of policy tools available to promote clean energy – from feed-in tariffs to tradable credits to government grants – but irrespective as to which tools are chosen, the private sector must have faith that they will remain in force for duration of their projects. Uruguay, for example, has applied its energy policy consistently. As a result, Uruguay has attracted higher level of investment than their much larger neighbor Argentina where government distrust has significantly hampered investment. Renewable energy targets are one effective way of signaling a government's long-term commitment to renewable energy, but there no is one-size-fits-all approach.

Adding to the complications, some countries do not have established regulatory frameworks for microgrids and their governments may need to work with banks or outside consultants for technical assistance in developing legal and regulatory regimes, all of which comes at a cost. In designing a new regulatory framework, incumbent utility incentives – which often allow utilities to earn a rate of return only on direct investment – may need to be realigned to ensure proper management of microgrid infrastructure that is financed through non-utility sources, such as development bank grants. Governments must also ensure that their support does not crowd out private sector investment or disincentivize consumers from paying what is necessary to maintain the microgrid systems.

#9 Accounting for Transportation Difficulties

Several of the off-grid communities that were examined at the workshop and in preparatory conversations are located in very remote regions that are difficult to reach either by road or waterways. This can introduce substantial logistical challenges because the Powerpack solution that Tesla incorporates in its typical microgrid projects, which has 210 kWh of storage capacity, weighs approximately 5500 pounds and cannot be assembled onsite. As such, the equipment has to be shipped in one piece either via large trucks or boats, which can be impossible for some remote sites. The Powerpack also provides more storage capacity than many small off-grid sites require, especially when they are in the initial stages of electrification and demand is quite low. To overcome these challenges, Tesla recommends using smaller modular battery systems composed of standardized units that can be added to over time as load grows. This type of modular, or "kitted," battery solution can be deployed rapidly and is easy to transport to remote sites via standard pickup trucks.

#10 Designing Microgrids to be Maximally Resilient to Storms

As indicated in the introduction, the worsening effects of climate change underscore the need to build more resilient power systems in Caribbean nations. As the Earth continues to warm, scientist expect storms to become stronger, with increased wind speeds and precipitation. Climate models predict that rising sea levels also will result in greater flooding of coastal cities, and increased frequency of storms in the Caribbean region.

Diesel generation – the dominant form of energy in many island states -- is not resilient. Fuel shortages often follow storms to ocean-bound countries,[22] and storms can cause many diesel generators to go offline. Functioning solar microgrids, on the other hand, can provide energy as soon as the sun shines, but are also vulnerable to storm damage. Tesla's solar microgrid systems are designed to withstand high wind speeds of Category 4 and 5 hurricanes. In terms of resiliency, the foundations and racking of solar arrays

---

[22] *See supra* note 4.

are more difficult to reinstall than the solar panels, which are increasingly cheap and can be replaced fairly easily so long as the foundations remain intact. Solar array designs will continue to evolve to meet resiliency goals in the most cost-effective manner.

In addition to replacing diesel generation, governments must develop policies that incentivize storage and decrease reliance on centralized power plants and transmission – a frequent cause of electrical system blackouts. Puerto Rico's post-storm woes are due in large part to the great number of felled transmission lines and the over-reliance on centralized generation. Rebuilding transmission lines takes time and distributed solutions which are closer to the load can significantly minimize recovery time. Burying power lines is another way to enhance grid resiliency but is often cost-prohibitive.

The different outcomes in Cuba and Puerto Rico in response to Hurricanes Irma and Maria illustrate the benefits of distributed solutions for promoting resilience. This year, Hurricane Irma struck Cuba shortly before Hurricane Maria hit Puerto Rico and the two storms were of similar magnitude. Cuba managed to restore power to ninety percent of the island within five days, whereas the majority of Puerto Rico was still in the dark a month after Hurricane Maria's landfall. This difference was due at least in part to Cuba's heavy investment in distributed energy resources, particularly in rural areas, over a decade ago. Other Caribbean states can follow this example.

Part III — Concluding Reflections

This marks the third year that NYU has held a workshop examining the case for microgrids in remote regions and the third year that we have found evidence that renewable energy powered microgrids could lower the cost of electricity production at locations examined. Nevertheless, microgrid deployment in these regions remains limited and many of the obstacles to deployment that we observed in our first workshop, such as limited technical capacity and difficulty accessing low-cost financing for projects, persist. With climate change accelerating,[23] and the Caribbean region facing increasingly dire threats to their existing power infrastructure, the need to surmount these challenges has never been more urgent. Thankfully, an increasingly committed and diverse group of donors, from the UAE to private philanthropic organizations, are mobilizing to accomplish this task.

***

The authors gratefully acknowledge Tesla Inc. and the United Arab Emirates' Ministry of Foreign Affairs and International Cooperation for their generous support of this Report and the Workshop on which it is based. We would like to make particular mention of HE Majid Al-Suwaidi, Tristan Glenwright, Dane McQueen, Nick Reale, and Robert Rudd for their visionary leadership and commitment to expanding renewable energy access throughout the developing work.

---

[23] *See, e.g.*, John Abraham, *Earth's Oceans are Warming 13% Faster Than Thought, And Accelerating*, THE GUARDIAN (March 10, 2017), *available at* https://www.theguardian.com/environment/climate-consensus-97-per-cent/2017/mar/10/earths-oceans-are-warming-13-faster-than-thought-and-accelerating.