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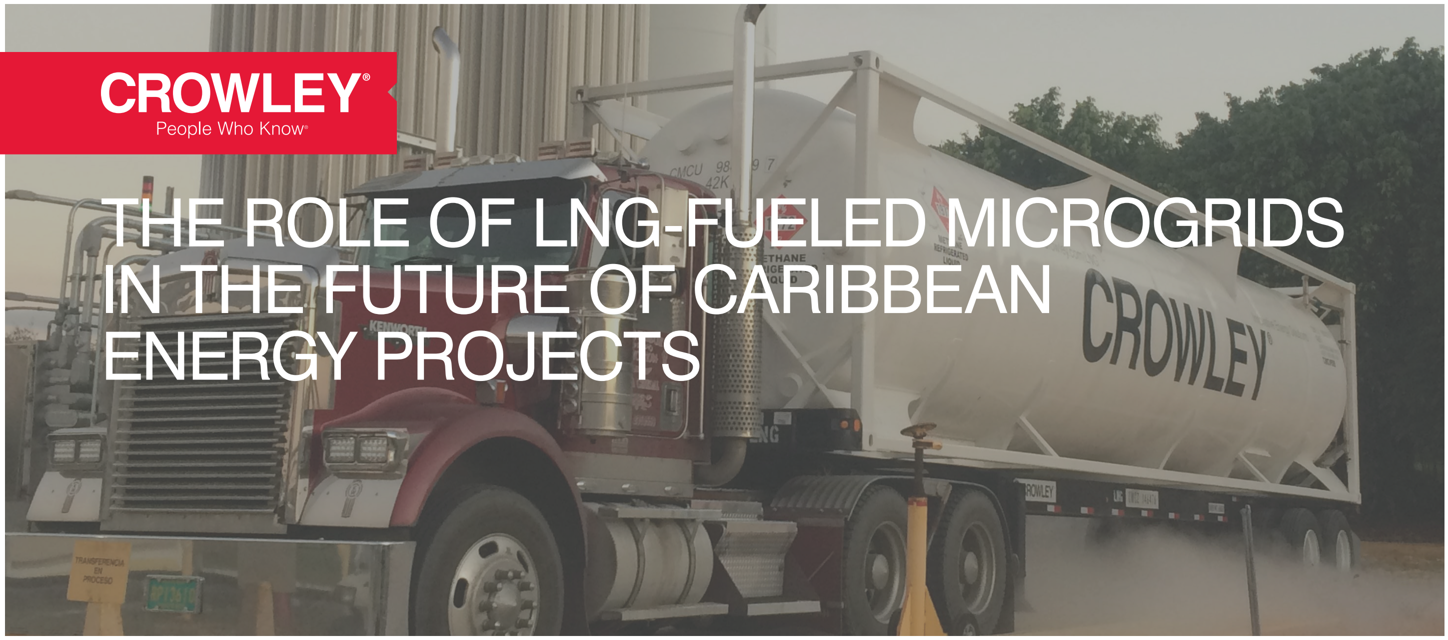



# THE ROLE OF LNG-FUELED MICROGRIDS IN THE FUTURE OF CARIBBEAN ENERGY PROJECTS

## INTRODUCTION TO MICROGRIDS

Traditionally, the commercial buildings, industrial facilities and residential areas of a country, state or region have obtained electricity supply by connecting to "the grid," an electrical power system supplied by central power generation sources. As the 21st century progresses, technological advancements have eventuated increased energy usage as well as a spike in awareness by energy users in both climate concerns and the need for grid resiliency. In its 2017 Annual Energy Outlook, the U.S. Energy Information Administration forecasted a steady 0.3-percent growth annually in total U.S. energy consumption and 1.0-percent annual growth internationally[1].

As technology expands and globalizes, access to electricity has become crucial in practically every segment of human life. Hospitals, schools, agriculture, financial markets, business centers, industrial facilities, etc., all rely on sustainable electricity, and the users continue to identify transgressions in the traditional grid model. Aside from contending with increased energy consumption – traditional utilities strive to reduce grid congestion and manage peak loads – a central utility provider acts as a single point of failure for most markets which results in concentrated risk where generation or transmission issues effect all users. This is especially true in times of power outage, natural disaster or other emergency situations where power outages can be felt by an entire populace.

This potential exposure has played a major role in prompting cities, communities, facilities and campuses to reevaluate traditional grid-sourced power connectivity in favor of local, autonomous power generation and supply. "Microgrids" provide users with the ability to isolate from a larger grid, making the serviced area more resilient and tailored to the needs and characteristics of a local market. Microgrids generally operate while still connected to a larger grid, but can disconnect and operate independently using local energy generation in times of emergency or for other reasons (financial, operational, etc.). Microgrids can be powered by distributed generators, batteries, and/or renewable resources, providing low-cost clean energy and resiliency to their users[2].

Microgrids have been installed throughout the continental U.S. and continue to be promoted on a basis of power resiliency for users in a diverse size range. In 2011 New York University (NYU) successfully installed a campus microgrid using natural gas-fired power generation with an output capacity of 13.4 megawatts. The following year, 2012, NYU went "island-mode," or separated from the local-grid completely, during Hurricane Sandy and continued to provide reliable power to the campus during and after the storm[3].

Recent forecasts predict that 200 megawatts of microgrid projects will come online worldwide by 2020, with some aggressive estimates reaching 300 megawatts[4]. Because of their resiliency during emergencies, discussions on the feasibility of microgrids seem to be centralized among high-frequency disaster areas, such as Japan or California. However, in the aftermath of Hurricanes Irma and Maria in 2017, which left thousands of homes and business without power for months, the Caribbean has become the new focal point.

[1] U.S. Energy Information Administration - EIA - Independent Statistics and Analysis. (2017, September 14). Retrieved December 11, 2017, from https://www.eia.gov/outlooks/aeo/data/browser/#/?id=1-IEO2017

[2] Microgrid Features and Benefits. (n.d.). Retrieved December 11, 2017, from https://www.districtenergy.org/microgrids/about-microgrids97/features

[3] Examples of Microgrids, New York University. (n.d.). Retrieved December 11, 2017, from https://building-microgrid.lbl.gov/new-york-university

[4] Walton, R. (2015, March 18). Going small: Microgrids are good for reliability, but are they good business? Retrieved December 11, 2017, from https://www.utilitydive.com/news/going-small-microgrids-are-good-for-reliability-but-are-they-good-busines/376365/


## EMERGENCE OF MICROGRIDS IN CARIBBEAN ENERGY PLANNING

It was previously detailed that most worldwide energy consumers receive power from interconnection with a centralized electricity grid. In the Caribbean, this is especially true as typically the power-supply needs of most islands are served by a single utility often managed by any given island's respective government. Electrical grids in the Caribbean face many challenges, foremost amongst them being the lack of access to pipeline natural gas, which in comparison constitutes the largest fuel source for U.S. primary power generation[5]. As a result, Caribbean utilities continue to burn inefficient traditional fossil fuels, such as fuel oil or diesel, solely due to lack of supply of fuel alternatives. Most Caribbean utilities have committed to reducing fossil fuel usage in the next 10 to 20 years by supplanting generation with renewable power production, however the capital cost of such options, along with the general shortage of land to field these systems, is a barrier to those commitments[6].

Additionally, the economic climate on some islands, paired with poor credit and restricted capital access for government-controlled utilities, has led to aging assets and subpar maintenance on generation assets and transmission equipment, sometimes resulting in rolling blackouts[7]. These same credit and capital issues have also caused Caribbean utilities to lag behind their U.S. counterparts in reaping the benefits of technological advancement, including high-efficient engines, reduced line-loss and reduced carbon footprint.

The coalescence of these issues has escalated over time and the destruction of the 2017 hurricane season appears to have prompted power users in the islands to push forward in considering disconnection from their primary grid in favor of self-managing power production and supply through private microgrids. Necker Island in the British Virgin Islands (BVI), home to Virgin Group founder Richard Branson, is campaigned as a success case for microgrids. The small 74-acre island is powered by 300 kilowatts of solar power, a 900-kilowatt wind turbine and a 500-kilowatt battery using advanced microgrid controls.

[5] November 2017. (n.d.). *Monthly Energy Review*. Retrieved December 11, 2017, from https://www.eia.gov/totalenergy/data/monthly/pdf/mer.pdf.

[6] Cardwell, D. (2014, February 06). Caribbean Islands Agree to Swap Diesel Power for Renewable Sources. Retrieved December 12, 2017, from https://www.nytimes.com/2014/02/07/business/energy-environment/caribbean-islands-agree-to-swap-diesel-power-for-renewable-sources.html

[7] Outages increase as Puerto Rico company crumbles amid crisis. (2017, April 11). Retrieved December 11, 2017, from http://www.foxnews.com/world/2017/04/11/outages-increase-as-puerto-rico-company-crumbles-amid-crisis.html

The aftermath of 150-mile-per-hour winds from Hurricane Maria left more than half of Puerto Rico without electricity seven weeks after landfall on September 20, 2017, and more than 70 percent of power consumers without electricity on the U.S. Virgin Islands (USVI) of St. Croix and St. John. Necker Island, however, regained power supply the day after landfall thanks to its microgrid, even despite loss of some its solar panels[8].

Unfortunately, most Caribbean power consumers lack the luxury of Richard Branson's funds or developable land. In those islands still recovering from the storms, time is also a luxury. In the wake of the hurricanes there is no shortage of prospectors offering complex microgrid solutions to high-profile energy users in the Caribbean, arguing that renewable-powered microgrids allow devastated islands to "start over" with a more advanced clean slate, having the existing power infrastructure essentially removed by circumstance in the same way that Europe rebuilt a more efficient grid following the destruction of World War II. Other industry experts argue that while renewable microgrids are indeed an ideal solution to many of the Caribbean's resiliency and electricity infrastructure woes, they come at the costs of land and capital, which may be accentuated from desperation for consistent electricity supply, and that more basic, fossil-fuel fired microgrids would be a lower-cost solution with less lead time, more available resources and the availability for scalability to renewables as the region re-stabilizes over time[9].

It can be assumed that the many different facilities or communities interested in microgrids in the Caribbean will have varied capital appetites, risk exposure, lead-time requirements, and energy-mix aspirations resulting in an arena where deployable microgrids will be tailored to each customer's geopolitical profile, but it can be determined with reasonable confidence that progressing onward to 2018 the market for microgrids in the Caribbean is ascending to new heights.

## CARIBBEAN MICROGRID CANDIDATES

In a 2011 white paper authored by Microgrid provider Siemens AG, six criteria were identified to determine microgrid candidacy of an end-user[10]. In the Caribbean market, candidates could be industrial facilities, industrial parks, hospitals, government campuses, commercial parks, residential areas, resorts, etc. **The six criteria are:**

**1**

End-user has funding available and can tolerate a 10 to 15 year payback period on energy project investment;

**2**

End-user is dependent on continuous, uninterrupted supply of electricity;

**3**

End-user is dependent on a physical and cyber secure power system solution;

**4**

End-user is planning for growth or energy transformation;

**5**

End-user has no regulatory barriers to install a microgrid;

**6**

End-user is a proponent of altruism and harbors concerns that the main grid faces reliability risks and is concerned about the environmental impact of low-efficiency traditional fossil fuels.

[8] Sweet, C. (2017, November 15). After the storms, it's microgrid season in the Caribbean. Retrieved December 12, 2017, from https://www.greenbiz.com/article/after-storms-its-microgrid-season-caribbean

[9] Peter Fairley Posted 13 Oct 2017 | 16:00 GMT. (2017, October 13). Why Solar Microgrids May Fall Short in Replacing the Caribbean's Devastated Power Systems. Retrieved December 12, 2017, from https://spectrum.ieee.org/energywise/energy/the-smarter-grid/should-a-devastated-caribbean-leap-forward-to-renewable-power-and-microgrids

**Independent microgrid candidates may exist on many of the Caribbean islands, of which a general profile of each is detailed below:**

**TABLE 1:** CARIBBEAN GDP, POWER PRODUCERS, FUEL MIX AND AVERAGE RATES[11]

| ISLAND | GDP ($ BILLION) | PRIMARY UTILITY | AVERAGE COMMERCIAL kWh | FUEL MIX | | | |
|---|---|---|---|---|---|---|---|
| | | | | PETROLEUM | NATURAL GAS | COAL | RENEWABLE |
| Anguilla | $0.28 | Anguilla Electricity Company Ltd. | $0.31 | 100% | 0% | 0% | 0% |
| Antigua & Barbuda | $1.61 | Antigua Public Utilities Authority | $0.39 | 100% | 0% | 0% | 0% |
| Aruba | $2.81 | WEB Aruba N.V. And N.V. Elmar | $0.28 | 85% | 0% | 0% | 15% |
| Bahamas | $11.40 | 1. Bahamas Electricity Corp.; 2. Grand Bahama Power Company | $0.37 | 74% | 0% | 26% | 0% |
| Barbados | $7.00 | Barbados Light & Power Company | $0.30 | 100% | 0% | 0% | 0% |
| British Virgin Islands | $0.50 | British Virgin Islands Electricity Corp. | $0.29 | 30% | 0% | 0% | 70% |
| Curacao | $3.13 | Aqualectra | $0.32 | 87% | 0% | 0% | 13% |
| Dominca | $1.02 | Dominica Electricity Services Limited | $0.39 | 71% | 0% | 0% | 29% |
| Dominican Republic | $135.70 | Haina Basic Energy Ltf. is Largest Among Multiple Utilities | $0.19 | 40% | 31% | 15% | 14% |
| Grenada | $1.46 | Grenada Electricity Services Ltd. | $0.44 | 99% | 0% | 0% | 1% |
| Guadeloupe | $11.68 | Electricité De France | $0.18 | 52% | 0% | 31% | 17% |
| Haiti | $18.54 | Electricité d'Haïti | $0.37 | 85% | 0% | 0% | 0% |
| Jamaica | $25.13 | Jamaica Public Service Company Ltd. | $0.39 | 94% | 0% | 0% | 6% |
| Montserrat | $0.58 | Montserrat Utilities Ltd. | $0.55 | 100% | 0% | 0% | 0% |
| Puerto Rico | $64.80 | Puerto Rico Electric Power Authority | $0.21 | 72% | 18% | 8% | 2% |
| Saint Martin | $0.13 | Electricite De France / N.V. Gebe | $0.36 | 100% | 0% | 0% | 0% |
| Saint Kitts & Nevis | $0.95 | St. Kitts Electric Company / Nevis Electric Company | $0.27 | 94% | 0% | 0% | 6% |
| Saint Lucia | $1.38 | Saint Lucia Electricity Services Ltd. | $0.34 | 99% | 0% | 0% | 1% |
| St. Vincent/ Grenadines | $1.20 | St. Vincent Electricity Services | $0.30 | 78% | 0% | 0% | 22% |
| Turks & Caicos | $0.63 | FortisTCI | $0.32 | 99% | 0% | 0% | 1% |
| U.S. Virgin Islands | $3.79 | Virgin Islands Water And Power Authority | $0.40 | 100% | 0% | 0% | 0% |

[10] Dohn, R. L. (2011). The business case for microgrids. Siemens AG. Retrieved December 12, 2017, from https://w3.usa.siemens.com/smartgrid/us/en/microgrid/Documents/The%20business%20case%20for%20microgrids_Siemens%20white%20paper.pdf

[11] Island Energy Snapshots. (n.d.). Retrieved October 8, 2018, from https://energy.gov/eere/island-energy-snapshots

## THE CASE FOR LNG-POWERED MICROGRIDS IN THE CARIBBEAN

The availability of low-cost and efficient liquefied natural gas (LNG) or shale gas in North America, in conjunction with continuous LNG containerized supply availability to Caribbean islands may provide an optimum solution for potential microgrid users. In Caribbean areas where major upgrades to generation and transmission capacity is not likely to occur in the near-term future due to financial or geopolitical reasons, microgrids powered by LNG provide a more immediate, lower-cost alternative to renewable power, such as wind, solar and biomass, whose infrastructure and installation costs have not decreased sufficiently enough to enable cost competition with fossil fuels[12].

LNG is essentially pipeline natural gas that is refrigerated to -260 degrees Fahrenheit, condensing the volumetric energy to 600 times its size and converting the gaseous energy into a cryogenic liquid for ease of transport. In its cryogenic, liquid form, LNG is a much safer fossil fuel when compared to traditional petroleum products given the non-explosive nature of the liquid[13]. Facilities with access to pipeline natural gas in the mainland U.S. refrigerate the gas and "liquefy" it to a cryogenic state for either storage and/or transport via truck or vessel. In 2014, Crowley Maritime Corporation began shipping 40-foot containers of LNG from the United States for non-utility purposes in Puerto Rico, and in 2016 New Fortress Energy and AES Dominicana began shipping equal sized containers to Jamaica and Barbados, respectively, for utility power generation. LNG is available for virtually all islands in the Caribbean on an immediate basis for containerized scale projects, and large-scale, vessel-supplied bulk projects are in development.

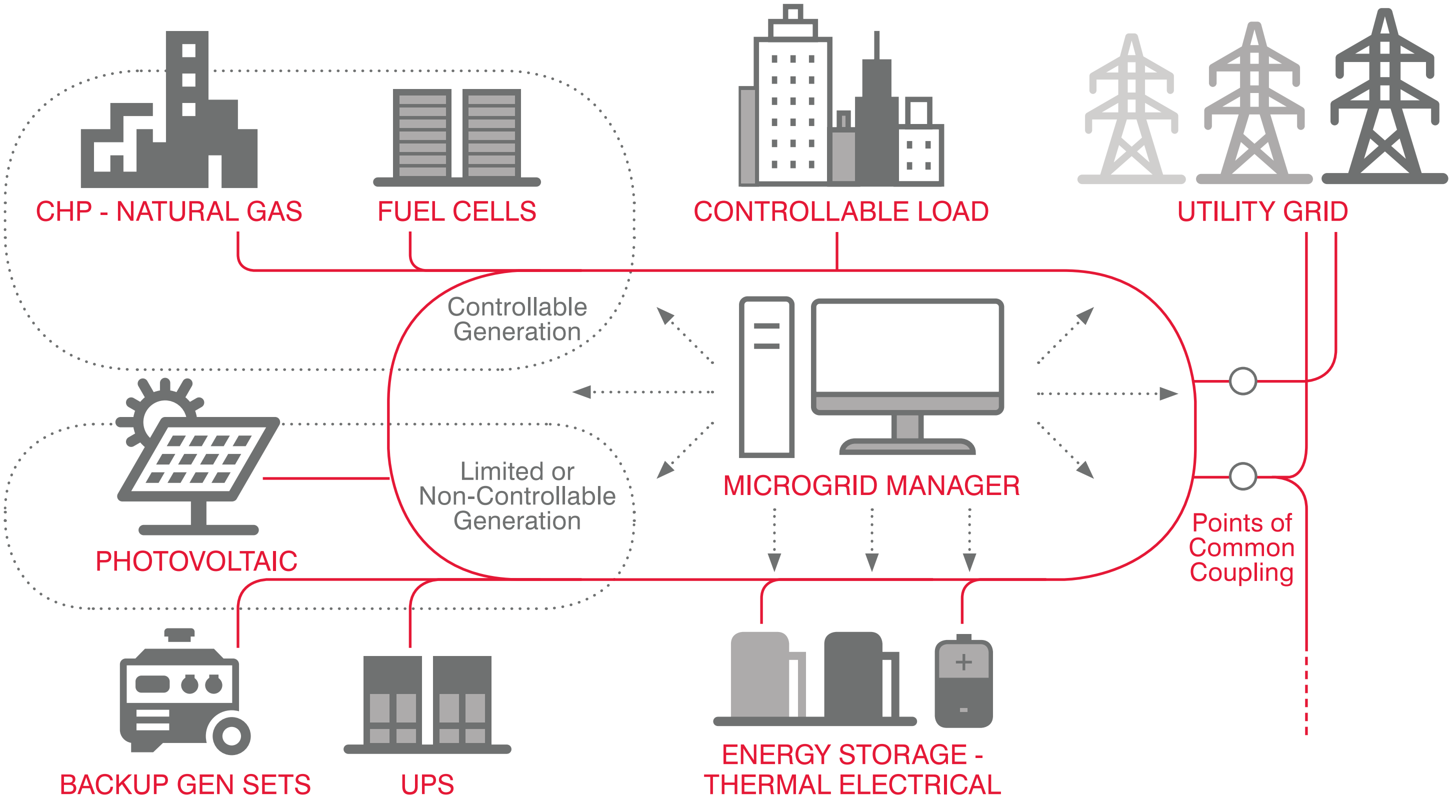
For LNG-powered microgrids, the supply chain would be similar to today's fuel deliveries to industrial customers: Microgrid managers would install cryogenic storage for LNG and subsequent vaporizer systems that would convert the LNG back to its gaseous state for engine consumption, and LNG suppliers would replenish the LNG as it's consumed. The natural gas would be primary used as a fuel source for either turbine or reciprocating engine-based power generation and energy storage and could accompany renewable power sources or act as a single source.

**40-foot containers of LNG from the United States for non-utility purposes in Puerto Rico shipped by Crowley from the United States in 2014**


[12] Farhangi, H. (2017). Smart microgrids: lessons from campus microgrid design and implementation. Boca Raton: Taylor & Francis, a CRC title, part of the Taylor & Francis imprint, a member of the Taylor & Francis Group, the academic division of T & F Informa, plc.

[13] Askren, H. (2013, April 26). Liquefied Natural Gas Safe and Fun, Advocates Say. Forbes. Retrieved December 13, 2017, from https://www.forbes.com/sites/mergermarket/2013/04/26/liquefied-natural-gas-safe-and-fun-advocates-say/#7d23734aca64

**TABLE 2:** EXAMPLE OF A MICROGRID MODEL[14]




If fossil-fuels are considered over renewables, either as a short or long-term microgrid fuel solution, users would reap the energy efficiency and emission-reduction benefits of LNG versus traditional fossil fuels.

**TABLE 3:** CARBON DIOXIDE EMISSIONS PER MMBTU[15]

| FUEL | POUNDS OF CO2 EMITTED PER MMBTU |
|---|---|
| Coal (anthracite) | 228.6 |
| Coal (bituminous) | 205.7 |
| Coal (lignite) | 215.4 |
| Coal (subbituminous) | 214.3 |
| Diesel Fuel and Heating Oil | 161.3 |
| Gasoline (wihtout ehtanol) | 157.2 |
| Propane | 139 |
| Natural Gas | 117 |

## MICROGRID STAKEHOLDERS

To understand future development of microgrids in the Caribbean it is critical to identify key stakeholders involved in the development of the potential projects. **Crowley notes that these include:**

1. **Community:** Caribbean electricity users on a general basis
2. **User:** Potential end-users of microgrids. Industrial complexes, residential communities, military installations, government complexes, school campuses, hospitals, etc.
3. **Microgrid:** Owner/Operators of installed microgrids
4. **Macrogrid:** The local private or public utility and grid operator
5. **Incentive and Constraint Makers:** Local government, foreign incentive providers
6. **Suppliers:** Fuel suppliers to power the microgrid, system manufacturers, financing providers, etc.

[14] Microgrids: An Old Concept Could Be New Again. (2017, August 1). Power Magazine. Retrieved December 13, 2017, from http://www.powermag.com/microgrids-an-old-concept-could-be-new-again/

[15] U.S. Energy Information Administration - EIA - Independent Statistics and Analysis. (n.d.). Retrieved December 13, 2017, from https://www.eia.gov/tools/faqs/faq.php?id=73&t=11

## POTENTIAL MICROGRID OPPORTUNITIES

Immediately following the 2017 hurricane catastrophes in Puerto Rico and the U.S. Virgin Islands, the U.S. Department of Energy sent surveyors to the islands to evaluate opportunities to improve and install grid resiliency mechanisms. A November 2017 web post from the Department of Energy's Assistant Secretary for the Office of Electricity Delivery and Energy Reliability stated that the office had identified 200 critical locations that would benefit from microgrids, including water-treatment plants and hospitals. The communication went on to explain that the Office was also in the process of investigating another 400 additional potential sites throughout Puerto Rico and the Virgin Islands[16]. Other potential locations in the Caribbean are sure to follow suit and have increased interest in deployable microgrid systems for key infrastructure components based on resiliency success stories and to avoid the energy fall-out experienced in Puerto Rico.


Regardless of a company's position in the microgrid commercial ecosystem model, the Rocky Mountain Institute, with collaboration the Clinton Climate Initiative, identified a multi-step process that an integrator, or team of integrators, would likely need to take to plan, develop and install a microgrid[17]. **The process has been slightly adjusted to support LNG-fueled microgrids:**

1. Align stakeholders on a shared vision of what the microgrid solution is.
2. Identify existing vulnerabilities in the grid and the opportunities to mitigate those vulnerabilities with a microgrid.
3. Forecast the electricity demand.
4. Identify all available energy resources including solar, wind, hydro, biomass, geothermal, diesel and LNG.
5. Analyze energy generation options and the impacts of the microgrid on the existing grid, along with costs.
6. Perform a detailed financial, engineering and economic analysis.
7. Determine the right financial and contractual structure for the solution and customer.
8. Support the contract negotiation process.
9. Prepare the site for development and commercialization.
10. Commission the system with the local island utility, the contractor(s) and any third-party engineers.

[16] Walker, B. J. (2017, November 22). How the Energy Department is Helping to Restore Power in Puerto Rico and the U.S. Virgin Islands [Web log post]. Retrieved January 3, 2018, from https://www.energy.gov/articles/how-energy-department-helping-restore-power-puerto-rico-and-us-virgin-islands

[17] Doig, S. (2017, September 19). Rebuilding a resilient, renewable Caribbean. Retrieved January 03, 2018, from https://www.greenbiz.com/article/rebuilding-resilient-renewable-caribbean

## POTENTIAL MICROGRID CHALLENGES

Microgrid connection to, and disconnection from, the local grid is a complex operation that must be clearly defined from all feasible perspectives, including regulatory, environmental, procedural, legal and user perspectives. Because the regulatory framework not only in the Caribbean but also in much of the world was developed and is governed assuming centralized utility distribution, existing regulations may be untailored and constraining to microgrid solutions[18]. Additionally, some local utilities may have charges associated with disconnection and reconnection to the main power grid, or unbundling charges, plus any tax or tariff charges, which would each play a crucial role in the financial evaluation of microgrids. Some island municipalities also restrict partial-energy distribution unless it's on an all-or-nothing basis.

In the Caribbean, obtaining funding for the development and planning of microgrids may also be a challenge given the poor credit and financial resources of most Caribbean islands. Even those U.S. islands impacted by the 2017 storm season are technically not subject to congressional funding for microgrid construction, as the Stafford Act, which governs U.S. funding for disaster rebuilding, rules that funding must be applied to projects to rebuild stricken areas to the operational status prior to the disaster, and not newly implemented or more efficient projects.

[18] Kerlero, G. (2017, February). Urban Microgrids (Abstract, ENEA Consulting, 2017) [Abstract]. Retrieved January 3, 2018, from http://www.enea-consulting.com/wp-content/uploads/2017/02/Urban-Microgrids-Public-report_VF3.pdf

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