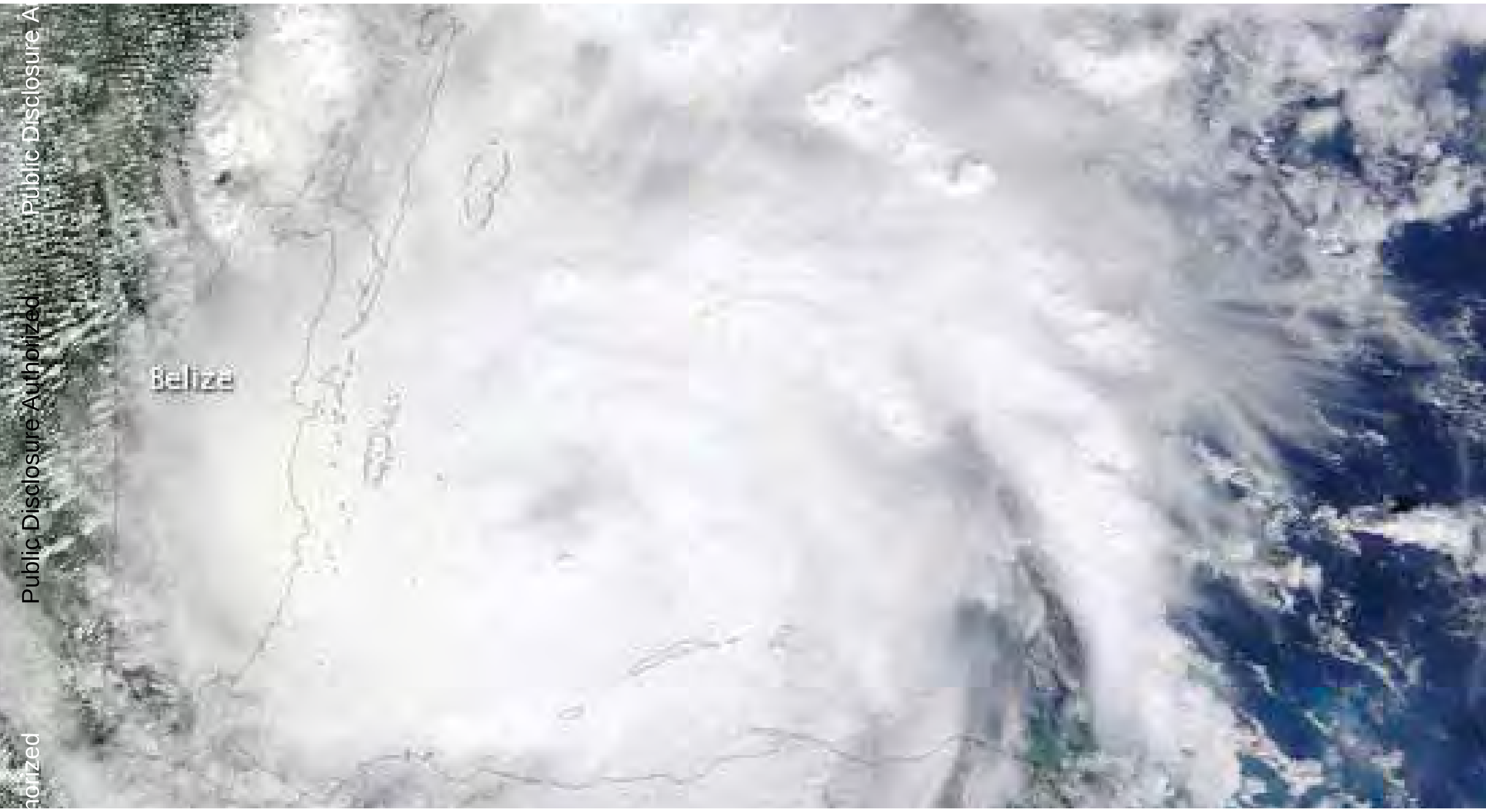
THE POWER SYSTEM IN THE EYE OF THE STORM

The Call for Energy Resilience and Climate Adaptation in Belize



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ESMAP
Energy Sector Management Assistance Program

THE POWER SYSTEM IN THE EYE OF THE STORM

The Call for Energy Resilience and Climate Adaptation in Belize

Migara S. Jayawardena
Borja Garcia Serna
Jace Jeesun Han

Migara S. Jayawardena is a Senior Energy Specialist in the Energy and Extractives Global Practice at the World Bank and the Task Team Leader of the Energy Resilience for Climate Adaptation Project (ERCAP)

Borja Garcia Serna is a former Energy Specialist Consultant at the World Bank

Jace Jeesun Han is an Energy Specialist Consultant at the World Bank

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FOREWORD

Honorable Minister Frank Mena
Minister of State for Ministry of Finance, Public Service, Energy & Public Utilities

Belize is a country that is blessed with history and beauty. It has unrivaled marine life in the Caribbean Sea along the longest barrier reef in the Northern Hemisphere. Our lush tropical forests not only serve as a habitat to an array of wild life, but also conceal ruins from ancient Mayan civilizations that thrived centuries ago. The true beauty of Belize, of course, is its people—a multi-ethnic community at a cultural cross road living in peace and harmony. A large and growing number of tourists visit Belize to experience these wonders, which has become a key economic driver. Bountiful resources contribute to agricultural industries, fisheries and logging that play an important role in economic growth. The relatively recent discovery of oil is further exemplifying the importance of the energy sector in Belize. These developments have helped our economy grow with prosperity shared among many. However, these hard earned gains are fragile, and could easily face set-backs.

One major concern we often grapple with is extreme weather, which is likely to get worse in the future because of climate change. As the title of this paper indicates, Belize is often in the *Eye of the Storm.* Our geographical location makes Belize highly susceptible to hurricanes and tropical storms that frequent the Caribbean. They often lead to significant damages and economic losses, which serve as major set-backs to our development progress. Belize's infrastructure is particularly vulnerable, and the power sector is no exception. High winds knocking down power lines, flooding of energy infrastructure, storm surges along the extensive coastal areas damaging electrical equipment, electrical faults from fallen trees, and increasingly unpredictable rainfall patterns causing volatility in hydropower availability—these are all realities that we live with in Belize. While we have little control over the weather and the climate, we do have the power to take action to better adapt to such adversity.

I welcome this paper and its accompanying analyses that served as a basis for the interventions planned under the *Energy Resilience for Climate Adaptation Project* with support from the World Bank through the Global Environment Facility (GEF) and technical assistance from the Energy Sector Management Assistance Program (ESMAP). The authors apply a novel approach evaluating the impact of several past storms and hurricanes on the power system by identifying specific "events" that led to a variety of infrastructure damage and electricity service disruptions. Such an analysis lends valuable insights into not only the resulting financial losses to the power company, but even more significantly, the broader economic impact due to the unserved electricity. It highlights the need to harden energy infrastructure and strengthen the institutional capabilities so as to enhance the resilience of the power system in order to minimize damages and service disruptions from future storms and hurricanes. The paper also illustrates a set of scenarios that is particularly important in identifying and justifying various actions Belize

Electricity Limited (BEL) plans to take in order to improve system reliability in the face of extreme weather. We are grateful to the World Bank and GEF for helping us implement these reforms.

While the analysis in this paper was carried out specifically for the power system in Belize to help identify its vulnerabilities, the analytical approach applied by the authors is certainly applicable to other countries facing similar concerns, both in the region and globally. Therefore, I am pleased that this work is being more broadly disseminated to inform a wider audience with interest in energy resilience and climate adaption.

Minister Frank Mena
Minister of State for Ministry of Finance, Public Service, Energy & Public Utilities

MESSAGE FROM THE WORLD BANK COUNTRY DIRECTOR

Addressing the impacts of climate change is a development imperative. Therefore, the World Bank places great importance in supporting countries that take actions in reducing the harmful impacts of climate change. This is the case of Belize, where the World Bank in recent years has strategically bolstered its effort to enhance resilience in order to reduce vulnerabilities to the impacts of climate change and natural hazards.

Belize is often affected by extreme weather events, frequently facing hurricanes and tropical storms. The impacts of these storms can be devastating, causing casualties, damaging property, and leading to disruptions in services that are vital to a thriving economy. Steady development progress can suddenly be set back. The impact on infrastructure services can have particular significance because of its permeating role throughout the economy facilitating productive activity and the provision of social services; and the substantial costs associated with infrastructure damage recovery. The urgency and need to address these issues is perfectly exemplified by Hurricane Earl that made landfall in Belize on August 4, 2016. The high winds and heavy flooding that resulted reportedly made key roads and bridges impassable, water services inoperable in directly impacted areas, and caused major disruptions to electricity services.

In response, the World Bank is assisting the Government of Belize (GoB) to enhance its resilience against extreme weather by building climate resilient roads and making the power system better prepared and resilient to storms, hurricanes and natural hazards.

This report presents an innovative approach to identify and analyze particular vulnerabilities in the power sector in Belize; and helps formulate and validate potential solutions. Evaluating past extreme weather events helped us better understand future risks and potential disruptions to electricity services. The World Bank team benefitted greatly from the close collaboration with officials from Government and the national electricity utility (BEL) as well as other partners. The financial support of the Energy Sector Management Assistance Program (ESMAP) and the Global Environmental Facility (GEF) was also critical. Ultimately, the analysis helped shape the design of the Energy Resilience for Climate Adaptation project in Belize.

I am pleased to share this analysis which I think is very relevant for countries across the Caribbean that face similar challenges, but can also be applied in other countries where power sectors are vulnerable to extreme weather and climate change.

Sophie Sirtaine
Country Director for the Caribbean
The World Bank

ACKNOWLEDGEMENT

Migara S. Jayawardena, Borja Garcia Serna and Jace Jeesun Han

This paper analyzes the impact of two hurricanes and a tropical storm that affected Belize in order to identify some key vulnerabilities in the power system to extreme weather, which is likely to be exacerbated due to climate change. By addressing these weaknesses, Belize can significantly enhance its energy resilience and adaptive capacity. The authors carried out the analyses and wrote the paper during the preparation of the Energy Resilience for Climate Adaptation Project (ERCAP), which is an initiative by the Government of Belize (GoB) that is being supported by the World Bank with funding from the Special Climate Change Fund (SCCF) of the Global Environment Facility (GEF). The ERCAP is designed to assist the GoB undertake demonstrative measures and targeted pilot investments that would enhance energy resilience in the country, and could subsequently be mainstreamed and scaled-up for greater impact.

The paper primarily relies on information provided by the Belize Electricity Limited (BEL), the national power company in Belize. The authors wish to acknowledge the collaboration of BEL and a number of its officials in providing input to the paper. In particular, invaluable insights were provided by Ernesto Gomez (Senior Manager, Energy & Material Supply), Jose Moreno (Senior Manager, Transmission & Distribution, Safety & Environment), Derek Davies (Senior Manager, System Planning & Engineering), Rolando Santos (former Senior Manager, System Planning & Engineering), Kevin Longsworth (Manager, Control Centre), Herschel Armstrong (Senior Engineer- System Planning, Engineering and Design), Guadalupe Rosado (Superintendent, Northern Operations), Rodney Baird (Superintendent, Central Operations), and Khadija Usher (Trainee Engineer, Power Generation Planning). A number of other BEL personnel also provided comments during the various discussions and presentations around different versions of the paper. Additional guidance was provided by officials from the GoB including Colin Young (former CEO of Ministry of Energy, Science & Technology and Public Utilities (MESTPU)), Ambrose Tillett (Director for Energy), and Ansel Dubon (Project Coordinator). Noureddine Berrah (Energy Advisor Consultant) and Chrisantha Ratnayake (Senior Power Engineer Consultant) from the World Bank shared extensive insights in shaping the analyses. Xiaoping Wang (Senior Energy Specialist) and Pierre Audinet (Senior Energy Economist) from the Energy Sector Management Assistance Program (ESMAP), and Rawleston Moore from the Global Environment Facility (GEF), also provided input that is reflected in the document. Maite Lasa and Hua Du made important contributions during the preparation of the paper.

The paper also benefited from the financial support of the World Bank's ESMAP and the GEF, for which the authors are grateful. While many people provided valuable information and guidance, it is noted that the findings, interpretations, and conclusions expressed in this paper are entirely those of the authors and should not be attributed in any manner to the World Bank Group, to members of its board of executive directors or the countries they represent, BEL or the Government of Belize.

EXECUTIVE SUMMARY

Belize is an upper middle-income country that is located in the Caribbean Sea, making the country vulnerable to extreme weather and natural hazards. As global temperatures rise due to climate change, these extreme weather patterns are expected to intensify, increasing the risks.

Over the last century and half, there have been 57 hurricanes and tropical storms that have impacted Belize. This is in addition to the tropical monsoons routinely faced by the country. Models predict that there will be an increase in intensity of such storms in the Caribbean due to climate change.

The power system in Belize is particularly vulnerable to extreme weather and climatic risks. This report presents an analysis carried out by the World Bank working with Belize Electricity Limited (BEL), which reviewed two past hurricanes and a tropical storm, and evaluated its impacts on electricity supply. It considers the damages to infrastructure, revenue losses to the power company due to disruptions in service, and the overall economic impact of the unserved energy.

- Hurricane Dean, which struck Belize in 2007 was a fast moving storm with strong winds reaching 165 miles per hour causing significant damages along its path. The hurricane caused a near country-wide electricity blackout, and it took nearly a week before service was fully restored.
- Hurricane Richard, which made landfall in 2010, was a large storm that covered a wide swathe of the country with heavy precipitation. It had sustained winds of 90 miles per hour. The resulting damages to the transmission and distribution lines significantly reduced BEL's ability to dispatch its main hydropower stations that make up half the domestic installed capacity. The disruption in electricity supply affected over 35,000 customers (over 45% percent of BEL's total customer base).
- Tropical storms, such as Alex in 2010, are more common and frequently impact Belize. Tropical Storm Alex had wind gusts ranging from 40 to 63 miles per hour and brought with it heavy precipitation. It caused a number of damages to the distribution system that cut off customers depressing demand by about 10 percent. While tropical storms typically don't cause damages at the scale of more intense hurricanes, they disrupt electricity services with greater frequency.

The impact of extreme weather events on the power system leads to several types of financial/economic effects. They include the cost of repairing and rebuilding damaged electricity infrastructure, lost revenue to the utility due to the resulting electricity service disruptions, and the greater impact on broader economic activity because of the unserved energy. The infrastructure damage from hurricanes Dean and Richard were as much as half a million US dollars, which is significant for a utility the size of BEL. The wide-ranging outages resulted in revenue losses that exceeded a quarter million US dollars. However, the economic impact resulting from the value-added losses in GDP from the unserved energy is much higher, estimated to be as much as US$3–US$5 million for each hurricane. In comparison, the GDP impact from Tropical Storm Alex was over US$300K. The overall loss assessment due to Hurricanes Dean and Richard on the broader economy beyond the power sector impacts were estimated at over US$80 million and US$35 million respectively.

Addressing the vulnerabilities to extreme weather and climatic impacts is an economic imperative for Belize, and will require enhancing the resilience of the power sector. This implies strengthening the existing infrastructure and operational capabilities to minimize damages and disruptions during extreme weather events; and improving the capacity in the country to respond rapidly to and recover efficiently from the residual damages that would still occur.

Analyzing the sequence of events that led to some of the significant damages and service disruptions experienced during Tropical Storm Alex and Hurricanes Dean and Richard provides insights into some of the specific vulnerabilities in the power system. Several such *illustrations* are presented in this paper. These illustrations highlight the need to address several key vulnerabilities given past experience as well as potential events that have been avoided previously but could materialize in the near future.

- BEL's single backbone, radial transmission system needs to be adequately segmented in order to contain faults and prevent cascading outages – something that occurred during both Hurricanes Dean and Richard causing major service disruptions.
- There is a considerable need to strengthen the transmission structures and lines, especially sections where there is substantial weakening of wooden structures and corrosion in metal fittings. While a catastrophic collapse of the transmission lines have been prevented thus far due to an aggressive maintenance program conducted by BEL, progressive weakening of the lines poses a high risk of a major "downing " that would lead to significant outages and service disruptions.
- Several of the faults during Hurricanes Dean and Richard were caused by trees falling and damaging transmission lines. Vegetation related damages are a common occurrence that impact the distribution system during storms as well.
- While the impacts on the transmission lines were significant during the storms evaluated, a majority of the damages from extreme weather impact the distribution systems causing services to be disrupted. In fact, during Hurricanes Dean and Richard, about 90 percent of the recorded faults were in the distribution system. In Tropical Storm Alex, all faults were in the distribution system. Distribution damages were primarily due to fallen branches, downed poles, and tangled wires.
- Improving the speed and quality of response to emergency situations and efficient and effective recovery is essential for operating a resilient power system. At present, BEL has a Hurricane Preparedness Plan, but its restoration work following storms is done in a more ad-hoc basis. Its response during emergencies is also hampered due to an outdated communication system, inadequate access to damaged infrastructure, and limitations in systems operation capabilities.

The World Bank, with funding from the Global Environment Facility's (GEF's) Special Climate Change Fund (SCCF), is helping Belize enhance the resilience of its power system. The analysis presented in this report, along with engineering reviews and discussions with BEL and the government, helped identify and validate some of the key resilience enhancing measures that will be included in the Energy Resilience for Climate Adaptation Project (ERCAP).


Mexico
Belize
Guatemala
Honduras

1. BELIZE AT HIGH RISK FROM CLIMATE CHANGE

Climate Change poses considerable risks for the Caribbean region, and Belize is particularly vulnerable. Belize is an upper middle income country with a population of about 350,000 people and an approximate GDP of $4,600 per person. Adjacent to Mexico and Guatemala, its location exposes the country to the Caribbean Sea, making Belize prone to extreme weather and natural hazards. As global temperatures rise due to climate change, these extreme weather patterns are expected to intensify, progressively exposing Belize to greater climate risks. Along the coastal areas, this could be in the form of rising sea levels, increased intensity of tropical storms and hurricanes, more damaging floodings, rapid shoreline erosion, and saltwater intrusion. Climatic influences also affect the entire country beyond coastal areas, where fluctuations in rainfall, for instance, can undermine agricultural production and impact the reliability of hydroelectric generation.

Exposure to extreme weather, especially powerful hurricanes and tropical storms, highlights these vulnerabilities, as it has led to major setbacks in economic development and efforts to alleviate poverty. A significant number of hurricanes and tropical storms that traverse across the Caribbean make landfall in Belize before dissipating. Such storms are often accompanied by high winds that can damage infrastructure, significant precipitations that lead to flood damage, or a combination of both. Belize City, where a majority of the population resides, is a coastal town that is particularly vulnerable to high storm surges and inundation. The major tourist areas that generate considerable revenue for the country are also susceptible to disruption since most are located in the coastal areas along the Caribbean Sea. In 1961, Hurricane Hattie, which caused significant damages in Belize City, then the capital city of the country, resulted in costs that were estimated at 600 percent of GDP, and killed 400 people.[1] More recently, in 2000, Hurricane Keith caused damage exceeding 45 percent of GDP; and in 2001, during Hurricane Iris, storm surges submerged Belize City causing damages estimated at 25 percent of GDP.[2] Tropical Storm Arthur in 2008 also caused extensive damage to critical infrastructure as well as the agriculture sector.[3] Since 2000, no less than thirteen tropical storms and hurricanes landed in Belize (see Figure 1), and the frequency and intensity of such extreme weather events are likely to increase due to the impacts of climate change. This will further increase vulnerabilities as it stands to threaten lives as well as livelihoods in the country, preventing sustainable development. Considering that a significant portion of the population is poor or susceptible to falling into poverty, climate change impacts are sure to test the resilience of Belize in the future.

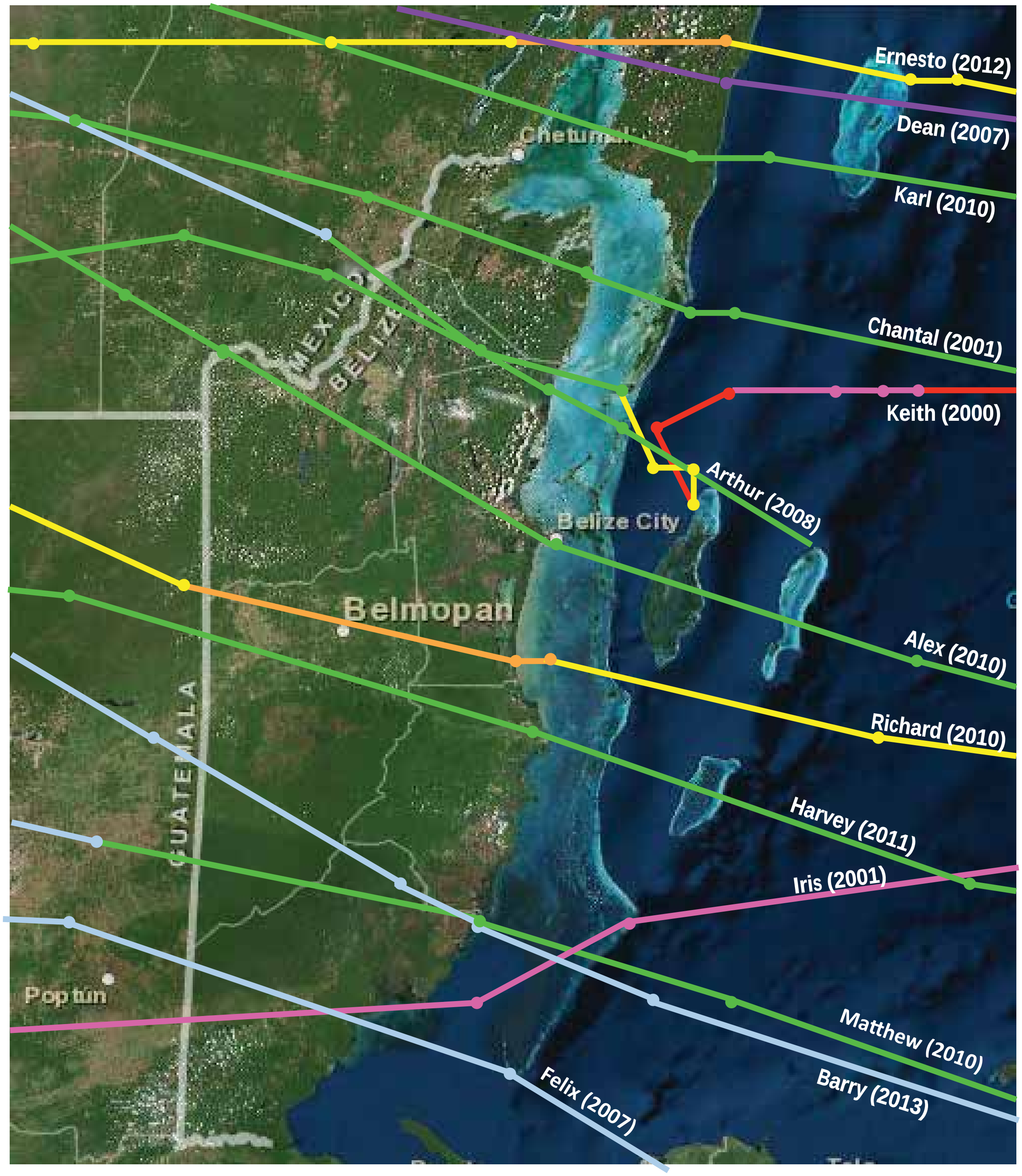
Such vulnerabilities have led the United Nations to identify Belize as one of the most susceptible countries in the world to climate change.

1 EM-DAT International Disaster Database, Centre for Research on the Epidemiology of Disasters (CRED)

2 World Bank, Country Partnership Strategy for Belize, July 2011

3 Ibid.

FIGURE 1. Trajectory of Hurricanes and Tropical Storms making Landfall in Belize
(Years 2000–15)



Storm Category:	H5	H4	H3	H2	H1	TS/SS	TD/SD
Wind speeds:	>156 mph	131–155 mph	111–130 mph	96–110 mph	74–95 mph	39–73 mph	<39 mph

Source: United States National Hurricane Center.

2. INCREASED RESILIENCE OF INFRASTRUCTURE IS ESSENTIAL

The resilience of infrastructure to extreme weather and climate risks, including in the energy sector, is critical for sustainable development. Adequate infrastructure services are essential for facilitating economic growth, in particular, to support key service sectors such as tourism and agriculture that drive the development in Belize's economy. The country's high debt levels and fiscal challenges in recent years have made it difficult to adequately invest in the construction and maintenance of roads, energy and water infrastructure. As a result, infrastructure resilience would be reduced without adequate adaptation measures to cope with future climate related risks. This has particular significance in the energy sector, especially electricity infrastructure, which is oftentimes severely affected by hurricanes and tropical storms. Therefore, appropriate investments are needed in order to ensure sustained power supply through resilient transmission and distribution infrastructure. The Government of Belize (GoB) has recognized such vulnerabilities, and sought the support of a number of development partners, including the World Bank, to identify and support investments that would increase the resiliency of the country's infrastructure. The Energy Resilience for Climate Adaptation Project (ERCAP) is part of the efforts that the World Bank is undertaking to support the country. The ERCAP will provide grant funds from the Special Climate Change Fund (SCCF) of the Global Environment Facility (GEF) to assist the GoB in undertaking demonstrative measures and targeted pilot investments that would enhance energy resilience and can subsequently be mainstreamed and scaled-up for greater impact.

The remainder of this paper focuses on vulnerabilities of the power sector infrastructure in Belize to extreme weather. More specifically, it will evaluate the impacts of two recent hurricanes and a tropical storm, on the electricity infrastructure and the disruptions in services that resulted. The paper then identifies specific areas of vulnerability in the power system in Belize, and potential solutions to address them. The analysis in the paper is carried out as a part of the preparation of the ERCAP; and contributed to the selection of initial pilot activities and investments that will be funded by the project.


ICE

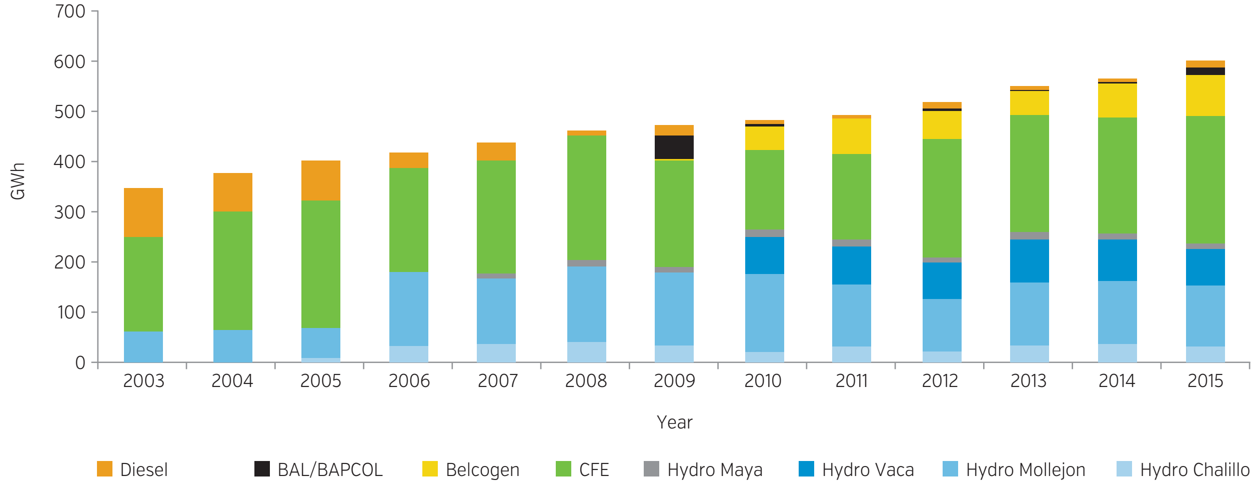
3. THE POWER SYSTEM IN BELIZE

The failure of the energy system can have significant economic ramifications and lead to important damages. The total installed power generation capacity in Belize is 110 MW, with additional capacity of up to 50 MW of imports available through a contractual arrangement with Mexico's power utility, Comisión Federal de Electricidad (CFE). Peak demand is around 86 MW,[4] with demand growing at approximately five percent per annum. Electricity is supplied through a domestic power generation mix that is comprised of hydropower (50 percent), diesel and fuel oil (38 percent), and biomass (12 percent), in addition to imports from Mexico. Belize Electricity Limited (BEL), the national power company, directly owns and operates 26 MW of diesel-based generation,[5] while it purchases the remainder from independent power producers (IPPs) and Mexico's CFE. The electricity generated domestically in 2015 accounted for 58 percent of the total electricity consumption: nearly 39 percent was from hydropower, 14 percent from biomass, 5 percent from diesel and fuel oil. The remaining 42 percent were imported from CFE. While the electricity supply arrangement with Mexico provides a reliable source, the Government of Belize (GoB) would like to utilize more domestic sources for power generation in order to enhance the country's energy security. While hydropower is an indigenous resource, droughts and changing rainfall patterns that are likely to be exacerbated by climate change, have raised reliability concerns about the dominance of the technology going forward. The concerns were partly allayed through the introduction in 2009 of 13.5 MW of generation capacity fired by sugar cane bagasse (biomass). The complementarity of hydropower and bagasse, due to its offsetting seasonality, enhances the resilience of the overall power system and improves the generation mix. Since most of the

4 Energy Report 2014, Government of Belize

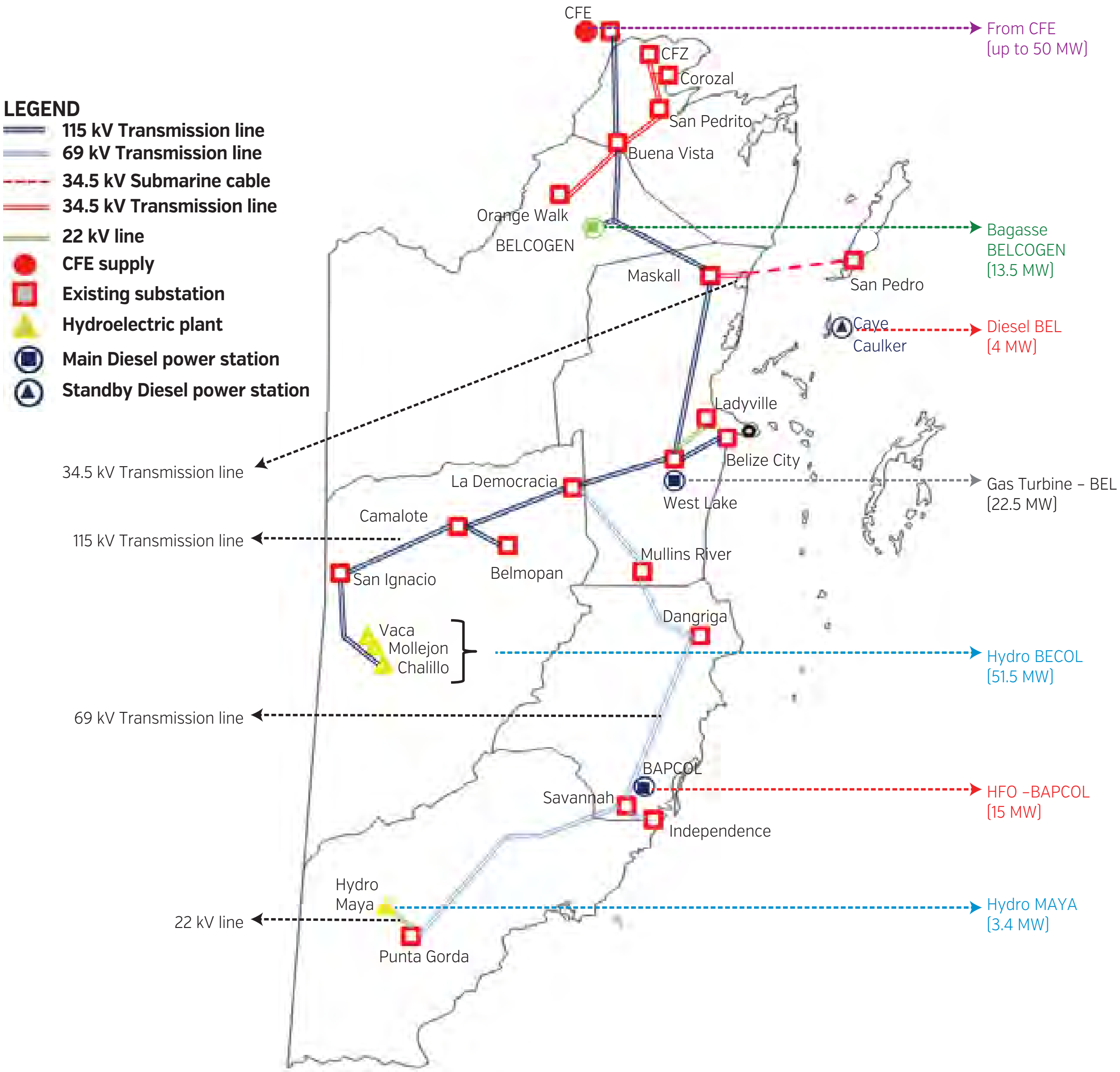
5 includes BEL's 22.5 MW gas turbine (GT) power plant that operates utilizing diesel.

FIGURE 2. Net Power Generation in Belize



Source: Belize Electricity Limited.

FIGURE 3. Diagram of the Generation and Transmission System in Belize (2016)



Source: Belize Electricity Limited.

sugar cane bagasse produced in Belize is already utilized, options for alternative crops suitable as a fuel for power generation are being considered.

The electricity in Belize is transported through a single circuit transmission network that extends about 400 miles across the country, feeding various distribution systems. As illustrated in Figure 3, the transmission system includes different voltage levels: 115 kV in the northern, central and western sections of the country, 69.5 kV in the central and south sections, a 34.5 kV in the northern section, and a 34.5 kV under-sea link to the San Pedro island from the Maskall substation.[6] The transmission link with Mexico is a 115 kV line with a rated capacity of 65 MW. The single circuit radial transmission network is also an important reliability concern. If one section is affected by faults or weather damages, the integrity of the whole network can be compromised,

[6] In addition, the Maya hydropower plant is connected through a 22 kV line to the transmission network.

as power from available generation units and/or CFE cannot be transmitted to consumers. BEL would then be forced to cut off load at some of the load centers and/or operate its diesel-based power plants at sizable costs. Another major concern with the transmission network arises from the progressively reduced structural strength of several sections of wooden poles due to corrosion degradation of laminated cross-arms in water logged and saline areas, wood decay, threats of bush fires and damage caused by woodpeckers. While BEL has not had any major transmission disruptions due to downed poles, the progressive weakening of parts of the system poses a considerable risk that could lead to major outages, especially during hurricanes with high winds. To address these challenges, BEL is undertaking an aggressive maintenance plan replacing poles where necessary in its transmission and distribution systems.

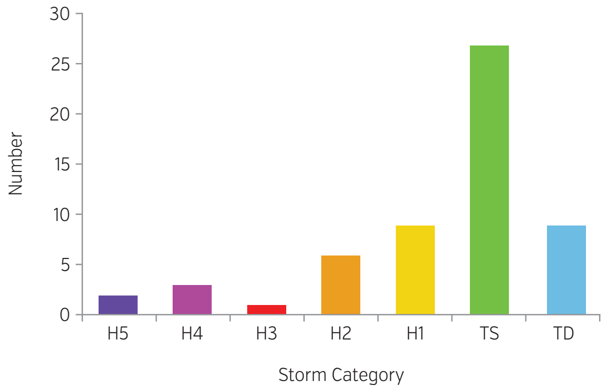
The electricity system in Belize also includes distribution networks operating at 22 kV, 11 kV and 6.6 kV in various towns throughout the country. They mostly operate without stress although some of the 22 kV lines are excessively long feeding distant areas and leading to low voltages. Areas of concern with regards to system vulnerability are: a) single supply substation with one step-down transformer to medium voltage supplying each city; and b) the distribution systems of the largest city (Belize City) and the capital city (Belmopan) are still primarily operated at respectively 6.6 kV and 11 kV networks[7]. If these issues are not adequately addressed, damages to the substations or sections of the transmission and/or the distribution networks during a hurricane could lead to widespread and prolonged outages.

[7] The newly developed 22 kV lines are mostly feeding the peripheral areas and not the central, inner cities.

4. VULNERABILITIES OF THE POWER SECTOR TO EXTREME WEATHER

Belize's power sector is already vulnerable to extreme weather events that are expected to be more intense and frequent due to climate change. The transmission and distribution system already sustain considerable damage during hurricanes and tropical storms. Without further strengthening and implementing response and recovery measures, the situation will worsen. Based on available data tracked since 1864, Belize experienced 21 hurricanes of which about a quarter were rated either category 4 or 5 with wind speeds in excess of 130 miles per hour, 27 tropical storms and 9 tropical depressions[8] (see Figure 4). The table in the following figure 5 provides the main characteristics of the thirteen extreme weather events that impacted Belize more recently since 2000. It does not include less severe storms and monsoon rains that occur yearly, which also impact the power system and progressively make it more vulnerable. A particular concern going forward is that future impacts could be much more frequent as the overall cyclone activity in the Caribbean and wider North Atlantic Basin has shown a dramatic increase since 1995. While attribution of these weather patterns to climate change is still under debate, both frequency and duration of Atlantic hurricanes displayed statistically significant increasing trends and there has been a sustained increase in the proportion of category 4 and 5 hurricanes in the recent periods.[9]

FIGURE 4. Number of Hurricanes and Storms by Category [since 1864]



Source: Authors based on data from the National Oceanic & Atmospheric Administration, United States Department of Commerce.

Evaluating past storm damage provides an indication of the vulnerabilities and impacts that may become even more severe in the future. Based on data gathered and documented by BEL during two past hurricanes and a tropical storm, the remainder of Chapter 4 attempts to identify the critical events that affected the power system, and evaluate the resulting impact on generation capacity and transmission and distribution failures that led to supply disruption (shortfall and duration) in electricity services. Estimating the economic costs resulting from the disruption in services and impact on end-users will provide a proxy for the development setbacks that arise from extreme weather events due to the vulnerabilities that exists in the power system in Belize.

Tropical Storm Alex

Tropical Storm Alex struck Belize with heavy rainfall. Alex made landfall in Belize City around 6:00 p.m. (2400 UT)[10] on June 26, 2010. All clear was declared by the Government of Belize (GoB) at 7:30 am (1330 UT) on the following day indicating that

[8] National Oceanic & Atmospheric Administration, United States Department of Commerce.

[9] Webster et al, "Changes in Tropical Cyclone Number, Duration, and Intensity in a Warming Environment", 2005.

[10] Universal Time.

FIGURE 5. Summary Table of Hurricanes and Tropical Storms that Impacted Belize (from 2000–14)

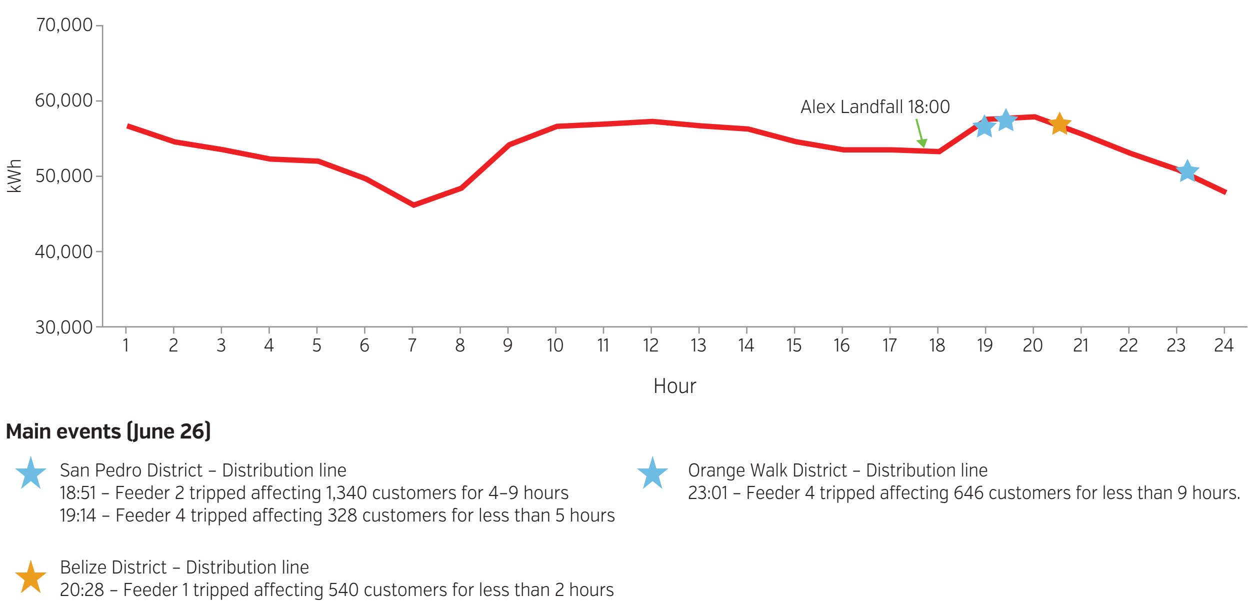
No	Hurricane Name	Year	Max Wind (mph)	Hurricane Category*	Districts along Storm Trajectory	Landfall	All Clear**
1	Keith	2000	138	H4	Belize, Orange Walk	9/30/00	10/04/00
2	Iris	2001	144	H4	Toledo	10/08/01	10/09/01
3	Chantal	2001	69	Tropical Storm	San Pedro, Corozal	08/21/01	08/21/01
4	Dean	2007	190	H5	Corozal (near southern Mexico)	08/21/07	08/21/07
5	Felix	2007	23	Tropical Depression	Toledo	09/04/07	09/04/07
6	Arthur	2008	46	Tropical Storm	Belize, Orange Walk	05/31/08	06/02/08
7	Alex	2010	63	Tropical Storm	Belize, Orange Walk	06/26/10	06/27/10
8	Karl	2010	63	Tropical Storm	Corozal (near southern Mexico)	09/15/10	09/16/10
9	Matthew	2010	40	Tropical Storm	Stan Creek, Toledo, Cayo	09/25/10	09/25/10
10	Richard	2010	98	H2	Belize, Cayo, Orange Walk	10/24/10	10/25/10
11	Harvey	2011	63	Tropical Storm	Stan Creek, Cayo	08/20/10	08/20/10
12	Ernesto	2012	98	H2	Corozal (near southern Mexico)	08/07/12	08/08/12
13	Barry	2013	35	Tropical Depression	Stan Creek, Toledo, Cayo	06/17/13	06/18/13

Source: National Oceanic and Atmospheric Administration, United States Department of Commerce.
*Category: based on the Saffir-Simpson scale.
** All Clear: National Emergency Management Organization declares "All Clear" when hurricane has passed and there is no substantial risk.

the danger from the storm had passed. As with many storms that impact Belize, Alex took a northern turn as it moved west towards Mexico with wind gusts measuring 40–63 mph. Within Belize, it impacted the districts of Belize, Orange Walk, and Corozal.[11] Most of the country experienced heavy rains as a result of Alex. For example, near the Pine Ridge Mountain

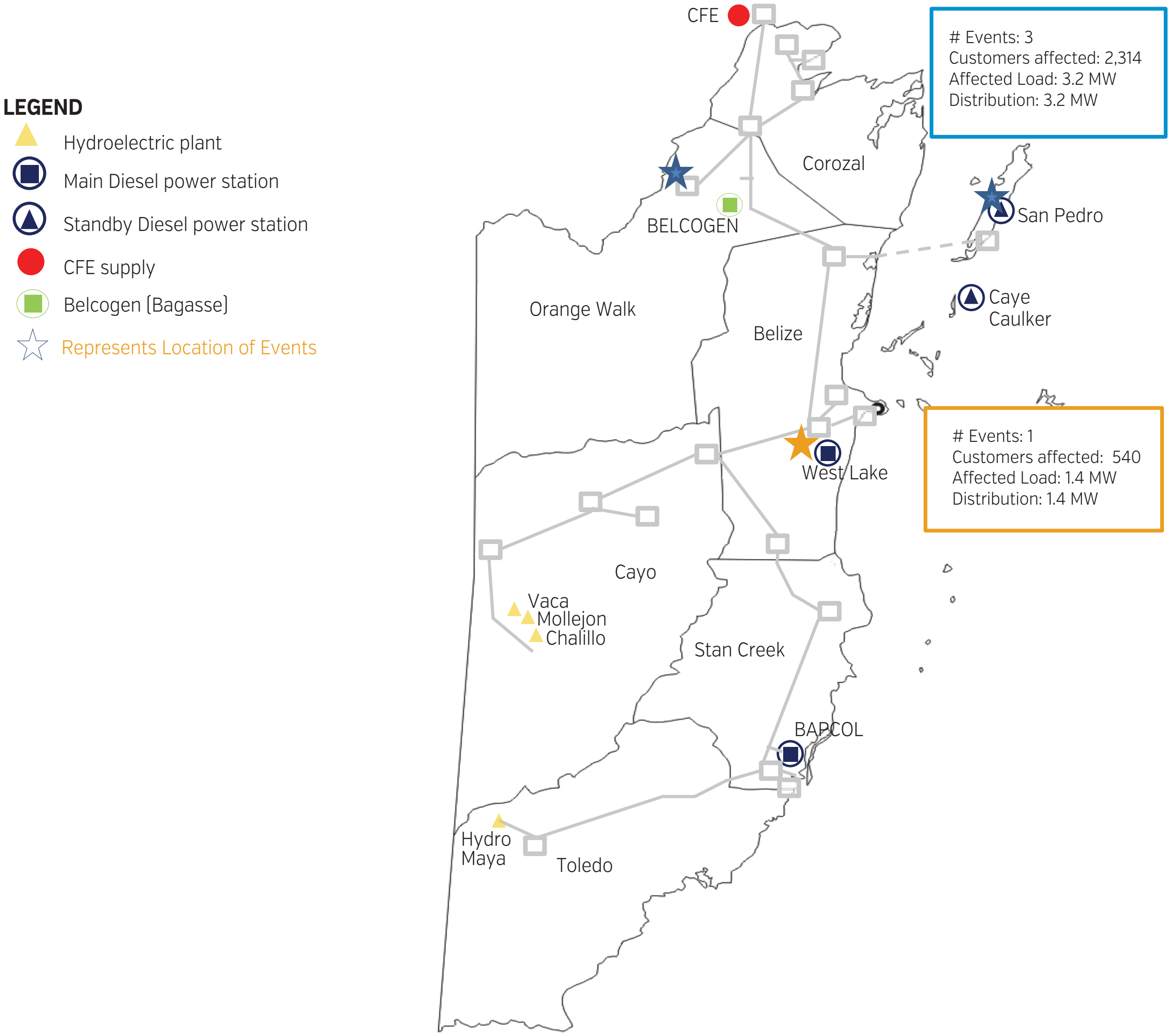
[11] "Situation Report, Tropical Storm Alex Impacts Belize", the Caribbean Disaster Emergency Management Agency (CDEMA).

FIGURE 6. Impact of Tropical Storm Alex on Hourly Dispatched Electricity Generation



Source: Belize Electricity Limited.

FIGURE 7. Location and Impact of Tropical Storm Alex on Power System



Source: Belize Electricity Limited.

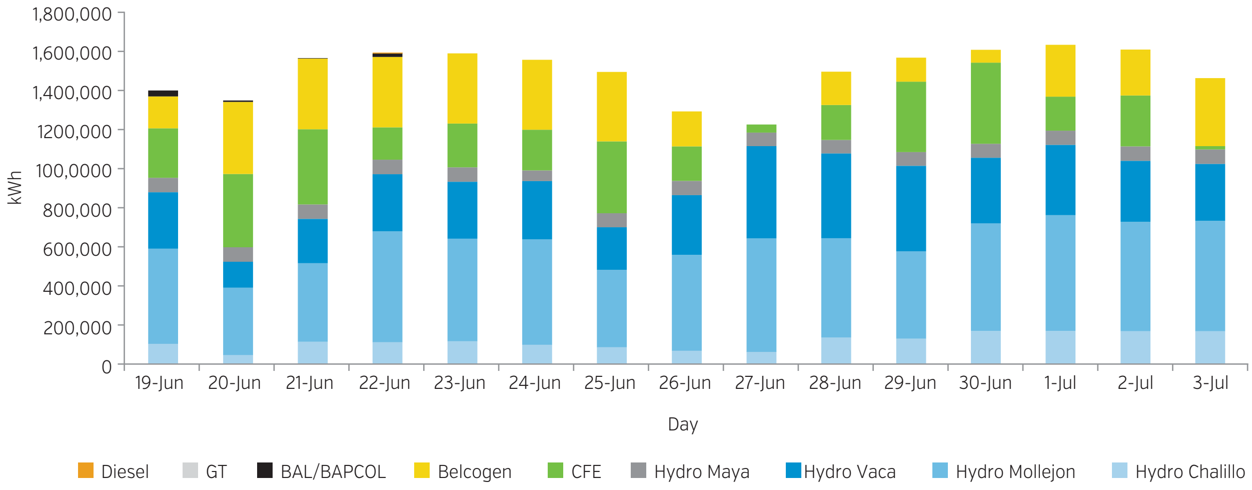
close to where most of the hydropower in the country is generated, 180 millimeters (mm) of rain was measured on the day Alex made landfall exceeding the average rainfall for the entire month of June, which is 123 mm.[12] As a result, the Macal, Mopan, and Belize Rivers were forced to flood.[13]

Alex's impact on the power system was not widespread, but electricity dispatch was reduced as a result of distribution system faults. While the transmission system did not sustain significant damages due to Alex, the distribution system experienced four faults recorded by BEL's dispatch center. As seen in **Figure 6**, there was a steady increase in load towards the normal evening peak as Alex made landfall. However, the storm caused several distribution faults that led to outages cutting off nearly 3,000 customers, some as long as nine hours. As a result, the evening demand was depressed by about 15% compared with the previous week. As illustrated in **Figure 7,** the first faults

[12] "Tropical Storm Alex the first named storm of the 2010 Atlantic Hurricane Season", Technical, National Meteorological Service (NMS), Belize, 2010.

[13] Ibid.

FIGURE 8. Daily Electricity Generation by Power Plant during Tropical Storm Alex



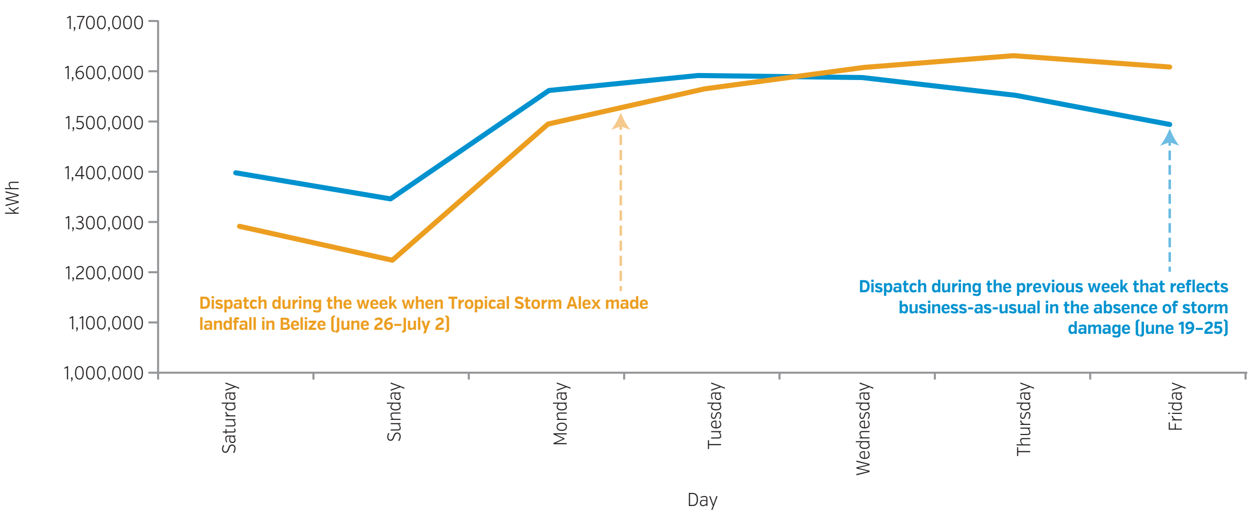
Source: Belize Electricity Limited.

were reported in the island of San Pedro, followed by others in the districts of Belize and Orange Walk. Primary causes of the faults were tripped feeders and damaged distribution poles resulting in outages that ranged from 2 to 9 hours.

Power outages during Tropical Storm Alex reduced weekly electricity consumption by nearly 10 percent, compared to a week earlier. Figure 8 shows about 10 percent decreases in total daily electricity generation on June 26th and 27th (the day of landfall and the following day) compared with the same days during the previous week (June 19th and 20th). This decrease can be attributed to the reduction in load as due to service interruptions as well as consumers curtailing activities (i.e. closure of stores and firms) as a result of the storm. The suppressed demand lasted for about 22 hours.

As demand recovered the day after Alex's landfall, BEL supplanted power generated from biomass

FIGURE 9. Dispatch Comparison during Tropical Storm Alex and Business-As-Usual Scenario



Source: Belize Electricity Limited.

and electricity imports due to increased availability of hydro as a result of the storm. Figure 8 shows that the daily generation by the major power plants of the system during the week before and after Alex's landfall. The storm related faults during the evening of June 26th resulted in a decrease in demand, which led BEL to reduce dispatch from CFE and suspend dispatch from Belcogen although both generation sources remained operational: (a) Belcogen's generation fell from 355,404 kWh on June 25th, the day before the landfall, to 179,714 kWh on June 26th, the day of the landfall, and was reduced to zero on June 27th, the day following landfall. Belcogen's generation levels remained noticeably reduced until June 30th before dispatch began to increase; and (b) CFE imports from Mexico fell from 366,680 kWh on June 25th, the day before the landfall, to 175,410 kWh on June 26th, the day of the landfall, then to 41,560 kWh on June 27th, the day after the landfall. CFE imports peaked again when it reached 413,950 kWh on June 30th. As the hydro levels topped off the reservoirs during Tropical Storm Alex, BEL continued to utilize more than 1,000,000 kWh of hydropower each day for at least an additional week since it would have been the least cost option based on the merit order of dispatch.

The estimated loss of revenue incurred by BEL amounted to over BZ$ 100,000 (US$ 50,000). Figure 9 shows the daily energy generation during the week of Alex's landfall and the preceding week. The unserved energy due to Alex is estimated as the difference between the energy dispatched during June 26th and July 2nd, the week of Alex's landfall, and the energy dispatched during the previous week of June 19th and 25th that was unaffected by the storm. The unserved energy during this period amounted to 115,913 kWh, resulting in an estimated BZ$ 51,813[14] (US$ 25,907)[15] of lost revenue for the utility, based on BEL's 2010 average sales price of BZ¢ 45/kWh[16] (US¢ 22/kWh).

The impact of the unserved energy on GDP is estimated at about BZ$ 670,000 (US$ 335,000). Belize's 2010 nominal GDP was BZ$ 2,794,226,900 (US$ 1,397,113,450)[17] and BEL's total net generation of electricity was 483,270,087 kWh indicating that the value added to GDP per kWh is BZ$ 5.78 (US$ 2.89).[18] On this basis, the loss of GDP value-added to Belize as a result of unserved energy due to Alex is estimated at BZ$ 670,199 (US$ 335,100).[19]

Hurricane Dean

Dean was a Category 5 hurricane with high-speed winds but with minor rainfall. Hurricane Dean landed along the Yucatan Peninsula near the town of Mahahual on Mexico's Caribbean Coast, about 50 miles northeast of Corozal Town in northern Belize on August 21, 2007 at 1:45 a.m. (0745 UT). The GoB declared "all clear" at 1:00 p.m (1900 UT) on the same day. Dean was a fast moving category 5 hurricane with maximum sustained winds of about 165 miles per hour. Due to the rapid westward motion of Hurricane Dean, the accumulated rainfall over northern Belize was not as significant as forecasted.

Instantaneous and significant impacts brought the power system to almost a total blackout. Dean's impacts on the power sector have been reviewed and quantified based on BEL's internal reports, which record all the events affecting supply and dispatch of power during the operation of the system. **Figure 10** shows that the system began experiencing problem about two hours prior to Hurricane Dean's landfall as distribution lines failed to sustain the high-speed winds. In the first six hours of the manifestation of Dean (and about four hours after its landfall), the dispatched energy decreased by more than half (from about 41,717 kWh to about 16,224 kWh) mainly due to the failure of distribution lines. The system began to recover, but soon the failure of a transmission line brought the system to an almost total blackout.

Most of the problems in the power system during Hurricane Dean were located in the northern region, in the vicinity of where it made landfall. Figure 11 shows that most of the documented events by BEL's dispatch center (10 out of 13) were located in the northern region of the country,

[14] BZ$ 0.447/kWh (average 2010 sales price/kWh rounded up to three decimals) * 115,913 kWh;

[15] the exchange rate used in this paper for 2007 and 2010 is BZ$ 2 = US$ 1, based on the World Bank Development Indicators for official exchange rates.

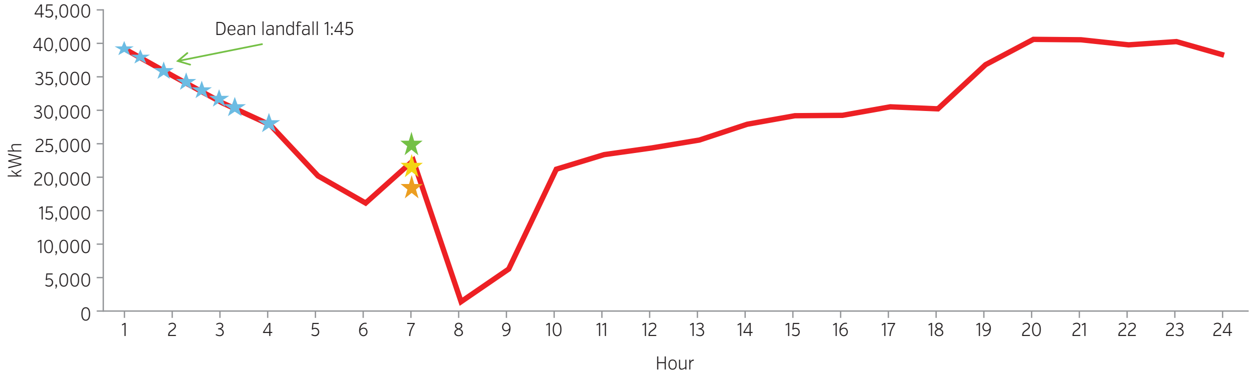
[16] BZ$ 190,526,000 (BEL's 2010 annual revenue) / 426,233,000 kWh (BEL's 2010 total sales in kWh).

[17] World Bank Development Indicators, GDP (current US$).

[18] US$ 1,397,113,450 (Belize's 2010 nominal GDP) / 483,270,087 kWh (BEL's 2010 total net electricity generation)

[19] US$ 2.89/kWh (GDP value-added per kWh, rounded to two decimals) * 115,913 kWh.

FIGURE 10. Impact of Hurricane Dean on Hourly Dispatched Electricity Generation



Main events (August 21st)

San Pedro District – Distribution line
00:32 – Feeder 1 tripped affecting 870 customers for 23 hours
00:47 – Feeders 2, 3 & 4 tripped affecting 3,139 customers for 14 hours

Corozal District – Distribution line
01:12 – Feeder 1 tripped affecting up to 3,277 customers for 4 to 6 days
01:57 – Feeder 2 tripped affecting 2,063 customers for 4 days
02:12 – Feeders 3, 4 & 5 tripped affecting up to 5,426 customers for 4–6 days

Orange Walk District – Distribution line
02:36 – Feeder 1 tripped affecting 450 customers for 19 hours
02:50 – Feeder 4 tripped affecting 612 customers for 33 hours
03:35 – Feeders 2 & 3 tripped affecting 4,782 customers for 18 hours

Cayo, Belize, Toledo and Stan Creek Districts – Transmission line
06:23 – System outage in various districts affecting 49,525 customers for 2–4 hours

Source: Belize Electricity Limited.

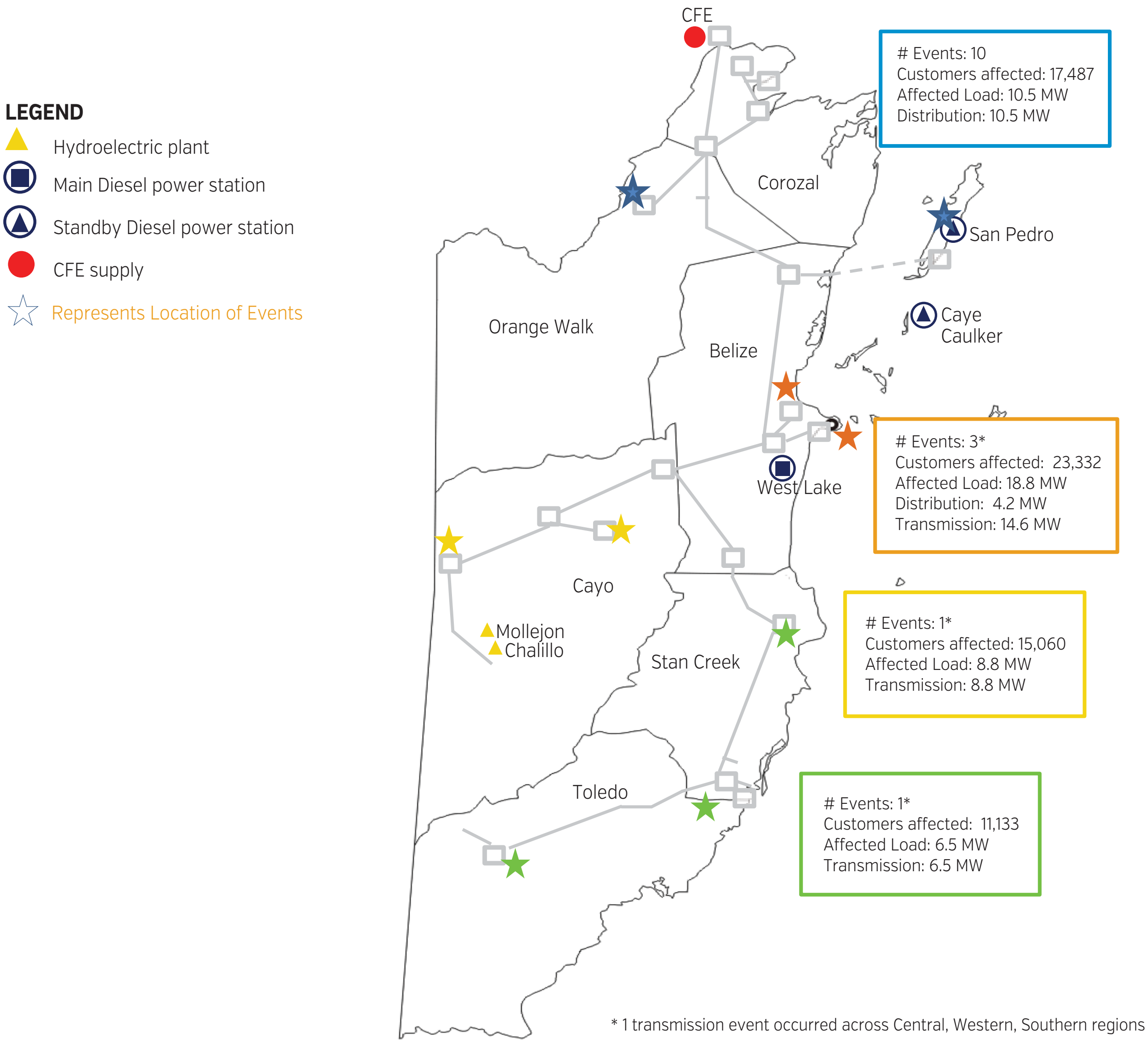
where the highest wind speeds were recorded and where the electricity system is more vulnerable to extreme weather conditions due to the lack of segmentation. The rest of events were located in the Central (Belize and Ladyville systems), Western (Belmopan and San Ignacio systems) and Southern regions (Dangriga, Independence and Punta Gorda systems).

Hurricane Dean affected BEL's daily generation mix, significantly increasing the cost of supply. Figure 12 shows the daily generation by the major power plants of the system during the week before and the week after Hurricane Dean's landfall. The total generated electricity on Tuesday August 21st (day of landfall) was about 54 percent of the previous and following Tuesdays' generation. The shortfall of generated electricity was mainly due to: (a) the interruption of imports from Mexico as Hurricane Dean caused a supply cut by 96 percent, compared to the previous week's supply. On August 22nd, imports resumed but at a lower level as they amounted to about 42 percent of the imports compared with August 15th and about 54 percent of the imports on the day before the landfall; and (b) the disruption of hydropower generation as the electricity generated by the Chalillo and Mollejon hydropower plants could not be dispatched due to transmission and distribution failures. On August 21st, the generation from the Chalillo hydropower was reduced by 120,559 kWh (78 percent less from the previous week), and generation from Mollejon hydropower plant was reduced by 247,729 kWh (40 percent less than the previous week).

BEL fell back on diesel-fired units to minimize the impact of the lost imports and hydropower generation. To compensate for the loss of imports and reduction of hydropower generation on August 21st and 22nd, BEL operated its diesel fired gas turbine to generate 178,176 kWh and 272,384 kWh respectively and its diesel unit to generate 43,861 kWh and 63,518 kWh respectively. On August 23rd, imports increased to 775,610 kWh, a 42 percent increase from the previous week before returning to average levels, as hydropower generation was dispatched to levels preceding the landfall of Hurricane Dean.

The disruption was sudden but the recovery was slow. Figure 13 presents the daily power generation showing the sudden disruption of the daily power supply caused by Hurricane Dean and the slow recovery as the system did not reach the daily dispatched

FIGURE 11. Location and Impact of Hurricane Dean on Power System

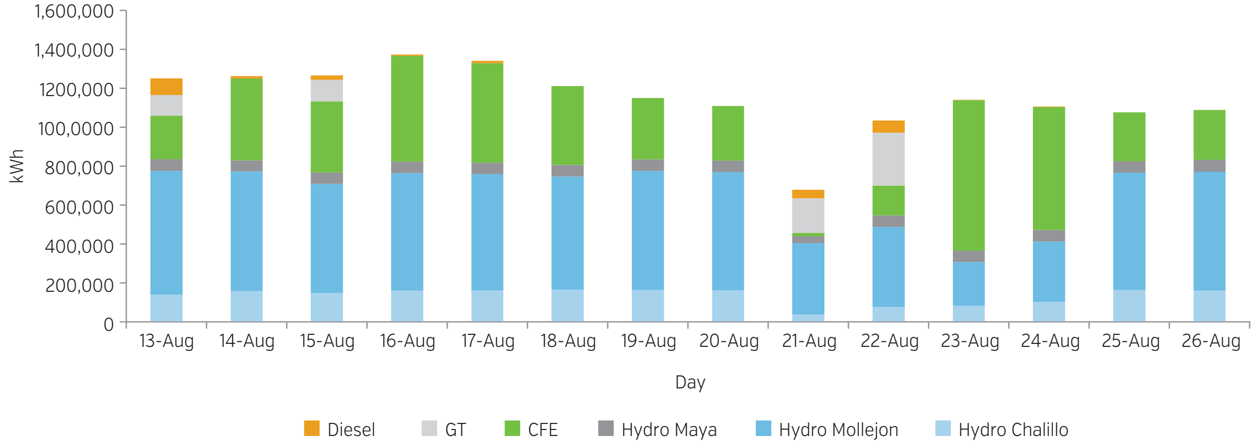


Source: Belize Electricity Limited.

electricity level until August 27th, 6 days after the hurricane reached landfall. In the San Pedro area, BEL pointed out that it took them 24 hours to solve the problems with the feeders and 4 to 6 days to restore power supply in the severely affected Corozal area. However, restoration of supply was not fully achieved in the San Pedro area as the local news reported[20] that by August 24th there were still few customers on the north side of the island without electricity. The situation in the Corozal and Orange Walk districts imposed more drastic measures as the National Emergency Management Organization (NEMO) decided on August 21st to impose a nighttime curfew from 8:00 pm (August 21st) until 6:00 am (August 22nd). On August 22nd, the Corozal district was still on a blackout and power was restored to only 50 percent of customers in Corozal town by August 24th. The north of Orange Walk district was also affected by failures of feeders and suffered blackouts. It took 33 hours to fully restore electricity supply.

[20] Great Belize Television/Channel 5, "B.E.L. reports progress in restoring power", August 24, 2007.

FIGURE 12. Daily Electricity Generation by Power Plant during Hurricane Dean



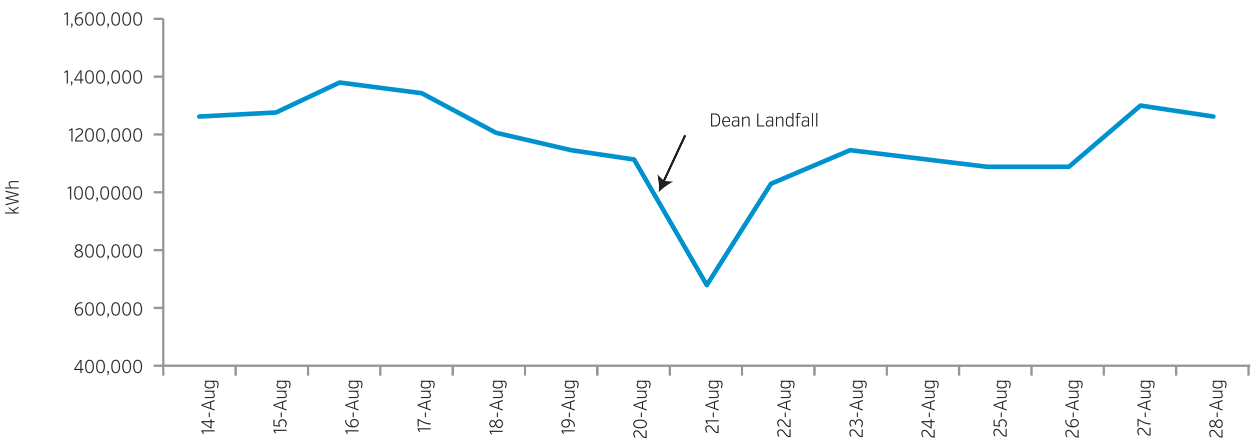
Source: Belize Electricity Limited.

Most of BEL's reported events were related with distribution system failures and led to significant amounts of un-served energy. Twelve out of the reported 13 events were related to distribution system failures. The failures in the Northern region (Corozal, Orange Walk and San Pedro systems) were the most acute, with 17,487 customers identified as being affected (24 percent of total BEL's customer base). The Corozal system was the most affected of the three regions with an estimated 7,634 customers losing power. It took 4 to 6 days to fully repair the Northern system.

Transmission failures were fewer and shorter but they impacted higher numbers of customers. At 6:23 am on August 21st, failures of the transmission lines in the Western, Central and Southern systems affected all the feeders. The power outages lasted from 2 to 4 hours and affected 49,525 customers, about 68 percent of BEL's customer base.

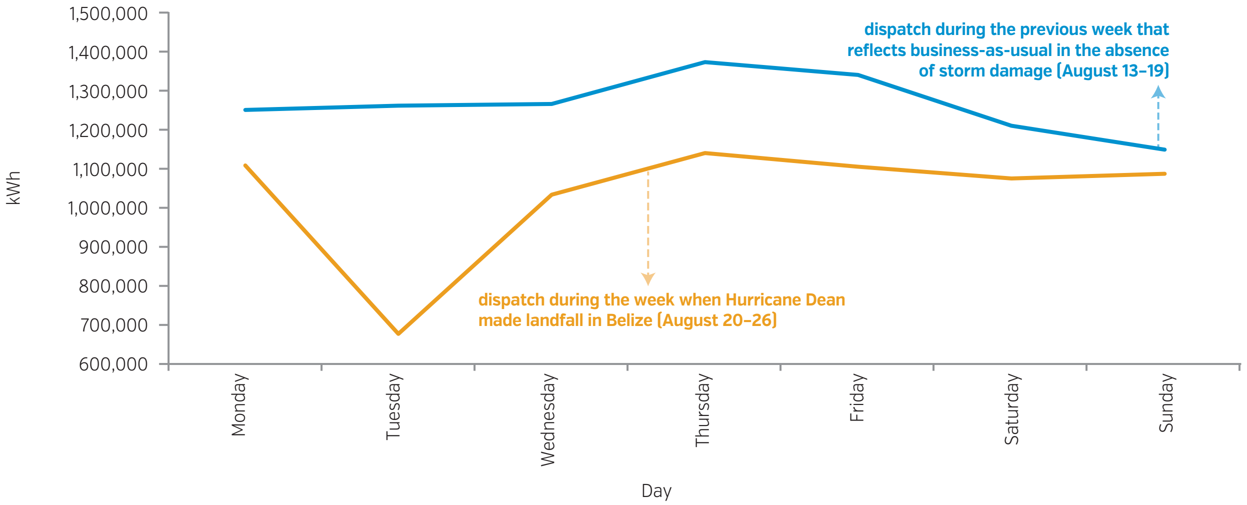
The estimated loss of revenue incurred by BEL amounted to nearly BZ $700,000 (US$ 350,000). The estimated un-served energy due to Hurricane Dean can be estimated as the difference between the energy dispatched from the 13th to 19th of August (the week preceding Dean when there would have been a more normal consumption pattern) and the energy dispatched from August 20th to 26th of August when the hurricane was impacting Belize. **Figure 14**

FIGURE 13. Daily Dispatched Electricity as Hurricane Dean made landfall



Source: Belize Electricity Limited.

FIGURE 14. Dispatch Comparison during Hurricane Dean and Business-As-Usual Scenario



Source: Belize Electricity Limited.

shows the energy dispatched during these two weeks. The estimated un-served energy as a result of Hurricane Dean amounted to 1,624,100 kWh valued at the 2007 BEL's average sale price of BZ¢ 42/kWh[21] (US¢ 21/kWh). BEL's loss of revenue is estimated at BZ$ 678,979[22] (US$ 339,490).

An initial macro assessment of the damages due to Hurricane Dean indicated that the broader GDP losses resulting from unserved energy is closer to BZ$ 10 million (US$ 5 million). In 2007, Belize's nominal GDP amounted to BZ$ 2,581,085,100 (US$ 1,290,542,550)[23] and BEL's total net generation of electricity was 438,708,589 kWh, indicating that a kWh consumed generated added BZ$ 5.88 (US$ 2.94)[24] value to the GDP. On this basis, the lost value added to GDP during Hurricane Dean due to power outages is therefore estimated at BZ$ 9,555,182 (US$ 4,777,591).[25]

Economic losses are well beyond the damages incurred by BEL and the power system. The preliminary Damage Assessment and Needs Analysis (DANA) report issued by the Public Utilities Commission, estimated the damages to the BEL at BZ$1 million (US$ 0.5 million). They are in line with the damages reported in BEL's 2007 annual report. Additional detailed damage assessments were not carried out by BEL or the GoB thereafter. However, the Economic Commission for Latin America and the Caribbean (ECLAC) "Macro socio-economic assessment of the damage and losses caused by hurricane Dean", published December 17, 2007, estimated the total impact of the hurricane (damages & losses) to the economy at BZ $179 million (US$ 90 million), about 7% of GDP. Damages to assets and stocks represented 53% of the total while losses accounted for the remaining 47%.

Hurricane Richard

Richard was a hurricane with strong winds and heavy rainfall. Hurricane Richard made landfall on October 24, 2010, 20 miles south of Belize City, at approximately 5:00 p.m. (2300 UT) and followed a westerly track through Belize and Cayo districts before crossing to Guatemala. The "all clear" was declared by the GoB at 6:30 a.m. (1230 UT) on the following day. Richard was a Category 2 hurricane with sustained winds of 90 miles per hour and recorded gusts of 115 miles per hour. Much of the

21 BZ$ 159,600,000 (BEL's 2007 annual revenue) / 381,759,000 kWh (BEL's 2007 total sales in kWh).

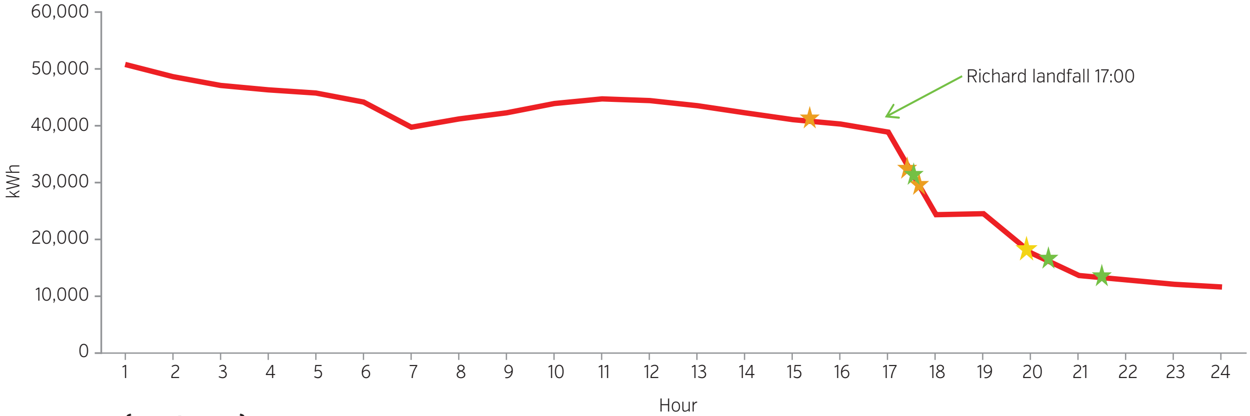
22 BZ$ 0.418/kWh (average 2007 sales price/kWh rounded up to three decimals) * 1,624,100 kWh.

23 World Bank Development Indicators, GDP (current US$).

24 US$ 1,290,542,550 (Belize's 2007 nominal GDP) / 438,708,589 kWh (BEL's 2007 total net electricity generation).

25 US$ 2.94/kWh (GDP value-added per kWh rounded to two decimals) * 1,624,100 kWh.

FIGURE 15. Impact of Hurricane Richard on Hourly Dispatched Electricity Generation



Main events (October 24)

Belize District – Distribution line: System restoration, HV lines, affecting:
14:30 – 623 customers for 3 days
16:47 – 7,252 customers for 1–2 days
16:52 –5,003 customers for 2 days
17:03 – 8,061 customers for 1 day
17:13 – 540 customers for 3 days

Toledo District –Transmission line
16:56 – fallen tree affecting 3,492 customers in Punta Gorda for 1 day

Stan Creek District
Transmission lines
16:56 – fallen tree affecting 3,382 customers in Independence (1 day)
1,039 customers in Dangriga and Mullins systems (3–4 days)

Distribution line: System restoration, HV lines affecting:
19:41 – 1,697 customers for 1–2 days
20:55 – 2,539 customers during 1 day

Cayo District
Transmission lines
19:23 – Fall of poles and tangling of wires affect 9,300 customers during 1–2 days in San Ignacio

Distribution lines
19:23 – Feeder failures affecting 6,726 customers for 1–2 days

Source: Belize Electricity Limited.

damages associated with Hurricane Richard were caused by the strong winds and heavy flooding that covered most of the country.

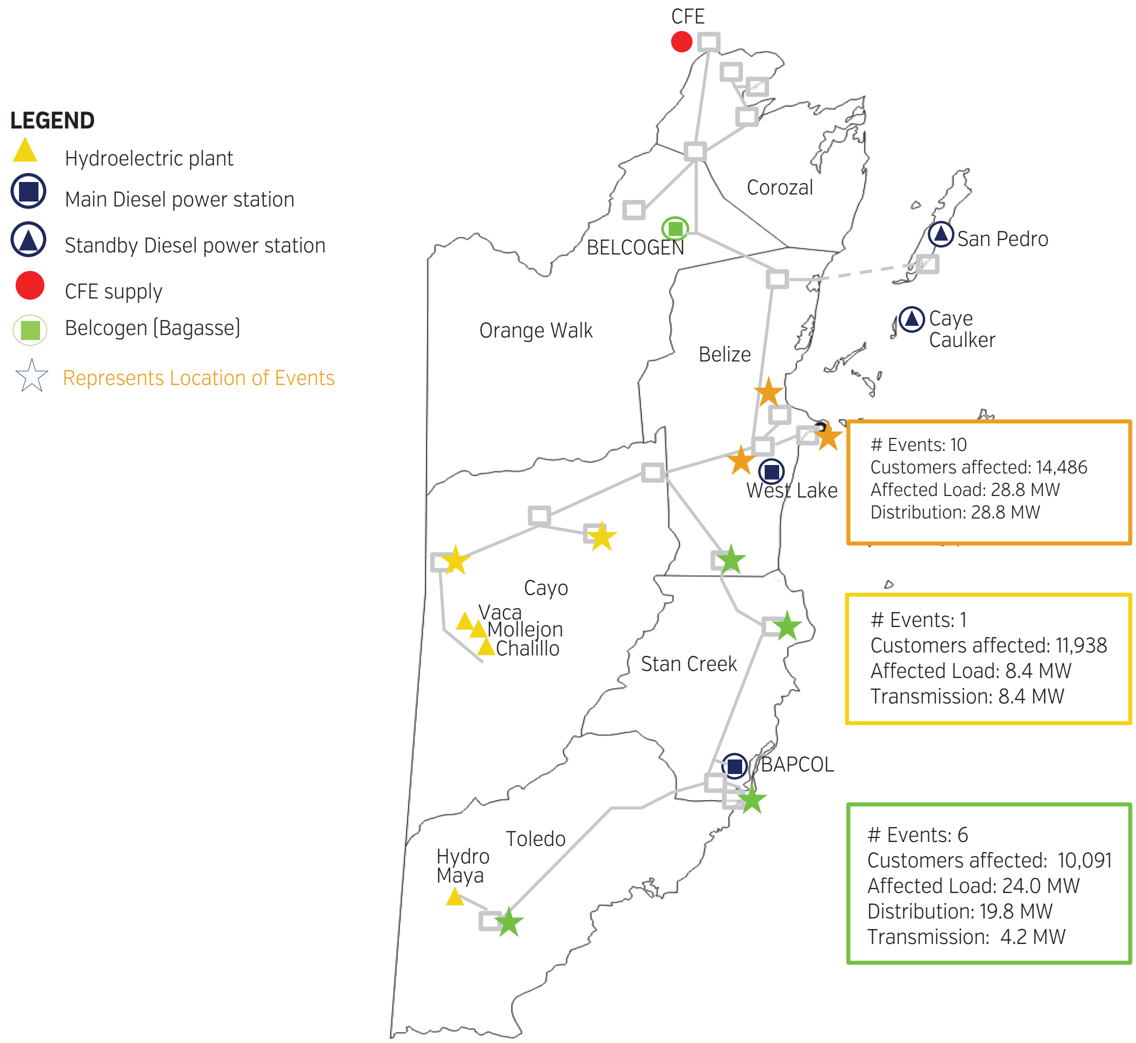
Hurricane Richard brought the power system to a near blackout in about 6 hours. Figure 15 shows that the system began experiencing problems about two hours prior to the landfall of Richard due to problems on high voltage (HV) lines around the Ladyville area in Belize district. As soon as the hurricane landed, a chain of events drastically reduced the hourly generation from 40,095 kWh to about 13,494 kWh in just five hours. Most of the issues were related with system restoration outages and with problems in the distribution and transmission lines caused by fallen trees, poles knocked down and wires tangled as a consequence of high speed winds.

Richard affected mainly the central and western regions through Belize and Cayo districts towards Guatemala. As shown in **Figure 16**, most of the documented events by BEL's dispatch center (11 of 17) were located in the central and western regions of the country. The westerly track of the hurricane caused major blackouts in the central regions (Belize, Ladyville and Mullins River systems) and the Western regions (Belmopan and San Ignacio systems). The remaining 6 events were located in the Southern region (Dangriga, Independence and Punta Gorda systems).

The damages in the power system persisted for several days following Richard's landfall. Some of the documented events by BEL's dispatch center (9 of 17) occurred during the four days following Richard's landfall on October 24th. On October 25th, the Southern regions (Independence, Dangriga and Punta Gorda systems) suffered complete blackouts due to failures of distribution lines. On October 27th, the power in the Central region (Ladyville and West Lake systems) was interrupted to repair a faulty HV line. Finally, on October 28th, a large area in Belize suffered power outages due to a faulty insulator damaged by the Hurricane.

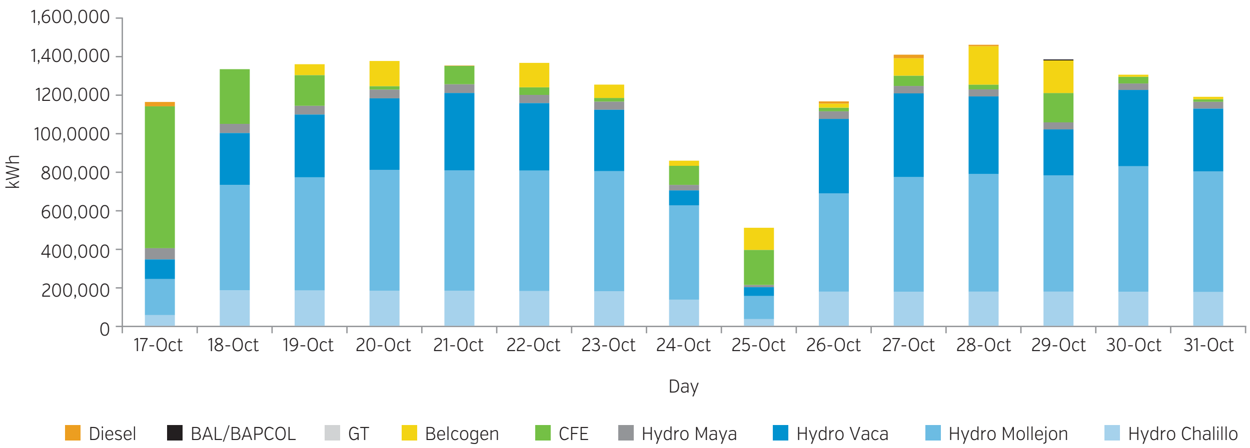
Hurricane Richard affected severely BEL's hydropower generation, interrupting the dispatch from

FIGURE 16. Location and Impact of Hurricane Richard on Power System



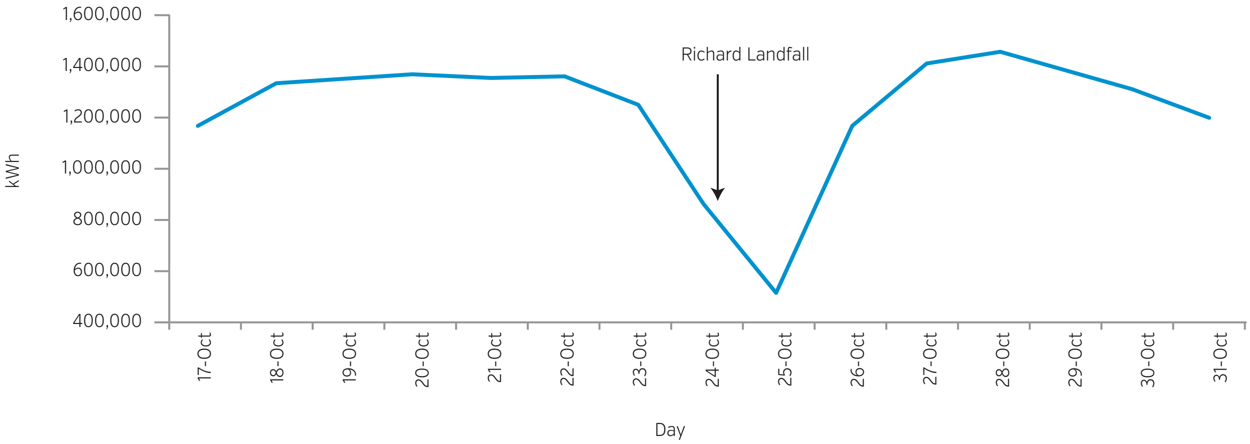
Source: Belize Electricity Limited.

FIGURE 17. Daily Electricity Generation by Power Plant during Hurricane Richard



Source: Belize Electricity Limited.

FIGURE 18. Daily Dispatched Electricity as Hurricane Richard made Landfall



Source: Belize Electricity Limited.

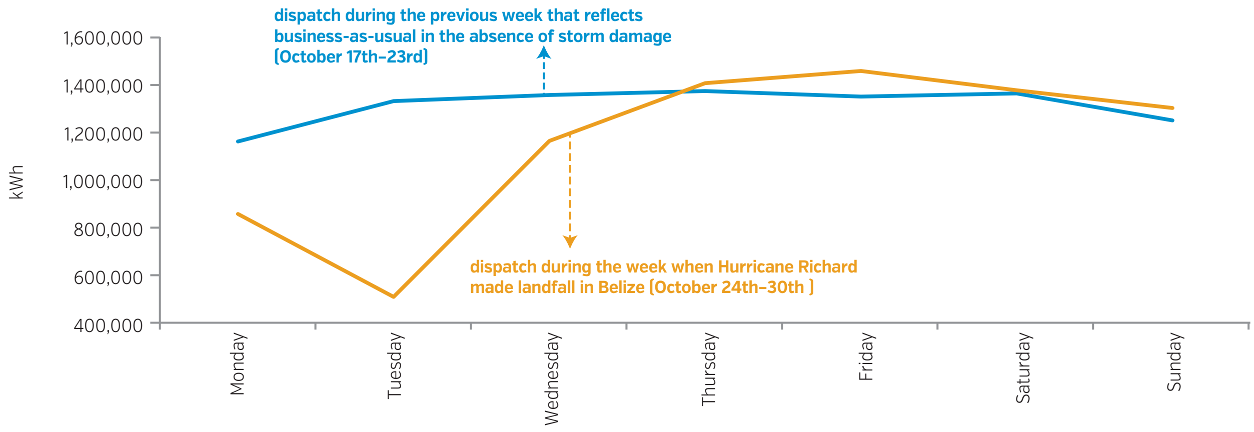
all of the hydropower plants and impacting the daily generation mix. Figure 17 shows the daily generation by the major power plants of the system during the week before and the week after Richard's landfall. The total generated electricity on October 24th and 25th when Hurricane Richard made its impact in Belize, were respectively 74 and 38 percent of the electricity generated during the previous week on October 17th and 18th.

The shortfall of generated electricity was mainly due to the system's inability to dispatch hydropower. In comparison to the same day during the following week on October 31st, the day When the hurricane made landfall on October 24th, the electricity generated at Hydro Chalillo was 39,514 kWh less (23 percent less), at Hydro Mollejon was 136,325 kWh less (22 percent less), and at Hydro Vaca was 248,586 kWh less (76 percent less). The generation of all the hydropower plants were interrupted on October 24th; Hydro Vaca was fully interrupted for 4 hours, Hydro Mollejon for 20 hours, Hydro Chalillo for 23 hours , and Hydro Maya for 26 hours. The decrease in hydro generation was even more severe on October 25th; in comparison to the same day during the previous week on October 18th, Hydro Chalillo's generation was reduced by 149,282 kWh (81 percent), Hydro Mollejon's was reduced by 427,762 kWh (78 percent) and Hydro Vaca's generation was reduced by 222,734 kWh (83 percent) .

BEL compensated the loss of hydropower generation by increasing imports from CFE, and generation from Belcogen and diesel engines. To compensate for the loss of hydropower generation on October 24th and 25th, BEL increased the imports from CFE until October 25th before the hydropower generation was almost restored. On the 25th of October, generation of Belcogen was increased to 114,371 kWh from 26,573 kWh of the previous day to minimize the impact of hydropower generation losses. On October 26th, 27th and 28th, BEL relied on diesel engines to meet local demand of electricity, generating as much as 19,191 kWh per day.

Like Hurricane Dean, Hurricane Richard's disruption was sudden and the recovery slow. Figure 18 presents the daily power generation showing the sudden disruption of power supply caused by Richard and the slow recovery, as the system did not reach the normal daily generation of electricity until October 27th. From 6 pm on October 24th until the same time on the following day, the generated electricity was half or less than the observed levels the week before, causing drastic reduction of supply in Central, Western and Southern regions. The Central and Western regions were badly affected and BEL pointed out that it took 1 to 3 days to restore generation and meet the demand. In the town of La Democracia in Belize District, there was also a blackout due to extensive damages on the western transmissions lines along the Western Highway up to the village of Blackman Eddy. Local media also reported that the local village of Lords Bank in the same district was without electricity for up to 3 days

FIGURE 19. Dispatch Comparison during Hurricane Richard and Business-As-Usual Scenario



Source: Belize Electricity Limited.

after the hurricane made landfall.[26] In the Southern region, many areas in the Stan Creek and Toledo districts were effected, but power was restored to most areas one day after landfall. Media reports indicated that there were some exceptions in the towns of Middlesex, St. Margaret's, Mullins River, Dangriga and the Hummingbird Community—where restoration of service took longer.

The distribution lines were the most affected by high-speed winds. There were numerous transmission and distribution damages that extended across a large geographical area covering multiple districts reflecting the significant size of the hurricane. The distribution line failures impacted 29,663 customers (about 39 percent of BEL's total customer base) while the transmission line failures impacted 13,726 customers (about 18 percent of BEL's total customer base). The main cause for the damages was the high-speed winds causing the collapse of poles (mainly distribution), tangling wires and knocking down trees and antennas on high voltage lines. The central region (Ladyville, West Lake, and the Belize City systems) was severely impacted by Hurricane Richard affecting a total of 14,486 customers.

Transmission failures were fewer but impacted a large number of customers and led to a high load loss. At 4:56 p.m. on October 24th, there were failures in the western transmission line due to a fallen tree, which impacted over 8,000 customers. At 7:23 p.m., the high speed winds knocked down poles and caused wires to tangle creating serious damages along the Western Highway from La Democracia to the village of Blackman Eddy badly affecting the Western region leaving 11,938 customers in the San Ignacio and Belmopan load centers without power.

The distribution line experienced failures in the southern and central region even after the Hurricane left mainland Belize, affecting a significant number of customers. On October 25th, there were some residual impacts from the hurricane with distribution line failures affecting the Southern region beginning after 5:30 p.m. In the Independence, Punta Gorda, and Dangriga systems, 9,088 customers (12 percent of BEL's total customer base) were affected. In the Central region, distribution line failures that occurred from October 25th to 28th affected another 5,843 customers.

The estimated loss of revenue incurred by BEL due to Hurricane Richard amounted to nearly BZ$ 500,000 (US$ 250,000). Figure 19 shows the daily energy generation during the week of Richard's landfall and the preceding week. The unserved energy due to Richard is estimated as the difference between the energy dispatched from October 24th to the 30th during the week of the hurricane compared

[26] Channel 7 News, "Progress with Power Restoration", October 27, 2010.

with the energy dispatched from October 17th to the 23rd when the system was unaffected by the hurricane. The unserved energy amounted to 1,109,795 kWh resulting in an estimated BZ$ 496,078[27] (US$ 248,039) of lost revenue for BEL, based on the BEL's 2010 average sales price of BZ¢ 45/kWh[28] (US¢ 22/kWh).

The impact of the unserved energy on GDP is estimated at about BZ$ 6.4 million (US$ 3.2 million). Belize's 2010 nominal GDP was BZ$ 2,794,226,900 (US$ 1,397,113,450)[29] and BEL's total net generation of electricity was 483,270,087 kWh indicating that a kWh generated entails BZ$ 5.78 (US$ 2.89)[30] of added value to the economy. On this basis, the total amount of un-served energy during Hurricane Richard was 1,109,795 kWh implying an estimated GDP loss of BZ$ 6,416,741 (US$ 3,208,371).[31]

The total economic losses in Belize due to Hurricane Richard are well beyond the damages incurred by BEL and the power system. The Initial Damage Assessment Report (IDA) issued by the NEMO on October 27th, 2010, BEL estimated initially its losses/recovery costs as being BZ$ 250,000 (US$ 125,000). The absence of electrical power also disrupted water systems in some rural communities as they did not have back up generation capabilities to sustain the operation of water pumps. The preliminary assessment estimated a total impact of the hurricane (direct losses + potential economic losses) on the economy at BZ$71 million (US$ 35 million), or about 3 percent of GDP.

[27] BZ$ 0.447/kWh (average 2010 sales price/kWh rounded up to three decimals) * 1,109,795 kWh.

[28] BZ$ 190,526,000 (BEL's 2010 annual revenue)/426,233,000 kWh (BEL's 2010 total sales in kWh).

[29] World Bank Development Indicators, GDP (current US$).

[30] US$ 1,397,113,450 (Belize's 2010 nominal GDP) / 483,270,087 kWh (BEL's 2010 total net electricity generation).

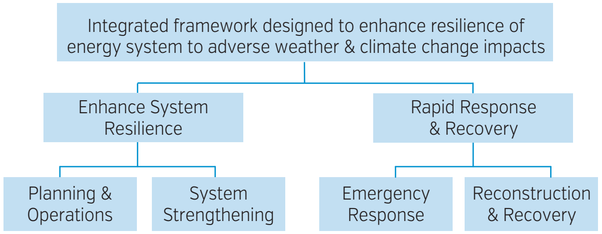
[31] US$ 2.89/kWh (GDP value-added per kWh rounded up to two decimals) * 1,109,795 kWh.

5. BUILDING RESILIENCE FOR ENHANCED CLIMATE ADAPTATION

The GoB is taking action to enhance climate resilience in the country, including in the energy sector. The previous analyses identified the vulnerabilities that extreme weather and climatic events pose for the power sector in Belize, and attempted to quantify the resulting economic and financial impacts. The GoB recognizes that there are significant measures that can be taken in order to enhance its resilience to extreme weather events and better adapt to climatic impacts. Some of the steps GoB has already taken in this regard include: (a) enactment of the Disaster Preparedness and Response Act (2003),[32] which is the primary legislation governing disaster risk management (DRM) in the country; (b) establishment of the National Emergency Management Organization (NEMO), with representation from the Government Cabinet, to ensure effective coordination of the multiple agencies responsible for implementing the DRM legislation; and (c) adoption of the National Climate Resilience Investment Plan (2014) that is designed to mainstream and ensure the consistency of climate adaptation investments with the country's national planning. The energy sector is represented in varying degrees in all these efforts that provide a legal, policy, and institutional framework for advancing measures for enhancing resilience.

A risk management framework for enhancing resilience of the power system to adverse weather and climate change impacts would primarily focus on the following aspects: 1) strengthening the existing infrastructure and operational capabilities to minimize damages and disruptions, and 2) improving the domestic capacity to respond rapidly and recover efficiently from the residual damages that would still occur. The power system in Belize could be physically strengthened ('hardened') and better strategically planned to improve its capacity to withstand the impacts of regular as well as extreme weather events. Such measures may not eliminate all future impacts on the power sector from storms and hurricanes, but they could significantly reduce the likelihood and the negative impacts of such outcomes. Since some damages are inevitable irrespective of preventive actions taken, having in place an improved plan to quickly respond to emergencies and rapidly restore services will further minimize service disruptions and the overall impacts of storms on the power sector. Financial protections and institutional mechanisms can also be utilized to enhance the resilience framework by shifting the risks from extreme weather towards others who are better placed and capable of bearing them. A similar Integrated Risk Management Framework, as illustrated in **Figure 20,** is applied in designing the ERCAP supported by the World Bank and GEF to assist Belize address some of its critical energy resilience and climate adaptation concerns.

FIGURE 20. Framework for Energy Resilience and Climate Adaptation



Source: Authors, adapted from Ebinger and Vergara, "Climate Impacts on Energy Systems", The World Bank, 2011.

By further evaluating the impact of past tropical storms and hurricanes, it will help illustrate specific vulnerabilities of the power system, and

[32] Initially issued in year 2000, revised in 2003.

identify measures that can be taken to enhance resilience in order to avoid similar damages and disruptions from occurring in the future. Analyzing the sequence of events that led to some of the significant damages and service disruptions experienced during Tropical Storm Alex and Hurricanes Dean and Richard provides insights into some of the specific vulnerabilities in the power system. These *illustrations* focus on actual events that led to service disruptions and hypothetical events that have been avoided in the past but may materialize in the future. They also identify potential measures, which, if they had been in place at the time of the extreme weather event, would have either prevented or substantially reduced the damages or service interruptions. These illustrations helped identify and validate some of the priority activities that are included in the ERCAP with support from the World Bank through funding from GEF.

ILLUSTRATION 1: Segmentation of the Transmission Network

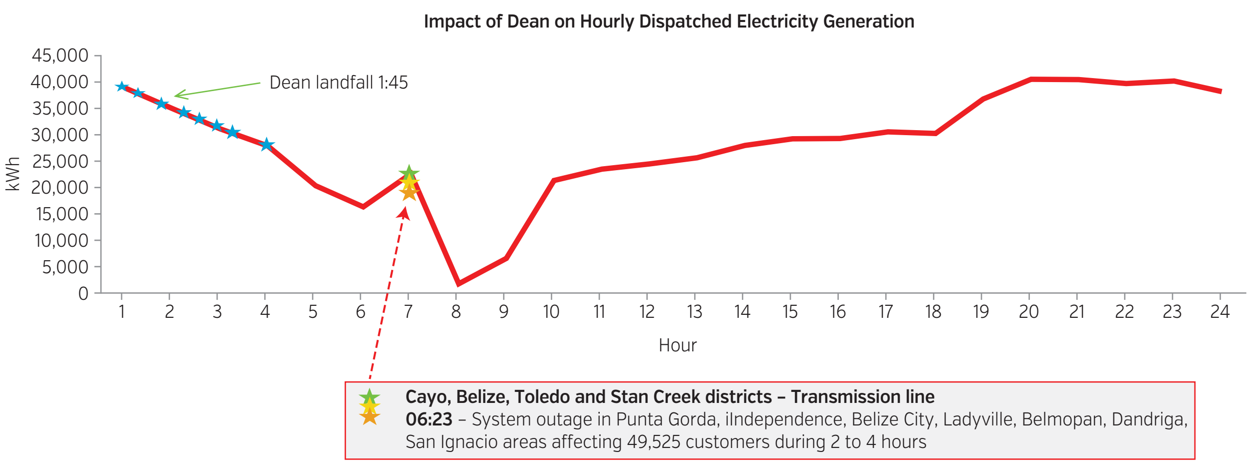
BEL's transmission system lacks adequate segmentation, making it vulnerable to extreme weather. When BEL's transmission network was originally constructed, many substations were supplied from 'Tee off' or spur lines without segmentation between adjacent substations, which made the entire transmission line vulnerable in case of faults or disturbances.[33]

Hurricane Dean, in 2007, illustrates the extent to which the transmission network is exposed during extreme weather due to inadequate segmentation of the system. Revisiting the impact of Hurricane Dean on the hourly dispatched energy in Figure 21, the system steadily deteriorated initially due to the damage caused by high winds to the distribution system in northern Belize. However, as illustrated in the Figure 21, at 6:23 am, the transmission system began to experience cascading faults that affected the whole line and caused a near blackout of the entire power system in the country.

During Hurricane Dean, a fault that occurred at a CFE transmission lines in Mexico led to a series of cascading "trips" that left the entire transmission system on the Belize mainland inoperable. Hurricane Dean, which brought winds in excess of 165 mile per hour through northern Belize and bordering region of Mexico, triggered a series of

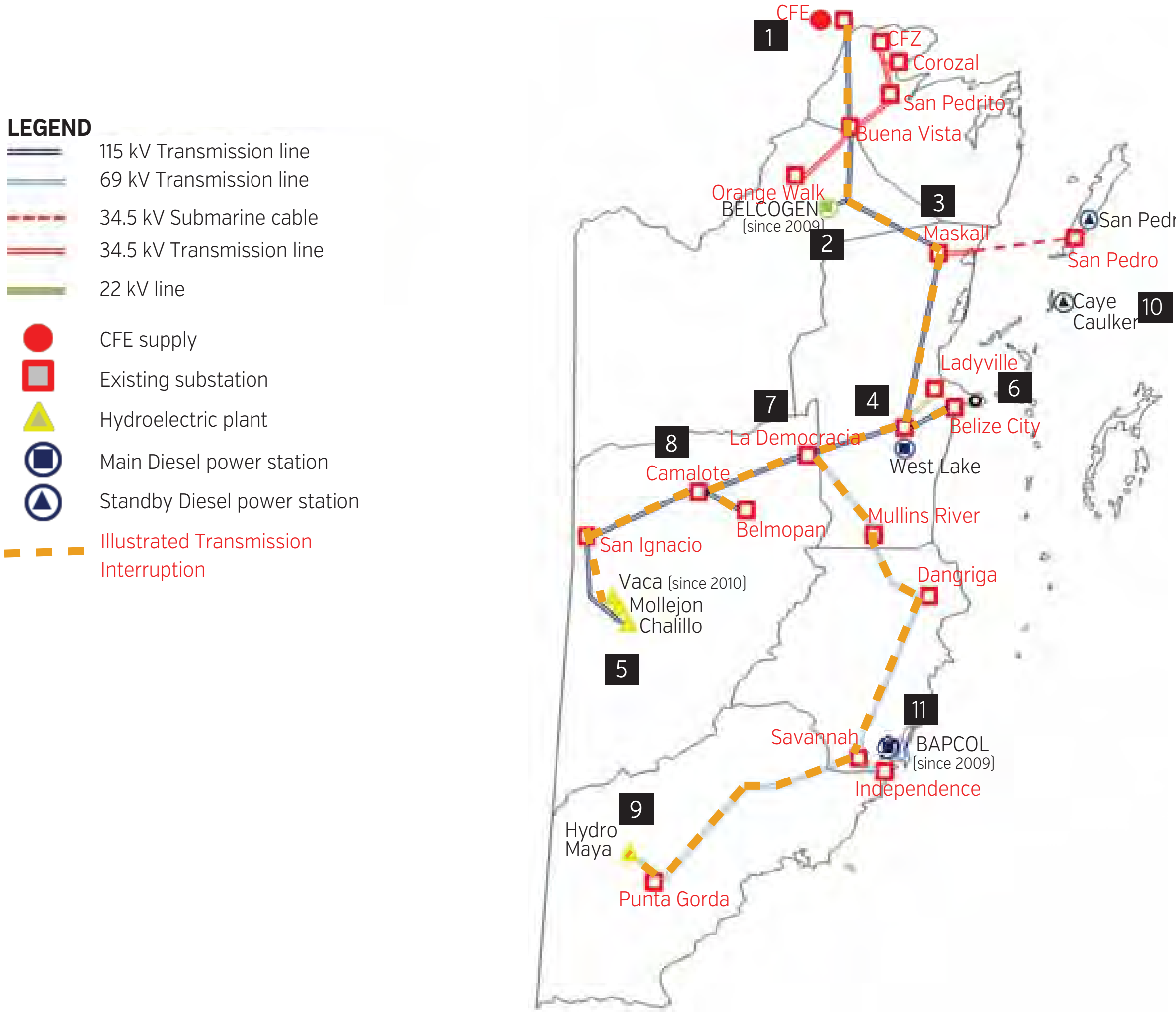
[33] Power line faults have many causes: lightening discharges, trees touching the line, two phases short-circuiting, insulation failures, etc. most of which occur during adverse weather conditions. These 'faults' can be transient or permanent. In the case of transient faults, disturbances are cleared naturally (e.g. when the lightening surge decays or a branch touching the line burns out). In such cases the line will 'hold' when re-energized by switching 'on' the circuit breaker. In the case of permanent faults, disturbances are not cleared and the line will not 'hold' until the cause of the fault has been removed physically (e.g. when a damaged insulator is replaced or a grounded conductor is re-strung).

FIGURE 21. Transmission Failure during Hurricane Dean and its impact on Electricity Dispatch



Source: Belize Electricity Limited.

FIGURE 22. Cascading Disruptions in the Transmission Network during Hurricane Dean



Source: Belize Electricity Limited and author illustrations.

disruptions that began on the Mexican side but rapidly spread to render the Belize transmission system inoperable. The series of disruptions to the BEL transmission network, which is graphically illustrated with corresponding numerical references in **Figure 22**, are as follows:

- CFE transmission lines in Mexico near the border with Belize experienced a fault due to a fallen tree at 6:23 am on August 21st, interrupting power supply to BEL's system (Reference location 1 in Figure 22). This is the main substation that supplies up to 50 MW of power generation capacity from CFE to BEL.
- The fault at the CFE substation triggered a cascade that resulted in the northern part of the 150 kV transmission line in Belize, up to the Westlake substation, becoming inoperable (Reference distance from 1 to 4).
- Due to the inoperable northern transmission line, electricity from the Westlake power plant (Reference location 4) also could not be evacuated to supply the northern part of Belize.
- The "trip" in the northern transmission line then continued to cascade leading to the western transmission line from Westlake to beyond San Ignacio to become inoperable (Reference distance from 4 to 5).
- As a result, Hydro BECOL (Reference location 5), which is the largest domestic power plant in Belize, could not evacuate the bulk of its power, and was reduced to supplying a limited

local area. The transmission disruptions on the western line also cut off electricity supply to the capital Belmopan, amongst other significant cities in the west of the country.

- The "trip" in the western transmission line also extended east from the Westlake substation (Reference location 4) to Belize City (Reference location 6), cutting off electricity supply to the largest and most populated city in the country.
- The cascading transmission "trips" then affected the 69 kV southern transmission line from La Democracia to Punta Gorda (Reference distance from 7 to 9) and the 22kV connection to the 7 MW Hydro Maya power plant, cutting electricity service to the southern part of Belize.
- As a result of this cascading disturbances, practically the entire transmission network in Belize was affected and the country experienced a near-blackout. Only the isolated small grid in Caye Caulker (Reference location 10) remained operational.

These events resulted in the dispatch of only 3.5 percent of the electricity supplied on August 14th, a week before the events. Consequently, more than 64,000 customers (about 88 percent of BEL's customer base) lost power, although none of the power plants sustained significant damage due to the hurricane.

Hurricane Dean's impact on the power system in Belize could have been significantly reduced if the transmission system was adequately segmented. If the transmission network had been segmented at key substations, then the damage at the CFE transmission lines (Reference location 1) would have been isolated to BEL's northern transmission line section. By enabling the system to decouple the transmission and isolate the section affected by the fault, the rest of the transmission network in Belize could have remained energized and most of the power system operational. The loss of significant supply from CFE in Mexico would have still posed a challenge, but given the multiple other generation sources in the BEL system, they could have been brought online to make up for the shortfall. For example, additional electricity could have been supplied from the 22.5 MW Westlake power plant, which is a gas turbine that operates on diesel. While operating the Westlake power plant would have been a costlier option than electricity purchased from CFE at that time, it would have nevertheless been a useful temporary solution that could have avoided the major blackout that Belize faced during Hurricane Dean. Since Hurricane Dean, there is now a 13.5 MW Belcogen biomass co-generation power plant (Reference location 2) that is in operation, commissioned in 2009. If Belcogen had been in operation at the time of Hurricane Dean, it would have been another power generation node that would have been cut off from the system due to cascading faults as a result of the lack of segmentation; and would have had an even greater impact. Therefore, it can be concluded that had there been adequate segmentation of the system with circuit breakers at the time of Hurricane Dean, it could have prevented the cascade of "trips" from spreading beyond the Maskall substation (Reference location 3), and avoided the near-system wide blackout of the system. Under such a scenario, only an estimated 13,000 or about 18% of BEL customers would have been impacted from the transmission failure compared with the 64,000 that were actually effected.

During Hurricane Richard in 2010, Belize also faced an extended transmission failure due to a "trip" that cascaded. On October 24th, at 7:23 pm, several transmission poles fell tangling the wires on the 115 kV western transmission line (Reference distance from 7 to 8), between the substations at La Democracia and Camalote. Since the western transmission line was not segmented at the time, the fault cascaded and rendered the entire western transmission line inoperable for over 20 hours. As a result, the 51.5 MW Hydro Becol (Reference location 5) was unable to dispatch, cutting off supply to San Ignacio and the capital, Belmopan. Over 18,000 customers (23% of BEL's total customer base) were effected. If the western transmission line was segmented with circuit breakers at the time, the fault could have been isolated between the substations at La Democracia and Camalote (Reference locations 7 and 8, respectively), and as a result, much fewer customers (only those between the two substations) would have been impacted and electricity supply from Hydro Becol to the key cities of Belmopan and San Ignacio would have continued.

BEL is making efforts to segment its transmission lines throughout the system, which is being supported by the World Bank and GEF. Given its past experience with adverse weather, BEL has installed some protections to segment parts of its transmission although some critical substations that are generation nodes remain unsegmented. Since these unsegmented sections makes the transmission system vulnerable during a future tropical storm or hurricane should a line damage occur in these areas, BEL, through the ERCAP, is expected to install switchyards at Belcogen (Reference location **2**), and Bapcol[34] (Reference location **11**), with line circuit breakers for the 'in' and 'out' of each transmission line section. At Belcogen in the north, the line will be segmented to two sections: from CFE supply to Belcogen, and from Belcogen to Maskall. At Bapcol in the South the line will be segmented to two sections: from Dangriga to Bapcol and from Bapcol to Savannah. This would effectively complete the needed segmentation of BEL's existing transmission network until further expansion and system upgrades are considered.

ILLUSTRATION 2: Strengthening of Transmission Network Structures

BEL's transmission line structures are deteriorating and could jeopardize the resilience of the overall power system. It is important for the reliability and resilience of the power system to prevent or limit damages to the transmission lines, including from 'downing' of the structures during tropical storms and hurricanes, as they can lead to extended power supply outages affecting large numbers of consumers. Large power companies usually design and build their main transmission in-line with secure standards utilizing self-supporting lattice steel structures. This practice, however, can be too costly for a small utility such as BEL, which utilizes wooden pole structures for its transmission network, a substantially lower cost option.

Specific portions of the transmission lines remain particularly vulnerable to increasing climatic events even if they were avoided until now. Regular inspections carried out by BEL have revealed that certain portions of the transmission line are experiencing substantial corrosion of the anchors, guy wires and attachments. Many sections of the transmission line have also been affected by premature wood decay due to termite attack and fungal growths. Some transmission poles have also developed longitudinal cracks ('checking'), which weaken them and make way for further decay by allowing fungal growth. Bush fires have also affected some of the poles.[35] Such signs are a warning of the increasingly greater possibility that strong winds generated from future tropical storms or hurricanes would cause a number of already weakened poles to collapse. This has been avoided to date due to BEL's inspections, aggressive approach to maintenance, and through temporary limited fixes. However, the weakened state of the structures could lead to catastrophic damages to large sections of the transmission line, causing significant power shortages for extended periods.

A transmission section that was identified by BEL as being particularly vulnerable due to its weakened state is the line from Maskall to Westlake. It is responsible for transporting significant amount of electricity from CFE and other generators in Belize to multiple load centers in the country. Successive storms and hurricanes will continue to batter and further weaken the structures along this line making them progressively more vulnerable to a catastrophic collapse. While such a major event has been prevented to date, this illustration explores disruptions that could be caused due to the downing of some of the weakened poles. The hypothetical events are graphically illustrated with corresponding numerical references to **Figure 23**:

- A collapse of transmission structures along the 115 kV transmission section between Maskall and Westlake substations (Reference distance from **1** to **2** in Figure 23) due to high winds during a future storm or hurricane would truncate the power system in Belize. This section is particularly vulnerable as it passes through water logged and saline areas that have led to the corrosion of metal structures as well as wood decay and other factors that have weakened the infrastructure.

[34] The substation at Bapcol, located near Savannah and Independence, evacuates power from a 15MW high speed fuel oil plant, which is presently kept on stand-by by BEL as a back-up. The Bapcol power plant was not in existence at the time of Hurricane Dean, as it was commissioned later in 2009. However, segmentation at Bapcol is important for system reliability in BEL's current transmission network.

[35] BEL has reported losses of 5 poles per year due to bush fires.

- The result following such an occurrence would be the immediate cut off of power supply from the north and the loss of service to consumers along the inoperable transmission section. It would cut off electricity supply from CFE (Reference location 4) and the Belcogen bagasse co-generation power plant (Reference location 5) to the load centers in central and southern Belize.
- An estimated 24,500 customers (30 percent of the 2014 customer base) or more in the central area of Belize (Reference shaded area marked A) would experience extended loss of service as a result of the damage to the transmission line and its inability to evacuate power from the north.
- If the transmission damage would impact the southern part of the country creating electricity shortages, an additional estimated 11,000 customers would experience supply shortages (Reference shaded area marked B).
- Since the inability to evacuate electricity from the critical northern generation sources would leave Belize City, the country's largest load center, without supply, BEL would have to resort to operating the costlier, 22.5 MW diesel-fired gas turbine (Reference location 2). While this could reduce supply disruptions to Belize City, it would temporarily increase BEL's cost of supply.

There could be additional disruptions from a collapse of transmission infrastructure as a result of extreme weather compared with those indicated in the previous illustrative example. During inspections, weaknesses were also detected in the infrastructure that extends the transmission line from Westlake to Belize City. Damage to this section would lead to additional disruptions, which are also graphically illustrated with corresponding numerical references to **Figure 23**:

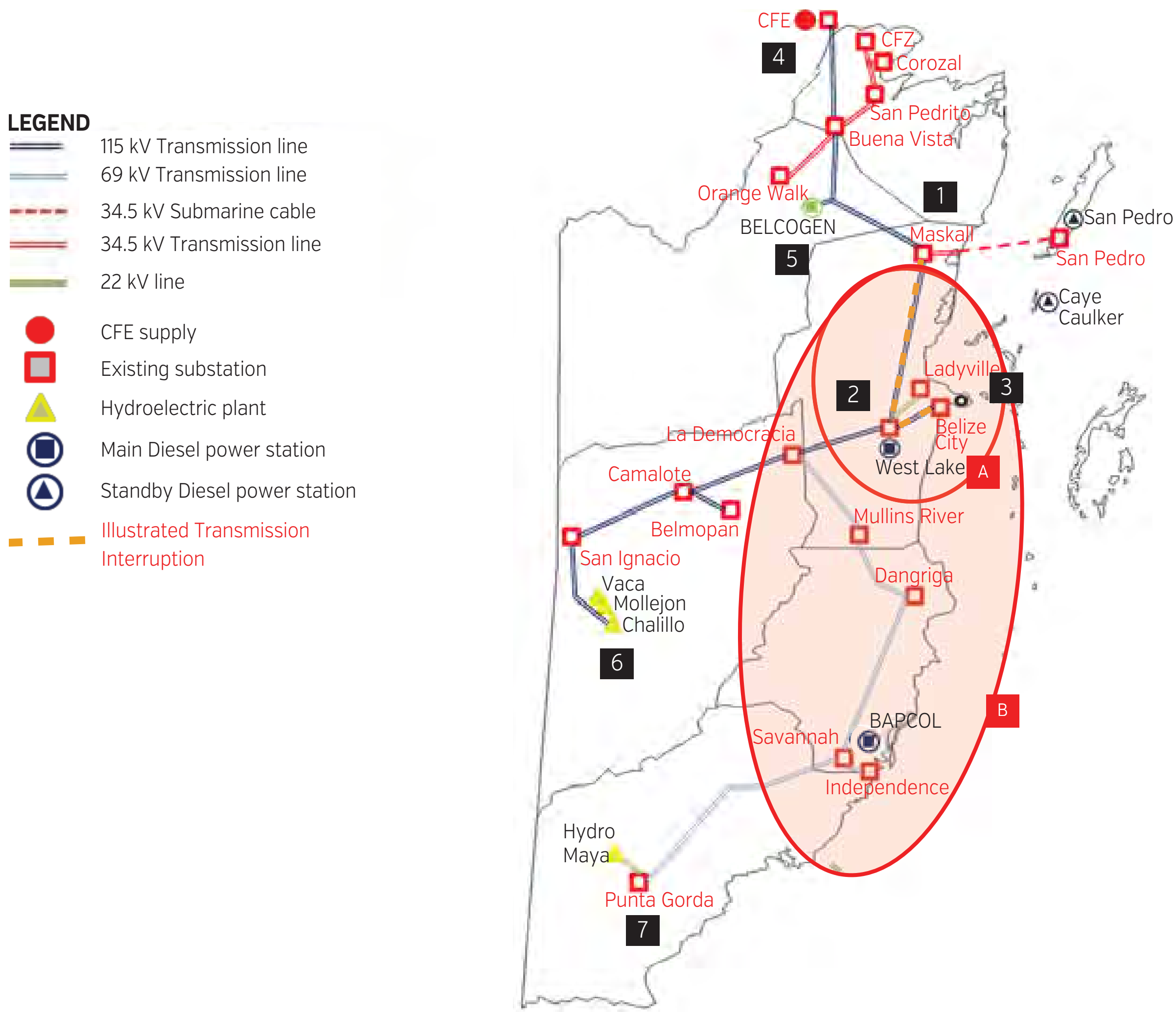
A collapse of transmission structures along the 115 kV transmission section between Westlake and Belize City (Reference distance from 2 to 3 in Figure 23) could occur because of weakened poles and infrastructure that would collapse from the impacts of a tropical storm or hurricane.

Coupled with the disruptions along the Maskall-Westlake transmission link (Reference distance from 1 to 2), the above event would leave Belize City (Reference location 3) without electricity, since electricity from the northern power stations (Reference locations 4 and 5) or the back-up facility at Westlake (Reference location 2) could no longer be evacuated to supply the Belize City distribution network. This would leave over 17,500 customers in Belize City without electricity (21 percent of BEL's 2014 customer base) until the lines can be restored.

BEL is taking measures to "harden" the transmission infrastructure to enhance resilience and ensure reliable operations, helping avoid catastrophic damage to the power system during future extreme weather events. The immediate focus is on the transmission sections from Maskall to Westlake substations and Westlake to Belize City substations, which were identified as being in particularly poor condition and most vulnerable. With World Bank and GEF support through the ERCAP, BEL plans to evaluate alternative line supports and new design standards for each type of terrain encountered along the identified transmission line routes. This may include various types of pylons such as fiber-glass, fiber reinforced polymer, pre-stressed concrete, as well as alternate support designs; to determine their suitability to the specific terrain and climate conditions. The evaluation would also review measures to rehabilitate/strengthen poles that are salvageable. The rehabilitation and replacement of transmission infrastructure along the Maskall-Westlake line (Reference distance from 1 to 2 in Figure 23) would significantly enhance resilience and minimize potentially major supply disruptions. It would considerably reduce the risk of interruption of imports from Mexico (Reference location 4) as well as from the Belcogen biomass co-generation plant (Reference location 5) and enable uninterrupted electricity supply to load centers in the central and southern areas of the country. If the upgrade also included the only transmission section linking Westlake to Belize City (Reference distance from 2 to 3 in Figure 23), it would prevent a potential blackout for over 17,500 customers based in the city.[36] The proposed evaluations and investments supported by the

[36] Resilience would also be strengthened due to the ongoing construction of a "by-pass" transmission link from Ladyville that is a little farther north that will provide another supply feeder from Westlake to Belize City.

FIGURE 23. Illustration of Potential Impacts from a Transmission Infrastructure Collapse

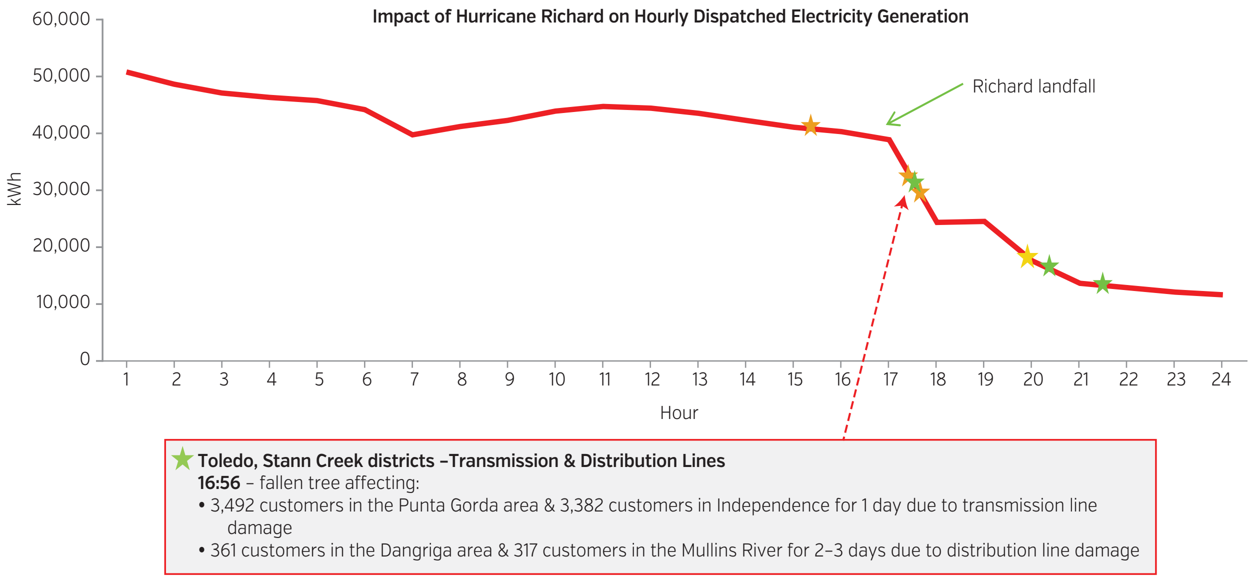


Source: Belize Electricity Limited and author illustrations.

ERCAP would immediately enhance the resilience of the system by strengthening the transmission sections that are the most compromised. It will also help BEL in deciding to strengthen existing standards or introduce new standards that are better adapted to characteristics of specific terrains traversed by the transmission lines, and apply them in the upgrade and expansion of the remainder of its transmission system across the country.

Segmenting the transmission network and hardening the infrastructure are complimentary and together provide greater resilience to the power system. Illustrations 1 and 2 in this Chapter highlight how each set of measures would enhance the resilience of the power system individually. However, together, they would provide greater security. For example, the strengthening of the poles and associated equipment along the transmission section from Maskall to Westlake (Reference distance from 1 to 2 in Figure 23) would help prevent a catastrophic collapse in that area, and avoid severe impact on the system. However, segmentation of the transmission line at the Maskall (Reference location 1) and Westlake (Reference location 2) substations, limits the impact of the collapse to the Maskall-Westlake line segment. It prevents additional "trips" north of Maskall and west of Westlake, providing an additional layer of resilience for the overall power system.

FIGURE 24. Transmission Disruption due to a Falling Tree on HV line during Hurricane Richard and its impact on Electricity Dispatch



Source: Belize Electricity Limited.

ILLUSTRATION 3: Improved Vegetation Management

Good vegetation management practices are vital to maintain system resilience especially in tropical climates. One of the highest recurrent maintenance costs in most utilities is vegetation management.[37] It can have even more significance in tropical climates where vegetation growth can be particularly aggressive. Excessive and unwanted vegetation can hinder management and upkeep of electrical infrastructure. It will impact BEL's system performance especially during storms as lines can be damaged due to falling trees/branches and during extended droughts when the risks of damaged structures from wildfires increase. BEL also indicated that inadequate vegetation management resulted in certain infrastructure being inaccessible during and after extreme weather events hindering their capacity for emergency response and recovery. BEL already has in place a vegetation management plan. It recognizes the need to further improve the company's practices given its importance to maintaining a resilient power sector operation.

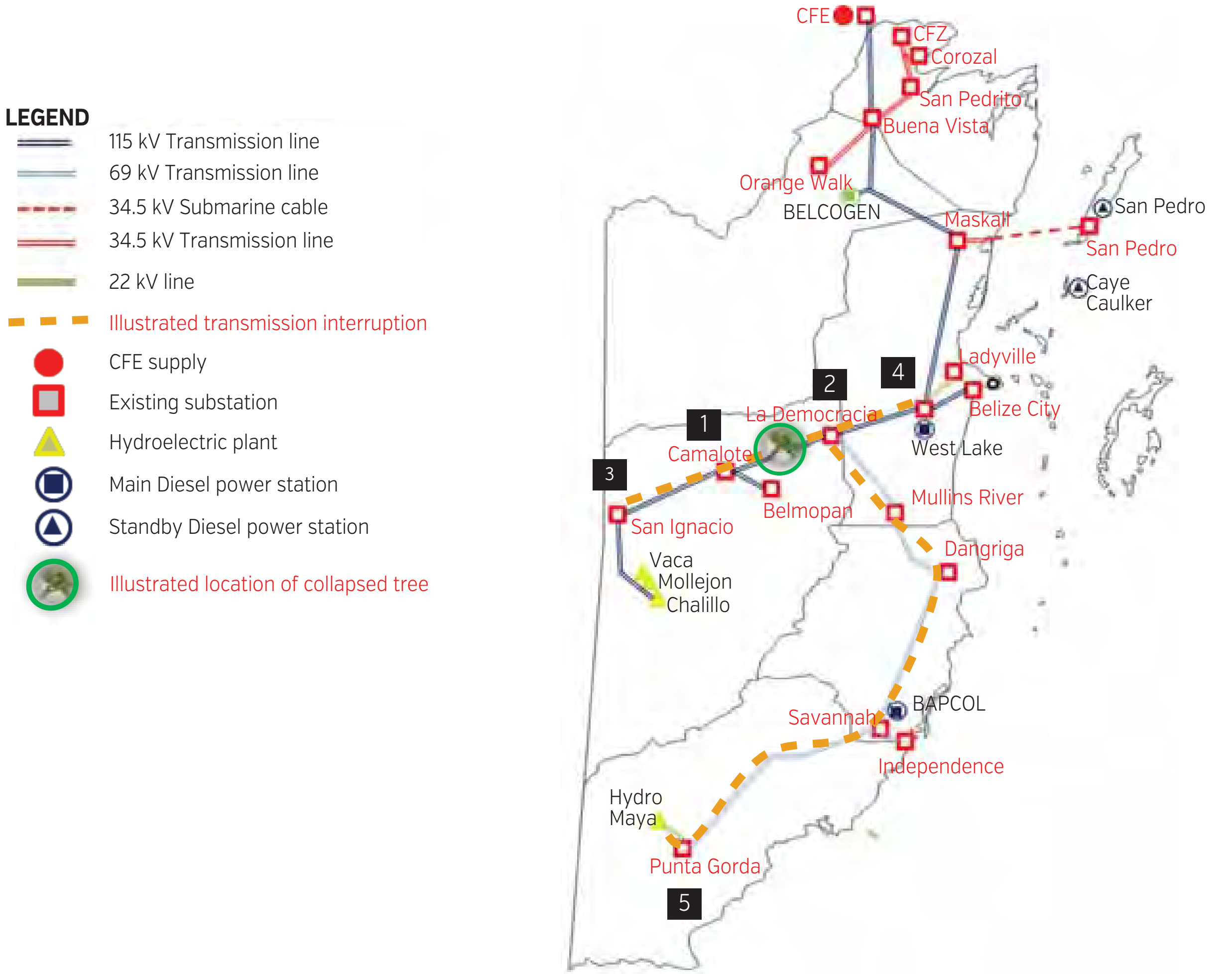
Hurricane Richard, in 2010, provides an illustration of the extent to which disruptions can extend due to a damage caused to the power lines from a fallen tree. Revisiting the impact of Hurricanes Richard in Figure 24 shows how, at 4:56 PM on October 24th, a fallen tree on a transmission line caused a succession of events that led to a significant reduction in the dispatched electricity.

A further review of the events surrounding the disruptions from the falling tree is graphically illustrated with corresponding numerical references in **Figure 25**:

- The impact of Hurricane Richard that swept across Central Belize resulted in a tree collapsing on the transmission line between the Camalote and La Democracia substations (Reference distance from **1** to **2** in Figure 25).
- This caused the failure of 115 kV line segment from Westlake to San Ignacio (Reference distance from **3** to **4** 115 kV.
- It also led to the failure of the 69 kV southern distribution line from the La Democracia to the Punta Gorda substations (Reference distance from **2** to **5**).
- While the 115 kV western line was quickly restored, the 69 kV southern distribution line remained inoperable for an additional 21 hours before it was repaired. As a result, over 7,500

[37] "Before And After the Storm: A compilation of recent studies, programs, and policies related to storm hardening and resiliency", Edison Electric Institute, Update 2014.

FIGURE 25. Illustration of Transmission Disruption due to Collapsed Tree during Hurricane Richard



Source: Belize Electricity Limited and author illustration.

customers in the southern part of the country, about 10 percent of BEL's 2010 customer base, remained without electricity service until the damage was repaired.

BEL plans to improve its vegetation management practices so it can proactively mitigate damages to its power infrastructure and increase access during emergency response operations to areas where damages occur. BEL would like to reduce the likelihood of events such as the one that occurred during Hurricane Richard. It is possible that with more effective vegetation management prior to Hurricane Richard, BEL could have prevented the tree falling and damaging its infrastructure avoiding the system outages that followed. It is even possible that better planned vegetation management would have increased accessibility for emergency vehicles and crews to locations with damaged infrastructure reducing the extensive time it took to energize the 69 kV southern distribution line. Therefore, through the ERCAP, BEL is expected to review its vegetation management practices to bring them in-line with best practice approaches necessary in a tropical climate. This might include various strategies to vegetation management based on emerging trends[38] such as identifying and targeting the removal of trees dangerous to the system in addition to routine trimming of branches and clearing ways; applying new bio-friendly techniques; and better coordinating with local concerned officials.

[38] Ibid.

FIGURE 26. Summary Table of Distribution Damage Sustained from Storms and Hurricanes

Geographical Region	North	Central	West	South	TOTAL
Tropical Storm Alex (2010)					
Faults on Distribution Line (#)	3	1	–	–	4
Customers Affected (#)	2,314	540	–	–	2,854
Affected Load (MW)	3.2	1.4	–	–	4.6
Hurricane Dean (2007)					
Faults on Distribution Line (#)	10	2	–	–	12
Customers Affected (#)	17,487	4,003	–	–	21,490
Affected Load (MW)	10.5	4.2	–	–	14.7
Hurricane Richard (2010)					
Faults on Distribution Line (#)	–	10	–	5	15
Customers Affected (#)	–	14,486	–	10,091	24,577
Affected Load (MW)	–	28.8	–	19.2	48.0

Source: Belize Electricity Limited.

ILLUSTRATION 4: Distribution System Infrastructure Strengthening

While transmission damage can lead to significant and extended outages, a large proportion of the storm damages occur in the distribution system. As shown in the table in Figure 26, there was widespread damage to the distribution system as a result of Hurricanes Dean and Richard, and Tropical Strom Alex. While Hurricane Dean triggered a CFE transmission fault in Mexico that cascaded through Belize's entire transmission system, most of distribution failures were concentrated along the path of the storm in northern and some part of central Belize. Hurricane Richard, on the other hand, was a storm that covered most parts of the country causing damages to a large number of distribution systems. In fact, 12 of the 13 faults recorded by BEL during Hurricane Dean impacted the distribution network and 15 of the 17 faults recorded during Hurricane Richard also impacted the distribution network. According to BEL, the damages were primarily due to heavy rains, winds and lightening as well as fallen trees/branches damaging the distribution infrastructure. As a result of the distribution failures during Hurricane Dean, over 21,000 BEL customers, nearly 30 percent of its customer base at the time in 2007, experienced service interruptions. During Hurricane Richard, the customers effected by the distribution failures totaled nearly 25,000, over 32 percent of its customer base at the time in 2010. All four recorded faults during tropical storm Alex were distribution related, and impacted nearly 3,000 customers.

Several factors contributed to the vulnerabilities of BEL's distribution system. Given the recurrent nature and destructive power of tropical storms and hurricanes, it is difficult to fully avoid damages to the distribution system in Belize during such weather events. In fact, distribution infrastructure can sustain damages even during tropical monsoons that are commonplace in countries such as Belize. Nevertheless, it is essential for system reliability and resilience that BEL carry out regular maintenance where the infrastructure is routinely tested, followed by rapid replacement or rehabilitation of equipment and infrastructure when necessary. BEL is attempting to progressively address some weaknesses that have been identified in its distribution network include the following:

- Routine inspections, strengthening and upgrading of distribution line poles, cross arms, and lines as well as conductivity improvement of ground wires.[39]
- Improvement of the vegetation management practices to sustain the integrity of the distribution network.

[39] BEL has indicated that the fittings in many distribution poles are removed and stolen for its metal content, requiring regular monitoring and replacement.

- Upkeep and maintenance of the grid substations since most of the distribution load centers are dependent on a single substation with a single transformer, thus limiting the alternate supply possibilities in the event of a major failure.
- Reinforcement of the design and equipment of the substations prone to flooding, which could damage or even render equipment unusable even after the waters subside. Therefore, equipment such as battery banks can be relocated to safer locations that may include elevated platforms to reduce the likelihood of flood damage.
- Strengthening of control buildings that have suffered damages to metal structural panels and rooftops, which make them particularly vulnerable to future storms unless they are strengthened or replaced.

The ERCAP will support investments in the relocation of battery banks in several locations and strengthening the control buildings as well as the upgrade in vegetation management practices. For various other distribution system related upgrades, BEL is being supported by the Caribbean Development Bank. BEL funds its own routine inspections and maintenance.

While the above-mentioned "hardening" measures will help upkeep the distribution system and reduce the scale and impact of likely damages during future weather events, it will be just as important for BEL to improve its preparedness to respond to some events and damages that are inevitable. Therefore, BEL will need to develop its response and recovery capabilities concurrently with its efforts to strengthen network infrastructure, in order to maximize the resilience of the power system. This is further elaborated in the next illustration.

ILLUSTRATION 5: Emergency Response and Recovery Planning

Past experience indicates that the efficiency and speed of response and recovery during extreme weather events could be improved to enhance resilience. While many of the system "hardening" measures identified previously will reinforce the power system to better withstand the impacts of extreme weather events, reviewing past experiences have also illustrated the need for BEL to develop its capacity to better respond to emergencies and quickly recover its full operational capability. For example, during Hurricane Dean in 2007, there were three events where the associated outages lasted between 4–6 days before service was fully restored. More than 10,000 customers or over 13 percent of BEL's customer base remained without service during this extended period. Similarly, there were outages that resulted from five events during Hurricane Richard in 2010 that required up to 2–4 days to restore full service to about 10,000 customers.

BEL is seeking to improve its preparedness capabilities to better respond to emergencies including extreme weather events. BEL has protocols in its Hurricane Preparedness Plan to respond to major weather events but it could be improved to meet latest industry practice and further reduce the time it takes to reconstruct and recover. There are also indications that improvements can be made to its infrastructure, system operations, and technological capabilities that will complement and facilitate the implementation of a revamped Emergency Response and Recovery Plan. For example, BEL's current communication network is outdated and often have patchy coverage, forcing BEL emergency workers at times to rely on cellular phones for communications during storms and hurricanes. BEL also acknowledges that they are often unable to quickly identify the causes and locations of disruptions when line segments get truncated severing communication, or the utility would be constrained to maintain system reliability if the main load control and dispatch center based in Belize City were to become inoperable. Therefore, BEL is planning to undertake the following actions as a part of improving its emergency response and planning capabilities:

- Preparation of a more effective **Emergency Response and Recovery Plan** by upgrading its existing Hurricane Preparedness Plan to include good practice recovery protocols. This would help to shift away from restoration actions taken on an *ad hoc* basis and increase the efficiency of the interventions and likely reducing the recovery time.
- Redesign of its **communication system** and shift to a new digital VHF network that will provide national coverage to all of its transmission and

distribution network locations. Additional relays are needed to enhance signals at some of the existing repeater stations in order to reduce dead spots and improve coverage; as well as purchase of several truck mounted repeater stations that can be rapidly deployed to areas where there is a major failure.

- Strengthening the **load control and dispatch capabilities** particularly when faced with extreme weather disruptions. This will include the construction of a back-up control and dispatch center in Belmopan should the primary facility in Belize City become inoperable or disconnected from parts of the power system.
- Coordination with the National Meteorological Service (NMS) to gain access to real-time **meteorological and hydrological data** through the installation of monitoring stations. The real time data would improve BEL's preparedness as well as response and recovery during extreme weather events.
- Installation of **Advanced Metering Infrastructure (AMI),** which has multiple functions, can also remotely provide information when electricity service is either disrupted or restored at the household level.
- Implementation of an **outage management system** that utilizes a combination of hardware and software that will identify, record and help BEL personnel better manage responses to faults and outages, including facilitating customer interface (including linkages to AMI). The data collected will also help evaluate the frequencies and durations of system outages.

The above enhancements to BEL's operations are being supported by the ERCAP with targeted GEF funds allocated to select activities.

6. THE ENERGY RESILIENCE FOR CLIMATE ADAPTATION PROJECT (ERCAP)

The GoB efforts to enhance energy resilience are being supported by the World Bank and GEF. As previously noted, an $8 million GEF grant is being provided through the World Bank to fund the ERCAP, which aims to demonstrate solutions that enhance resilience of the energy system in Belize to adverse weather and climate change impacts. The ERCAP is intended to support the energy sector related aspects of GoB's framework established through its NCRIP[40] and the Disaster Preparedness and Response Act. The ERCAP's design includes three major components: 1) Long-Term planning and capacity building for adaptation, 2) Demonstration measures to enhance resilience of energy sector, and, 3) Project implementation support and information dissemination for knowledge sharing. The project is expected to have an immediate impact by strengthening key areas of vulnerability, and also help mainstream some of the successful efforts so that they can be scaled-up in the broader energy sector over the long-term.

While the ERCAP is designed to address key vulnerabilities in the broader energy sector, most of its activities focus specifically on enhancing the resilience in Belize's power sector. The evaluations carried out and presented in this paper helped validate the various solutions that are proposed for implementation under the ERCAP. The solutions supported by the ERCAP include a complementary combination of technical assistance, specific investments, capacity building efforts, and knowledge sharing activities. BEL will be implementing a majority share of the activities under the ERCAP, since a major focus of the project is to strengthen the power system and the capabilities of the utility. This includes the following:

- Fully segment BEL's single backbone, radial transmission system so that it can contain future faults and prevent cascading outages.
- Strengthen the transmission structures along line sections especially where there is substantial weakening of wooden structures and corrosion in metal fittings by testing different materials to identify the most suitable options under various terrains.
- Improve BEL's vegetation management practices in order to minimize damages to infrastructure from falling trees and branches during adverse weather conditions, which lead to failures in the transmission and distribution system.
- Improve the operational and dispatch capabilities of BEL including in consideration of extreme weather and climatic impacts through the installation of a back-up control and dispatch center at Belmopan, gain access to real-time meteorological and hydrological data, and hydrological modeling of the Macal Catchment Area where most of the country's hydro power plants are located.
- Undertake as a part of the ERCAP a number of enhancements to its distribution system including improvements to the control buildings at select substations and relocation of battery banks there it is prone to flooding. This is in addition to various ongoing maintenance and repairs BEL undertakes with its own budget as well as a project under implementation with support from the Caribbean Development Bank.[41]
- Develop an Emergency Response and Recovery Plan and commensurate institutional capabilities for its implementation in order to improve the speed and quality of response to emergency situations and efficient and effective recovery.

[40] The World Bank is also supporting the GoB's efforts to address resilience in the transport sector under the NCRIP framework through the separate complementary Belize Climate Resilience Infrastructure Project (BCRIP).

[41] Electricity System Upgrade and Expansion Project.

BOX: Financial Arrangements to Address Catastrophic Risks in Belize

The ERCAP primarily focuses on physical investments and technical assistance activities. It is complemented by additional financial arrangements made by the GoB and BEL to address financial implications of catastrophic risks.

Caribbean Catastrophe Risk Insurance Facility – Private commercial insurance has become costly and unaffordable for many Caribbean countries, obliging them to resort to alternate measures. One such endeavor is the Caribbean Catastrophe Risk Insurance Facility (CCRIF), which was established in 2007 with the assistance of the World Bank, to pool resources to provide insurance that cover damages related to risks associated from tropical cyclones, earthquakes, and excess rainfall. The CCRIF has 17 member countries at present including Belize. The GoB currently subscribes to the tropical cyclone policy with coverage of US$16 million and earthquake policy with coverage of US$ 2.5 million. CCRIF insurance payouts can be channeled to support the energy sector.

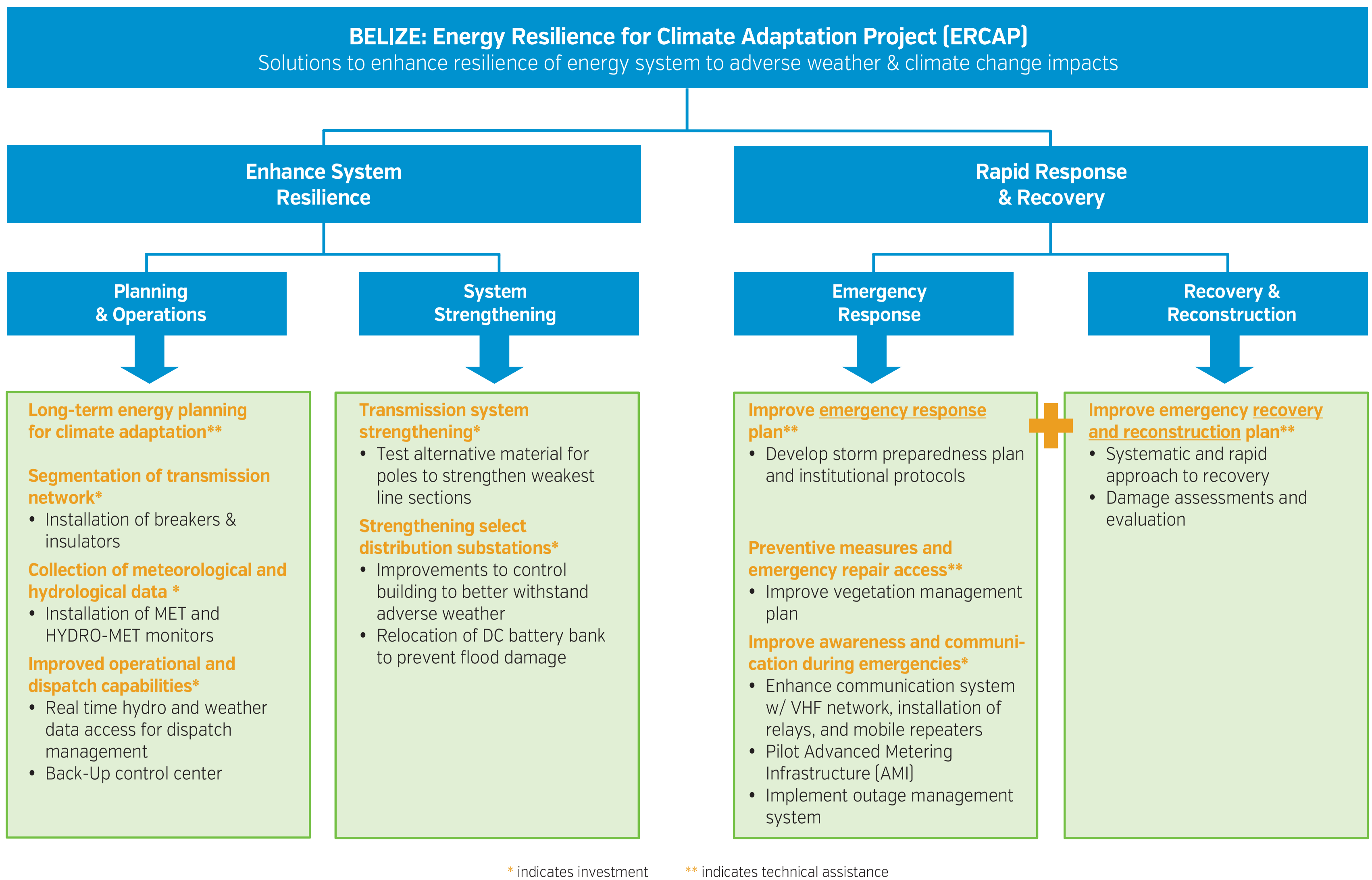
BEL Catastrophic Reserve Fund – Before 2002, the BEL obtained insurance coverage for its assets through private sources until the premiums in the Caribbean became cost-prohibitive. Since then, the GoB addresses the need for insuring assets through its utility regulator, the Public Utilities Commission (PUC), which mandates BEL to maintain a reserve fund of US$5 million on its balance sheet. During a natural-disaster-led emergency, BEL, in consultation with the PUC, may withdraw from the reserve fund to cover costs toward response and recovery in the power sector.

The response and recovery capabilities will be further enhanced through upgrades to BEL's communication system, and improvements to the management of utility/client interaction during emergencies including the implementation of an outage management system and piloting Advanced Metering Infrastructure.

These resilience enhancement measures by BEL supported by the ERCAP are presented in Figure 27 arranged according to the integrated risk management framework for energy resilience and climate adaptation, presented previously in Chapter 5.

The support provided through the ERCAP can make a significant contribution to enhancing the resilience of the power system in Belize, helping reduce the impacts of extreme weather..

FIGURE 27. Illustration of the ERCAP Framework and Design



Source: Authors.

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Written by | Migara S. Jayawardena, Borja Garcia Serna, and Jace Jeesun Han

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Energy Sector Management Assistance Program
The World Bank
1818 H Street, NW
Washington, DC 20433 USA

email: esmap@worldbank.org