Solar Hybrid Microgrids
in Emergency Power Management[1]

The Business Case
for Sustainable Infrastructure

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The Zofnass Program at Harvard

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1 Microgrids are onsite generation and storage resources that serve a localized load and can disconnect from the larger electric grid in the case of outages or instability. Hybrid systems incorporate generation assets—often renewables—and battery-based energy storage.

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ABSTRACT

In September 2017, Puerto Rico was devastated by two hurricanes in a row, Irma and Maria, which destroyed the power grid of the island. Louis Berger was commissioned by the Federal Emergency Management Agency (FEMA) to install and maintain hundreds of fossil fuel generators in an attempt to restore power for critical facilities. During that mission Louis Berger[2] sponsored a pro bono demonstration project to provide solar hybrid microgrid solutions under their social responsibility program "Give Back." In emergency response situations, the solar hybrid microgrids provide an environmentally friendly, reliable, and affordable alternative to fossil fuel generators. Apart from emergency response, solar hybrid microgrids can be used on a more permanent basis, especially in storm-prone areas, as an additional layer of resilience in the event of a future natural disaster. The first phase of Louis Berger's charitable program restored power for up to six months at a remote location in the mountains at the children's shelter Hogar Pequeño Joshua and at the adjacent Perla de Gran Precio Resident Treatment Center. Equally important to the environmental and social issues, the life cycle costing of solar hybrid microgrids can be as low as one-half of the life cycle cost of diesel generators, with operational costs being approximately a third that of diesel generators of the same uninterrupted power. Following the grid power restoration on the aforementioned facilities, the second phase of the program aimed at the long-term cost-effectiveness, flexibility, and resilience of the solar hybrid microgrids, whether they operate independently or connected to the power grid.

1. INTRODUCTION AND PROJECT DESCRIPTION

In September 2017, hurricanes Irma and Maria made landfall in Puerto Rico, causing devastating damage across the whole island and completely destroying the electrical grid. The 3.4 million inhabitants were left without power for weeks and in some cases months. In a mission to provide temporary power on important facilities, the U.S. Army Corps of Engineers (USACE) using its Advanced Contracting Initiative (ACI) mechanism transferred and installed hundreds of fossil fuel generators with funding from the Federal Emergency Management Agency (FEMA) to temporarily power areas that had been hardest hit. Generators were supplied to critical facilities, and in many cases microgrid technology was used to power several facilities at once. Typical microgrid installations combine one or more (1 to 2 MW) generators connected to transformers and other switching equipment to form a temporary power source. The generation equipment is connected to existing substations or directly into the main grid to power a variety of facilities on line.

Louis Berger has a long-term relationship with Puerto Rico through local and Federal government clients, including the United States Postal Service (USPS). Prior to the arrival of hurricane Irma, Louis Berger established a mission in Puerto Rico to support USACE, FEMA, the Defense Logistics Agency (DLA), and USPS for the recovery of affected infrastructure. After Hurricane María, Louis Berger was commissioned

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2   https://www.louisberger.com/, Louis Berger is a wholly- owned subsidiary of WSP.

to install, fuel, manage and maintain over 1,200 diesel generators and microgrids on the island, including for the Puerto Rico Aqueducts and Sewers Authority (PRASA) and municipalities like Naguabo, Villalba, Arecibo and the outer island of Culebra and Vieques. Louis Berger deployed more than 1,100 staff and independent contractors on the island.

Table 1. Project Data	
Project Name	Solar Hybrid Microgrids in Emergency Management
Savings	$18,033 three months operational savings (fuel and M&O) for a 20 kW-equivalent solar hybrid generator compared to a conventional 20 kW fossil fuel generator
Project type	Emergency response microgrids
Location	Various locations in Puerto Rico
Capacity	Two 20 kW-equivalent solar hybrid generators
Owner/client :	Louis Berger
Project team	Contractor: Louis Berger
	Engineer/Designer: Louis Berger/WestGen Power Solutions
	Project Manager: Michael Claycomb, Louis Berger
	Consultants:
Project lifespan	Up to 10 years
Current status	Ongoing
Funding model	Pro bono – Louis Berger "Give Back" program
Delivery method	Design-build-operate
Overall investment cost	$461,000
Design & construction cost	$88,400
O&M cost	$6,507 per three months per 20 kW-equivalent solar hybrid generator (off grid operation)
Source of funding	Louis Berger "Give Back" program

Besides the contracted work with FEMA, Louis Berger also proposed and tested a different strategy as a response to similar emergency situations. Rather than putting everything back together and hoping that future storms will not be as severe, Louis Berger suggested installing new systems that can withstand major storms with renewable energy sources. The belief is that distributed power generation offers

advantages over reliance on a central grid. Especially in storm-prone areas, small, trailer-mounted, solar hybrid microgrids should be the choice of the future as they are cleaner, mobile, resilient, and also cost-effective. To test this notion, Louis Berger self-funded and operated a solar hybrid power project in Puerto Rico through its "Give Back" campaign, which is part of the firm's corporate social responsibility program. The program was in partnership with WestGen and AEG.[3] Louis Berger provided multiple solar hybrid generator systems, solar lighting and solar heating equipment to support a remote community that lacked power in the aftermath of hurricanes Irma and María.

2. LOUIS BERGER/WESTGEN SOLAR HYBRID MICROGRID COMPONENTS

Microgrids are onsite generation and storage resources that serve a localized load and can disconnect from the larger electric grid in the case of outages or instability. Hybrid systems incorporate generation assets—often renewables—and battery-based energy storage.

The microgrid, or more accurately nanogrid, has been designed by Louis Berger in collaboration with WestGen, the OEM that supplied the equipment for this project. WestGen had been developing the technology for almost ten years, but as Greg Bilson, the CEO of the company explains[4] "…with the feedback and input of Louis Berger new equipment was designed to better serve the project". The microgrid consists of the WestGen Hybrid 25 generator and the WestGen Mobile Solar Module or "drone" that acts as extended solar generating capacity for the Hybrid 25.

Fig.1:   WestGen Hybrid 25, unfolded (left) and folded (right)

The WestGen Hybrid 25 is a high-performance solar/battery/diesel hybrid generator designed to replace conventional 25 kW, 110/240 V split-phase diesel generators. It has three solar panel trays, consisting of 6 panels each, with the two outer trays folding on top of the middle one for transportation. When folded,

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3   https://www.infrastructureusa.org/acecs-engineering-inc-louis-berger-helps-lead-puerto-rico-recovery/
4   Interview with Prof. Spiro N. Pollalis, January 28, 2019. Greg Bilson is the CEO of WestGen Power Solutions.

the unit is heavy to withstand strong winds, and the surfaces are protected from flying debris. According to the manufacturer, it can be used in a wide variety of applications besides emergency response situations, including construction sites, temporary power for residential and small commercial facilities, communication equipment, powering construction and repair tools, powering events, and providing permanent off-grid power supply for dwellings as well as remote scientific, communication, and military facilities.[5] The Hybrid 25 is configured to act as a mobile, behind-the-meter microgrid right out of the box, combining a behind-the-meter smart inverter with solar/battery storage system and a backup generator. It is built on a heavy-duty, off-road-capable and air-transportable platform. The system is capable of lowering the electrical bill during grid-connected operation as well as supplying emergency power in case of grid failure without any interruption in power supply, making it ideal for mission-critical applications. During off-grid operation, performing maintenance on the system's diesel component does not lead to interruption in power supply, making the system capable of 100% availability over extended periods of off-grid operation. No permanent installation is required, and unlike permanent photovoltaic installations, equipment can be easily secured and relocated during an adverse event, like a hurricane, and quickly redeployed afterward.

The capacity of the system can be extended with the addition of the WestGen Mobile Solar Module or "drone." The Module has the same solar panels as the WestGen Hybrid 25 without the battery and the diesel generator, so it actually has the ability to double the capacity of the system without having to add any other of the main features of the Hybrid 25, allowing further reduction in diesel fuel consumption or grid power use and further decreasing maintenance and refueling events. The modular, mobile extension of solar capacity means that deploying a larger system does not require larger vehicles or a larger contiguous unshaded area on site. The cost of the Mobile Solar Module ranges from one third to one half of the cost of the main unit.

In most applications the WestGen Hybrid 25 will provide 75% reduction in fuel consumption (or grid power use in a grid-connected mode) and maintenance costs, resulting in both lower lifetime operating cost and a significantly lower carbon footprint as compared to conventional diesel equipment. When it is combined with additional Mobile Solar Modules, the operating costs and fuel consumption can be even further reduced.

Solar hybrid mobile generators combine the environmental benefits of solar power and battery storage with the dependability of a diesel backup engine in an easy-to-transport generator to ensure 24/7 power to facilities and communities in need of emergency power. Benefits include easy and rapid deployment in remote locations, easy relocation, uninterrupted power supply, reduced need for fueling, limited emissions and fumes, and noiseless operations. Furthermore, they require minimal maintenance and have the flexibility to operate independently or in conjunction with other power sources and the main power grid.

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5   https://www.westgenpower.com/1

Solar hybrid microgrids can contribute to a decentralized, distributed power model of energy supply. Distributed power refers to a system of power that can generate power closer to the users, requiring less infrastructure and resulting in less loss during distribution. Centralized power, the current model for power, combines a system where power is generated in a central location and transmitted through a series of transmission and neighborhood distribution lines. Longer distance transmission and distribution lines are costly to maintain and are vulnerable to long-term power outages like those experienced in Puerto Rico.

Fig.2:   WestGen "drone" unfolded, the mobile solar module without batteries and the diesel generator

3. PROJECT DEVELOPMENT PROCESS – PHASE 1

The Louis Berger team had established a base in Puerto Rico before the first storm landed. The company's emergency response mission arrived in October following the FEMA contract. Local collaborators reported on the conditions and made an exploration first to identify potential places to install the solar hybrid microgrid alternative. The scope according to Michael Claycomb[6] of Louis Berger was to identify remote locations with difficult access to demonstrate the ability of the system to reach any location. Because of the emergency situation, permitting was not required and the team coordinated with NGOs operating in the region.

During the process of selecting a location, Louis Berger sponsored and provided power to the community Barrio Mameyes in Utuado for their Christmas event. It was the first installation of the system on the island. The event on December 17, 2017, in the damaged indoor basketball court of the community, was attended by 900 people, including 600 children. The WestGen generator was transported from San Juan

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6   Interview with Prof. Spiro N. Pollalis in Puerto Rico, November 5, 2018.

and it was connected on the same day to the main switch of the basketball court with the panels fully deployed and operational in minutes. The unit was installed in the remote location only for a day, showcasing the flexibility, transferability, and effectiveness of the system.

Fig.3:   Location of the solar hybrid microgrids

After the event, the system was installed in a hospital, but the grid power was restored just before it become operational. With no official information on when the power would be restored on each part of the island, the team resumed their effort to identify suitable locations, focusing on the most damaged areas. They preferred a remote location that would also be safe to avoid vandalism. After consulting local communities and evaluating several options, they chose the location of the Perla de Gran Precio (PDGP) and Hogar Pequeño Joshua (HPJ) in the remote mountain village of Barrio Nuevo, located in the municipality of Bayamón. PDGP is a rehabilitation center for women. HPJ was a care center for the children of PDGP mothers but now is a temporary shelter for children under 8 referred by the Department of the Family. PDGP and HPJ are adjacent and fenced with controlled access, each with their own gate and parking area. PDGP has two buildings, the main building and the residence, which together accommodate up to 50 residents. The two-story main building was severely damaged by the hurricanes, and during the microgrid installation was partially operational. The non-operational sections were the treatment area, the bedrooms, the gym, and the living room. Operational were the offices, laundry, and kitchen. The residence building also has two floors. The top floor accommodates up to 25 patients, with a refrigerator, radio, a small TV, and a few fans. The lower floor was used for storage, but the offices will eventually be moved there during the restoration of the main building. HPJ has one building and serves as the temporary shelter for up to 19 children. Their facilities include a laundry, refrigerator, kitchen, and a TV. The lower floor is for storage.

PDGP and HPJ shared a 100 kW diesel generator acquired years ago to cover for frequent power outages. After the hurricanes, they added a 7 kW generator for HPJ and left the 100 kW to energize the two PDGP buildings for 8 hours a day. Perla de Gran Precio was spending close to $2,000 per month to operate their generator for limited hours and services for their two buildings. By January, Hogar Pequeño Joshua had already acquired three 7 kW diesel generators for limited services and hours, spending approximately

$600 in diesel monthly. The storm also destroyed all the security lights on the premises. This represented a serious threat because they operate 24/7, have different shifts, and the whole region was in the dark. PDGP and HPJ had bedridden patients and medicines that required refrigeration. As a 24/7 temporary residence, they provide the daily meals for their patients. Therefore, continuous electrical power is essential.

Louis Berger provided pro bono for a limited time a WestGen HP25 hybrid-solar mobile generator for HPJ. For the two buildings of PDGP, they also donated a WestGen solar light tower and an AEG hybrid mobile generator. The donation was initially for six months or until power was restored. The WestGen hybrid solar generator with a diesel backup was assembled on a mobile rig. Its three panels of 22' wingspan, when deployed, collect the sunlight to power the building and charge the batteries. It can operate even at 30% sunlight. At night the structure is powered by the batteries. If the charge goes below a certain level, the diesel generator activates to recharge the batteries and power the building. The diesel generator was also programmed to turn on automatically for 1.5 hours before bedtime, to boost battery charge and avoid the noise of the diesel generator during quiet time. The microgrids stayed installed until the power was restored.

After the power restoration at Perla de Gran Precio in Bayamón, Louis Berger was looking for places that still needed power. Based on reports on local conditions and in the media, the team explored locations with expected delays in restoration that also met the criteria set for the installation of the solar hybrid microgrid. They looked at the southeast of the island, mainly Humacao and Yabucoa, entry point of hurricane María and two of the municipalities with the slowest power restoration. After evaluating several alternatives in the area, the Casa del Amparo nursing home in Humacao was selected, a facility that provides service to up to 23 patients and was without grid power since hurricane Irma. After the hurricane, Casa del Amparo received a donation of a 30 kW diesel generator with 140-gallon fuel tank. The generator ran for 20 hours a day and required refueling every week, with a cost of around $2,000 in diesel every month. The WestGen solar hybrid microgrid was installed on June 6, replacing their diesel generator until power restoration on July 9.

The installation of the solar hybrid microgrid in the various locations of Puerto Rico demonstrated the flexibility and reliability of the system. It provided continuous power without interruptions to the facilities where it was installed. Maintenance service requirements were kept to a minimum since it offered remote monitoring. It has significantly reduced the cost of fuel that was a major financial burden for the smooth operation of each institution. It showcased the flexibility of the system as it was easily relocated after power was restored in its first location. Deliris Rivera, Director of HPJ, and Lydia Rodriquez, Director of PDGP, confirmed[7] the smooth operation of the system and the uninterrupted power supply on both facilities. Rivera mentioned as the only disadvantage the size of the installation, which covered part of the already limited parking lot, but both managers expressed their satisfaction and gratitude for the operation of the system on their institutions. As Rodriquez emphasized, "We are very satisfied and very grateful that they have chosen us to provide the service… It was something that made a difference in our lives."

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7   Teleconferences with Judith Rodriquez, January 2019.

Besides its suitability for emergency response situations, the solar hybrid microgrid can be used as a semi-permanent installation for increased resilience in storm-prone areas, since the equipment can be protected and reinstalled as soon as the conditions improve, just a few hours after an extreme weather event. In that case the solar hybrid microgrid can be used independently or in combination with the main power grid, as the second phase of testing in Puerto Rico will showcase.

4. PROJECT DEVELOPMENT PROCESS – PHASE 2

The objective of the second phase according to Claycomb[8] is to prepare Perla de Gran Precio and Pequeño Joshua for the next hurricane season. Louis Berger installed temporarily a microgrid system until the end of the hurricane season. The second phase also includes the adjacent Hogar de Envejecientes, a nursing home not covered in phase 1. The project, in addition to the microgrid mobile hybrid-solar generator system, includes solar streetlights and solar water heaters to decrease the workload of the hybrid generators.
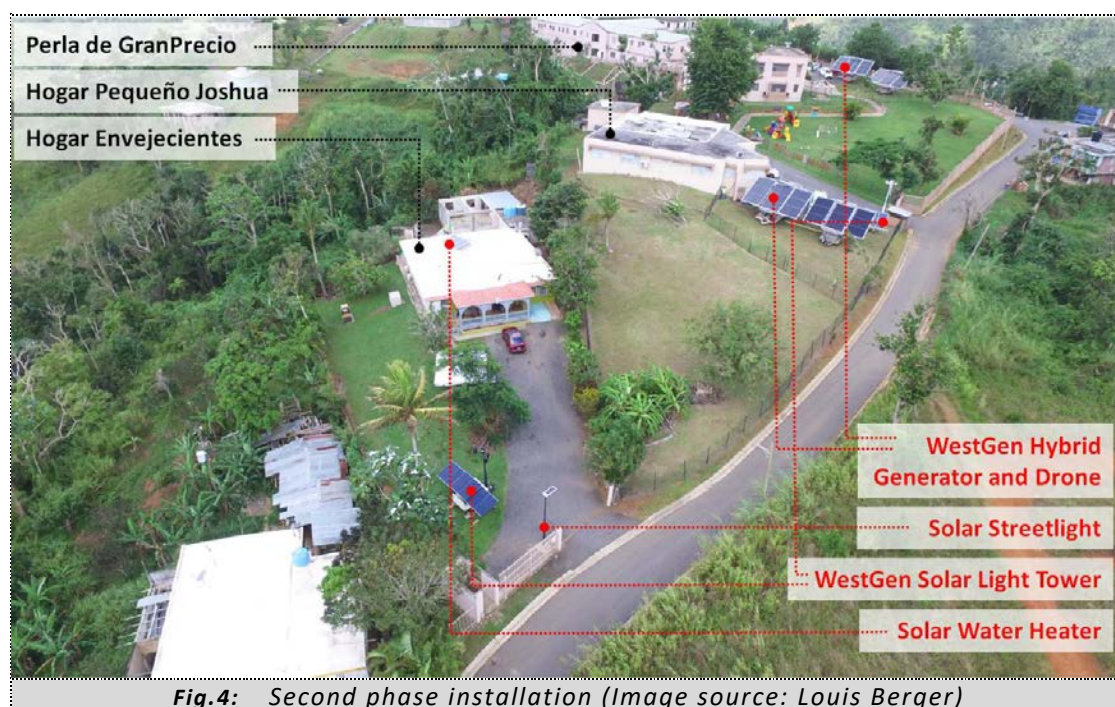
Fig.4:   Second phase installation (Image source: Louis Berger)

The microgrid consists of an arrangement similar to what was installed in the first phase. Two hybrid-solar mobile generators are used to supply the power demands of the four buildings. One is connected to Hogar Pequeño Joshua and the Hogar de Envejecientes and the other to the residence building of Perla de Gran Precio. To increase solar energy harvesting, each hybrid-solar system is paired with a Mobile Solar Module (MSM), a unit with solar panels but without the diesel generator. The microgrid also includes

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8   Iinterview with Prof. Spiro N. Pollalis in Puerto Rico, November 5, 2018.

three solar towers, one each for the entrances at Perla de Gran Precio, Hogar Pequeño Joshua, and Hogar de Envejecientes, to increase security during the night. Ten streetlamps were installed on the perimeter walls and around the building, and four solar water heaters were installed on the roofs of the buildings. The second phase integrates the power grid of PREPA as the backup to the solar power system. That means that the grid and not the generator is used to maintain the batteries and support periodic high loads, which is cheaper and avoids environmental impacts associated with diesel power generation. The generator enters as the backup only in the rare scenario that the solar power and the batteries are low and the grid is off. The WestGen solar hybrid microgrid had been tested before in an emergency management situation after the superstorm Sandy. However, The Puerto Rico application was the first used in conjunction with the main power grid.

5. SUSTAINABILITY

The WestGen solar hybrid microgrid system has significant environmental benefits, while it reinforces resilience against climate change. The sustainability benefits are particularly clear when compared to an equivalent diesel generator. In most applications, the WestGen H25 provided a 75% reduction in fuel consumption and the corresponding CO_2 emissions. When combined with additional mobile solar modules (drones), the fuel consumption and carbon footprint are further reduced. For example, the Puerto Rico case study contacted by Louis Berger resulted in CO_2 emissions of 4.4 metric tons for three months of operation of the 20 kW-equivalent solar hybrid microgrid, while the equivalent CO_2 emissions for a conventional 20 kW diesel generator would be 12.2 metric tons or almost three times as much. For the same period the fuel consumption of the solar hybrid microgrid is 436 gallons, while for the diesel generator it would be 1,199 gallons.

Besides the important environmental benefits, the solar hybrid microgrid significantly increases resilience, especially in extreme-weather, storm-prone communities. It is mobile, off-road-capable, and easily transportable, thus able to reach remote locations. It is quickly installed and operational, suitable for emergency response. When installed, it withstands extreme weather events since its solar panels are foldable and stack to each other. Folding and making the system weather resistant is also a fast process; it only takes half an hour or even 5 minutes if people are familiar with the procedure. The flexibility of the solar hybrid microgrid and its ability to provide uninterrupted power whether it is operating in on-grid or off-grid mode are the characteristics that make it suitable for remote and natural-disaster-vulnerable locations. Its smooth operation is much less dependent on fuel supply and maintenance work than a conventional fossil fuel generator. The three months comparison case study conducted by Louis Berger in Puerto Rico concluded that the power availability to the tested facility reached 100% with the solar hybrid microgrid, while with the conventional diesel generator it was 99.1%.[9]

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9   However, the sample size of the diesel generators was much larger.

6. ECONOMIC BENEFITS

The comparison conducted by Louis Berger in Puerto Rico showcased substantial operational savings by replacing a 20 kW diesel generator with a 20 kW equivalent solar hybrid microgrid.[10] As is the case with most renewable energy projects, the capital expenditure is much higher for the solar hybrid microgrid compared to a diesel generator, but in the long term the savings are significant.

The results from the three-month testing comparison on a remote shelter facility in Puerto Rico are visible on the following table[11]. The weekly electrical consumption of the facility was 379 kWh, totaling 4,548 kWh during the 90-day period. During that same time period, the diesel generator ran for 1,998 hours and needed maintenance service 9 times, while the generator of the solar hybrid microgrid ran for 396 hours and needed maintenance only once. The total maintenance cost for the diesel generator reached $9,554 while for the solar hybrid microgrid the cost was $1,061. In terms of fuel consumption, the diesel generator used 1,199 gallons at a total fuel cost of $14,985 whereas the solar hybrid microgrid diesel generator consumed 436 gallons with a cost $5,445. Adding maintenance and fuel cost together, the total operating cost for three months for the diesel generator was $24,540, while the cost for the hybrid microgrid was only $6,507. Consequently, for a period of only three months the net operational savings by replacing a conventional diesel generator with a solar hybrid microgrid reached a staggering $18,033. Furthermore, one should mention the volatility of fuel prices which in many cases can be even higher depending on the remoteness of the area, the local conditions, and the degree of devastation.

The comparison made evident that the operational savings are substantial. Although the capital cost for a solar hybrid microgrid is higher than for a conventional fossil fuel generator, the long-term savings are significant. While traditional initial equipment costs are $30,000 for a conventional 25 kW diesel generator, it has a 10-year total "all in" cost, for ownership plus O&M, of about $560,000. An equivalent solar hybrid system has an initial equipment cost of $175,000, but has a 10-year total "all in" cost of about $255,000.[12] On top of that, a conventional fossil fuel generator is limited to only 10,000 hours of operation while a solar hybrid microgrid has a 10-year lifespan regardless of its hours of operation, further reinforcing the efficiency and business case for the solar hybrid alternative.

According to Alex Nadolishny,[13] Principal Technology Expert at Louis Berger, "the capital cost for automation looks high but compared to the labor for manual operation and manual monitoring on site is dramatically cheaper; that's a positive lesson."

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10 According to Louis Berger, the results refer only to an emergency response case scenario and may not be applicable for a commercial use comparison.

11 Based on the presentation "Microgrids in Temporary Power Applications - Experience Implementing Substation-Level Diesel Microgrids and Facility-Level Hybrid Solar/Diesel Microgrids in Puerto Rico" by Alex Nadolishny, Program Manager Louis Berger USA, at the Zofnass Program for Sustainable Infrastructure workshop,Harvard Graduate School of Design, November 13, 2018.

12 James Conca, "A Ray of Sunshine Falls on Puerto Rico," Forbes, [Feb 08, 2018].

13 Interview with Prof. Spiro.N.Pollalis, January 28, 2019.

Location:	Puerto Rico, remote shelter facility	
Duration:	3 months	
Parameter	**Conventional 20 kW diesel generator**	**20 kW-equivalent hybrid generator**
Weekly electrical consumption (facility), kWh	379.0	
Total electrical consumption (over 90 days), kWh	4,548.0	
Peak load (observed), kW	12.5	
Average load (monthly average), kW	2.3	
Total generator run time (diesel engine), hrs	1,998.0	396.0
Power availability to the facility	99.1%	100.0%
Number of service events	9	1
Cost of service event, $*	$1,061.61	$1,061.61
Total service cost, $	**$9,554.51**	**$1,061.61**
Fuel burn rate, gal/hr.	0.6	1.1
Total fuel consumed, gal	1,198.8	435.6
Cost of fuel (delivered), $/gal**	$12.50	
Total fuel cost, $	**$14,985.00**	**$5,445.00**
Total CO2 Emissions, metric Tons	12.2	4.4
Total operating costs over the 3-month period, $	**$24,539.51**	**$6,506.61**
Net operational savings, $	**$18,032.90**	

Fig.5: *Case Study: operational benefits of replacing a 20kW diesel generator with a 20kW equivalent hybrid solar/diesel unit (Source: Louis Berger)*

CONCLUSION

The Louis Berger installation of solar hybrid microgrids in Puerto Rico showcased that there is a sustainable and cost-effective alternative to fossil fuel generators in emergency response situations, bringing, as Alex Nadolishny[14] of Louis Berger notes, a disruptive technology to a sector that has seen little innovation for decades. The three-month comparison between a solar hybrid microgrid and an equivalent fossil fuel generator proved that the operational savings are substantial.

Solar hybrid microgrids, though, are not just an emergency response solution. Their flexibility, adaptability, and resilience make them suitable also for permanent installation, especially in remote and storm-prone communities. After hurricane Maria devastated Puerto Rico, there has been a debate about what kind of power systems should be used to rebuild the energy infrastructure of the island. The focus should be on a new mix of a power supply based on renewable energy production with microgrid distribution. The solar hybrid microgrid installation showcases that we could test smaller stand-alone systems, based on these technologies, which could be scaled up as they demonstrate usefulness.[15] As Miguel Torres-Dias of Louis Berger mentions[16], "that's part of the evaluation we are performing at this moment, to test how we can keep scaling up the system as needed."

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14   Based on the presentation "Microgrids in Temporary Power Applications - Experience Implementing Substation-Level Diesel Microgrids and Facility-Level Hybrid Solar/Diesel Microgrids in Puerto Rico" by Alex Nadolishny, Program Manager Louis Berger US, at the Zofnass Program for Sustainable Infrastructure workshop, Harvard Graduate School of Design, November 12-13, 2018.
15   Conca, "A Ray of Sunshine Falls on Puerto Rico."
16   Interview with Prof. Spiro N. Pollalis in Puerto Rico, November 5, 2018. Miguel A. Torres-Dias is Associate Vice President and Director of Puerto Rico & USVI Operations of Louis Berger.

The installation and testing of solar hybrid microgrids increases awareness of the business case for planning sustainably, in addition to the benefits of cleaner energy. Furthermore, storm-prone communities need the resilience of distributed generation, especially as climate change causes extreme phenomena with increasing frequency and intensity.

ABBREVIATIONS

DLA   Defense Logistics Agency
FEMA   Federal Emergency Management Agency
HPJ   Hogar Pequeño Joshua
MSM   Mobile Solar Module
PDGP   Perla de Gran Precio
PRASA   Puerto Rico Aqueducts and Sewers Authority
PREPA   Puerto Rico Electric Power Authority
USACE   U.S. Army Corps of Engineers

SOURCES

The case study was based on:
- Interviews conducted by Prof. Pollalis in Puerto Rico on 7-8 November 2018 with Miguel Torres Diaz and Michael Claycomb, Louis Berger and Victor Oyola, Director of Vogars Advertising.
- The presentation "Microgrids in Temporary Power Applications - Experience Implementing Substation-Level Diesel Microgrids and Facility-Level Hybrid Solar/Diesel Microgrids in Puerto Rico" by Alex Nadolishny of Louis Berger US, at the Zofnass Program for Sustainable Infrastructure workshop that took place at the Harvard Graduate School of Design on 12-13 November 2018.
- Teleconferences with Greg Bilson, CEO of WestGen Power Solutions and Alex Nadolishny, Principal Technology Expert of Louis Berger, in January of 2019.
- Teleconferences with Deliris Rivera, Director of Hogar Pequeño Joshua shelter in Puerto Rico and Lydia Rodriguez, Director of Perla de Gran Precio shelter in Puerto Rico, in January 2019.
- Online sources:
  - https://www.infrastructureusa.org/acecs-engineering-inc-louis-berger-helps-lead-puerto-rico-recovery/
  - https://www.louisberger.com/news/relief-bound-puerto-rico-and-virgin-islands
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  - https://www.solarpowerworldonline.com/2018/01/shelters-puerto-rico-restored-mobile-solar-hybrid-power/
  - https://www.westgenpower.com/
  - https://www.windpowerengineering.com/business-news-projects/blog/distributed-renewable-energy-may-formula-puerto-ricos-hurricane-recovery/

EXHIBIT A: WestGen Hybrid 25 specifications
(after WestGen)

EXHIBIT B: Envision® Checklist

This section examines the sustainability performance of the project after applying the self-assessment tool[17]. The Envision® Checklist does not replace the use of Envision® Rating System nor provide Envision® accreditation. It is a free-standing assessment tool for comparing sustainability alternatives or to prepare for a more detailed sustainability assessment. The checklist is organized into the main five categories of impact of Envision®: Quality of Life, Leadership, Resource Allocation, Natural World, and Climate and Risk.

The project performed very well on the categories of Leadership and Climate and Risk, scoring positively on all 16 applicable questions on Leadership category, and on 9 out of 11 questions on Climate and Risk category, reinforcing that way the commitment of all stakeholders on sustainability and resilience against future hazards. On the Quality of Life category the project performed fairly well, scoring positively on 8 out of 13 applicable questions. Due to its small scale and mobile nature, the project has small impact on the categories of Resource Allocation and Natural World where the majority of credits are not applicable. On Resource Allocation the project scored positively on 13 out of 18 applicable questions while on the Natural World category only 2 out of 46 questions were applicable with a positive score on both questions.

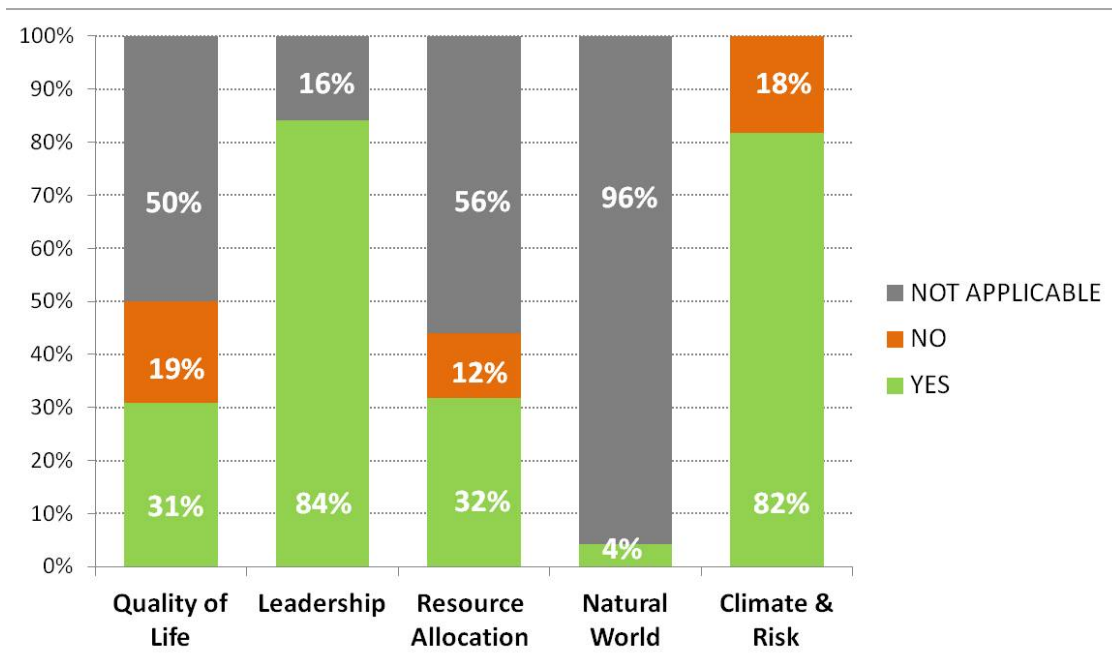*Fig.6:* *Envision Checklist results*

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[17] The Envision Checklist self-assessment was conducted by the Zofnass Program and does not constitute an endorsement of the Institute for Sustainable Infrastructure (http://www.sustainableinfrastructure.org/).
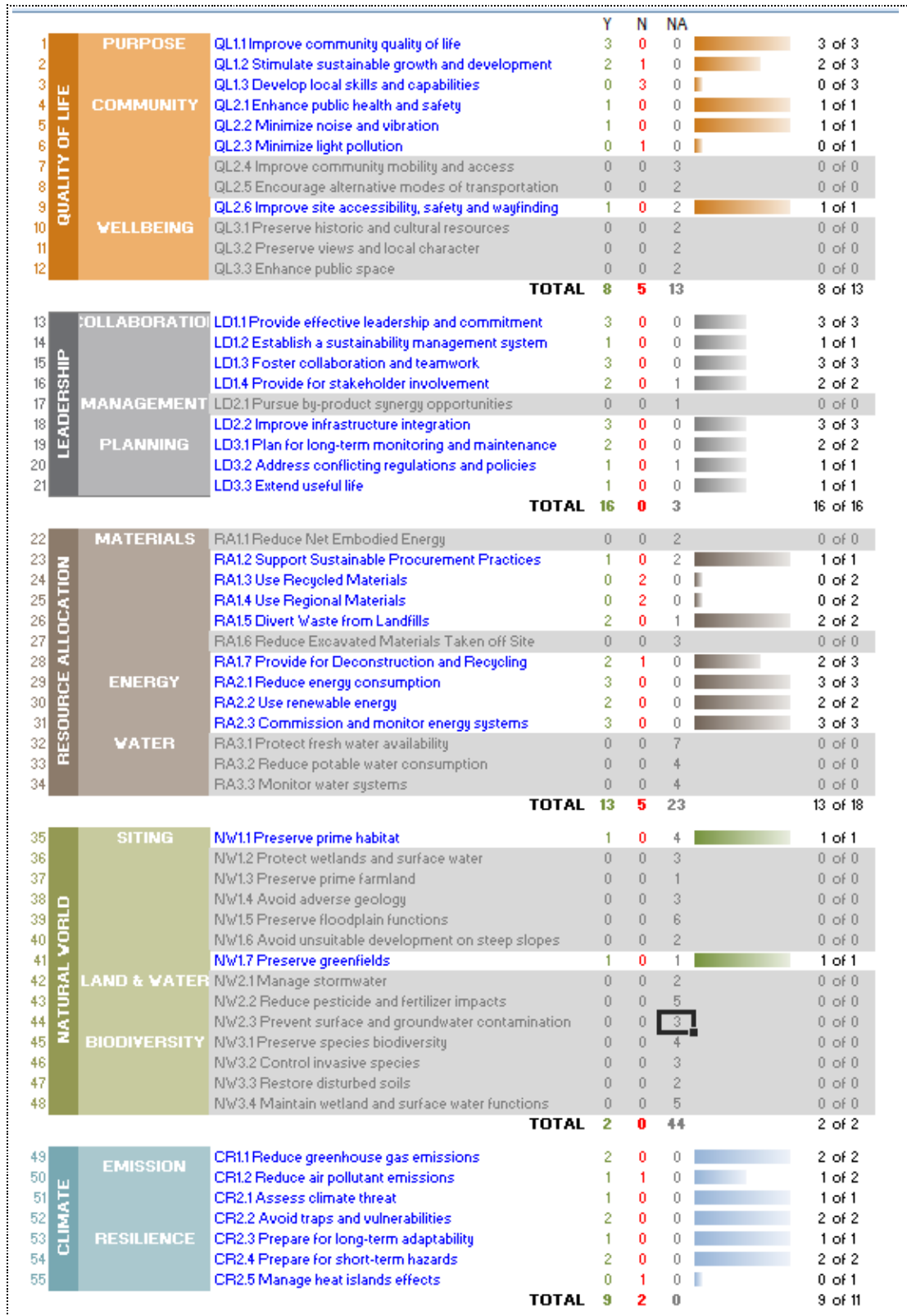
Fig.7: *Envision Checklist scoreboard*

			Y	N	NA		
1	PURPOSE	QL1.1 Improve community quality of life	3	0	0		3 of 3
2		QL1.2 Stimulate sustainable growth and development	2	1	0		2 of 3
3		QL1.3 Develop local skills and capabilities	0	3	0		0 of 3
4	COMMUNITY	QL2.1 Enhance public health and safety	1	0	0		1 of 1
5		QL2.2 Minimize noise and vibration	1	0	0		1 of 1
6		QL2.3 Minimize light pollution	0	1	0		0 of 1
7		QL2.4 Improve community mobility and access	0	0	3		0 of 0
8		QL2.5 Encourage alternative modes of transportation	0	0	2		0 of 0
9		QL2.6 Improve site accessibility, safety and wayfinding	1	0	2		1 of 1
10	WELLBEING	QL3.1 Preserve historic and cultural resources	0	0	2		0 of 0
11		QL3.2 Preserve views and local character	0	0	2		0 of 0
12		QL3.3 Enhance public space	0	0	2		0 of 0
		TOTAL	**8**	**5**	**13**		**8 of 13**
13	COLLABORATION	LD1.1 Provide effective leadership and commitment	3	0	0		3 of 3
14		LD1.2 Establish a sustainability management system	1	0	0		1 of 1
15		LD1.3 Foster collaboration and teamwork	3	0	0		3 of 3
16		LD1.4 Provide for stakeholder involvement	2	0	1		2 of 2
17	MANAGEMENT	LD2.1 Pursue by-product synergy opportunities	0	0	1		0 of 0
18		LD2.2 Improve infrastructure integration	3	0	0		3 of 3
19	PLANNING	LD3.1 Plan for long-term monitoring and maintenance	2	0	0		2 of 2
20		LD3.2 Address conflicting regulations and policies	1	0	1		1 of 1
21		LD3.3 Extend useful life	1	0	0		1 of 1
		TOTAL	**16**	**0**	**3**		**16 of 16**
22	MATERIALS	RA1.1 Reduce Net Embodied Energy	0	0	2		0 of 0
23		RA1.2 Support Sustainable Procurement Practices	1	0	2		1 of 1
24		RA1.3 Use Recycled Materials	0	2	0		0 of 2
25		RA1.4 Use Regional Materials	0	2	0		0 of 2
26		RA1.5 Divert Waste from Landfills	2	0	1		2 of 2
27		RA1.6 Reduce Excavated Materials Taken off Site	0	0	3		0 of 0
28		RA1.7 Provide for Deconstruction and Recycling	2	1	0		2 of 3
29	ENERGY	RA2.1 Reduce energy consumption	3	0	0		3 of 3
30		RA2.2 Use renewable energy	2	0	0		2 of 2
31		RA2.3 Commission and monitor energy systems	3	0	0		3 of 3
32	WATER	RA3.1 Protect fresh water availability	0	0	7		0 of 0
33		RA3.2 Reduce potable water consumption	0	0	4		0 of 0
34		RA3.3 Monitor water systems	0	0	4		0 of 0
		TOTAL	**13**	**5**	**23**		**13 of 18**
35	SITING	NW1.1 Preserve prime habitat	1	0	4		1 of 1
36		NW1.2 Protect wetlands and surface water	0	0	3		0 of 0
37		NW1.3 Preserve prime farmland	0	0	1		0 of 0
38		NW1.4 Avoid adverse geology	0	0	3		0 of 0
39		NW1.5 Preserve floodplain functions	0	0	6		0 of 0
40		NW1.6 Avoid unsuitable development on steep slopes	0	0	2		0 of 0
41		NW1.7 Preserve greenfields	1	0	1		1 of 1
42	LAND & WATER	NW2.1 Manage stormwater	0	0	2		0 of 0
43		NW2.2 Reduce pesticide and fertilizer impacts	0	0	5		0 of 0
44		NW2.3 Prevent surface and groundwater contamination	0	0	3		0 of 0
45	BIODIVERSITY	NW3.1 Preserve species biodiversity	0	0	4		0 of 0
46		NW3.2 Control invasive species	0	0	3		0 of 0
47		NW3.3 Restore disturbed soils	0	0	2		0 of 0
48		NW3.4 Maintain wetland and surface water functions	0	0	5		0 of 0
		TOTAL	**2**	**0**	**44**		**2 of 2**
49	EMISSION	CR1.1 Reduce greenhouse gas emissions	2	0	0		2 of 2
50		CR1.2 Reduce air pollutant emissions	1	1	0		1 of 2
51		CR2.1 Assess climate threat	1	0	0		1 of 1
52		CR2.2 Avoid traps and vulnerabilities	2	0	0		2 of 2
53	RESILIENCE	CR2.3 Prepare for long-term adaptability	1	0	0		1 of 1
54		CR2.4 Prepare for short-term hazards	2	0	0		2 of 2
55		CR2.5 Manage heat islands effects	0	1	0		0 of 1
		TOTAL	**9**	**2**	**0**		**9 of 11**