Resilient by Design: Enhanced Reliability and Resiliency for Puerto Rico's Electric Grid

Executive Summary

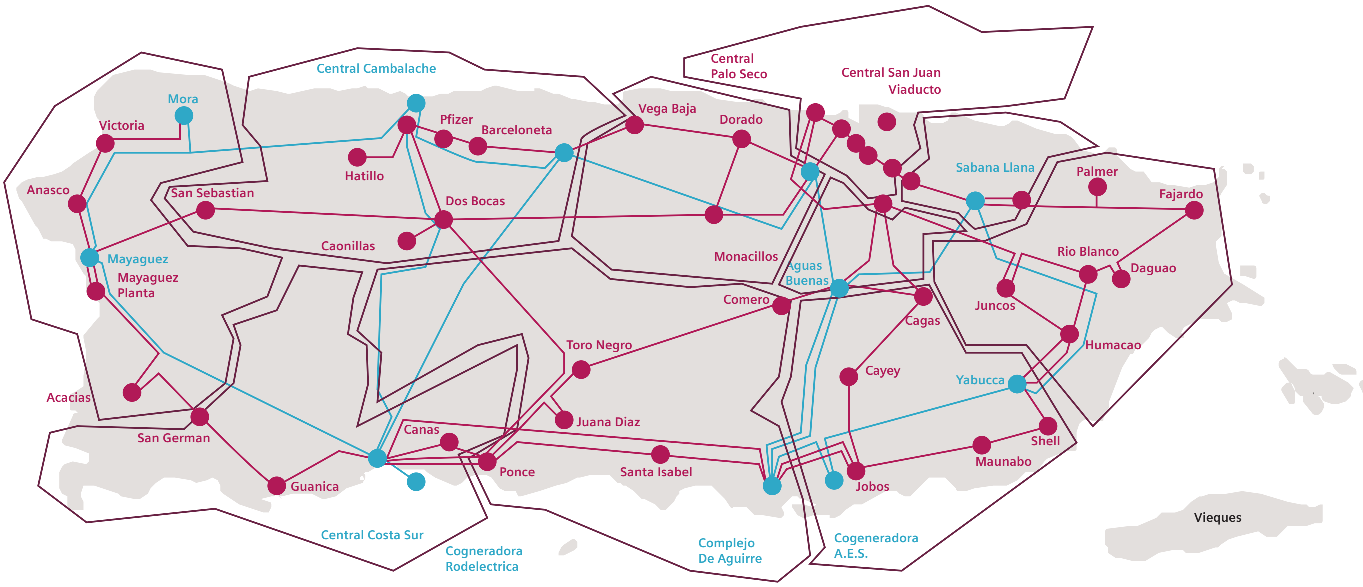
A reliable electrical grid is the backbone of any city or society – and it becomes even more essential in the face of the inherent geographical isolation risk faced by an island community. Since its last Integrated Resource Plan (IRP) in 2015, Puerto Rico's electric power system has experienced significant upheaval.

The massive devastation caused by hurricanes Irma and Maria – combined with the steep drop in the cost of renewables and battery-based energy storage – offer Puerto Rico a rare and powerful opportunity to redesign its power system, producing a significantly more resilient grid by design that will ensure a steady flow of cleaner and higher quality power for its residents and businesses. Siemens commissioned this report to inform the next IRP that will guide the grid rebuilding and development for Puerto Rico, leveraging 170 years of experience across a broad spectrum of energy generation, distribution and energy storage solution breakthroughs.

By analyzing often-competing objectives such as cost, reliability and resiliency, we begin our analysis with a "base case" conceptual plan focused on cost and reliability, representing a traditional centralized energy system – similar to what Puerto Rico had before Irma and Maria, with conventional power generation sited in the south and north of the island. Next, we identify the additional requirements needed for a resilient "enhanced case" system – clearly necessitated by the recent storms and their catastrophic impacts – and determine how supply would have to be modified and redesigned or moved to add greater resiliency.

To achieve the vision of a more renewable, resilient and reliable Puerto Rico electric system, our recommended plan incorporates a series of mini-grids, a different design for energy management that systematically improves resiliency by separating the existing grid into pockets of critical loads served by distributed resources that can operate in both grid-connected and island modes. Mini-grids are distinguished from microgrids in that they utilize existing distribution infrastructure, and can be sized much larger than typical microgrids, for example, encompassing the San Juan region. The proposed 10 mini-grids will cover most of the island and can each withstand or recover very quickly from a catastrophic weather event.

Possible Mini-grid Coverage



The base case strategy achieves 20% Renewable Portfolio Standards (RPS) including large and small combined cycle gas turbines (CCGT), solar photovoltaic (PV) and battery-based energy storage. By comparison, the resilient enhanced case strategy enables the grid to reach 35% renewable penetration for a lower-emission mix of generation resources with more energy storage, distributed solar and small CCGT units, strategically located to form each mini-grid as detailed in the report.

The resilient enhanced case strategy provides critical energy resiliency against future high impact events to the grid through reduced dependence on centralized thermal resources, use of distributed renewable generation and ability to store energy shifting daytime production to the night peaks. The enhanced case results in a slightly higher levelized cost of energy (LCOE) – 7% higher over the base strategy – which is a modest increase when considering the devastating impacts to the economy if just one of the events that the system is designed to absorb were to happen again. After these recovery costs are considered, the resilient enhanced case strategy is expected to be the least cost option.

The table below shows the main parameters and results of the base case and enhanced case as well as a typical mini-grid.

		New Units (Renewable includes existing)							
	Peak Demand (MW)	Large CCGT (MW)	Small CCGT (MW)	Solar PV (MW)	Wind (MW)	Storage (MW / MWh)	LCOE $/MWh	Reserve Margin	Penetration (%)
Base Case – Reliable & Economic	2,800	1,265	717	1,668	121	243 / 1458	89.51	31%	20%
Proposed Resilient Enhanced Case	2,800	1,265	931	3,048	121	319 / 1914	95.74	39%	35%
Typical Mini-Grid (in islanded operation mode, only during catastrophic events)	312	0	183	512	0	99 / 594	152.49	n/a	50%

This report is organized as follows:

Section 1: Introduction that provides background and objectives

Section 2: Approach that describes the methodology followed

Section 3: Provides a summary of the Capital and Operating Cost Assumptions

Section 4: Presents the main results for the Base Case; Economic and Reliable

Section 5: Provides the results for each of the selected mini-grids

Section 6: Presents our view for the Cost-Effective, Reliable, & Resilient system

Section 7: Incorporates an analysis should the Aguirre Offshore Gas Port not be built and there are no other new liquefied natural gas (LNG) terminals on the island

Section 1
Introduction

The catastrophic impact of hurricanes Irma and Maria highlighted the vulnerability of Puerto Rico's aging electric power systems. In light of current events, Siemens has conceptualized how a future IRP could strike an acceptable balance among multiple objectives including cost, reliability, and resiliency, as well as diversified, distributed, and renewable power generation.

The fundamental changes since the 2015 IRP include:

- Dramatic reductions in the capital costs of renewable generation – including solar PV and wind – combined with increased efficiency and associated capacity factors, result in competitive LCOE and power purchase agreement (PPA) price expectations (the 2015 IRP considered prices in the order of $180/MWh vs possible costs of $80 to $100/MWh).
- Significant reduction in cost of battery-based energy storage, both in terms of battery and balance-of-plant costs.
- Significant reduction in PREPA's served load that is expected to continue due to energy efficiency measures.
- Clear need to provide further resiliency beyond the original IRP's scope that relied on currently existing generation in the north that once supplemented by the new Palo Seco generation, would serve the load in the north following a north-south system separation; while the south would be supplied by the main generation in the island. The system fragmentation observed after hurricane Maria demonstrated that this was insufficient.

This report details how the integrated power system could look after the full implementation of the proposed plan, when outdated equipment not compliant with the federal Mercury and Air Toxics Standards has been retired and replaced by renewable generation supported by storage – new flexible base load combined cycle units (CCGT) and smaller CCGTs, and other peaking units (such as storage and reciprocating engines).

Assumptions in our approach include:

- Two of the lowest cost generation resources are assumed to continue operation, including the AES coal-fired plant and the EcoEléctrica combined cycle plant.
- With respect to the AES coal-fired plant, there are important concerns on its long-term viability as a base load unit. However, maintaining it in the plan is conservative, and the cost differential with respect to a more resilient system based on renewable generation will only be less if these units significantly reduce their dispatch.
- The San Juan combined-cycle power plant (CCPP) is assumed to continue in operation – possibly with investments to increase its reliability and flexibility – as well as the Mayagüez aero-derivative generation. Other generation is assumed retired.
- The Aguirre Offshore Gas Port (AOGP) is built into the base case, however consideration needs to be given should it be cancelled without a replacement LNG terminal.
- PREPA will be able to renegotiate or cancel existing Power Purchase Agreements (PPA) for new solar PV generation and benefit from the reduced prices.

Section 2

Approach

In the development of this vision for PREPA's future system we seek to balance two competing objectives: make the system more reliable and efficient, and make it resilient to future disruptive events.

System reliability is based on performance during high-probability, low-impact events – e.g. a generator or line tripping during peak load and when other facilities are in maintenance. The system has to be secure with no overloads or load shedding allowed, and it has to be low cost as this is the way it operates most of the time.

On the other hand, resiliency is based on infrequent, low-probability events with very large impacts – e.g. a major hurricane. In this case a resilient system is able to anticipate, mitigate, absorb and recover in a timely way from disruptive events. Cost is no longer as critical a factor; instead, maintaining access to electricity and quality of life for residents and businesses becomes the most important consideration. Load shedding is expected, but it should be managed through periodic rotating interruptions.

Our objective is to identify a system that balances economic and reliability requirements with resiliency expectations. We begin by assessing how the supply would look if only cost and reliability were the guiding requirements, which constitutes our baseline. Next we identify what additional requirements should be included for a resilient system, and based on this analysis, determine how an "economic and reliable system" would have to be modified to align with the resiliency needs.

Resilient System Approach

Our approach to resiliency is first to identify electrical islands or mini-grids in which the system could naturally be split during a major event. These islands or mini-grids must be:

a) Geographically compact;

b) Require limited 115 kV and 38 kV facilities for its integration, which could be hardened to withstand major storms, and;

c) Must have internal generation to substantially supply the load for extended periods of time.

With respect to this last requirement, we accepted up to 5% energy curtailment that would be managed by rotating blackouts or absorbed by the natural reduction on load that should happen due to the major event itself. Figure 2-1 below represents a preliminary attempt to define the mini-grids, and it is meant to convey enough information to illustrate our vision for the new IRP with the understanding that the delineation of actual borders is beyond the scope of this effort.

Each mini-grid has a core and periphery. The core is expected to reflect the critical loads that should not lose supply or be able to be reconnected within a relatively short period of time (e.g. one week) in the event that they do. The periphery includes other important loads, but due to their geographical location it may take longer – perhaps a few weeks – to reconnect them to the mini-grid.

Figure 2-1: Possible coverage of mini-grids

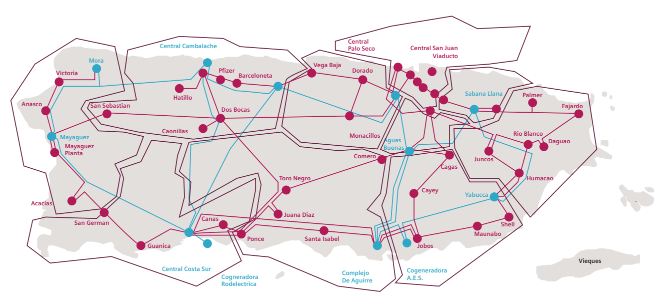


Table 2-1 on the next page represents how the system would look once each mini-grid is consolidated and the main 115 kV connections internal to the mini-grid have been reestablished. In summary, the served load in each of the mini-grids might initially be less than noted in Table 2-1, at least shortly after a major event.

Table 2-1 shows the expected "normal" peak load to be supplied at each of the mini-grids as well as the existing generation that was assumed to remain available. Our analysis concludes that the typical mini-grid serves about 280 MW. The considered total load of PREPA's system was assumed to be about 2800 MW and includes effects of energy efficiency improvements. This was modeled after a typical 8760 hour profile for a system like PREPA's with a 74% load factor, and accounts for effects of energy efficiency (as mentioned earlier) and demand response, particularly on industrial loads.

Table 2-1: Mini-grids Considered

No.	Mini-grid	Total Load MW	Thermal Generation Kept MW	Plants / note
1	BARCELONETA	212	0	Cambalache assumed retired / replaced
2	MAYAGÜEZ	224	220	Aero-Mayagüez
3	COSTA SUR	246	506.9	EcoEléctrica
4	JAYUYA	218	526.9	Aguirre CC repowered
5	YABUCOA	286	454	AES Coal
6	HUMACAO	266	0	Older 21 MW GTs not considered
7	VEGA BAJA	288	0	Small landfill gas may be present
8	SAN JUAN	513	359	San Juan Combined Cycle
9	AGUAS BUENAS	312	0	
10	SABANA LLANA	279	0	
	TOTAL	**2844**		

Table 2-2 below provides an overview of the 115 kV and 230 kV substations contained in each mini-grid.

Table 2-2: 115kV and 230 kV Stations of the Mini-grids

No.	Mini-grid Name	Substations at 230 kV	Main Substations at 115 kV
1	BARCELONETA	Manatí, Barceloneta	San Sebastián, Hatillo, Caonillas, Dos Bocas, Radar, Ciales, Barceloneta, Pfizer
2	MAYAGÜEZ	Mayagüez, Mora	Mayagüez, Anasco, Victoria, Acacias
3	COSTA SUR	Costa Sur, EcoEléctrica	Costa Sur, San German, Guánica, Canas
4	JAYUYA	Aguirre	Jayuya, Aguirre, Santa Isabel, Ponce, Juana Diaz, Toro Negro
5	YABUCOA	Yabucoa, Guayama	Yabucoa, Shell, Maunabo, Jobos, Cayey, Caguas
6	HUMACAO		Humacao, Juncos, Daguao, Rio Blanco, Fajardo, Palmer
7	VEGA BAJA	Bayamón	Vega Baja, Dorado, Bayamón, Cana, Bo. Pinas, Monterey, Corozal, Morovis
8	SAN JUAN		Central Palo Seco, Central San Juan, Viaducto, Isla Grande, Hato Rey, Martin Peña, Cachete, Monacillos
9	AGUAS BUENAS	Aguas Buenas	Aguas Buenas, Buen Pastor, Villa Betina
10	SABANA LLANA	Sabana Llana	Sabana Llana, Berwind, Canóvanas

Each mini-grid is envisioned to have its own independent Mini-grid Energy Management System (MGEMS) for safe and economic operation (e.g., fuel consumption conservation) to ensure it can continue operating independently for extended periods of time (e.g., the months it could take until the mini-grid can be integrated back to the main system). Additionally, the mini-grid will facilitate the reconfiguration of the system by providing known amounts of load and a sound system that the main grid can interconnect to during black-start efforts.

It is important to highlight that our vision is complementary to other actions that are expected to be carried out at the customer level – for example, where micro-grids would provide service to smaller critical loads (few MWs) until the mini-grids reach them or are connected to the main grid.

Details on the supply to each mini-grid are provided in Section 5.

Economic & Reliable System Approach

To estimate the minimum investments required for a reliable and economic system we used a Planning Reserve Margin based on unforced capacity of at least 30%, and a spinning reserve equal to or greater than the size of the largest unit online. With respect to new base load capacity expansions, we added a new F-Class CCGT at Costa Sur fueled by natural gas, and in Aguirre we considered the repowering of the existing combined cycle and, provided that the AOGP is developed, one F-Class CCGT. In the case that the AOGP is not developed, nor any other new LNG terminal, then the new F-Class CCGT that would otherwise be installed at Aguirre is assumed to instead be installed at Costa Sur where there should be transmission capacity available due to the retirement of Costa Sur 5 & 6.

The balance of the conventional generation to supply the load is assumed to be small units CCGT or reciprocating engines that would be distributed around the island.

The penetration of renewable resources was set at a minimum of 20% as per the long-term RPS, which we assumed would be increased as required to minimize the total (all-in) costs or to satisfy the needs for resiliency as discussed above.

Storage was sized to minimize the all-in costs (including capital) by reducing curtailment and displacing peaking generation (both in terms of needed installed capacity and dispatch). See Section 4 for additional details on the procedure to determine a possible Economic & Reliable system.

Section 3

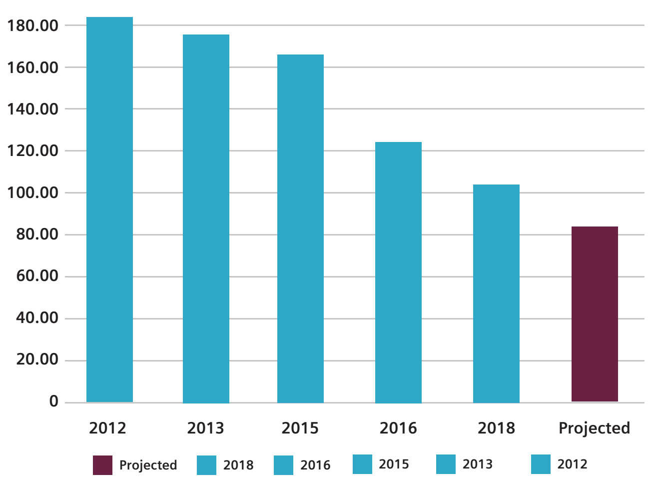
Capital and Operating Costs

Siemens reviewed the declining trend in installed cost of solar power due to reductions in PV module and inverter prices and higher module efficiency. To these costs we added the need to reinforce Puerto Rico PV projects to make them resilient to Category 4 hurricane events, changes in federal income tax rates and solar bonus depreciation provisions.

Our findings indicate that installed PV cost in Puerto Rico should be under $102 / MWh when taking 2018 prices into consideration. However, for the redesign proposed in this analysis, we went further and estimated an average PV price of $81.8 / MWh (80% of cost) as likely for the period of implementation of the new IRP.

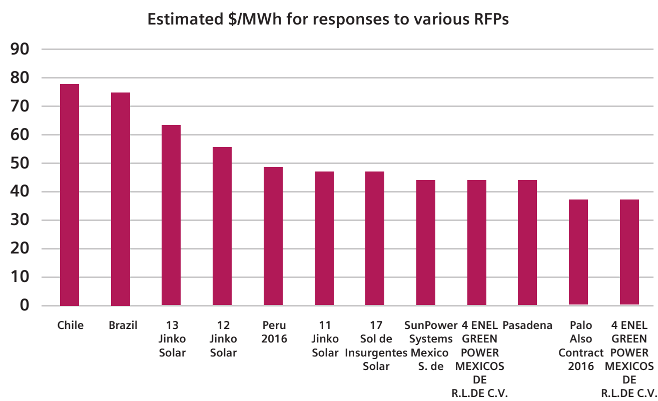
The figure below shows the evolution of our estimated prices for a 50-MW PV array installed in Puerto Rico, including the interconnection costs, over time and our projection for this document. As noted in the chart, the trend supports our assumptions on price.

Figure 3-1: Total Cost (LCOE) for a 50 MW PV array in Puerto Rico estimated evolution over time



A cost of about $80 / MWh is also consistent taking into consideration other recent bids, once differences in reinforcements for hurricane winds and capacity factor are accounted for. Moreover it should be noted that PV prices are highly dynamic, and prices lower than those in the chart below have been observed.

Figure 3-2: Total Cost (LCOE) various RFPs



Storage

We selected 6-hour battery energy storage systems (BESS) as the storage technology to be considered in this study. The reason for this selection is that the main functions of these devices would be to shift energy produced during daytime by the solar PV for consumption during the evening peak, and reduce the need for peaking thermal generation during that period, particularly when operating in mini-grid isolated mode. However, 4-hour storage was considered and could be deemed optimal after additional study.

We estimated an average cost of $1,200/kW for the implementation of the plan, based on the fact this technology is experiencing continued price reductions as well as testing new configurations – like sharing inverters between solar PV and BESS – both of which can lead to potential cost savings.

Table 3-1: Cost of Storage

Duration and Installed Cost	2018	2020	2025	2030
Long (6 hrs)				
per kW	$2,270	$1,800	$1,200	$1,000
per kWh	$380	$300	$200	$165
Medium long (4 hrs)				
per kW	$1,600	$1,280	$840	$700
per kWh	$400	$320	$210	$175
Medium short (2 hrs)				
per kW	$1,080	$875	$600	$500
per kWh	$540	$435	$300	$250
Short (half hour)				
per kW	**$630**	**$510**	$350	$290
per kWh	**$1,260**	**$1,020**	$700	$580

Source: NYSERDA issued in March 2018.

Conventional Generation

The table below shows the main parameters of the baseload thermal generation considered in our assessment. The parameters correspond to the expected performance considering the technology in place, but may be different from actual values. As previously indicated, AES' two units were estimated to be kept in service to provide a conservative view of the plan.

Table 3-2: Exiting Generation Considered

	Max MW	Min MW	Heat Rate MMBTU/ MWh	Var O&M $/MWh	Fixed O&M $/KW-yr	Availability	Note
AES 1	227	166	9.8	6.90	76	90%	Cannot cycle on-off for renewable
AES 2	227	166	9.8	6.90	76	90%	Cannot cycle on-off for renewable
EcoEléctrica	507	275	7.7	2.80	17	92%	Can cycle weekly on-off on weekends

In addition to the units above, we considered the Combined Cycle 2x180 MW at San Juan and the aero-derivative combustion turbines at Mayaguez 2x55 MW available. However, because these units burn diesel, they are expected to largely provide reserve capacity.

New baseload units considered

The table below shows the main operating parameters for the new baseload units considered. These are highly efficient and flexible units, and in the case of the Aguirre CC Repowering, has one of the lowest capital costs.

Table 3-3: Baseload Units

	No.	Max MW	Min MW	Heat Rate MBTU/MWh	Variable O&M ($/MWh)	Fixed O&M ($/kW-year)	CapEx ($/kW)
Aguirre F-Class	1	369	115	7.31	4.77	16.65	1051
Aguirre CC Re-powered	2	263	105	7.58	4.77	16.57	739
CS F-Class	1	369	115	7.31	4.77	16.65	1051
Total Baseload		1,265					

New smaller thermal units considered

The table below shows the main operating parameters for the new small thermal units that will complement the fleet. They are assumed to burn diesel (ULSD) because of their remote locations away from potential natural gas supplies. These units will be located near load centers and are a critical element of the mini-grids' power supply. Also, like the units above, these units are highly efficient and flexible, though their fuel costs are much higher than gas-fired F-Class CCGTs.

These units were chosen to provide reasonable heat rates (fuel efficiency) in a range of block sizes (15 and 42 MW) to fit the smaller mini-grids' load profiles. They can load-follow down to 50% of rated load, and the small unit size minimizes the spinning reserve required to account for loss of a single unit. This is important for stable mini-grid operation when disconnected from the main grid.

Unit ratings are conservative assuming annual average turbine inlet conditions of 78F, 73% relative humidity and sea level. Performance was calculated in Thermoflow GT Pro software with our cost estimates. We included average degradation over unit life in net output (2.5%) and net heat rate (1.5%.) We assumed HHV/LHV ratio of 1.06 for diesel/ULSD.

Table 3-4: Peaking Units

	No.	Max MW	Min MW	Heat Rate	Variable O&M	Fixed O&M	CapEx ($/kW)
SGT-750	4	42	21	7.64	3.00	23.03	$1,375.21
SGT-400, 14.4	5	15	0	8.29	3.00	23.03	$2,075.57

Section 4

Base Case: Economic and Reliable

To provide a reference case, we considered a number of factors including estimating what the supply for the Puerto Rico Electric System would look like after the retirement of inefficient generation, incorporation of new flexible generation, and the impact of the reduction in cost of photovoltaic generation and storage.

The results presented below are only indicative, based on key simplifying assumptions for selection of new units and simulation of dispatch, as well as an approximate representation of the Puerto Rico load and generating plants. Specifically, in addition to the units at AES and EcoEléctrica that are assumed to remain in service, the units at Mayagüez and the San Juan Combined Cycle will be largely off-line providing reserves. AES Coal was kept in service to provide a conservative view and its retirement will only increase the benefits of renewable generation, reducing the cost differential with respect to a plan that provides resiliency to the system.

The plan was developed with these assumptions:

- There will be three new large CCGT, as noted earlier, that will replace thermal units Costa Sur 5 & 6 and Aguirre 1 & 2, and which will burn natural gas at a high level estimated cost of $8.0 per MMBtu, assuming AOGP achieves commercial operation.
- Renewable generation penetration increases and storage will be used to find "least cost" of supply, starting from a minimum of 20% penetration.
- Distributed generation (behind the meter) is included in the renewable generation above. Future studies may segregate this from utility-scale generation, but for the objectives of this view, this is considered adequate.
- To supply the balance of load after the assets above are dispatched and maintain operating reserves of at least 30% or above, new smaller flexible generation (SGT-750 and SGT-400) are added to the system. These units will be assigned to the mini-grids and are expected to run on ultra-low sulfur diesel (ULSD) at an estimated cost of $19 per MMBtu.

We used a simplified model to simulate the dispatch of generation units, the estimation of fuel costs (including natural gas, coal and ULSD), performance of storage, renewable curtailment, and need for smaller flexible generation. This model considers an 8760 hourly typical load profile, and first dispatches the renewable generation using representative solar and wind profiles for Puerto Rico, setting the AES and EcoEléctrica units at their minimum run level. If the net result is negative (more generation than load), it goes to storage or the excess is curtailed if storage reaches its limits. In case that it is positive (i.e. there is still load to be supplied), it is first supplied by AES and EcoEléctrica going from the minimum to the maximum, followed by the new base loaded units being brought online at the minimum and in a coordinated manner to increase production to optimize the use of storage (e.g, preferably used at the night peak). Finally, if after the dispatch of storage there is still load to be supplied, the new smaller CCGT are then brought online. This model has many limitations, as maintenance requirements are only considered indirectly in the operating reserve requirements; in addition, the hourly generation dispatch could be optimized, but in our case we dispatched generation based on merit order.

For the economic assessment, the main parameter we considered when selecting the supply mix was the total cost in $/MWh (also called the Levelized Cost of Energy (LCOE)). This cost includes the fuel costs, fixed and variable O&M costs, and the carrying value of the required capital costs. This carrying value was calculated as an annuity considering an average asset life of 28 years and a real discount rate (after inflation) of 7% for the conventional generation. For storage and PV, we used a model that takes into account the ITC and degradation of battery performance. The multiplier for storage is 10.5%, and for PV we used the estimated cost per MWh presented earlier.

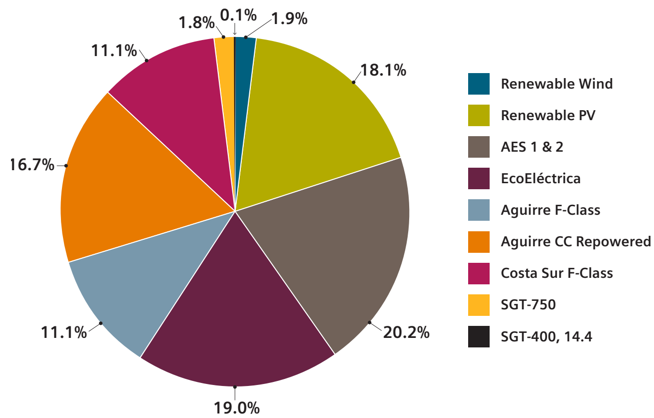
Using the model we identified that the least-cost scenario would occur at levels of renewables penetration of about 20% to 25%, with storage online as detailed below to provide energy shifting and the required operating reserves that would otherwise necessitate the installation of additional peaking generation.

The table below shows the main annual results for the plan with 20% penetration. Here we observe approximately 1,668 MW of PV generation were installed (includes the existing PV generation), there are 243 MW/1,458 MWh of new storage (BESS, and approximately 720 MW of new smaller CCGT were added to the case. The balance of the generation comes from either existing units (including wind generation) or the three new base load F-Class combined cycle plants. Table 4-1 below shows the energy supply by source, where we note that renewables contribute 1.9% of the energy from wind generation and 18.1% from PV for a total penetration of 20%.

Table 4-1: Results Summary for Integrated System; 20% Penetration

	MW	MWh	Total $	Total $/MWh	CF or Curtailment
Load	2800	18,149,851	1,624,505,596	89.51	74.0%
Renewable Wind	121	338,684.6	52,834,793	156	32.0%
Renewable PV	1,668	3,291,285.6	268,568,907	82	22.5%
AES 1 & 2	454	3,664,201.6	200,025,469	55	92.1%
EcoEléctrica	507	3,444,124.9	311,791,246	91	77.5%
Aguirre F-Class	369	2,020,354.8	168,763,126	84	62.5%
Aguirre CC Re-powered	527	3,026,995.4	241,669,427	80	65.6%
Costa Sur F-Class	369	2,018,516.1	168,609,535	84	62.4%
SGT-750	379	332,267.1	104,238,753	314	10.0%
SGT-400, 14.4	338	22,449.6	73,012,341	3,252	0.8%
Curtail-ment	823	8,275			0.2%
Storage	243 MW/1,458 MWh	6,783	25,689,600	351	5%

Figure 4-1: Energy Supply by Source



With respect to supply costs, we note in Table 4-1 the total cost for PV ($82 / MWh) is competitive with the cost of the new base load units considered (the F-Class). However, for increasing levels of PV penetration, deploying storage is necessary to achieve the full potential of this resource, minimizing curtailment (0.2% in this case) and reducing the need to dispatch new generation for the evening peak. Storage was incorporated into the scenario with deployments sized to both minimize the total cost and result in adequate operating reserves.

A total cost of supply of $89.5 / MWh and required capital investments of approximately $5.2 billion are estimated for the implementation of this plan, not including transmission investments. The table below provides the topline results; we note that the largest cost component is new PV generation.

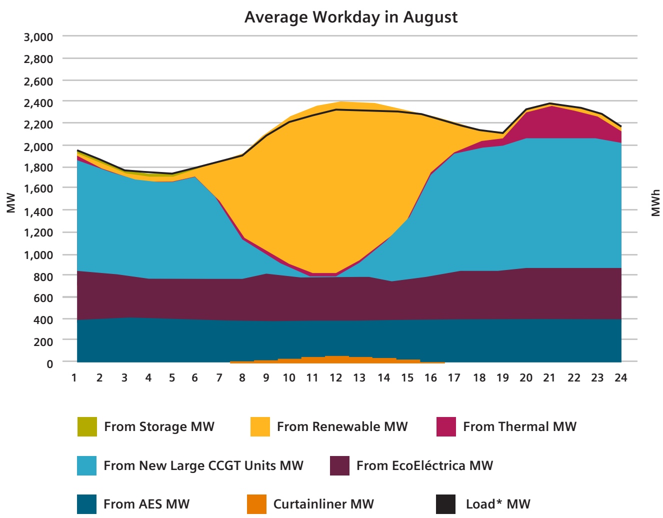
Table 4-2: Base Plan Main Results

Economic Results	
Penetration %	20%
Variable Gen Costs $/MWh	49.4
Total Cost $/MWh	89.51
Capital Cost $000	5,170,019

Capital Cost Detail	MW	$/kW	$000
Capital Cost Storage	243 MW/1,458 MWh	$1,200	291,600
Capital Cost PV	1,668	$1,493	2,490,048
Capital Cost New Base CCGT	1,265	$921	1,165,262
Capital Cost New Small CCGT	717	$1,705	1,223,108
Total			**5,170,019**

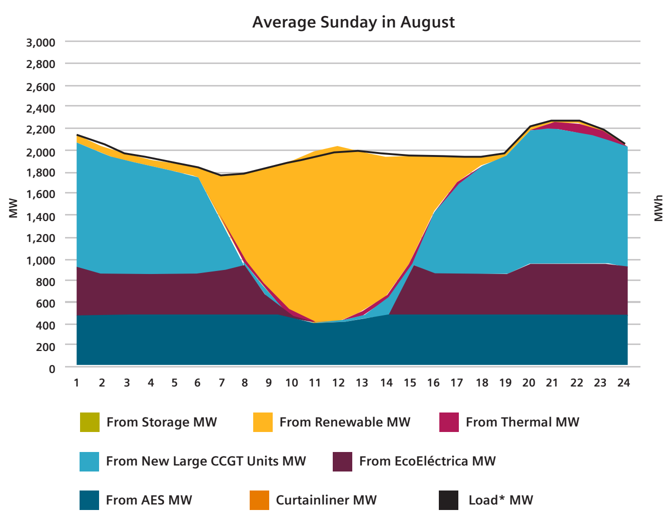
With respect of the efficiency of the dispatch, the figure below shows the average dispatch for workdays in August. Note that during daytime hours, dispatch of the flexible large new CCGT (F-Class) is brought down to zero. Given the relatively low levels of penetration and the fact that the new CCGT (if online), cannot operate below 50%, EcoEléctrica generation is increased as the CCGT's are turned off. Equally notable in this case is that storage provides little contribution to energy dispatch and is largely providing reserve capacity, and solar PV curtailment is negligible.

Figure 4-2: Average hourly dispatch for Workdays in August



Similarly, on a Sunday of the same month we observe that when EcoEléctrica is taken offline, there is negligible curtailment on average, and there is also very limited dispatch of thermal units. During noontime, the variability of the solar resource is managed by the large CCGT in combination with the smaller CCGT and EcoEléctrica is turned off during peak renewable production hours.

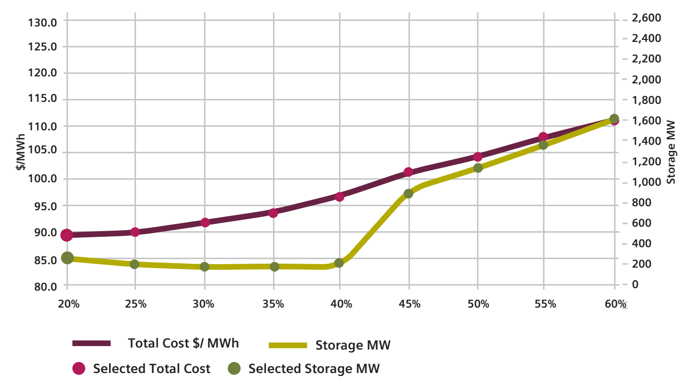
Figure 4-3: Average Hourly Dispatch for Sundays in August



When considering figures 4-2 and 4-3, it is important to understand the data above represent hourly averages that may include values equal to zero for significant periods of time. This is reasonable as the objective is to illustrate the dispatch used in the evaluation is reasonable and adequate for this level of analysis.

Finally, as noted in the figure below, increases in the level of PV penetration would result in increased total supply costs, subject to the assumptions made in this report. A level of PV penetration of about 20% to 25% would be adequate if the scenario focuses on only reliability and minimum costs but not resiliency.

Figure 4-4: Effect of Penetration on Costs



Section 5

Resilient Design: The Mini-grids

As presented earlier, our approach to resiliency is rooted in the capability of the system to be segregated into various self-sufficient mini-grids for long periods of time.

The mini-grids are envisioned to be supplied by a combination of renewable generation (PV arrays and existing wind turbine generation), storage, and the new small CCGTs described above that would be located closer to the load. The exception to this approach are those mini-grids that will be formed around the existing plants assumed to remain in service, or the new larger combined cycle plants at Aguirre and Costa Sur.

We selected the supply mix for the mini-grids seeking to minimize the Total Cost of Supply that included both the cost of fuel and the carrying cost of capital. The variables used for the minimization were a) the level of renewable penetration, i.e., the percentage of the energy supplied from these sources, and b) storage both in size and time of deployment (to minimize the need for conventional generation). Given these two variables, the amount of thermal generation required to supply the load was determined and the overall supply cost minimized. As mentioned earlier, we allowed up to about 5% rotating load shedding with respect to the original forecasted load however, it is possible that the natural attrition of the load during the event leading to the separation would make this unnecessary. We developed an optimization tool that identified the minimum by sequentially scanning solutions.

Again, this is only our approximation as detailed analysis would have to include iterating with the optimal supply mix as determined for the integrated operation of the island and minimizations of deviations between the system required for resiliency and one that provides reliability at least cost. Also, the new and the existing large generation may have load regulation challenges when operating in mini-grid mode, which also warrants consideration. However, for the formulation of this vision this analysis is considered adequate.

Table 5-1 shows a summary of the identified additional generation requirements (PV and new thermal) by each mini-grid. As can be observed, mini-grids 3 to 5 may not need any additional generation, but this may require verification on the capability of the thermal units that supply them and, if necessary, modifications to add load-following flexibility and frequency regulation.

Table 5-1: Generation Requirements for the Mini-grids

				Additional Generation Requirements for Mini-grids				
No.	**Mini-grid Name**	**Total Load MW**	**Thermal Generation Kept MW**	**New SGT 750**	**New SGT 400**	**PV**	**Storage**	**Note**
1	BARCELONETA	212	0	126	14.7	313	30.0	
2	MAYAGUEZ	224	220			294	4.9	Thermal provided by Mayaguez
3	COSTA SUR	246	506.9					EcoEléctrica & New CCGT at Costa Sur makes up the supply
4	JAYUYA	218	526.9					Aguirre Repower, New CCGT and Pattern Wind makes up the supply
5	YABUCOA	286	454					AES Coal makes up the supply (this many need to be revisited)
6	HUMACAO	266	0	168	14.7	317	15.6	
7	VEGA BAJA	288	0	168	14.7	474	90.9	
8	SAN JUAN	513	359	42	14.7	674	22.3	San Juan CC makes the bulk of new thermal
9	AGUAS BUENAS	312		168	14.7	512	98.6	
10	SABANA LLANA	279		168	14.7	459	49.0	
TOTAL		**2844**		**842**	**88.2**	**3043**	**311.3**	

To illustrate the optimization process followed we present below the results for the BARCELONETA, MAYAGÜEZ, HUMACAO, VEGA BAJA, SAN JUAN, AGUAS BUENAS and SABANA LLANA mini-grids followed by the results of the balance of the mini-grids.

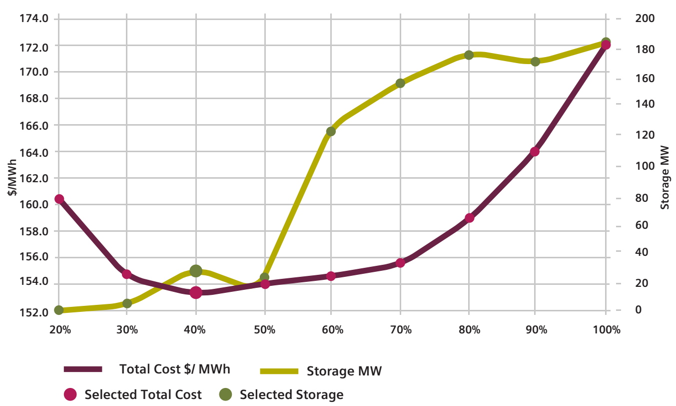
BARCELONETA Mini-grid
The optimal level of penetration that minimized the total costs of supply for the BARCELONETA mini-grid was found to be 40%, which is equivalent to 279 MW of PV with 28 MW/168 MWh of storage. The table below provides the supply load and mix including the new small combined cycle units (the SGT 750 and SGT 400).

Table 5-2: BARCELONETA Mini-grid Supply Mix

Load / Supply Summary	MW	MWh	Load / Capacity Factor
Load	212	1,374,529	74%
Storage	28	33,099	14%
PV MW	279	549,812	23%
New Small CCGTs	136	795,736	67%

The figure below shows that for this mini-grid a penetration of 40% minimizes the total cost of supply and required about 28 MW of 6-hour storage.

Figure 5-1: BARCELONETA Mini-grid Penetration and Storage Selection



As shown in Table 5-3, the total cost of supply is about $154/MWh with approximately $653 million in investments, PV being the largest component followed by the thermal generation.

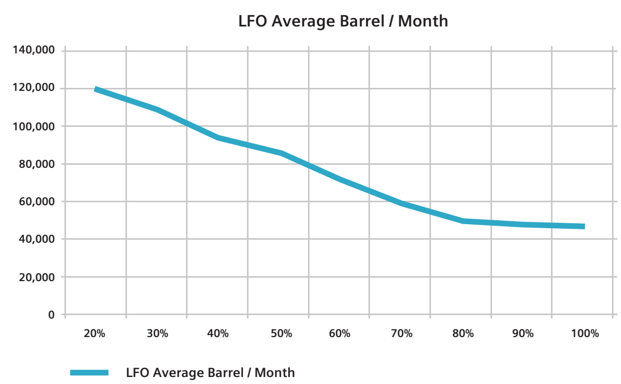
Table 5-3: BARCELONETA Mini-grid Main Results

Economic Results	
Penetration %	40%
Variable Gen Costs $/MWh	94.2
Total Cost $/MWh	153.60
ULSD Avg Barrel /month	94,522
Capital Cost $000	653,358

Capital Cost detail	MW	$/kW	$000
Capital Cost Storage	28	$1,200	33,120.00
Capital Cost PV	279	$1,493	415,964
Capital Cost SGT 750	126	$1,375	173,759
Capital Cost SGT 400	15	$2,076	30,514.40
Total			**653,357.80**

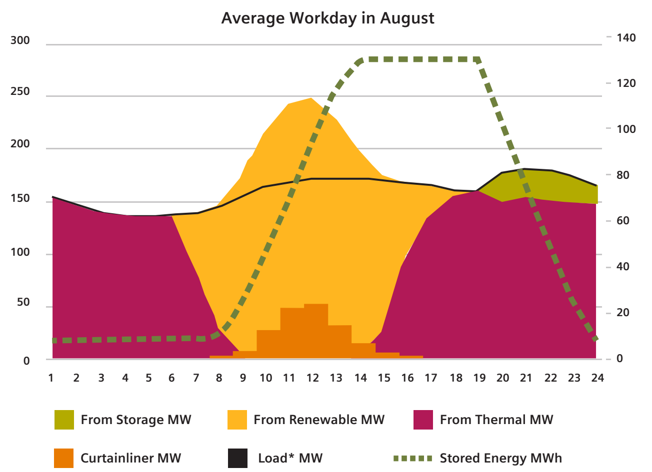
The high level of penetration and hence the investments in PV is understandable considering that the alternative is burning liquid fuels (ULSD) that would also need to be stored locally. The figure below shows the expected monthly consumption.

Figure 5-2: BARCELONETA Mini-grid Fuel Consumption as Function of Penetration



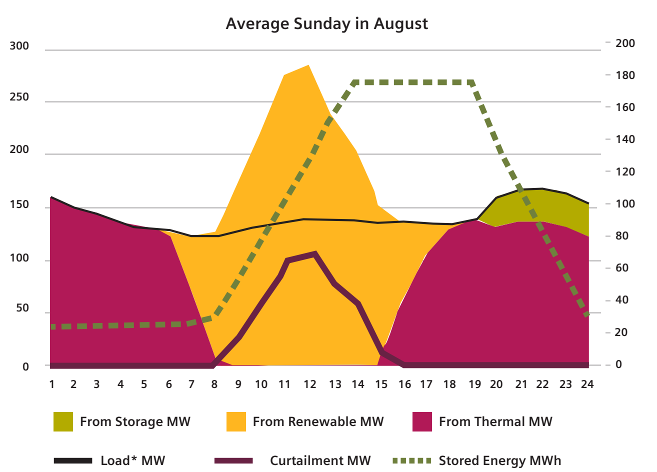
With respect to the dispatch, the model is producing reasonable results. The figure below shows a dispatch for the average workday in August. In this figure we note that storage and PV are being used to minimize the production of thermal units, including the supply of the peak, where storage makes the main contribution.

Figure 5-3: BARCELONETA Mini-grid Workday in August Supply



Similarly, Figure 5-4 shows the supply for an average Sunday in August where we note the same behavior as before. In this case, however, due to the reduced load, the curtailment is somewhat higher as the storage reaches its limits on capacity initially (MW) and then on energy storage (MWh).

Figure 5-4: BARCELONETA Mini-grid Sunday in August Supply



MAYAGÜEZ mini-grid

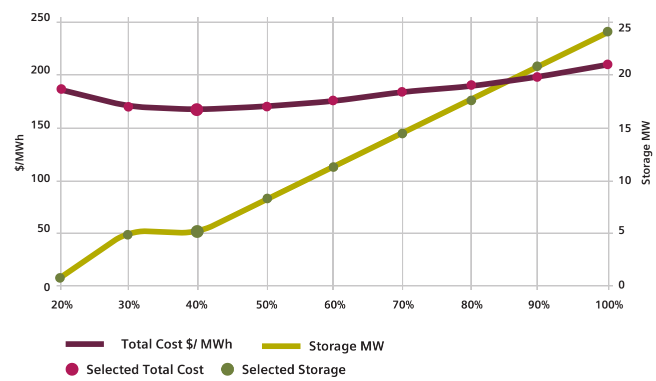
The total costs of supply for the MAYAGÜEZ are minimized using a level of penetration of 40%, which is equivalent to 294 MW of PV with 5 MW of storage. The table below provides the supply load. No additional combined cycle units are needed in the mini-grid due to the presence of the Mayagüez aero-derivative units.

Table 5-4: MAYAGÜEZ Mini-grid Supply Mix

Load / Supply Summary	MW	MWh	Load / Capacity Factor
Load	224	1,451,895	74%
Storage	5	11	0%
PV MW	294	580,758	23%
New Small CCGTs	–	–	–

The figure below shows that for this mini-grid a penetration of 40% minimizes the total cost of supply with negligible (5 MW) amounts of storage.

Figure 5-5: MAYAGÜEZ Mini-grid Penetration and Storage Selection



As shown in Table 5-5 (next page), the total cost of supply is about $170/MWh with approximately $476 million in investments, PV being the largest component followed by the thermal generation. The needed storage for the economic operation of this mini-grid appears to be negligible.

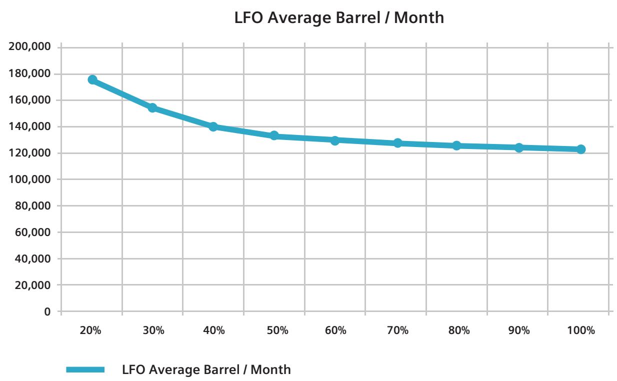
Table 5-5: MAYAGÜEZ Mini-grid Main Results

Economic Results	
Penetration %	40%
Variable Gen Costs $/MWh	134.9
Total Cost $/MWh	169.44
ULSD Avg Barrel /month	142,067
Capital Cost $000	475,772

Capital Cost detail	MW	$/kW	$000
Capital Cost Storage	5	$1,200	5,880.00
Capital Cost PV	294	$1,493	439,377
Capital Cost SGT 750		$1,375	
Capital Cost SGT 400	15	$2,076	30,514.40
Total			**475,771.51**

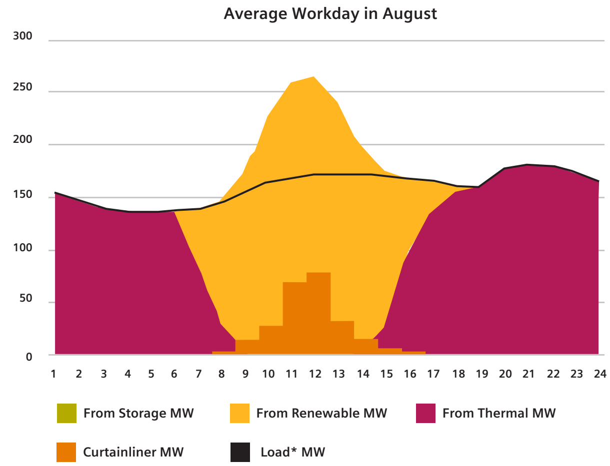
The high level of penetration and hence the investments in PV is understandable considering the alternative is burning liquid fuels (ULSD) at the Mayagüez aero-derivatives, fuels that would also need to be stored locally. The figure below shows the expected monthly consumption.

Figure 5-6: MAYAGÜEZ Mini-grid Fuel Consumption as Function of Penetration



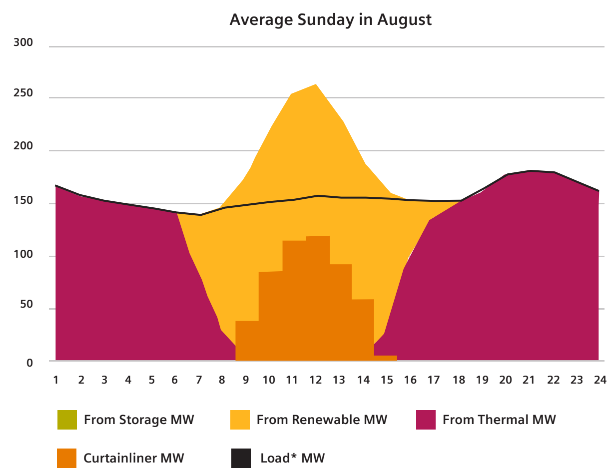
With respect of the dispatch, the model is again producing reasonable results. A dispatch for the average workday in August is presented in the following figure. We note that while there is curtailment on this initial analysis, the cost did not justify the installation of storage. Further detailed analysis may modify this view.

Figure 5-7: MAYAGUEZ Mini-grid Workday in August Supply



For an average Sunday in August, note the same behavior as before with the curtailment being somewhat higher due to the reduced load.

Figure 5-8: MAYAGÜEZ Mini-grid Sunday in August Supply



HUMACAO Mini-grid

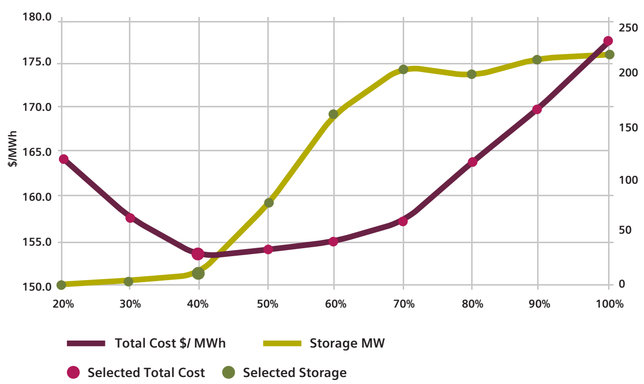
The optimal level of penetration that minimized the total costs of supply for the HUMACAO mini-grid was found to be 40%, which is equivalent to 317 MW and of PV with 16 MW/96 MWh of storage. The following table provides the supply load and mix including the selected new small combined cycle units (the SGT 750 and SGT 400).

Table 5-7: HUMACAO Mini-grid Supply Mix

Load / Supply Summary	MW	MWh	Load / Capacity Factor
Load	266	1,725,508	74%
Storage	16	18,921	14%
PV MW	317	626,002	23%
New Small CCGTs	163	968,039	68%

For the Humacao mini-grid a penetration of 40% minimizes the total cost of supply and includes about 16 MW of storage.

Figure 5-9: Penetration and Storage Selection



As shown in Table 5-6 the total cost of supply is about $154/MWh with approximately $755 million in investments, PV being the largest component followed by the thermal generation.

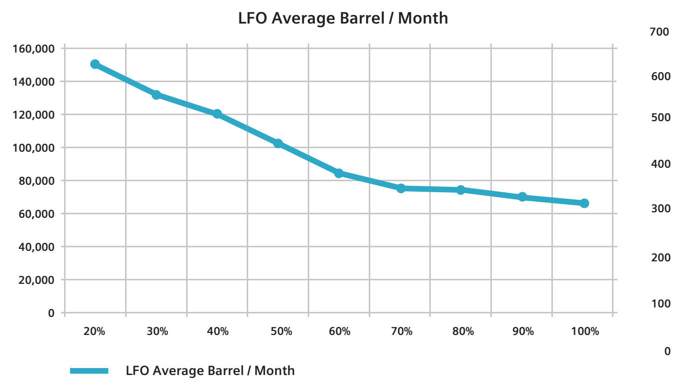
Table 5-8: HUMACAO Mini-grid Main Results

Economic Results	
Penetration %	40%
Variable Gen Costs $/MWh	94.3
Total Cost $/MWh	153.67
ULSD Avg Barrel /month	119,047
Capital Cost $000	754,520

Capital Cost detail	MW	$/kW	$000
Capital Cost Storage	16	$1,200	18,720.00
Capital Cost PV	317	$1,493	473,607
Capital Cost SGT 750	168	$1,375	231,679
Capital Cost SGT 400	15	$2,076	30,514.40
Total			**754,519.72**

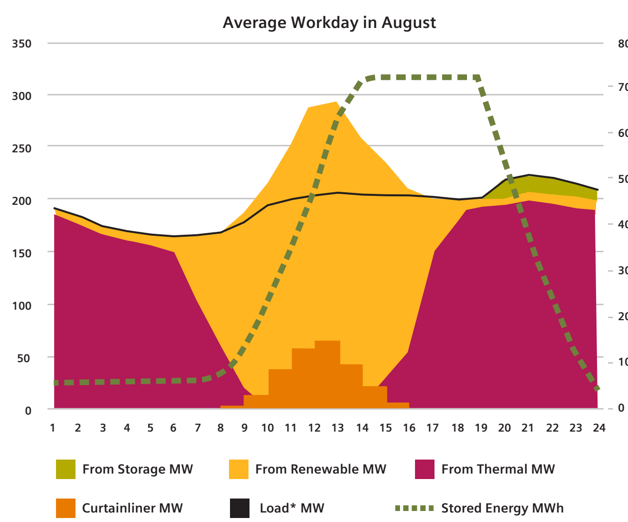
As before the high level of penetration of renewable generation is understandable considering that the alternative is burning expensive liquid fuels (ULSD) that would also need to be stored locally. The figure below shows the expected monthly consumption as function of the penetration.

Figure 5-10: HUMACAO Fuel Consumption as Function of Penetration



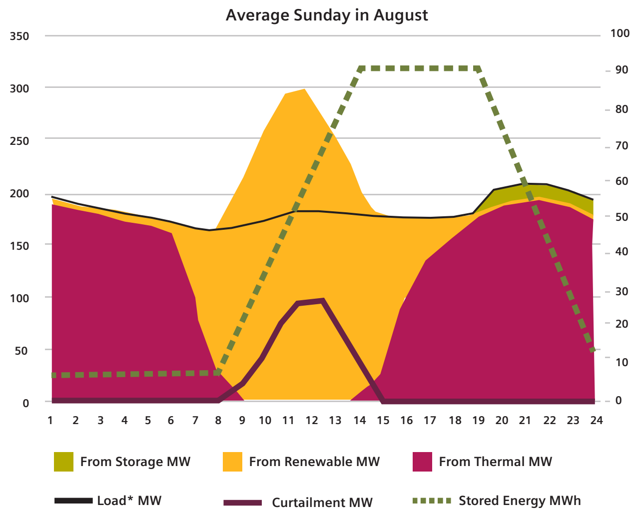
The figure below shows a dispatch for the average workday in August. In this figure we note, as before, the storage and the PV are being used to minimize the production of the thermal units, including the supply during the peak where storage makes its main contribution.

Figure 5-11: HUMACAO Mini-grid Workday in August Supply



The figure below shows an average Sunday in August where we again note, due to the reduced load, the curtailment is somewhat higher as the storage reached its limits on capacity initially (MW), and then on energy storage.

Figure 5-12: HUMACAO Mini-grid Sunday in August Supply



VEGA BAJA Mini-grid

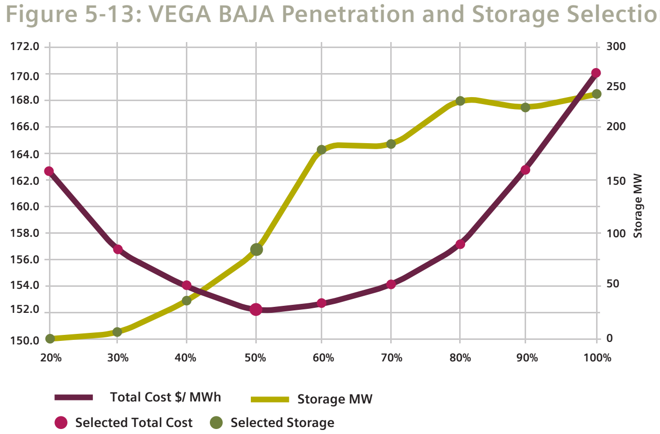
The optimal level of penetration that minimized the total costs of supply for the VEGA BAJA mini-grid was found to be 50% equivalent to 474 MW and of PV with 91 MW/546 MWh of storage. The table below provides the supply load and mix including the selected new small combined cycle units (the SGT 750 and SGT 400).

Table 5-7: VEGA BAJA Mini-grid Supply Mix

Load / Supply Summary	MW	MWh	Load / Capacity Factor
Load	288	1,868,809	74%
Storage	91	144,160	18%
PV MW	474	934,405	23%
New Small CCGTs	172	934,628	62%

The figure below shows that for this mini-grid a penetration of 50% minimizes the total cost of supply with about 91 MW of storage.

Figure 5-13: VEGA BAJA Penetration and Storage Selection



As shown in Table 5-8 the total cost of supply is about $152/MWh and there is approximately $1.1 billion in investments, PV being the largest component followed by the thermal generation.

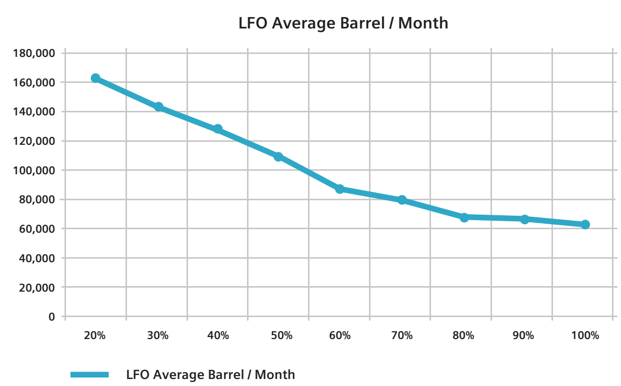
Table 5-8: VEGA BAJA Main Results

Economic Results	
Penetration %	50%
Variable Gen Costs $/MWh	82.6
Total Cost $/MWh	152.19
ULSD Avg Barrel /month	111,902
Capital Cost $000	1,078,204

Capital Cost detail	MW	$/kW	$000
Capital Cost Storage	91	$1,200	109,080.00
Capital Cost PV	474	$1,493	706,931
Capital Cost SGT 750	168	$1,375	231,679
Capital Cost SGT 400	15	$2,076	30,514.40
Total			**1,078,204.32**

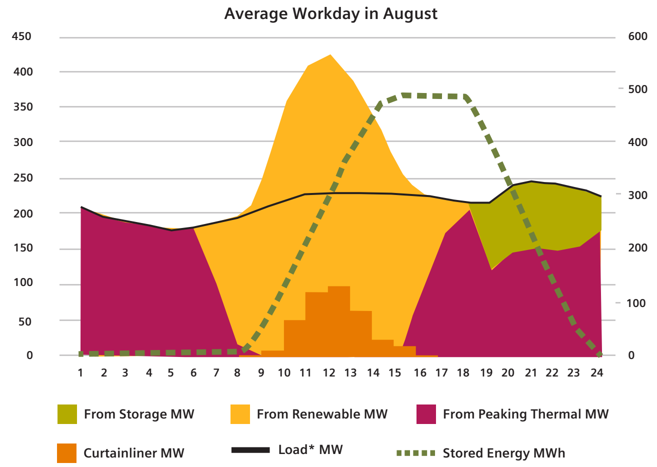
Again in this case the high level of penetration and hence the investments in PV can be understood considering that the alternative is burning liquid fuels (ULSD) that would also need to be stored locally. The figure below shows the expected monthly consumption.

Figure 5-14: VEGA BAJA Mini-grid Fuel Consumption as Function of Penetration



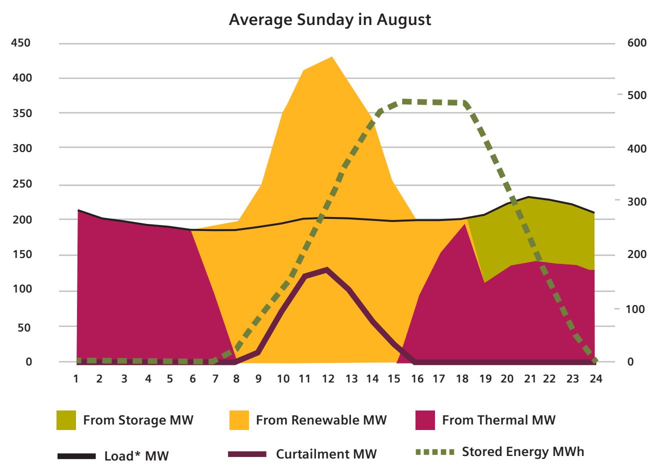
With respect to the dispatches, Figure 5-15 shows a dispatch for the average workday in August. In this figure we note that the storage and the PV are being used to minimize the production of the thermal units, including the supply of the peak, where storage makes its main contribution.

Figure 5-15: VEGA BAJA Mini-grid Workday in August Supply



As can be observed below for an average Sunday in August there is again higher curtailment as the storage reached its limits on capacity initially (MW), and then on energy storage (MWh).

Figure 5-16: VEGA BAJA Mini-grid Sunday in August Supply



SAN JUAN Mini-grid

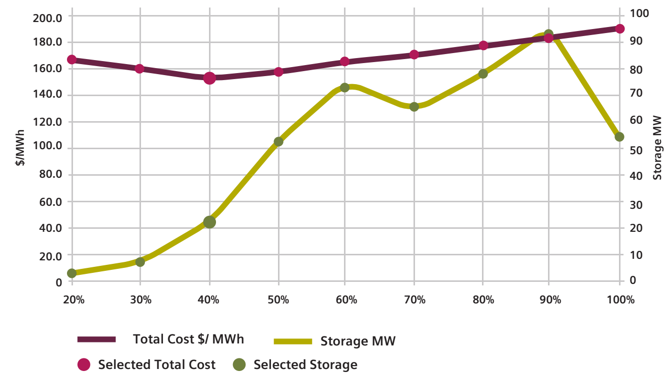
The optimal level of penetration that minimized the total costs of supply for the SAN JUAN mini-grid was found to be 40% equivalent to 674 MW and of PV with 22 MW/ 132 MWh of storage. The table below provides the supply load and mix including the selected new small combined cycle units (the SGT 750 and SGT 400).

Table 5-9: SAN JUAN Supply Mix

The figure below shows that for this mini-grid a penetration of 40% minimizes the total cost of supply with about 22 MW of storage.

Load / Supply Summary	MW	MWh	Load / Capacity Factor
Load	513	3,323,229	74%
Storage	22	28,783	15%
PV MW	674	1,329,292	23%
New Small CCGTs	93	98,868	12%

Figure 5-17: SAN JUAN Penetration and Storage Selection



As shown in the table below the total cost of supply is about $156/MWh and there is approximately $1.1 billion in investments, PV being the largest component followed by thermal generation.

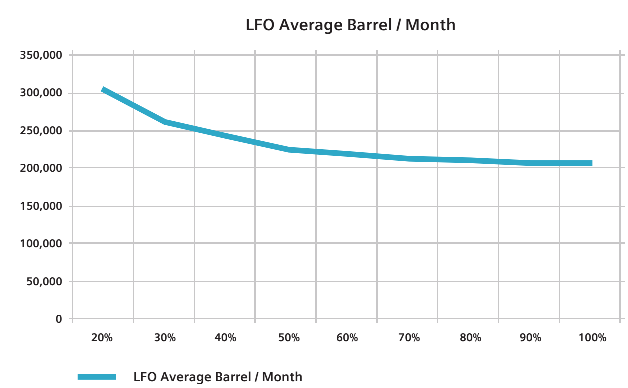
Table 5-10: SAN JUAN Mini-grid Main Results

Economic Results	
Penetration %	40%
Variable Gen Costs $/MWh	114.5
Total Cost $/MWh	156.37
ULSD Avg Barrel /month	244,411
Capital Cost $000	1,120,880

Capital Cost detail	MW	$/kW	$000
Capital Cost Storage	22	$1,200	26,760.00
Capital Cost PV	674	$1,493	1,005,686
Capital Cost SGT 750	42	$1,375	57,920
Capital Cost SGT 400	15	$2,076	30,514.40
Total			**1,120,880.27**

The high level of penetration and hence the investments in PV is understandable considering the alternative is burning liquid fuels (ULSD) that would also need to be stored locally. The figure below shows the expected monthly consumption.

Figure 5-18: SAN JUAN Mini-grid Fuel Consumption as Function of Penetration



With respect to the dispatch, the model is producing reasonable results. The figure below shows a dispatch for the average workday of August. In this figure we note that the storage and the PV are being used to minimize the production of the thermal units, including the supply of the peak, where storage makes its main contribution.

Figure 5-19: SAN JUAN Mini-grid Workday in August Supply

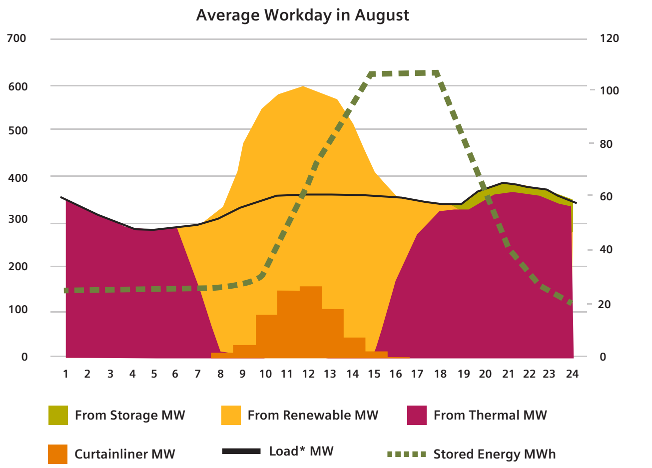
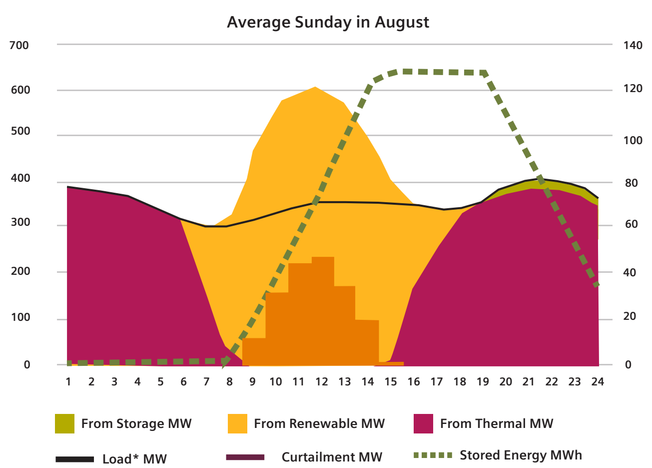


Figure 5-20 shows the supply for an average Sunday of August.

Figure 5-20: SAN JUAN Minigrid Sunday in August Supply



SABANA LLANA Mini-grid

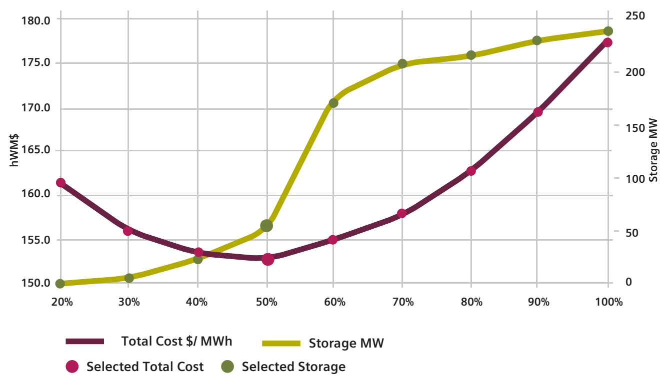
The optimal level of penetration that minimized the total costs of supply for the SABANA LLANA mini-grid was found to be 50% equivalent to 459 MW and of PV with 49 MW / 249 MWh of storage. Table 5-11 provides the supply load and mix including the selected new small combined cycle units (the SGT 750 and SGT 400).

Table 5-11: SABANA LLANA Supply Mix

Load / Supply Summary	MW	MWh	Load / Capacity Factor
Load	279	1,810,755	74%
Storage	49	82,216	19%
PV MW	459	905,378	23%
New Small CCGTs	163	925,908	65%

The figure below shows that for this mini-grid a penetration of 50% minimizes the total cost of supply with about 49 MW of storage.

Figure 5-21: Penetration and Storage Selection



As shown in the next tables, the total cost of supply is about $152/MWh and there is approximately $1.0 billion in investments PV being the largest component followed by the thermal generation.

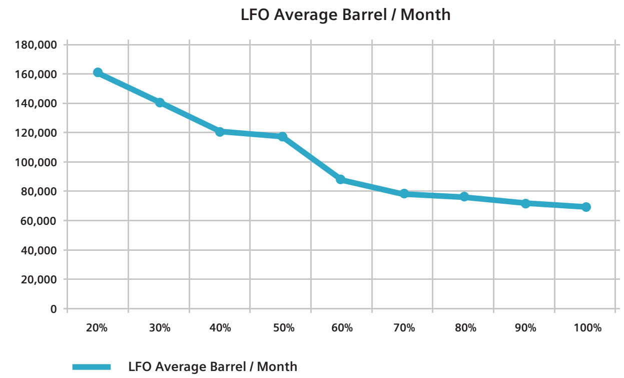
Table 5-12: SABANA LLANA Mini-grid Main Results

Economic Results	
Penetration %	50%
Variable Gen Costs $/MWh	87.0
Total Cost $/MWh	152.87
ULSD Avg Barrel /month	114,698
Capital Cost $000	1,005,964

Capital Cost detail	MW	$/kW	$000
Capital Cost Storage	49	$1,200	58,800
Capital Cost PV	459	$1,493	684,971
Capital Cost SGT 750	168	$1,375	231,679
Capital Cost SGT 400	15	$2,076	30,514
Total			**1,005,963**

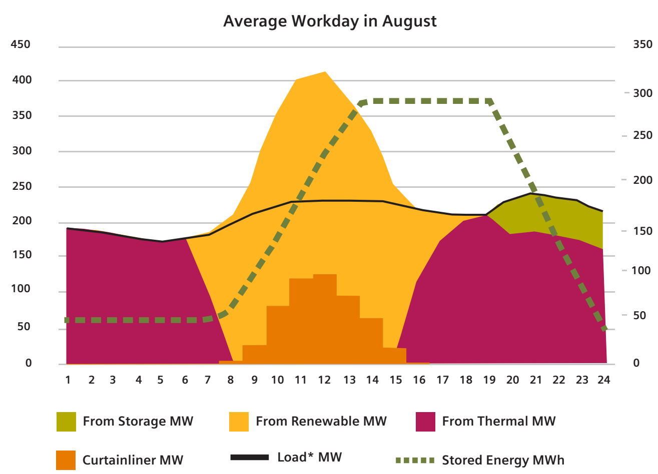
The high level of penetration and hence the investments in PV are again a function of the alternative being liquid fuels (ULSD). The figure below shows the expected monthly consumption.

Figure 5-22: SABANA LLANA Mini-grid Fuel Consumption as Function of Penetration



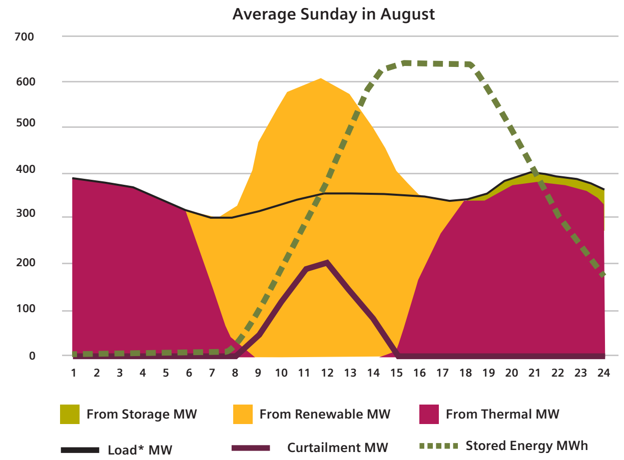
The next figure shows a dispatch for the average workday of August. As was the case for prior mini-grids, we note that the storage and the PV are being used to minimize the production of the thermal units, including the supply of the peak, where storage makes its main contribution.

Figure 5-23: SABANA LLANA Mini-grid Workday in August Supply



The next figure represents the supply for an average Sunday in August, where the curtailment is again higher as the storage reached its limits on capacity (MW) initially and then on energy storage (MWh).

Figure 5-24: SABANA LLANA Mini-grid Sunday in August Supply



AGUAS BUENAS Mini-grid

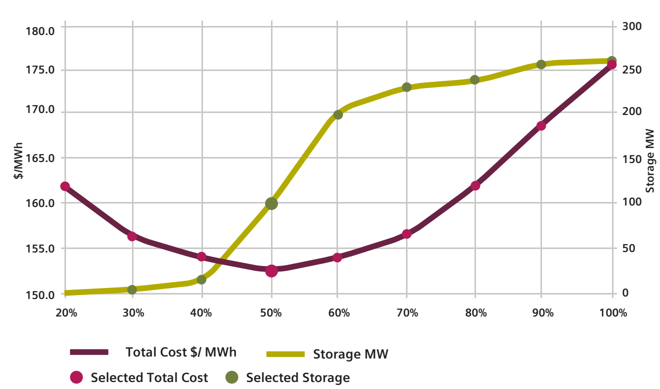
The optimal level of penetration that minimized the total costs of supply for the AGUAS BUENAS mini-grid was also found to be 50% equivalent to 512 MW of PV and with 99 MW /594 MWh of storage. The table below provides the supply load and mix including the selected new small combined cycle units (the SGT 750 and SGT 400).

Table 5-13: AGUAS BUENAS Mini-grid Supply Mix

Load / Supply Summary	MW	MWh	Load / Capacity Factor
Load	312	2,021,557	74%
Storage	99	151,045	17%
PV MW	512	1,010,779	23%
New Small CCGTs	182	994,582	62%

The figure below shows that as before for this mini-grid a penetration of 50% minimizes the total cost of supply with about 100 MW of storage.

Figure 5-25: AGUAS BUENAS Penetration and Storage Selection



As shown in Table 5-14, the total cost of supply is about $152/MWh and there is approximately $1.1 billion in investments, PV being as before the largest component followed by the thermal generation.

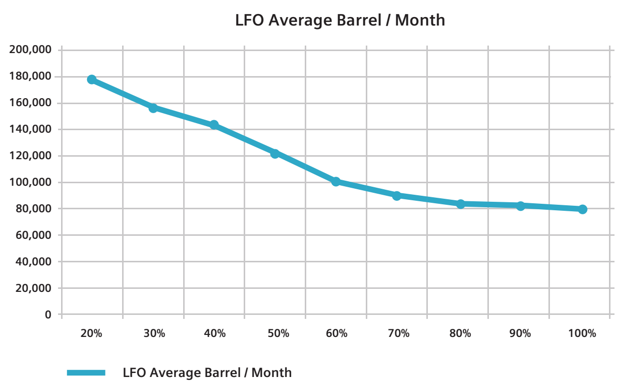
Table 5-14: AGUAS BUENAS Main Results

Economic Results	
Penetration %	50%
Variable Gen Costs $/MWh	83.1
Total Cost $/MWh	152.49
ULSD Avg. Barrel /month	121,802
Capital Cost $000	1,145,166

Capital Cost detail	MW	$/kW	$000
Capital Cost Storage	99	$1,200	118,260
Capital Cost PV	512	$1,493	764,713
Capital Cost SGT 750	168	$1,375	231,679
Capital Cost SGT 400	15	$2,075	30,514
Total			**1,145,165**

As before, the high level of penetration allows the avoidance of burning liquid fuels (ULSD) as shown in figure below for this mini-grid.

Figure 5-26: AGUAS BUENAS Fuel Consumption as Function of Penetration



With respect to the dispatch, the model is producing results in line with our observations above with respect to the storage dispatch and effects in curtailment.

Figure 5-27: AGUAS BUENAS Mini-grid Workday in August Supply

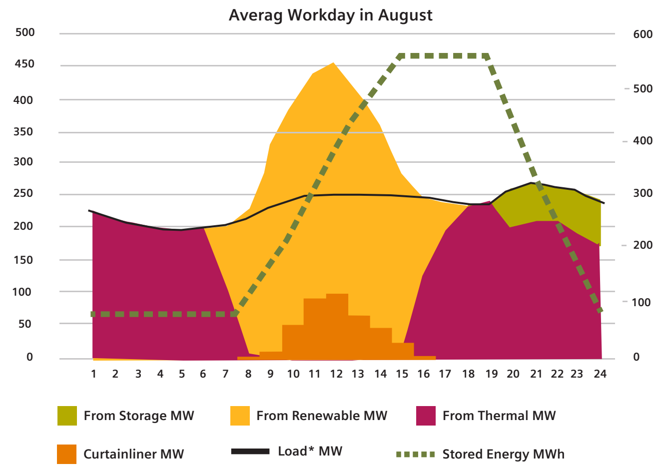
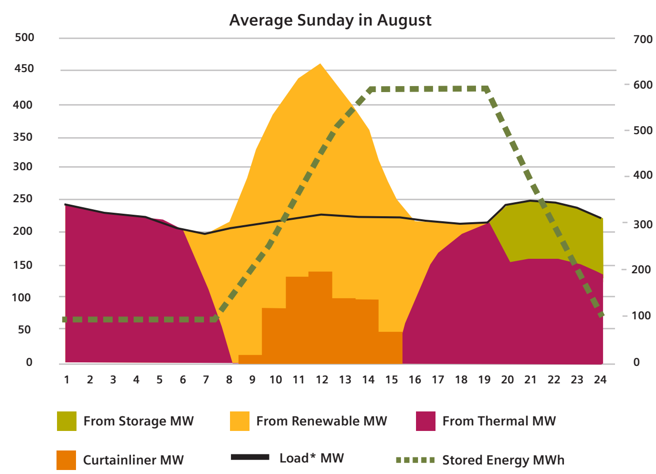


Figure 5-28: AGUAS BUENAS Mini-grid Sunday in August Supply



Section 6

Vision Case: Reliable, Economic and Resilient

As shown in Table 6-1 the mini-grids require 311 MW of storage, 3,043 MW of PV and about 931 MW of smaller combined cycle units to be deployed to them. With this target we modified the penetration and storage requirements on the model that optimizes the entire system, and with 35% penetration, we achieve the requirements of the mini-grids. We note however that the mini-grids require about 213 MW of small, additional generation that would not dispatch for integrated operation. This additional generation could, at least in part, be deployed as portable generation to be assigned as necessary to those mini-grids if the system became generation deficient.

Table 6-1: Comparison between integrated system results and mini-grids requirements

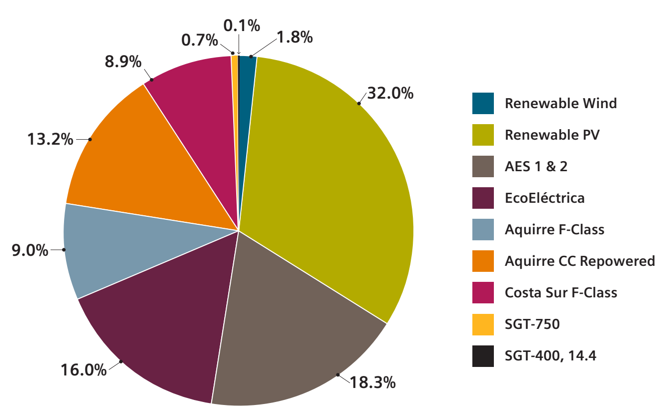
	35% Penetration Case MW	Needed for Mini-grids MW
Storage	319	311
PV	3,048	3,043
SGT 750 & 450	717	931
Additional Small Generation	213	

Table 6-2 shows the main annual results for the reliable and resilient design where we observe the 3,050 MW of PV generation installed (includes the existing PV generation), the 319 MW/864 MWh of new storage (BESS), and the approximately 931 MW of new smaller CCGT including those that were added to the case by the model (717 MW), and the additional requirements mentioned above. The balance of the generation is either existing units (including wind generation) or the three new base load F-Class combined cycle plants. Figure 6-1 below shows the energy supply by source, where we note that the renewable contributes 1.9% of the energy from wind generation and 32% from PV for a total penetration of 33.9 % penetration. The difference to the target of 35% is due to the fact that approximately 8.8% of the renewable generation is being curtailed.

Table 6-2: Results Summary for Integrated System; 35% Penetration

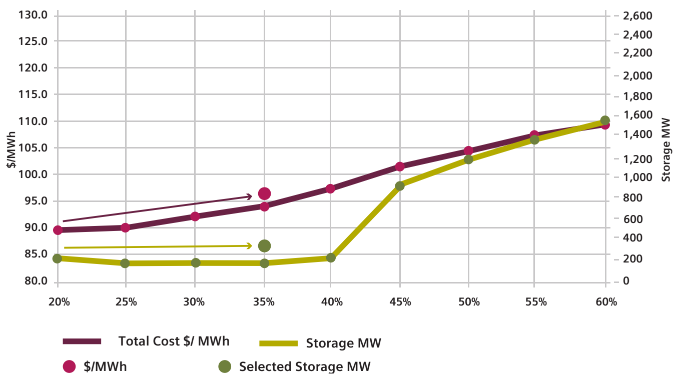
	MW	MWH	Total $	Total $/MWh	CF or Curtailment
Load	2800	18,149,851	1,737,690,345	95.74	74.0%
Renewable Wind	121	338,684.6	52,834,793	156	32.0%
Renewable PV	3,048	6,013,763.3	490,723,084	82	22.5%
AES 1 & 2	454	3,428,433.8	189,370,159	55	86.2%
EcoEléctrica	507	3,009,649.4	284,014,727	94	67.8%
Aguirre F-Class	369	1,691,456.0	147,960,274	87	52.3%
Aguirre CC Repowered	527	2,473,723.1	205,479,887	83	53.6%
Costa Sur F-Class	369	1,672,953.9	146,341,800	87	51.7%
SGT-750	379	124,366.0	73,098,407	588	3.7%
SGT-400, 14.4	338	11,289.7	71,202,306	6,307	0.4%
Additional Gen	**213**		**30,659,789**		
Curtailment	**1,662**	**557,915**			**8.8%**
Storage	**319**	**494,304**	**46,005,120**	**93**	**18%**

Figure 6-1: Energy Supply By Source



As can be observed in the figure and tables below, the total cost of supply for the reliable, economic, and resilient system comes out to be about 95.7 $/MWh which is only about 7.0 % higher than the base case (89.5 $/MWh) due to the increased penetration and the additional storage required. This relatively minor cost increase will offer a true return on investment to all stakeholders in the form of energy resiliency against future events and extremely costly outages and restoration efforts.

Figure 6-2: Effect of Providing Resiliency to the System



Approximately 47% additional capital would be required largely in new PV generation (84% of the increase), followed by new small CCGT (12% of the increase) and storage (4% of the increase). This is shown in the table below, and again represents an investment towards energy resiliency with a payback to all stakeholders through cost avoidances from outages and restoration efforts.

Table 6-3: Total Cost and Capital Requirements for the Resilient Plan and Comparison with the Base Strategy

Total Cost $/MWh			95.74	89.51	6.24	7.0%
			Resilient	Base	Increase	
Capital Cost Detail	MW	$/kW	$000	$000	$000	%
Capital Cost Storage	319	$1,200	383,376	291,600	91,776	31%
Capital Cost PV	3,048	$1,493	4,549,761	2,490,048	2,059,712	83%
Capital Cost new Base CCGT	1,265	$921	1,165,262	1,165,262		0%
Capital Cost new small CCGT	931	$1,630	1,516,520	1,223,108	293,412	24%
Total			7,614,919	5,170,019	2,444,900	47%

The figures below show typical dispatch for representative days; the average of the workdays in August, a high load day of August, average of the Sundays in August and the averages of workdays and Sundays in April. In these figures we note how the dispatch of the thermal generation and storage minimizes the curtailment of renewable generation and displace the smaller CCGT that would be burning diesel (ULSD). The objective in presenting an actual day is to show the dispatch without the effects of averaging. As can be observed below, in this high load day the curtailment only occurs when the storage is charging at its maximum MW rate or reaches its maximum energy storage limit. The storage is then dispatched during the peak and only minimal use is made of the small CCGTs.

Finally, it should be noted that while we approximated an efficient use of the storage, further cost reductions could be possible using advanced optimization programs. However, the implemented logic produces reasonable results while considering the BEES charging limitations (MW), which is the driving constraint in most of the cases behind the curtailment. It displaces the smaller costly generation whenever there is energy stored that is not reserved for emergency use.

Figure 6-3: Entire System Supply: Workdays in August

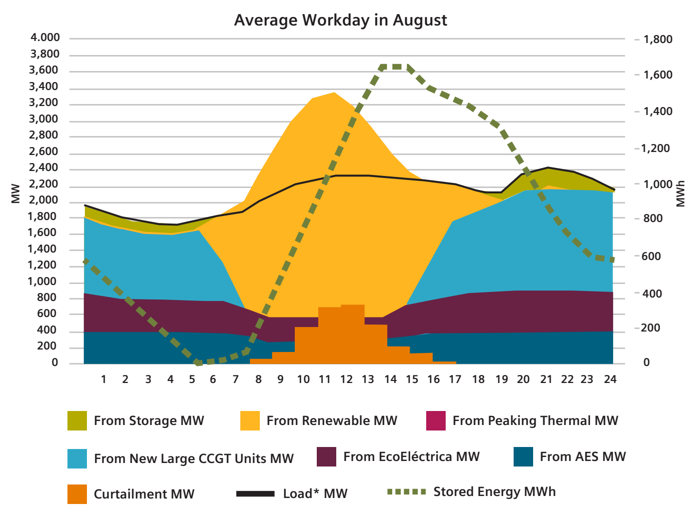


Figure 6-4: Entire System Supply: A High Load Day in August

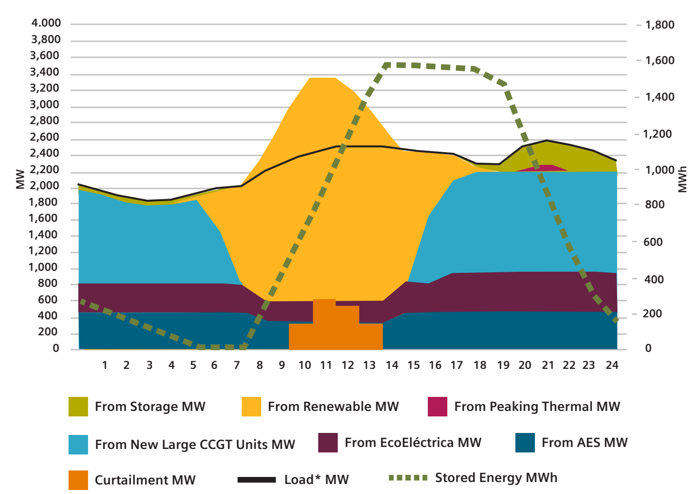


Figure 6-5: Entire System Supply: Sundays in August

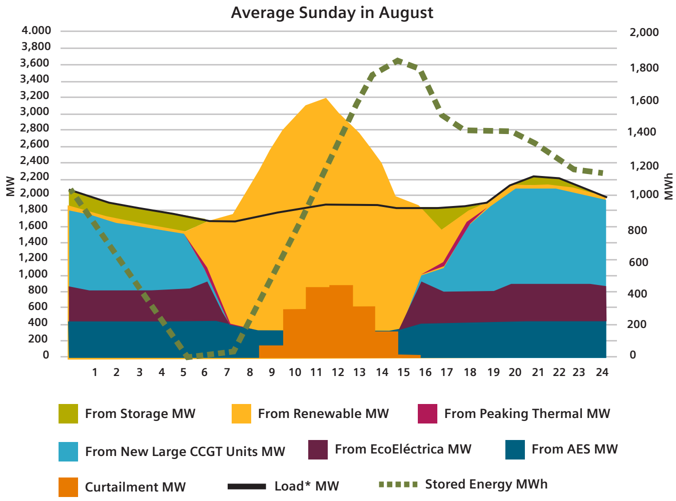


Figure 6-7: Entire System Supply: Sundays in April

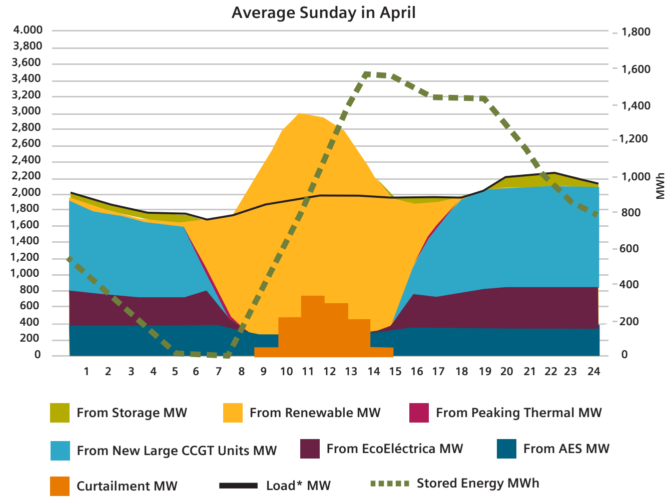
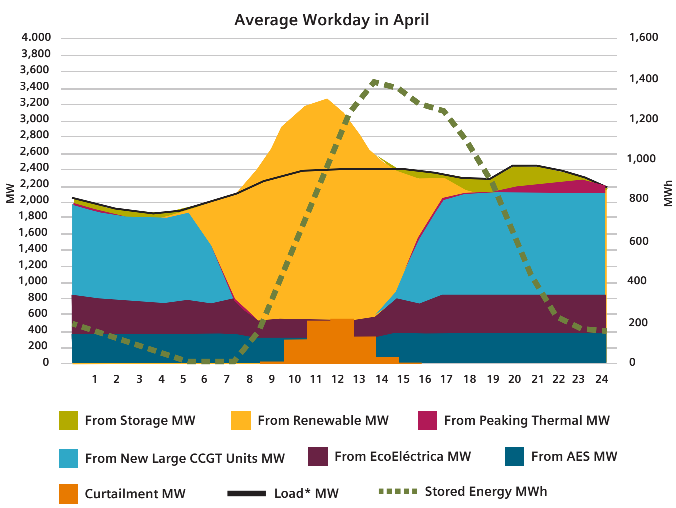


Figure 6-6: Entire System Supply: Workdays in April



Section 7

Impact of AOGP Cancellation and No Additional LNG Terminals

In the eventuality that the AOGP is cancelled and no additional LNG terminals are built on the island, the supply for the thermal generation (outside Costa Sur) will be more costly. For this exercise we used diesel (ULSD) as the alternative as it would otherwise be used to fire the repowered Aguirre CC. In line with making conservative assumptions with respect to the base load fleet, we assumed that in this case there would be two F-Class CCGT installed at Costa Sur instead of one when Costa Sur 5 & 6 retire.

In this case the optimal level of penetration, based on the assumptions in this document, increased from 20% to 25% with a total cost of supply of 120 $/MWh.

Under this situation the incremental cost for resiliency reduces to 4.4% (107.379 $/MWh versus 102.8 $/MWh) and the required capital costs for the resilient system increase by 32% over the base system as illustrated in the tables and figures below.

Figure 7-1: Effect of Providing Resiliency to the System for the No-New-LNG Scenario

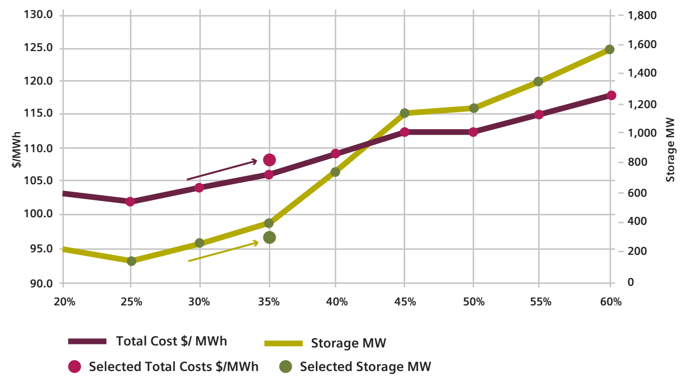


Table 7-1: Resilient Versus Base Strategy for the Situation Where There is No Additional LNG Terminal

Total Cost $/MWh			107.39	102.83	4.57	4.4%
			Resilient	Base	Increase	
Capital Cost detail	MW	$/kW	$000	$000	$000	%
Capital Cost Storage	342	$1,200	410,760	202,020	208,740	103%
Capital Cost PV	3,048	$1,493	4,549,761	3,176,619	1,373,141	43%
Capital Cost new Base CCGT	1,265	$921	1,165,262	1,165,262		0%
Capital Cost new small CCGT	931	$1,630	1,516,520	1,223,108	293,412	24%
Total			**7,614,919**	**5,767,010**	**1,847,910**	**32%**

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