Energy and Climate Partnership of the Americas

Assessment of the Value of Investments in Resilience of Energy Infrastructure in the Caribbean

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Inter-American Development Bank

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1 Introduction

The purpose of this Report is to assess the value of investments to increase the resilience of energy infrastructure to withstand natural disasters in the Caribbean. In general, it appears that utilities and project developers do not directly incorporate the full potential impact hurricanes can have on an energy project when assessing the expected financial results. For this Report, we developed a simulation that allows us to measure the financial impact a hurricane may have on an energy infrastructure project in the Caribbean.

This Report is structured as follows:

- Section 2 provides our definition of resilience and how this applies to energy projects in the Caribbean
- Section 3 describes the impacts natural disasters have on both the electricity utilities and the economy as a whole
- Section 4 describes the assumptions used for the simulation and the key conclusions derived from the simulation.

2 Defining Resilience of Energy Infrastructure

The Caribbean hurricane season in 2017 highlighted the importance of having more resilient energy infrastructure. The region suffered significant damage to its energy infrastructure and was negatively impacted by widespread power outages as a result.

It is important to define what is meant by increasing the resilience of energy infrastructure. Merriam-Webster defines the word resilience as, "an ability to recover from or adjust easily to misfortune or change."[1] Based on this definition of resilience, increasing the resiliency of energy infrastructure would mean making investments necessary to decrease the impact of natural disasters on energy infrastructure, and consequently, the owner of that infrastructure, electricity consumers, and the economy in general.

For the purpose of this assignment, we propose the following hypothesis:

> *Investments to increase the resilience of energy infrastructure will increase the initial costs, or capital expenditures (CAPEX), of any project. However, in scenarios in which the project is hit in earlier years by more damaging hurricanes, the benefits of these investments will outweigh the costs.*

The purpose of the simulation carried out for this Report is to assess the value that can be created for an energy infrastructure project (in this case, a wind farm in the Caribbean) through investments to increase its resilience. This will allow us to test this hypothesis and assess the financial and economic feasibility of investments to increase the resilience of energy infrastructure in the Caribbean.

[1] Merriam-Webster Dictionary. https://www.merriam-webster.com/dictionary/resilience.

3 Identifying the Impact of Natural Disasters on Energy Infrastructure in the Caribbean

Power failures caused by natural disasters can have significant impacts directly on the utility and on a country's aggregate economy. Section 3.1 describes the damages that hurricanes cause to electricity utilities, such as the additional capital expenditures (CAPEX) required to recover from damages and the loss in revenue caused by service interruption. Then, Section 3.2 explains the impact hurricanes can have on the economy as a whole, as measured by the value of lost load.

3.1 Direct Impacts on Utilities

Natural disasters can have significant damage on energy infrastructure and the financial situation of electricity utilities. For this Report, we simulate the impacts a natural disaster can have on an electricity generation project. This is important for utilities or independent power producers (IPPs) to understand when making investment decisions. A natural disaster can lead to the following adverse impacts on an energy company in the Caribbean:

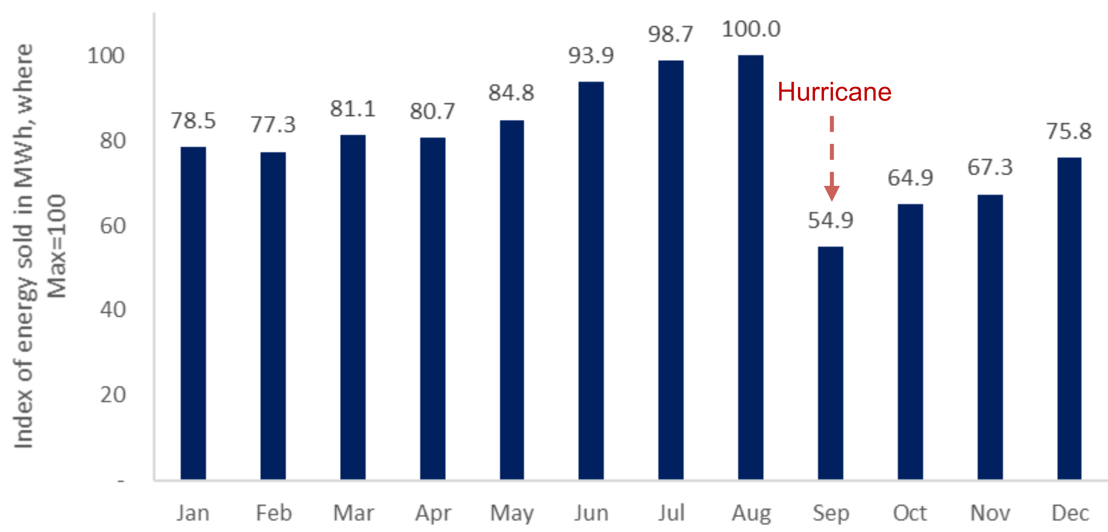
- The need for unexpected CAPEX to rehabilitate and/or replace all or parts of any fixed assets that are damaged
- Damages to existing fixed assets
- Loss in revenue from business interruption during the time the asset is not operational.

Hurricanes Irma and Maria in 2017 demonstrated the damaging effects hurricanes can have on electricity utilities in the Caribbean region. For example, one Caribbean utility suffered total damages worth approximately 37 percent of annual revenues from Hurricane Maria in 2017. The main damages and their financial impact were:

- The hurricane destroyed approximately 65 percent of the utility's generation and transmission assets
- The utility spent US$25 million to replace destroyed assets in 2017
- The hurricane damage caused a service interruption of approximately 60 days between September and December 2017. The financial impact of this damage was a loss in revenues of approximately 5 percent of the utility's annual revenues due to decreased electricity sales in the months following the hurricanes.

Figure 3.1 shows the utility's monthly electricity sales in MWh. The drop in sales in September demonstrates the impact Hurricane Maria had on the utility the month it struck.

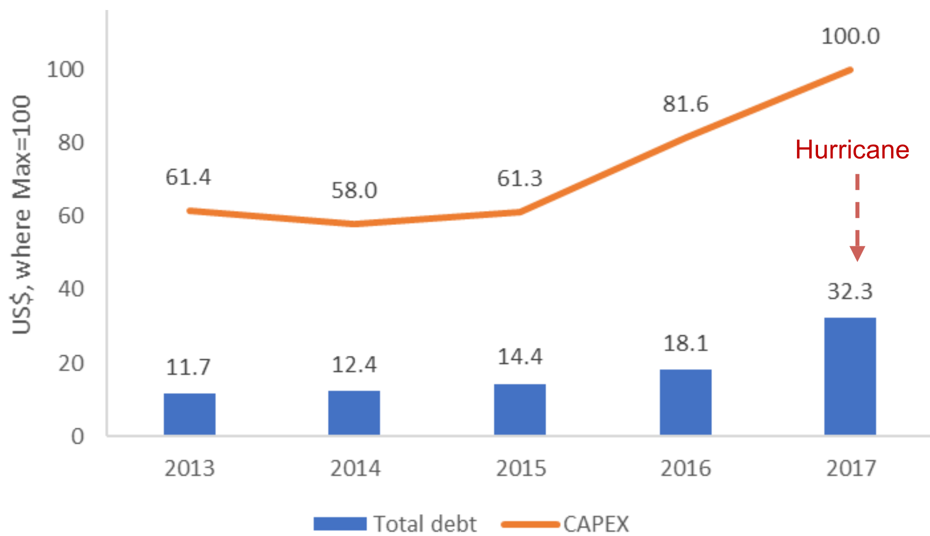
Figure 3.1: Total Electricity Sales, by Month (2017)



The figure above shows a 45 percent drop in electricity sales from August to September 2017 caused by the hurricane damage. The figure also shows the utility suffered from decreased sales for 4 months following the hurricane.

In addition to revenue losses, the utility also suffered from the unexpected need to increase CAPEX to rehabilitate assets damaged by the storm. Figure 3.2 below shows the increased CAPEX and total debt of the utility in 2017.

Figure 3.2: Hurricane Impact on CAPEX and Total Debt



As shown in the figure above, the utility's CAPEX increased 78 percent in 2017 from the previous year. This increase was to rehabilitate damage caused by the hurricane. Furthermore, to rehabilitate and replace damaged assets from the hurricane, the utility had to increase its total debt to finance these additional expenditures. Thus, in 2017, the company's total debt also increased by close to 23 percent from the previous year.

3.2 Impacts on the Economy as a Whole

Not only do the utilities incur damages from natural disasters, but interruptions in the power supply can cause significant disruptions to the overall economy. One measure of this impact is the value of the lost load, which is measured in US$ per kWh not supplied.[2] This value quantifies the damage caused by a power interruption and the loss of economic activities that occurs as result.

There are a number of methodological approaches to calculating the value of lost load. These approaches can be broadly categorized as either the willingness to pay approach, or the macroeconomic approach. The willingness to pay approach uses surveys to ask customers how much they are willing to pay to avoid a blackout.[3] The macroeconomic approach uses data such as information on the consumption of electricity by customer type (residential, industrial, and commercial) and the gross domestic product (GDP) to calculate the cost per kWh not supplied. In the case of generation assets, the amount of electricity provided to the overall system by the generation asset would also be required to calculate the value of lost load caused directly by the damage to that generation asset.

While we acknowledge that service interruptions can have serious impacts on the overall economy, our analysis focuses on assessing the costs of energy resilience at the project-level. Resilient energy infrastructure can certainly have significant benefits at the country-level, especially if a natural disaster occurs. However, by focusing on the project-level, the financial model and our analysis can be applied to specific investment decisions. As a starting point in promoting energy infrastructure resilience, comparing the internal rate of return (IRR) of investment options can demonstrate the potential value that investing in increased resilience can have for energy projects.

[2] London Economics International. 2013. "Estimating the Value of Lost Load." http://www.ercot.com/content/gridinfo/resource/2015/mktanalysis/ERCOT_ValueofLostLoad_LiteratureReviewandMacroeconomic.pdf.

[3] Thomas Schroder and Wilhelm Kuckshinrichs, 2015. "Value of Lost Load: An Efficient Economic Indicator for Power Supply Security? A Literature Review." *Frontiers Energy Research.* *https://www.frontiersin.org/articles/10.3389/fenrg.2015.00055/full.*

4 Simulating the Impact of Hurricane Damage on the Profitability of Energy Projects

To show the potential value that investing in energy infrastructure can have, we built a financial model to assess the expected value of increasing the resilience of energy infrastructure at the project level. The financial model allows us to simulate the impact a hurricane can have on an energy project. The financial model uses a single generation asset, a wind farm IPP in the Caribbean, as the focus of our analysis. The financial model simulates the impact a natural disaster would have on this wind farm under different scenarios related to investments in resilience, and the magnitude and timing of a hurricane. For simplicity, the simulation ignores the effects of insurance on the projects' financial results.

We present the assumptions and the key results of the simulation as follows:

- General assumptions of the simulation (Section 4.1)
- Assumptions related to the CAPEX needed to invest in resilience (Section 4.2)
- Assumptions related to a natural disaster occurring (Section 4.3)
- Impact of the hurricane on the project (Section 4.5)
- Key results of the simulation (Section 4.5).

4.1 General Assumptions of the Simulation

The simulation is based on a wind farm that sells electricity to a utility via a 15-year power purchase agreement (PPA). We assume that the price per kWh of electricity sold remains the same throughout the duration of the contract. The general assumptions that are applicable to all projects assessed in the financial model are presented in Table 4.1 below.

Table 4.1: General Assumptions and Key Inputs Used in the Model

Assumption	Value
Generation Units	
Capacity (MW)	20
Availability (%)	45%
Operating and Maintenance Costs	
Operating and maintenance costs per year (US$)	$320,000
Depreciation (%)	6.67%
Capital Structure	
Portion of CAPEX financed with debt (%)	70%
Portion of CAPEX financed with equity (%)	30%
Debt Terms	
Grace period (years)	2 years

Maturity (years)	10 years
Interest rate (%)	5%
Other Assumptions	
Duration of contract beginning at COD (years)	15 years
Discount rate (%)	12%
Corporate tax rate (%)	30%
Accounts receivable as percentage of annual revenue (%)	5%
Accounts payable as percentage of annual O&M costs (%)	10%
Inventories as a percentage of annual O&M costs (%)	10%
Working capital reserve (US$)	$2 million

In addition to the assumptions above, if a natural disaster occurs during the PPA, we assume the needed CAPEX would be financed with a debt-to-equity ratio of 70/30. Although the PPA could be extended at the end of the 15 years, the simulation assumes a full liquidation of the project at the end of the PPA. Thus, for simplicity, we assume that at the end of the 15 years, the IPP liquidates all the assets and pays off the liabilities in full, with any cash generated as a result being paid out in dividends that year.

4.2 Assumptions Regarding Investments to Increase Energy Infrastructure Resilience

To compare the value of investing in the resilience of energy projects, the simulation considers two types of projects. The types of projects are:

- An energy project with standard CAPEX, which does not include the additional costs needed to increase the resilience of the project. We assume this initial CAPEX to be US$40 million.
- A resilient energy project with additional initial CAPEX that is expected to increase the resilience of the project. We assume these projects will have an initial CAPEX that is 20 percent greater than the standard CAPEX, making the initial resilient CAPEX equal to US$48 million.[4] We also assume that the sale price of electricity for a resilient project will be higher to account for the additional CAPEX needed to increase the resilience of the project.

[4] This is consistent with recent similar studies. A National Renewable Energy Laboratory (NREL) report on assessing the costs of increasing the resilience of offshore wind projects in the Gulf of Mexico, assumes a 28 percent higher CAPEX for the hurricane-resilient project compared to the standard baseline project. Given the greater costs and risks of offshore wind projects, the initial CAPEX is expected to be slightly higher than an onshore project, such as the one considered in our simulation.

NREL. 2016. "Hurricane Resilient Wind Plant Concept Study Final Report." United States. https://www.nrel.gov/docs/fy17osti/66869.pdf (accessed 20 June 2018).

We assume that the sale price of electricity for both types of projects yields a 12 percent project IRR for a scenario in which a Category 3 storm occurs in Year 8. This assumption leads to the sale price of electricity to be US$102/MWh for a standard project and US$112/MWh for a resilient project.

4.3 Assumptions Regarding the Risk of a Hurricane

For the simulation, we use the following assumptions associated with the risks of a hurricane affecting the project:

- The probability that a hurricane will hit and impact the project
- The year after the project's commercial operation date (COD) in which the hurricane hits. The timing of the hurricane impacts the cash flows of the project. Projects that experience a hurricane sooner have a lower IRR at the end of the 15-year contract than ones that experience hurricanes later.
- The magnitude of damage caused by the hurricane, measured by the five categories established by the Saffir-Simpson scale. A Category 1 storm has the lowest magnitude of damage, while a Category 5 storm has the highest magnitude of damage.

These assumptions determine the level of damage caused by the hurricane, which is described in more detail in the next section.

4.4 Impact of the Hurricane on the Project

To quantify the damages incurred by a hurricane, the simulation uses the following two assumptions to measure the impact on a project:

- The impact of the natural disaster on the project, measured by the CAPEX required to make the asset operational again.
- The number of days in which the project is not operational due to damages and thus, not generating revenues.

To quantify the damages caused by the hurricane, we assume that the higher the magnitude of the storm, the greater the CAPEX needed to rehabilitate and/or replace damaged assets. The amount of CAPEX needed is calculated using a percentage of the initial CAPEX used to build the project. The simulation assumes that a resilient project is more likely to withstand damage caused by natural disasters. Therefore, we assume that the percentage of initial CAPEX needed to rehabilitate a resilient project will be half the percentage amount needed for a standard project.

Similarly, the simulation also considers the impact on revenues a hurricane would have on a project. We assume that the project will not generate revenues while it is not operational. Further, a standard project will take longer rehabilitate after a hurricane, causing a greater loss in revenues than a resilient project. We assume that the number of days of power outage after a hurricane are twice as much for a standard project than a resilient project.

The impacts associated with each magnitude of damage are presented in Table 4.2 below.

Table 4.2: Assumptions on Hurricane Risk and Incurred Damage

Magnitude of Hurricane	Standard CAPEX		Resilient CAPEX	
	% of Initial CAPEX Needed to Rehabilitate	Days of power outage	% of Initial CAPEX Needed to Rehabilitate	Days of power outage
No hurricane	None	0 days	None	0 days
Category 1	10%	5 days	5%	3 days
Category 2	20%	15 days	10%	8 days
Category 3	50%	30 days	25%	15 days
Category 4	60%	60 days	30%	30 days
Category 5	80%	120 days	40%	60 days

4.5 Key Results of the Simulation

The simulation allows us to compare the IRR of a standard project and a resilient project under a range of scenarios related to the magnitude and timing of a hurricane impacting the project. The results indicate that both a standard and a resilient project will meet the project's expectations of an IRR above or equal to 12 percent under the following scenarios:

- No storm hits the project
- A Category 1 storm hits in any year
- A Category 2 storm hits in any year
- A Category 3 storm hits in Year 7 or after
- A Category 4 storm hits in Year 9 or after
- A Category 5 storm hits in Year 12 or after.

Table 4.3 below shows the IRR results for a standard project under different scenarios related to the magnitude and timing of a hurricane.

Table 4.3: Simulated IRR Results for Standard Project

	Standard Project														
Year hurricane hits:	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Year 7**	**Year 8**	**Year 9**	**Year 10**	**Year 11**	**Year 12**	**Year 13**	**Year 14**	**Year 15**
No hurricane	13.4%	13.4%	13.4%	13.4%	13.4%	13.4%	13.4%	13.4%	13.4%	13.4%	13.4%	13.4%	13.4%	13.4%	13.4%
Category 1	13.4%	13.5%	13.7%	13.8%	13.9%	14.0%	14.1%	14.1%	14.2%	14.3%	14.3%	14.3%	14.4%	14.4%	14.4%
Category 2	12.3%	12.6%	12.8%	13.0%	13.2%	13.3%	13.5%	13.6%	13.8%	13.9%	14.0%	14.1%	14.1%	14.2%	14.3%
Category 3	9.8%	10.1%	10.5%	10.8%	11.2%	11.5%	11.8%	12.1%	12.4%	12.7%	12.9%	13.2%	13.3%	13.5%	13.7%
Category 4	9.0%	9.4%	9.7%	10.1%	10.5%	10.8%	11.2%	11.6%	11.9%	12.2%	12.5%	12.8%	13.0%	13.2%	13.4%
Category 5	7.7%	8.0%	8.4%	8.7%	9.1%	9.5%	10.0%	10.4%	10.8%	11.2%	11.6%	12.0%	12.4%	12.7%	12.9%

Table 4.4 below shows the IRR results for a resilient project under different scenarios related to the magnitude and timing of a hurricane.

Table 4.4: Simulated IRR Results for Resilient Project

	Resilient Project														
Year hurricane hits:	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15
No hurricane	13.4%	13.4%	13.4%	13.4%	13.4%	13.4%	13.4%	13.4%	13.4%	13.4%	13.4%	13.4%	13.4%	13.4%	13.4%
Category 1	12.8%	12.9%	12.9%	13.0%	13.0%	13.1%	13.1%	13.1%	13.2%	13.2%	13.2%	13.2%	13.2%	13.3%	13.3%
Category 2	12.2%	12.3%	12.5%	12.6%	12.6%	12.7%	12.8%	12.9%	12.9%	13.0%	13.0%	13.1%	13.1%	13.1%	13.2%
Category 3	10.8%	11.0%	11.2%	11.4%	11.6%	11.8%	12.0%	12.1%	12.3%	12.4%	12.5%	12.6%	12.7%	12.8%	12.9%
Category 4	10.3%	10.5%	10.8%	11.0%	11.2%	11.5%	11.7%	11.8%	12.0%	12.2%	12.3%	12.4%	12.6%	12.7%	12.7%
Category 5	9.4%	9.7%	10.0%	10.2%	10.5%	10.8%	11.0%	11.3%	11.5%	11.7%	11.9%	12.1%	12.2%	12.4%	12.5%

Comparing the IRRs for the standard and resilient projects, the simulation leads to the following conclusions:

- The standard project always generates greater returns in scenarios in which a Category 1 or Category 2 storm occurs at any point during the project
- If a Category 3 hurricane hits in Year 7 or before, the resilient project will yield greater returns. If a Category 3 hurricane hits after Year 7, the standard project yields greater returns
- If a Category 4 hurricane hits in Year 9 or before, the resilient project will yield greater returns. If a Category 4 hurricane hits after Year 9, the standard project yields greater returns
- If a Category 5 hurricane hits in Year 12 or before, the resilient project will yield greater returns. If a Category 5 hurricane hits after Year 12, the standard project yields greater returns.

Table 4.5 below shows the difference between the IRRs for a standard project and a resilient project. Scenarios in which the difference is positive, means that the returns in that scenario are greater for the standard project. Scenarios in which the difference is negative, means that the returns in that scenario are greater for the resilient project. In sum, the actual return on an energy project in the Caribbean depends directly on the timing and magnitude of a potential hurricane strike.

Table 4.5: Difference in IRR Results between Standard Project and Resilient Project

	Standard Project IRR - Resilient Project IRR														
Year hurricane hits:	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15
No hurricane	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Category 1	0.006	0.007	0.008	0.008	0.009	0.009	0.010	0.010	0.010	0.011	0.011	0.011	0.011	0.012	0.012
Category 2	0.001	0.002	0.003	0.004	0.005	0.006	0.007	0.008	0.008	0.009	0.009	0.010	0.010	0.011	0.011
Category 3	(0.010)	(0.009)	(0.007)	(0.006)	(0.004)	(0.003)	(0.001)	0.000	0.002	0.003	0.004	0.005	0.006	0.007	0.008
Category 4	(0.013)	(0.012)	(0.010)	(0.009)	(0.008)	(0.006)	(0.005)	(0.003)	(0.001)	0.001	0.002	0.003	0.005	0.006	0.007
Category 5	(0.017)	(0.017)	(0.016)	(0.015)	(0.014)	(0.012)	(0.011)	(0.009)	(0.007)	(0.005)	(0.003)	(0.001)	0.001	0.003	0.004

Key

(orange)	Standard project yields greater returns
(green)	Resilient project yields greater returns

The results demonstrate that when building energy projects in the Caribbean, project developers should consider the potential costs that could be caused by hurricane damage. This is difficult because it is impossible to predict the timing and magnitude of a hurricane, which means the actual return to the project could differ substantially from the expected IRR. For example, in this simulation, the IRR for a standard project ranged from 7.7 percent to 14.4 percent, depending on the timing and magnitude of the hurricane. The IRR for a resilient project ranged from 9.4 percent to 13.4 percent.

The smaller range in the project IRR suggests that a resilient project provides more certainty over the returns of the project, especially if hurricanes are expected to increase in frequency and intensity. However, a resilient project also means that more CAPEX will be needed, which requires a higher sale price for electricity.

To account for potential losses caused by hurricane damage, project developers would have to increase the sale price of electricity. Increasing the sale price allows a project to guarantee a 12 percent IRR in more damaging scenarios. As previously mentioned, to calculate the sale price of electricity used in the simulation, we assumed an expected IRR of 12.1 percent for the project if a Category 3 storm hits in Year 8. For a resilient project to expect a 12 percent return in a scenario in which a Category 5 storm hits in Year 3, the sale price would need to increase to US$130/MWh. This is a 16 percent increase from the price used in the simulation. In most cases, most of this increase would be passed through to the customers.

The tradeoff between higher electricity costs and greater resilience to natural disasters raises a policy question regarding how the costs of increasing resilience of energy projects should be shared between the customers and the project developer.