PUBLIC UTILITIES COMMISSION

BELIZE ELECTRICITY LIMITED

BELIZE CONSOLIDATED PROJECT PLAN

ROCKY MOUNTAIN INSTITUTE

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ABOUT US

ABOUT THE MINISTRY OF PUBLIC SERVICE, ENERGY, AND PUBLIC UTILITIES

The Ministry of Public Service, Energy, and Public Utilities pursues a mission to promote sound management practices conducive to effective public, electoral and energy administration.

ABOUT BELIZE ELECTRICITY LIMITED

Belize Electricity Limited (BEL) Is the primary distributor of electricity service in Belize, Central America. BEL pursues a mission to provide reliable electricity at the lowest sustainable cost, stimulate national development, and improve the quality of life in Belize.

ABOUT THE BELIZE PUBLIC UTILITIES COMMISSION

The purpose of the Public Utilities Commission is to regulate the electricity, water, and telecommunications sectors in Belize to efficiently provide the highest quality services at affordable rates, ensuring the viability and sustainability of each sector.

ABOUT THE CLINTON FOUNDATION

The Clinton Foundation convenes businesses, governments, NGOs, and individuals to improve global health and wellness, increase opportunity for girls and women, reduce childhood obesity, create economic opportunity and growth, and help communities address the effects of climate change. The Clinton Climate Initiative (CCI) collaborates with governments and partner organizations to increase the resilience of communities facing climate change while reducing greenhouse gas emissions. CCI has helped generate over 63,000 MWh of clean energy annually in the Caribbean and East African Islands.

ABOUT ROCKY MOUNTAIN INSTITUTE

Rocky Mountain Institute (RMI)—an independent nonprofit founded in 1982—transforms global energy use to create a clean, prosperous, and secure low-carbon future. It engages businesses, communities, institutions, and entrepreneurs to accelerate the adoption of market-based solutions that cost-effectively shift from fossil fuels to efficiency and renewables. RMI has offices in Basalt and Boulder, Colorado; New York City; Washington, D.C.; and Beijing.

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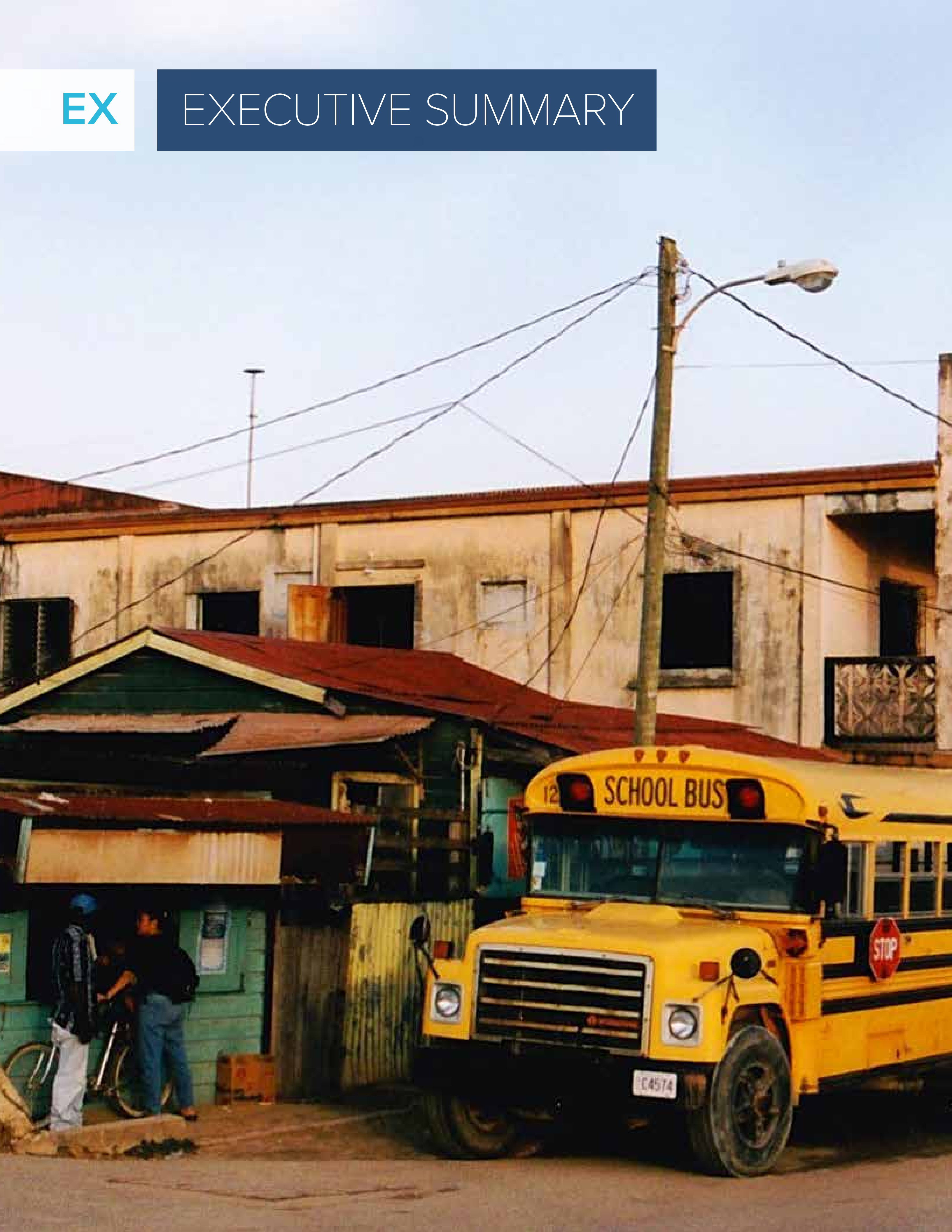
EX

EXECUTIVE SUMMARY



EXECUTIVE SUMMARY

Belize has completed a consolidated project plan (CPP) to identify opportunities within the electricity sector that offer significant economic, social, and environmental benefits for Belizeans. The CPP explores options for Belize's electricity sector, and the impacts that specific investment decisions have on long-term priorities. It is the result of an inclusive process involving multiple stakeholders informed by an objective and integrated analysis. The CPP was completed in partnership with the Belize Ministry of Public Service, Energy, and Public Utilities (MPSEPU); Belize Electricity Limited (BEL); and the Belize Public Utilities Commission (PUC). The team from Rocky Mountain Institute (RMI) and the Clinton Climate Initiative (CCI) supported the data gathering and analysis as an independent and objective third party.

Belize's current electricity system is well-managed, and reaches 92 percent of the country's population. At the same time, there exist new opportunities to improve the electricity sector for all Belizeans. The CPP recommends actions both for advancing energy access, and investing in new resources at the grid scale.

To realize Belize's energy access goals at the lowest cost, the CPP recommends the development of remote microgrids rather than extending the grid for six specific rural communities. The total savings of electrifying these six communities with hybrid microgrids as opposed to extending the grid would be US$1.5 million over 20 years.[i] While grid extension is the least-cost option for some communities, remote microgrids are clearly lower cost for these six communities, and bring other benefits such as direct local involvement in each community's electricity system.

For grid-scale options, the CPP recommends implementing a 10-year energy efficiency program to save 218 million kWh, or 20 percent of total electricity needs, by 2036. At a cost of approximately US$6 million over a 20-year period, pursuing an aggressive energy efficiency approach can save nearly US$42 million beyond the Reference scenario.[ii] In addition, the CPP recommends continuing the procurement process for Belize's first 15 MW of solar photovoltiacs (PV) (currently underway), adding a minimum of 5 MW of additional solar PV, and adding 18 MW of wind power to the energy mix. Investing in energy efficiency and new renewable energy resources in Belize has the potential to reduce cost volatility by 55 percent compared to the reference scenario. These technologies also have the potential to create between 7,000 and 12,500 jobs over the 20-year time frame explored in the CPP.

IMPORTANCE OF LONG-TERM ENERGY PLANNING

Belize faces pressing challenges to build an energy system that meets the needs of the country. A clear understanding of these challenges is essential to assess opportunities and the implications of various energy investment strategies across multiple sectors of Belizean society. Long-term energy planning envisions the future energy sector of Belize, revealing the most impactful pathways that harmonize current challenges and investment opportunities with long-term development goals amid a shifting resource landscape. Several of the leading challenges facing Belize's energy system include incomplete energy access, low energy independence, and cost volatility. Specifically:

- Eight percent of the population in Belize does not have access to electricity.
- Belize is highly dependent on imported electricity and experiences a lack of diversity in generation.
- Belize's electricity prices remain competitive

[i] A hybrid microgrid includes both renewable sources and fossil-fuel sources of electricity generation.

[ii] The Reference scenario includes only current planned projects and an additional interconnection with Mexico.

regionally, but generation costs are vulnerable to cost volatility related to both Mexican electricity imports and fuel imports.

Fortunately, declining costs and accelerated implementation levels associated with new energy technologies such as solar and wind, paired with cost-saving energy efficiency measures, can help Belize address some of these challenges. These developments create the potential for BEL to evolve and allow for new strategies that promote innovation. The CPP analysis shows that not all the resources identified in the 2013 RFP process align well with Belize's overall energy objectives, illustrating the limitations of a purely market-based approach to procuring new resources. This process identifies new opportunities based on system-level analysis to build Belize's energy system in a way that integrates all components in a consolidated plan.

SHARED ELECTRICITY SECTOR PRIORITIES

In order to outline the characteristics of the energy system of the future, CPP partners established a set of key goals along with supporting objectives and metrics. During this process, partners established their vision for their future energy system as one that secures energy access, promotes sustainable economic development, ensures security of electricity supply, and develops the least-cost system. Because energy access was emphasized as a critical objective, parties agreed that the CPP process would be divided into two parallel analyses:

1. An energy access analysis to assess whether nonelectrified communities should be electrified via microgrids or grid extension.

2. A grid-level analysis assessing potential resource investments over a 20-year horizon.

EXHIBIT 1

COMPARISON OF PROJECTED MICROGRID AND GRID EXTENSION NET PRESENT COSTS FOR SIX SELECT COMMUNITIES (US$)

COMMUNITIES	NO. OF HOUSEHOLDS	ESTIMATED ELECTRICAL DEMAND (KWH/Y)	MICROGRID NPC	GRID EXTENSION NPC	COST SAVINGS
SAN CARLOS	29	49,000	$75,000	$580,000	$505,000
PINE HILL	39	66,000	$101,000	$315,000	$214,000
OTOXHA	52	83,000	$128,000	$500,000	$372,000
CRIQUE SARCO	64	102,000	$157,000	$348,000	$191,000
SAN VINCENTE	77	122,300	$200,000	$440,000	$240,000
SAN BENITO POITE	91	144,500	$230,000	$544,000	$314,000
TOTAL FOR SIX COMMUNITIES	**352**	**566,800**	**$891,000**	**$2,408,000**	**$1,517,000**

1. ENERGY ACCESS ANALYSIS

To advance Belize's plans to achieve 98 percent energy access by 2020, the CPP process began with characterizing the electrical load profile of remote communities in Belize, then estimating the cost of extending the grid to each community, assessing the cost of a remote microgrid sized for each community, and comparing these to find the optimal pathway.

A Microgrid Option Costs Less Than Grid Extension for Small Communities

Analysis indicates that in general, smaller communities are often best served by remote microgrids, while larger communities (which typically have higher electricity load) are best served by extending the grid to reach them. The costs of both remote microgrids and grid extension are largely dependent on topography, distance from existing infrastructure, and the load of a community. Exhibit 1 lists the unelectrified communities that the CPP shows are no-regrets candidates for microgrids. The estimated net present costs (NPC) over 20 years and associated cost savings for hybrid microgrids versus grid extension are shown here. If these six communities were to be electrified through hybrid microgrids rather than electrified via grid extension, the system could save US$1.5 million in total costs over 20 years. If grants offset these microgrid costs, the savings will be even greater.

Each community is unique and, as illustrated in Exhibit 1, the difference in costs between the appropriate microgrid and grid extension can vary widely. For example, the cost of the microgrid at San Vincente is 55 percent lower than the cost of grid extension, while for San Carlos the cost of a microgrid is 88 percent lower than the cost of grid extension.

Microgrid System Design: Hybrid Systems with Lithium-Ion Batteries Are Least-Cost

For those communities that are best served by microgrids, the CPP analysis illustrates that 100 percent renewable systems are, on average, 53 percent more expensive than a hybrid microgrid (involving some diesel) over 20 years. The analysis revealed that lithium-ion batteries are more cost-effective than lead acid batteries for hybrid remote microgrids, due to longer life and lower cost of operation.

Recommended Next Steps Related to Energy Access

- **Funding:** For communities that have been identified as best served by microgrids, capital cost can be reduced by securing development grants. There are many grants available to fund these microgrids; a prioritized list of communities to target along with alignment between regulator, utility, and government on roles and responsibilities during a grant application will increase the likelihood of securing these grants.
- **Clarity:** Once funding is secured, additional due diligence must be done before the projects are ready for procurement. Project managers must run site and system audits, develop procurement documents, ensure permitting is in order, and acquire necessary land.
- **Procurement process:** An aggregated competitive procurement process in which several microgrid projects are procured at once can reduce the overall cost of the microgrid systems.

- **Preparing for long-term operation of system:** Local training and capacity building will be needed to ensure regular operation and maintenance is done on the system. Furthermore, there needs to be a plan for development of telecommunications for the remote monitoring and administration of the microgrids.

- **Educating community members:** Informing community members on the operation of their microgrid components can allow optimized use of the system, for example maximizing energy use during times when solar PV is producing electricity.

2. GRID-SCALE ANALYSIS

The grid-scale analysis portion of the CPP analyzed 11 discrete energy investment scenarios agreed upon by partners and how they contribute to the energy goals for Belize over a 20-year planning horizon to 2036. These goals are captured in the strategic objectives listed in Exhibit 2. This analysis shows the importance of long-term systems planning prior to the procurement of new resources. Most scenarios score higher than the Reference scenario, indicating that there are multiple options available that provide benefits beyond current plans. Several of the top-scoring scenarios have very similar scores, highlighting the importance of monitoring key variables and trends that could cause the scoring among these top scenarios to adjust.

EXHIBIT 2

OVERVIEW OF CPP SHARED GOALS AND STRATEGIC OBJECTIVES RELATED TO GRID-SCALE OPTIONS

GOAL	STRATEGIC OBJECTIVE
SUSTAINABLE ECONOMIC DEVELOPMENT	Increase investments occurring in the country
	Increase the number of jobs available
	Reduce the total cost of imported fuel and electricity
	Increase renewable energy penetration
	Increase efficiency of end use
SECURITY OF SUPPLY	Reduce cost volatility of electricity
	Increase reliability (during normal operation)
	Increase resiliency (response to external shock)
	Increase adaptability
LEAST COST	Least-cost generation expansion and operation

Spurring Sustainable Economic Development

While not the least expensive, the scenario containing new investments in hydro, biomass, solar, and wind resources scores the highest across all metrics evaluated. The CPP identified an opportunity to free up US$88 million that would otherwise be used to pay for energy imports, essentially offsetting the additional capital expenditure required to invest in new generating assets. In order to see these sustainable economic development benefits, the CPP suggests the construction of at least 5 MW of solar PV, 18 MW of wind, and development of the Chalillo 2 and Upper Swasey hydro projects. These investments should proceed following the implementation of the current planned projects, including the Santander 2 biomass plant and the 15 MW of solar PV identified in the 2013 RFP process.[iii]

New energy resources also spur job creation. The CPP findings show that between 7,000 and 12,500 jobs can be created in the 20-year time frame (although not all are permanent jobs). Scenarios with a high proportion of renewable resources generate up to 3.5 times the number of jobs as the Reference scenario. The recommendations of the CPP present a significant opportunity to expand jobs in Belize beyond the Reference scenario. This is especially true in the case of pursuing energy efficiency which, despite having lower overall job creation, has the highest ratio of permanent to temporary jobs of any technology modeled and significant potential to build capacity in Belize.

All scenarios require imported electricity from Mexico, although scenarios recommending higher levels of investment in domestic renewables reduce reliance on the interconnection by almost 50 percent compared with the Reference scenario. There is a potential to increase the amount of renewable energy generation by 15 percent while also increasing the diversity of renewable energy assets compared to the Reference scenario.

Ensuring Security of Supply

Upon examining the Reference scenario, the CPP illustrates that Belize must invest in reinforced interconnection, new capacity, or an aggressive energy efficiency (EE) program by 2034 in order to meet projected demand and maintain a reliable system. Although Belize has sufficient capacity to meet projected demand before 2034, the system would depend heavily on existing BAPCOL- and BEL-owned fossil fuel-based generators (high-cost resources) and would begin to strain the operation of the grid. The dependence on these fossil fuel generators will impact the country's ability to respond effectively to a sudden shock in fuel price and fluctuations in demand. Scenarios that aggressively pursue both EE and renewable energy illustrate a potential for reducing cost volatility by 55 percent compared to the Reference scenario. Findings from power flow analyses show that all scenarios are projected to have minimal impact on outage-duration hours. The most resilient scenarios

[iii] An assumption was made in the CPP analysis that funds do not flow out of Belize for investments in new renewable energy projects, which were assumed to be structured as Power Purchase Agreements.

are those with the highest percentages of renewable energy, because they also include greater diversity in generation technology and location. Pursuing aggressive EE, in particular, increases the adaptability of Belize's energy system by over 25 percent compared to the Reference scenario.

Belize's interconnection to Mexico is a unique asset that makes it more cost-effective to manage variations in the grid by purchasing electricity from the Mexican electricity market rather than by deploying in-country energy storage options. This analysis illustrates that increasing interconnection alone (as in the Reference scenario) will not address all of Belize's energy goals. However, reinforced interconnection combined with some renewable resources and EE provides Belize with added flexibility that is reflected in the high scores displayed by both interconnection scenarios in terms of security of supply.

Pursuing Least-Cost Electricity

In terms of net savings through 2036, the scenario containing new hydro, biomass, solar, and wind resources presents an opportunity to save over US$4 million in comparison with the Reference scenario. Pursuing EE aggressively (to save 20 percent of total electricity needs by 2036) offers a potential savings of approximately US$42 million compared with the Reference scenario and is the least-cost individual option explored in the CPP.

Cost savings derive from several different characteristics in each scenario. Scenarios with investment in EE and technologies such as solar PV have lower costs compared with scenarios such as the 2013 RFP. As one of the cheapest resources available to Belize,[iv] the interconnection with Mexico reduces the competitiveness of technologies such as storage.

Recommended Next Steps Related to Grid-Scale Resources

- **Currently planned projects:** Belize should reevaluate 2013 RFP proposed projects in the context of this analysis:
  - With the current modeled price, this study suggests moving forward with the 15 MW solar, Santander 2 biomass, and Chalilo 2 + Upper Swasey hydro projects.
- **Data collection:** Using the preliminary resource data in the models, onshore wind and solar look promising. However, available resource data is still preliminary. More robust data collection via anemometers at the top wind sites should be a priority before procuring wind projects.
- **EE implementation:** The CPP analysis shows that pursuing EE is highly favorable to the system and suggests the development of a centralized EE program to save 20 percent of total electricity demand and US$42 million by 2036 in comparison to the Reference scenario. The most cost-effective measures include efficient refrigeration, improved motors and belts, efficient lighting, and split unit air conditioning. In 2018, Belize should begin developing a utility-run EE program to offer incentives to increase the use of these measures.
- **Resource procurement:** Belize should run a new procurement process starting in 2020 to secure new capacity by 2025. The CPP analysis shows that, at current resource and cost estimates, Belize should complete a procurement process that secures: at least 5 MW of solar in addition to the planned 15 MW, and two onshore wind projects in Ambergris Caye and Maskall (up to 18 MW).

[iv] The cost of importing electricity and the contractual arrangements with Mexico are key variables that must be monitored regularly, as significant changes could cause changes in scenario scoring.

01 CONTEXT

CONTEXT

1.1 THE CURRENT ELECTRICITY SYSTEM

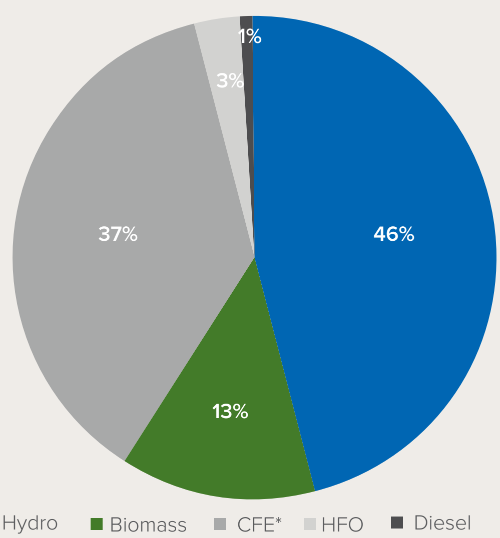
Current electricity generation in Belize is dominated by domestic hydropower and imported electricity from Mexico. Electricity flowing through Belize's transmission-level connection to Mexico (abbreviated CFE) at Chetumal in the north provided 37 percent of total electricity consumed in Belize in 2017. Over 95 percent of total generation for the connected grid system comes from a combination of CFE and several independent power producers (IPPs) that use both hydro and biomass as resources. Exhibit 3 shows the net electricity generation by source in 2017. Electricity from hydropower and other domestic resources is paid for via power purchase agreements (PPAs) between IPPs and the country's electrical utility, Belize Electricity Limited. The remaining 4 percent of Belize's electricity is provided by the IPP BAPCOL's Heavy Fuel Oil (HFO) plant in the Stann Creek district, and a diesel generator owned by BEL. In order to secure and manage these contracts, BEL works with the country's electricity regulator, the Belize Public Utilities Commission, to ensure reliable service and system operation.

Since a majority of the domestic generation is renewable, much of the carbon footprint of Belize's electricity sector comes from the its dependence on imported Mexican electricity. The Mexican grid is more carbon-intensive than the Belizean grid, with roughly 80 percent of electricity generation relying on fossil fuels, especially natural gas.

Both the domestic energy and the imported energy are transported throughout the country by BEL. BEL is the exclusive owner of transmission and distribution infrastructure in Belize, while also owning and operating a limited number of primarily diesel fuel-based assets; including a 2 MW system on Caye Caulker and a 22.8 MW backup generator in the Belize district. In recent

EXHIBIT 3

BELIZE'S SOURCES OF ELECTRICITY IN 2017



* CFE represents the portion of energy imported from Mexico

years, BEL has continued to improve the reliability of the country's grid, ensuring consistent, high-quality electricity is available to Belizeans during regular operation of the system. Exhibit 4 shows historical reliability metrics for the Belize transmission and distribution system, showing both the average duration (SAIDI) and frequency (SAIFI) of customer outages. Outages caused by hurricanes, IPPs, or vandalism (aspects outside of BEL control) are not included here, but are recorded separately by BEL. The 2015 grid reliability metrics are in line with 2015 averages for the Latin American and Caribbean region; BEL saw a SAIDI of 16.1 hours compared to the regional average of 27 hours, and a SAIFI of 12, matching the regional average.[1]

Furthermore, BEL, with oversight from the PUC, has ensured affordable electricity for the country. Belize's electricity tariffs are among the most competitive in the Caribbean region, and in line with the Latin American region. Exhibit 5 shows the 2016 average electricity tariff in Belize of US$0.18/kWh compared with the 2016 average for the Central American Integration System (SICA) of US$0.17/kWh,[2] and with the 2015 average for the Caribbean Community (CARICOM) of US$0.33/kWh.[3] Maintaining a low cost of electricity ensures affordable electricity is available for Belizeans, and also allows Belize to compete with others in the region to attract investment and tourism.

EXHIBIT 4

HISTORICAL RELIABILITY OF BELIZE'S TRANSMISSION AND DISTRIBUTION SYSTEM

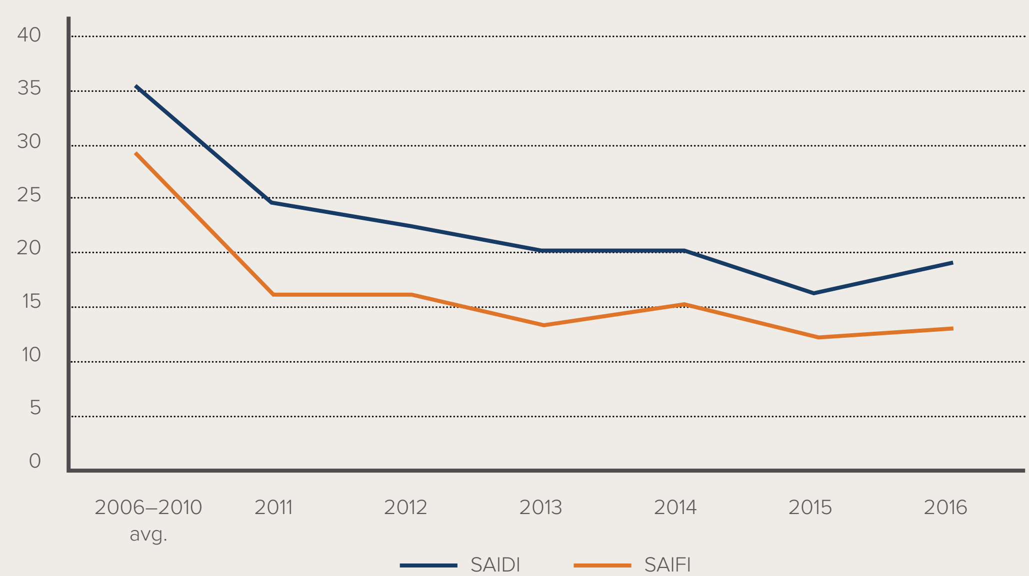
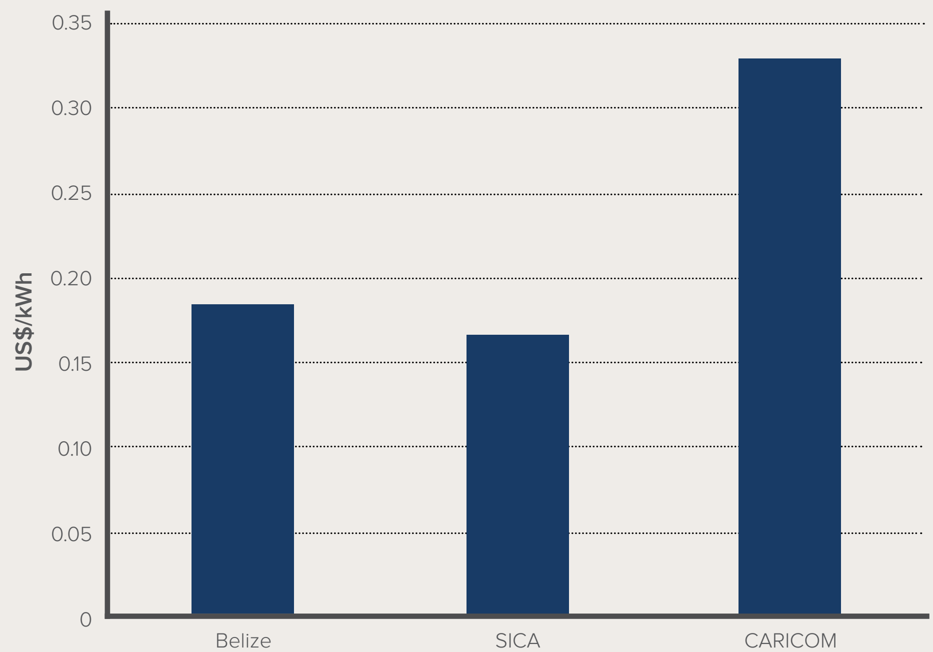


EXHIBIT 5

BELIZE'S AVERAGE ELECTRICITY TARIFF COMPARED TO REGIONAL AVERAGES



Belize has shown a desire to continue improving its energy system. In its nationally determined contribution (NDC) to the UNFCCC, Belize outlines a goal to achieve 85 percent renewable energy penetration by 2030 through a combination of hydro, solar, wind, and biomass, and reduction of transmission and distribution losses. BEL currently seeks to reduce transmission and distribution system losses from today's rate of 11 percent to the regional average of 8 percent by 2030. Despite the quality-of-service and cost improvements in Belize, there is a significant portion of the population, approximately 8 percent, that is not currently served by the electrical grid. However, BEL, along with the PUC, are working on increasing the level of access to electricity in the country. BEL has an expansion plan in place to reach 98 percent of the population by 2020. BEL will pursue this goal in accordance with the rates and policies enforced by the independent PUC.

Belize's ability to continue to provide low-cost and reliable electricity to an expanding portion of its population is challenged by more frequent and extreme weather events due to the effects of climate change. For example, projections for lower rainfall threaten the country's hydropower and biomass generation. In 2016, hydropower accounted for 43 percent of total domestic electricity generation with an installed capacity of 51.5 MW (see Appendix A for an overview of current electricity resources in Belize). A survey conducted by the Latin American Energy Organization (OLADE) predicted a 12 percent decrease in precipitation in the region between 2020 and 2039, and a 30 percent reduction in some Central American regions by 2090. Across the region, the report predicts that hydropower generation will decrease 39.5 percent by 2090 with supply cost increasing between 7 percent and 115 percent. Mollejon, Belize's largest dam in terms of capacity, faces a projected 6 percent water flow reduction by 2030 and a 35.2 percent reduction by 2090. The corresponding generation losses are 8.6 percent and 43 percent, respectively.[4] The majority of Belize's hydropower assets are located on the Macal River and are subject to similar vulnerabilities in a future with less precipitation.

In addition to impacting the country's hydro generation, changes in rainfall will impact Belize's biomass generation. Currently, electricity generated from biomass uses an abundance of sugarcane byproduct to fuel a 13.5 MW bagasse plant managed by the IPP Belcogen. Santander has also recently begun operation of a biomass facility near the capital, Belmopan, with the capacity to provide 8 MW of power to Belize's grid. Findings reported in Belize's Second National Communication (SNC) to the United Nations Framework Convention on Climate Change (UNFCCC) on the results of the CROPWAT model projected an 11.9 percent reduction in yield for sugarcane by 2028 with 12 mm less rainfall, and a 17.4 percent reduction by 2050 with 20 mm less rainfall.[5] In the event that this happens, it would reduce the supply of feedstock available to power this system, and force the country to turn to other means of electricity generation.

Not only will climate change pose a risk to Belize's generation assets, it also poses risks to transmission and distribution infrastructure that is vulnerable to hurricanes and other extreme weather events. Past hurricanes illustrate this potential risk. Hurricane Dean of 2007, for example, made landfall in Belize with 165 mph winds and brought the grid to total blackout due to damaged distribution lines and a disruption of the interconnection to the Mexican grid, cutting supply by 96 percent and lasting more than a week. By effectively cutting off the hydropower transmission lines, Hurricane Richard reduced system supply by roughly 50 percent in 2010. The assessment conducted by the Government

of Belize (GOB) and World Bank estimates that total economic losses from Dean and Richard are roughly US$80 million and US$35 million respectively.[6] Previously, Hurricane Keith of 2000 inflicted damage equal to an estimated 45 percent of national GDP, significantly reducing Belize's capacity to invest in climate resilient infrastructure to mitigate future losses.

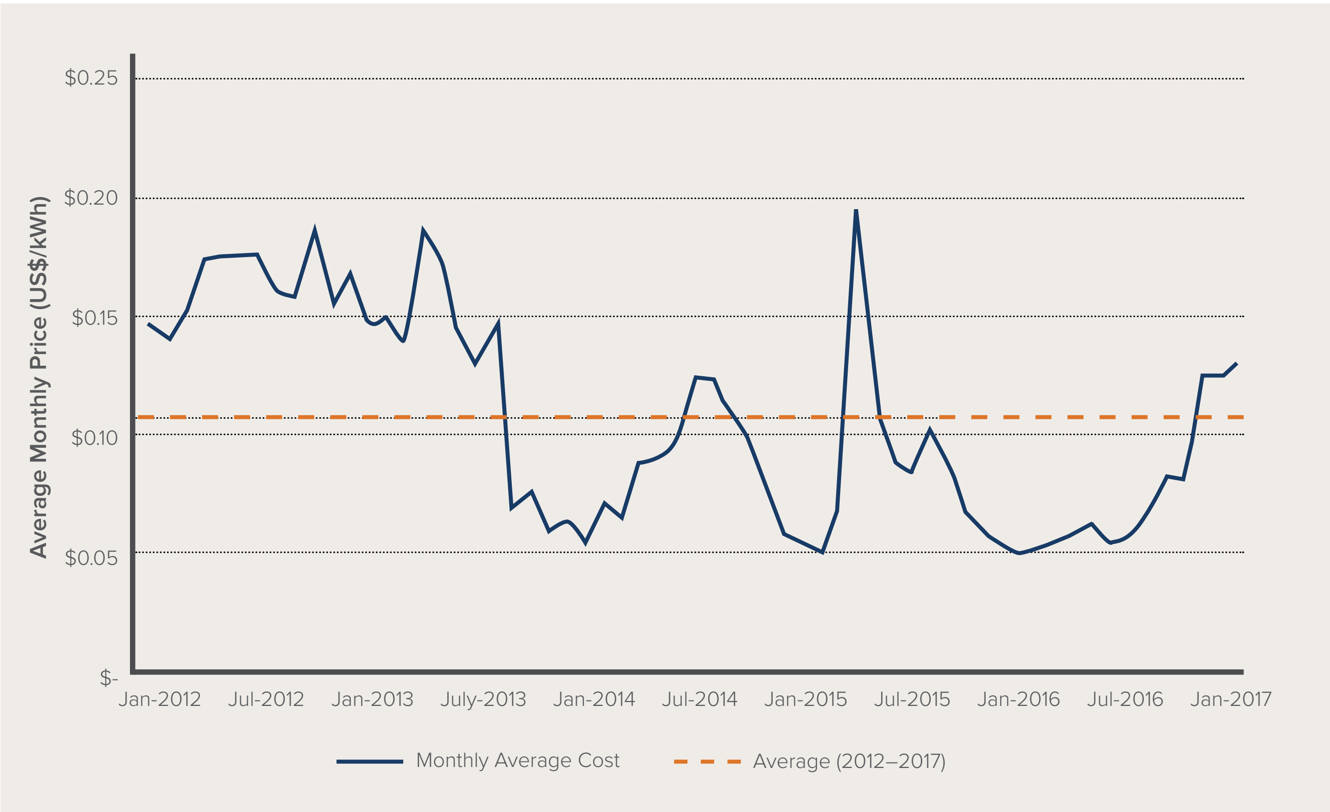
Fossil fuels have historically played a significant role in Belize's economy, fueling transport activities and electricity. The dependence on fossil fuels has created vulnerabilities in the electricity system due to the volatility of fossil fuel prices and dependence on fossil fuel imports for government revenue. Currently, the government is dependent on taxes on imported fuels for more than 10 percent of its annual revenue. This dependence on fuel taxes makes the government budget vulnerable to new technologies that reduce the consumption of fuel imports. The dependence on fossil fuel imports and electricity imports also adds price volatility risk to the energy sector in Belize. Imports, both in fossil fuels and CFE electricity, have been historically volatile (see Exhibit 6) and are projected to increase in the short term.[iii]

Furthermore, the dependence on imported energy makes it more difficult for Belize to stabilize its currency. Payments fulfilling PPA contracts held by IPPs and CFE imports lead to a significant outflow of US dollars causing the need for a larger internal reserve of Belizean dollars to maintain the current exchange rate. Further reliance on imports can also lead to a loss of domestic technical capacity in the country. External reports indicate that foreign direct investment in the energy sector has declined since 2008. However, the government has been approved for several grants and loans from multilateral organizations such as the United Nations Development Programme (UNDP) and the World Bank to pursue electrification and sustainable energy initiatives, which can decrease the dependence on energy imports while increasing financial investments in the country.[7]

[iii] According to BEL's 2018 CFE import cost forecast.

EXHIBIT 6

HISTORICAL CFE PRICES FOR 2012–2017 AT THE MARKET NODE WHERE BELIZE PURCHASES ITS ELECTRICITY



1.2 FUTURE OPPORTUNITIES

Given the available alternative sources of electricity generation at lower cost than fossil fuel-based resources, there is an opportunity to maintain and improve Belize's energy system and even further reduce dependence on imported fuels. Many of these opportunities emerged before the CPP analysis began, and the feasibility of several of these options is explored in more detail in this analysis.

Declining renewable energy prices and the high resource potential for technologies such as solar PV represent a large opportunity for Belize to develop capacity in renewable energy deployment. Belize's overall sustainability goals benefit from projected drops of 25 percent in solar costs and 30 percent in wind costs in the next 15 years. Growing interest in biomass generation and the development of the sugarcane industry could lead to further gains in this sector as sugarcane inputs become more readily available. Uncertainty around the future price of imports influences the optimal mix of resources in Belize's grid, and points to opportunities to diversify the electricity sector to be more insulated from volatility. Existing approaches to energy development enhance these vulnerabilities to external factors and threaten the stability of both the grid and national electricity prices.

In the face of extreme weather and future storms, the World Bank identified several opportunities to strengthen the electrical grid and energy infrastructure.

One of the main suggestions focuses around segmenting the highly centralized transmission system to prevent cascading failures that arise during hurricanes. It concludes that 90 percent of electricity shortages during a storm are related to damaged distribution infrastructure, and recommends that Belize invest in grid hardening to minimize these damages and increase resiliency.[8]

The current tariff structure disincentivizes BEL from investing in or promoting energy efficiency, even though energy efficiency is generally the least-cost individual resource option for the electricity sector. This points to further opportunities for the GOB and BEL to decouple their revenues from electricity sales and fuel imports, and move toward new programs to generate revenue for investments in a more resilient energy system. Previous reports also argue that decoupling BEL's revenues from strict energy sales will help to ensure both sustainability across the energy system and solvency of the utility in the face of a changing energy sector.[9]

02 CPP APPROACH

CPP APPROACH

Recognizing the opportunity to build on the benefits of the current electricity system while addressing near-term opportunities, leaders in Belize collaborated on a consolidated project plan. The CPP was completed in partnership with the Government of Belize, Belize Electricity Limited, and the Belize Public Utilities Commission. The team from Rocky Mountain Institute and Clinton Climate Initiative completed the analysis as an independent and objective third party. Additional technical support was provided by DNV GL, HOMER Energy, and NepCol International. This section describes the general CPP methodology and the specific analysis components that come together in this process.

Partners embarked on the CPP process with several key objectives in mind, including:

- Further alignment on a joint vision for the future of the electricity sector in Belize.
- Pursuing objective analysis to explore future needs, current assets, and new options that can contribute to Belize's electricity sector.
- Integration and consolidation of important previous studies and efforts related to electricity in Belize.
- Building a fact-based understanding of the impacts of various options in moving toward shared priorities for the electricity sector.

In addition, the CPP process was designed to utilize existing studies and efforts, and build upon them to identify new opportunities based on systems-level analysis to create Belize's future electricity system. The outcomes of the CPP process, described in this report, include a set of recommendations for actions to move toward the shared electricity-sector goals articulated by the CPP partners.

2.1 OVERARCHING GOALS

CPP stakeholders aligned on four key goals for the future of the electricity sector in Belize: (1) sustainable economic development, (2) security of supply, (3) least cost, and (4) energy access. These goals are shared across the GOB, BEL, and PUC, and provide a consolidated vision for Belize's electricity future. These shared goals drive the analysis and frame the recommendations of the CPP process.

2.2 ANALYSIS PROCESS

To analyze opportunities with respect to the four shared goals, the CPP included two parallel pieces of analysis, one focused on grid-scale options, and one focused on options for energy access. The grid-scale analysis focused on the national grid and examined several scenarios for supply- and demand-side resources, while the energy access analysis focused on finding the best

approach to reach communities that are not yet part of the BEL grid expansion plan. The results of each portion of the analysis come together to provide overall insights and recommendations for the future of the electricity sector in Belize, in relation to the shared goals. The approach for each portion of the analysis is described in this section.

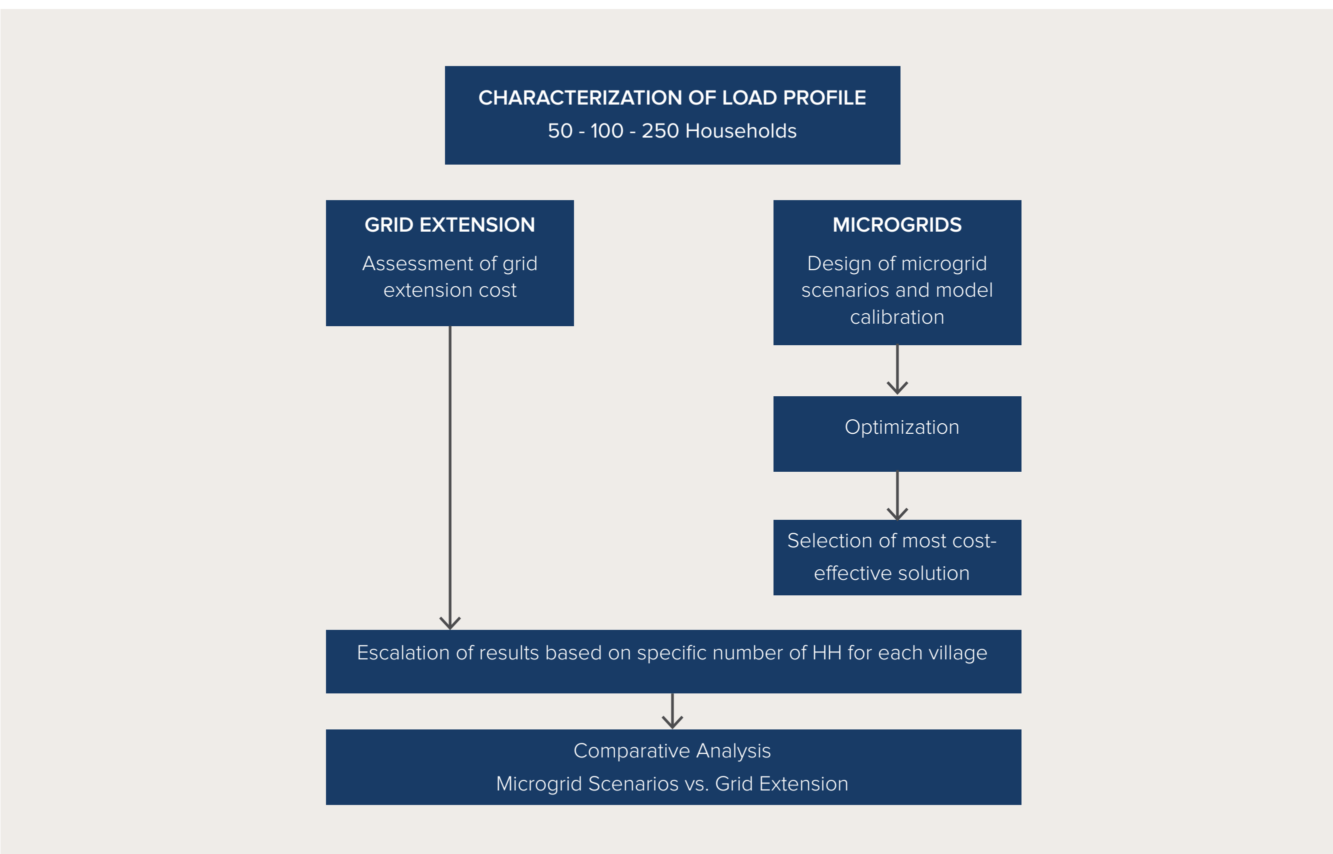
2.2.1 ENERGY ACCESS ANALYSIS

There are 64 communities in Belize that either have no access to electricity from the grid, or only have partial access. Partial access means there are houses that are classified as being in a community, but are not connected to the grid due to their distance from the existing distribution infrastructure in that community. Of these communities, 34 are classified as not connected to the grid at all and 30 are classified as partially connected. A list of these communities can be found in Appendix B.

BEL has a plan to to electrify 36 of these 64 total communities by 2020, through grid extension. This covers the 30 partially connected communities and six of the nonelectrified communities, leaving 28 nonelectrified communities in need of a plan for electrification. The CPP looks at all unelectrified communities to assess the cost-optimal method for electrification.

EXHIBIT 7

OVERALL CPP APPROACH FOR ENERGY ACCESS ANALYSIS



All stakeholders identifed universal access as a top priority, with grid extension and microgrids as possible routes for achieving this objective. Depending on the combination of different components, the economics of a microgrid solution can vary widely and may cost more than a grid extension option. The CPP energy access analysis compares different microgrid configurations with the estimated cost of grid extension for the 28 remaining communities, in order to provide guidance on the optimal route to providing energy access throughout Belize. Exhibit 7 shows the steps in the CPP energy access analysis process.

As indicated in Exhibit 7, the first step in the CPP energy access analysis involves the characterization of the community load profile. The team based this projection on typical habits of remote communities. As an example, the team assumed that energy-intensive chores such as using washing machines would occur during weekends. While washing machines may not seem to be a typical appliance that low-income families acquire when first electrified, interviews in the La Gracia community in Belize show that rural families desire to purchase this type of appliance. Exhibit 8 shows the final load profile as modeled for a typical weekday and

EXHIBIT 8

MODELED LOAD PROFILE FOR THREE REMOTE COMMUNITY SIZES

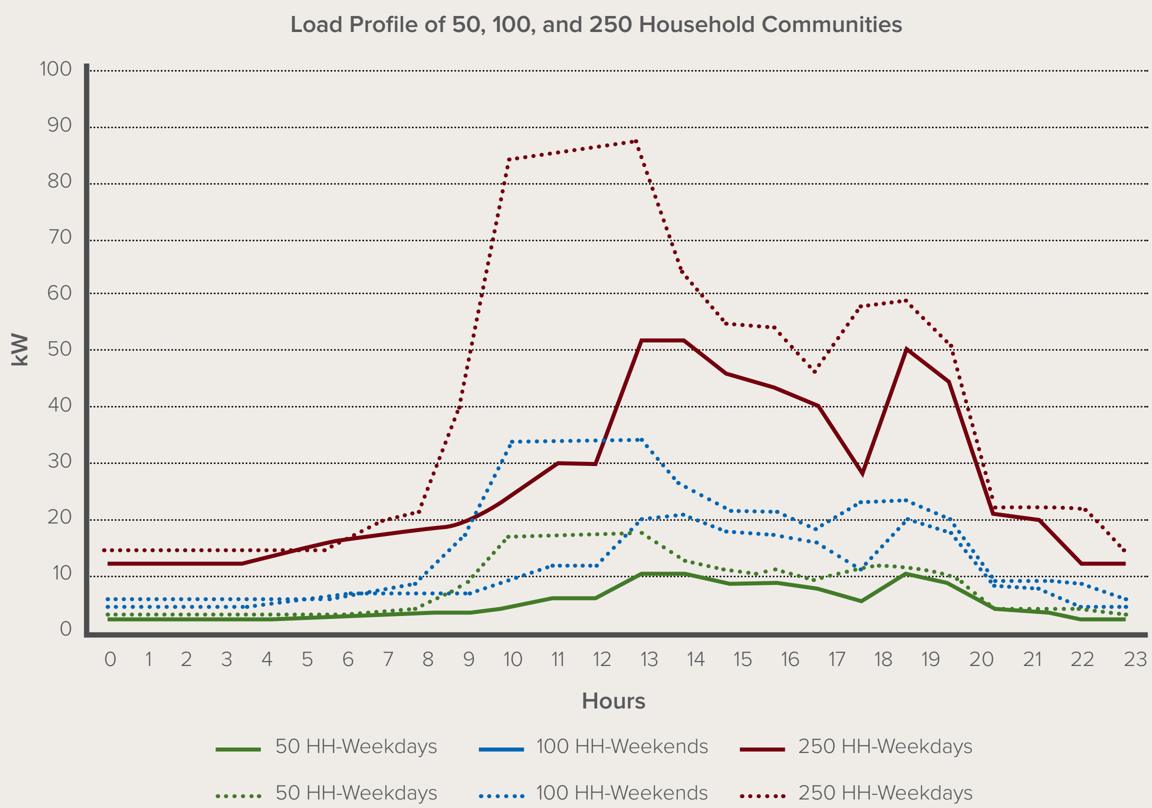


EXHIBIT 9

SCENARIOS TESTED IN CPP ENERGY ACCESS ANALYSIS

NO.	SCENARIO		
1	SPV + Lead Acid Storage		
2	SPV + Li-ion Storage		
3	SPV + Lead Acid Storage + Diesel Backup	Fuel Sensitivity	0.51 US$/L
4	SPV + Li-ion Storage + Diesel Backup		1.00 US$/L
5	Diesel Only		
6	SPV + Lead Acid Storage + LPG Backup		1.39 US$/$m^3$
7	SPV + Li-ion Storage + LPG Backup		
8	LPG Only		2.00 US$/$m^3$
9	Grid Extension		

weekend day for communities of 50 households (HH), 100 HH, and 250 HH. The observed weekend peak is due to the use of washing machines.

Next, microgrid techno-economic modeling was performed using the HOMER Pro software. Exhibit 9 describes an overview of the applied methodology and analyzed scenarios. For each microgrid scenario, the HOMER Pro software provides the optimal mix of resources, and calculates the net present cost of implementing and operating a microgrid with that mix over 20 years.
The final step in the energy access analysis was the comparison to grid extension costs. For this purpose, joint efforts with BEL enabled the calculation of unit grid extension costs, which were then applied to each community. The following elements were considered:

- Materials
- Labor
- Contracts
- Accommodation & Subsistence
- Transportation

The geographical information tool ArcGIS was utilized to calculate the distance between each community under consideration, and the nearest point on the distribution grid. The grid extension costs calculated by BEL were then scaled based on the distance to each of the communities under investigation. The analysis assumed that the communities closer to the grid will be electrified first, and then the grid will extend to reach farther communities. For example, the cost to extend the grid to Otoxha depends on the grid extension for Sunday Wood and Conejo Creek. If Conejo Creek were to be electrified with a microgrid, then the communities that are further out need to be reassessed accordingly. This is demonstrated in Exhibit 10.

EXHIBIT 10

MAP SHOWING SELECT COMMUNITIES AND POTENTIAL ROUTES FOR GRID EXTENSION

Finally, the team made a direct comparison of the NPC of grid extension to the NPC of implementing a microgrid for each of these communities. The results of this analysis appear in Section 3.

2.2.2 GRID-SCALE ANALYSIS

The CPP process included evaluation of resource options, development of a set of scenarios, definition of specific metrics related to the shared goals, and techno-economic and power system analysis to evaluate each of the scenarios. Exhibit 11 shows the overall CPP approach.

The energy generation potential of several resource options in Belize was first discussed and assessed. These options included expanding upon resources already used in Belize today such as hydro and biomass, as well as resources that have not yet been utilized in a significant way in Belize, including energy efficiency, solar, wind, natural gas, liquefied petroleum gas, energy storage, and additional interconnection to the Mexican grid. More details on the assessment of individual resource options, including projected costs for each, are included in Appendices C–I.

With resource options understood, the CPP team then agreed on a set of 11 discrete scenarios to test through the CPP modeling efforts, each containing a different combination of new electricity resources. Exhibit 12 displays the new resources added to the generation mix for Belize in these 11 scenarios:

- Reference (Ref)
- 2013 Request for Proposals (RFP)
- Hydro, Biomass (HB)
- Solar, Wind (SW)

- Hydro, Biomass, Solar, Wind (HBSW)
- Aggressive Energy Efficiency (Aggressive EE)
- Liquefied Natural Gas (LNG)
- Liquefied Petroleum Gas (LPG)
- Storage
- Interconnection + Hydro, Biomass, Solar, Wind (HBSW)
- Interconnection + Hydro

All scenarios include the addition of two new resources that are currently under development or negotiation, including:

- Santander 2, biomass, 8 MW of additional electrical output, operational in 2020.
- Solar PV, 15 MW (in three 5 MW sites), operational in 2020.

Partners converged around the use of a Reference scenario to compare against other scenarios, which contains no additional resources beyond these, leaning on the CFE interconnection and the construction of

EXHIBIT 11

OVERALL CPP APPROACH FOR GRID-FOCUSED ANALYSIS

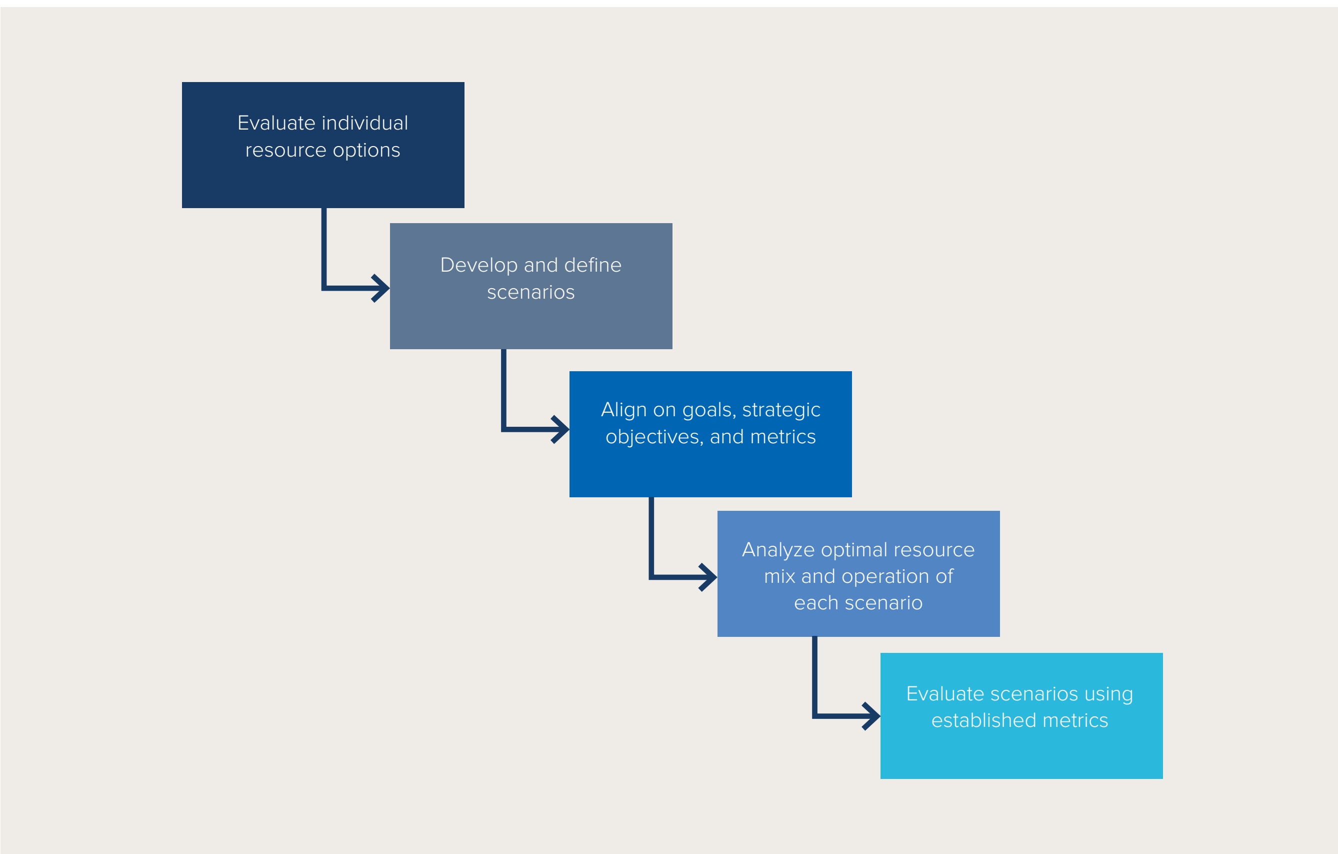


EXHIBIT 12

OVERVIEW OF RESOURCES INCLUDED FOR BELIZE IN 11 SCENARIOS, BEYOND REFERENCE SCENARIO INVESTMENTS

SCENARIO NAME	RESOURCES INCLUDED	
REFERENCE		15 MW Solar and 8 MW Santander-2 Biomass
2013 RFP		Ref + Chalillo-2 and Upper Swasey Hydro Projects and GSR Biomass Project
HB		Ref + Optimizes for Hydro and Biomass
SW		Ref + Optimizes for Solar and Wind
HBSW		Ref + Optimizes for Hydro, Biomass, Solar, and Wind
AGGRESSIVE EE		Ref + Aggressive Energy Efficiency; Optimizes for Solar, Wind, Hydro, and Biomass
LNG		Ref + Natural Gas
LPG		Ref + LPG
STORAGE		Ref + Optimizes for Solar, Wind, and Storage
INTERCONNECTION + HBSW		Ref + New Regional Interconnection; Optimizes for Hydro, Biomass, Solar, and Wind
INTERCONNECTION + HYDRO		Ref + New Regional Interconnection; Chalillo-2 and Upper Swasey Hdyro Projects

a new line to Mexico to meet increased load in later years. Analysis shows that the existing connection can no longer sustain projected demand after 2034, given both demand projections and operating reserve requirements of 10 percent of current load that were included in this analysis.

The 2013 RFP serves as a secondary base case which includes the Chalillo 2 and Upper Swasey dams as well as the large GSR biomass project currently under negotiation. The other scenarios contain different mixes of new resources in Belize, or an additional line connecting to CFE under both interconnection scenarios.

The Reference and 2013 RFP scenarios assume 3.4 percent sales growth per year (based on a recent cost-of-service study completed by DNV GL), while every other scenario assumes 2.8 percent sales growth per year given the implementation of energy efficiency through a programmatic approach. A total target for energy efficiency was calculated by Castalia in 2014 as part of the National Sustainable Energy Strategy (NSES). That study found a target of 24 percent savings from a 10-year program achieving 75 percent penetration among all customers using lighting, refrigeration, air conditioning, and other energy efficiency measures. For the CPP analysis, estimated customer penetration was scaled down for the core scenarios, resulting in total program savings of 10 percent in 2036.

The CPP also includes an Aggressive EE scenario considering implementation of an aggressive program based on higher penetration among customers leading to an additional 10 percent reduction in energy consumption by 2036 (20 percent in total against the

EXHIBIT 13

PROJECTED DEMAND WITH AND WITHOUT ENERGY EFFICIENCY

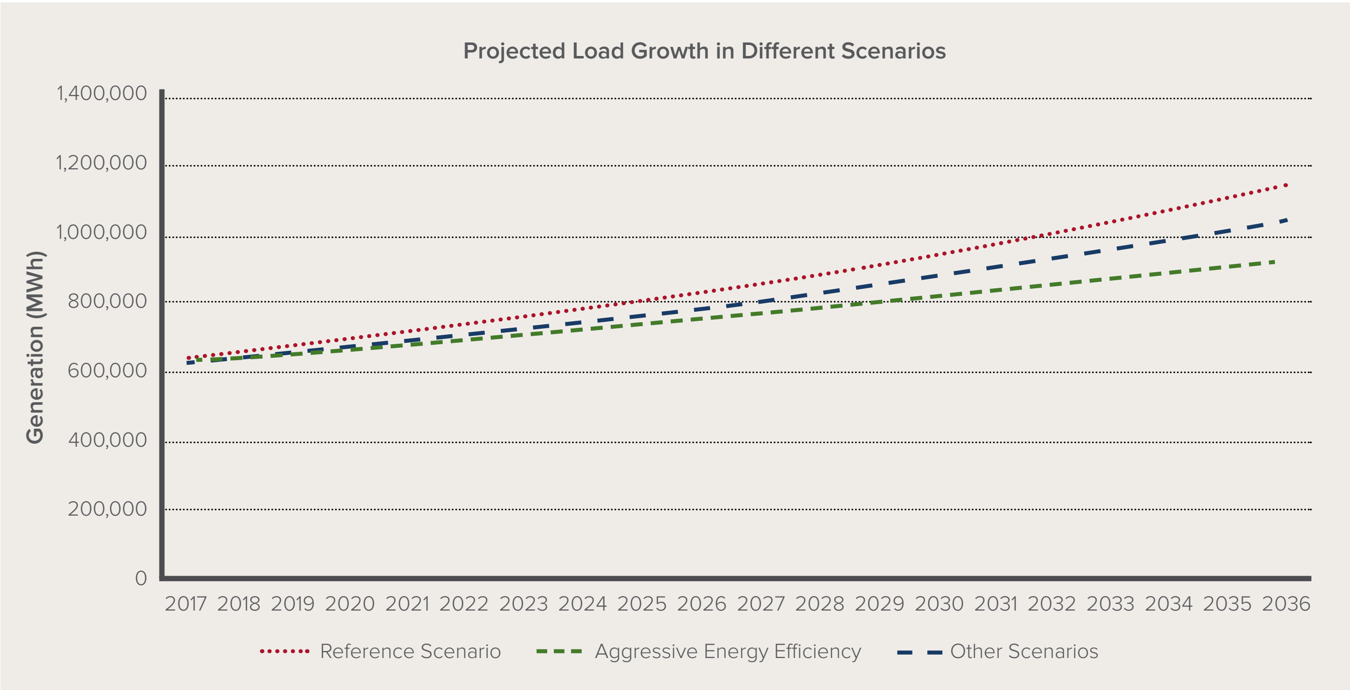
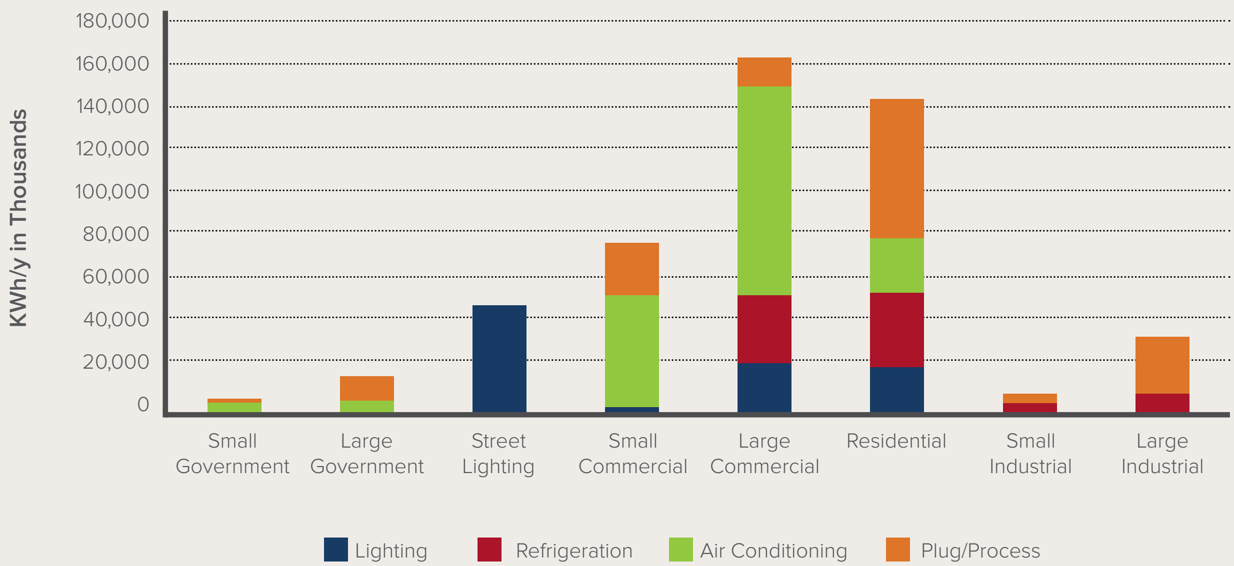


EXHIBIT 14

CURRENT ELECTRICITY END USE BY SECTOR IN BELIZE



* Source: WSP Analysis

Reference scenario). The resulting annual growth rate for electricity sales is 2.2 percent. Projected demand growth for all scenarios is shown in Exhibit 13.

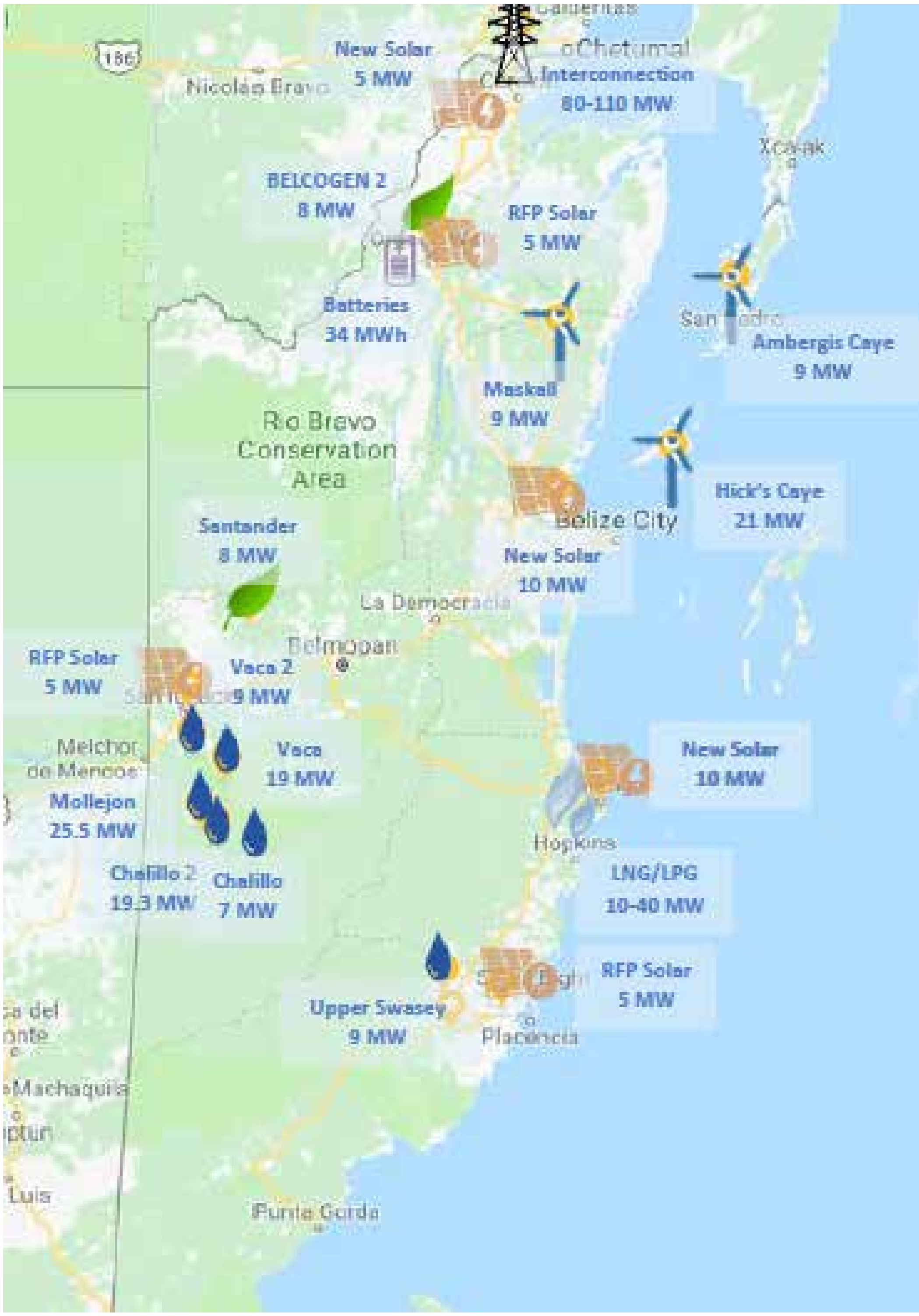
Projected savings from an EE program focus on the large commercial and residential sectors—the largest users of electricity in Belize (as shown in Exhibit 14). The program would focus on incentivizing improvements, with the largest savings coming from refrigeration in residential customers (7 percent of total EE savings) and air conditioning in large commercial properties (19 percent of total EE savings).

In addition to sales, all scenarios consider electricity system losses as well; all scenarios include a reduction in net electricity losses (technical and nontechnical) from 11.6 percent (the 2016 actual) to 8 percent in the coming years, which is the regional target level indicated by the IDB. In all scenarios, the energy model extends to the year 2036 for a total 20-year planning horizon.

With the type of resources in each of the scenarios defined, the team used the HOMER Pro software to determine the economically optimal installed capacity of each resource per scenario, based on capital and operating costs for the generation components. The HOMER Pro software completes an hourly dispatch of resources, to ensure that the basic requirements of load and operating reserves are met in every hour of the year. The team used HOMER Pro to model electricity needs in 2036, and to run multiple simulations of different resource mixes to meet those needs. The team then selected the least-cost option that contains the resources specified for each scenario. In order to illustrate the impact of various investments over

EXHIBIT 15

POTENTIAL NEW RESOURCES CONSIDERED IN VARIOUS CPP SCENARIOS



time, the team then used HOMER Pro to model each year of operation from 2017 to 2036, adding any new resources to the model in discrete investment years, namely 2025 and 2030. Exhibit 15 shows the potential projects modeled in various CPP scenarios, and their approximate locations in Belize.

The next steps in the grid-focused analysis involved using power systems expertise from DNV GL to first confirm the technical feasibility of each scenario by evaluating grid operations in each scenario through a power flow analysis, under both normal and contingency conditions. In addition, the team forecasted the expected impact on the duration of electricity system outages under each scenario.

After completing the techno-economic and power-systems analyses, the set of 11 scenarios were evaluated for their performance against the agreed-upon CPP metrics in relation to the overarching goals of sustainable economic development, security of supply, and least cost. Exhibit 16 lists the strategic objectives that were evaluated for each scenario, and the results of this evaluation are discussed in Section 3.

EXHIBIT 16

OVERVIEW OF CPP SHARED GOALS AND STRATEGIC OBJECTIVES RELATED TO GRID-SCALE OPTIONS

GOAL	STRATEGIC OBJECTIVE
SUSTAINABLE ECONOMIC DEVELOPMENT	Increase investments occurring in the country
	Increase the number of jobs available
	Reduce the total cost of imported fuel and electricity
	Increase renewable energy penetration
	Increase efficiency of end use
SECURITY OF SUPPLY	Reduce cost volatility of electricity
	Increase reliability (during normal operation)
	Increase resiliency (response to external shock)
	Increase adaptability
LEAST COST	Least-cost generation expansion and operation

03 RESULTS

RESULTS

3.1 ENERGY ACCESS ANALYSIS

The CPP analysis found that 35 of the 36 communities on BEL's plan for grid extension are indeed better served with grid extension. The outlier is Medina Bank, which is now under consideration for a grant to support development of a remote microgrid.

30 of these 36 communities are classified as partially electrified, however, there was no available data on the number of households that are without electricity within these communities. The physical separation between the houses and the distance from the distribution lines also impact the economics of investment decisions. The cost implications of microgrids or stand-alone solar systems should be considered if any of these houses are prohibitively far from the rest of the community.

For the remaining 28 communities that do not currently have a plan for providing energy access, the 20-year lifetime cost of various microgrid configurations was compared to that of grid extension. The energy access tool developed in the CPP highlights communities that are prime candidates for microgrids, empowering Belize to objectively assess which is the optimal solution to serve each community.

Analysis indicates that, in general, the smaller the community, the more likely it is better served by a remote microgrid. As the number of households increase, the costs between microgrids and grid extension start to converge, and above 250 households, there is little justification for microgrids. The number of households serves as a proxy for increasing load. The presence of an energy-intensive productive use can easily tip this balance. Additionally, the costs of both remote microgrids and grid extension are largely dependent on topography and distance from existing infrastructure.

Exhibit 17 shows the unelectrified communities that the CPP shows are no-regrets candidates for microgrids.

The estimated net present costs over 20 years and associated cost savings for hybrid microgrids versus grid extension are shown here. If these six communities were to be electrified through hybrid microgrids rather than electrified via grid extension, the system can save US$1.5 million in total costs over 20 years. If grants offset these microgrid costs, the savings will be even greater.

There are seven additional communities that are too close to call in terms of electrification options. These are Conejo Creek, Santa Elena, Sunday Wood, Santa Teresa, Santa Cruz, Dolores, and Seven Miles El Progreso. Productive uses in these communities or loads that are unaccounted for could tip the scale toward grid extension, which necessitates a community survey prior to electrification. The remaining communities are likely candidates for grid extension.

Each community is unique and, as illustrated above, the difference in costs between the appropriate microgrid and grid extension can vary widely. For example, the cost of the microgrid at San Carlos is 88 percent lower than the cost of grid extension,

EXHIBIT 17

COMPARISON OF PROJECTED MICROGRID AND GRID-EXTENSION NET PRESENT COSTS FOR SIX SELECT COMMUNITIES (US$)

COMMUNITIES	NO. OF HOUSEHOLDS	ESTIMATED ELECTRICAL DEMAND (KWH/Y)	MICROGRID NPC	GRID EXTENSION NPC	COST SAVINGS
SAN CARLOS	29	49,000	$75,000	$580,000	$505,000
PINE HILL	39	66,000	$101,000	$315,000	$214,000
OTOXHA	52	83,000	$128,000	$500,000	$372,000
CRIQUE SARCO	64	102,000	$157,000	$348,000	$191,000
SAN VINCENTE	77	122,300	$200,000	$440,000	$240,000
SAN BENITO POITE	91	144,500	$230,000	$544,000	$314,000
TOTAL FOR SIX COMMUNITIES	**352**	**566,800**	**$891,000**	**$2,408,000**	**$1,517,000**

while for San Vincente, the cost of the microgrid is 55 percent lower than the cost of grid extension. It is also important to note that specific HOMER models were not built for every community, but instead for representative communities of 50 HH, 100 HH, and 250 HH.

The choice of the energy access method, whether via grid extension or microgrid, has direct implications on the economics of the specific energy access project. It is important to note that the optimal size of the energy system is driven by electricity demand. The higher the load, the more attractive grid extension becomes. This trend can be seen in Exhibits 18–20. The vertical blue bars show the NPC of grid extension to each community. The green and pink lines show the NPCs of solar and battery microgrids (no fossil fuel component). The hybrid microgrids and fossil-fuel-only microgrids are shown in the other four lines, and fall within a similar band. Exhibit 18 shows all communities that are below 50 HH in size. Hybrid microgrids are the most cost-effective option for San Carlos and Pine Hill, but even fully renewable microgrids are more cost-effective than grid extension here. All other communities fall within the margin of error where detailed data-gathering on community demographics, productive uses in existence, and potential productive uses can be incorporated to tip this balance. For the communities of between 50 HH and 100 HH, similar insights can be taken from Exhibit 19, where Otoxha, San Vincente, Crique Sarco, and San Benito Poite are good candidates for microgrids, and Sunday Wood, Santa Teresa, Santa Cruz, and Seven Miles are within the margin of error. These remain key communities to

EXHIBIT 18

COST COMPARISON FOR GRID EXTENSION AND MICROGRID OPTIONS FOR 50 HH COMMUNITIES

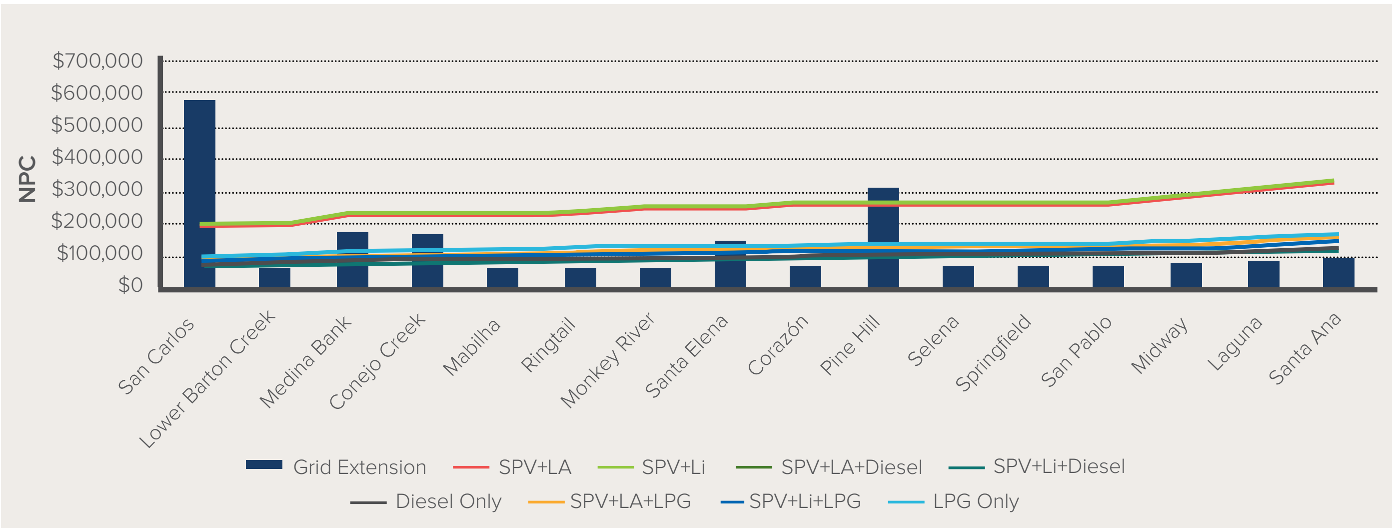


EXHIBIT 19

COST COMPARISON FOR GRID EXTENSION AND MICROGRID OPTIONS FOR 100 HH COMMUNITIES

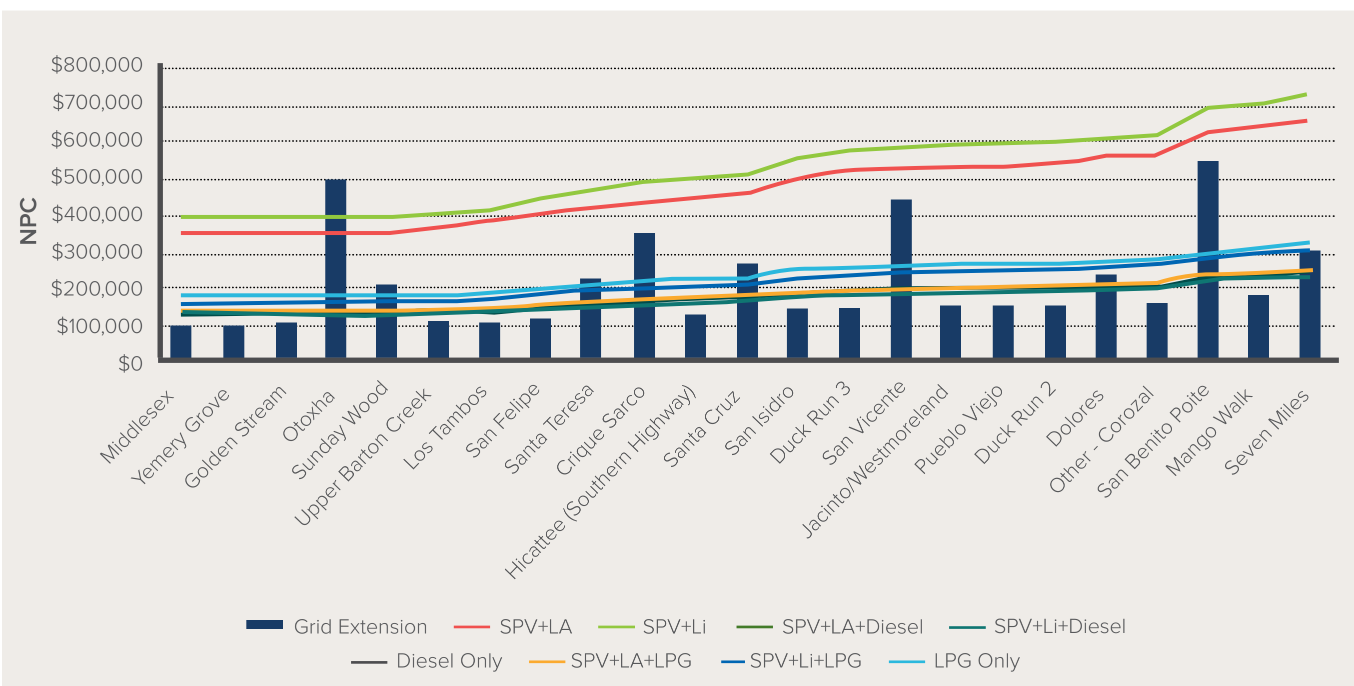
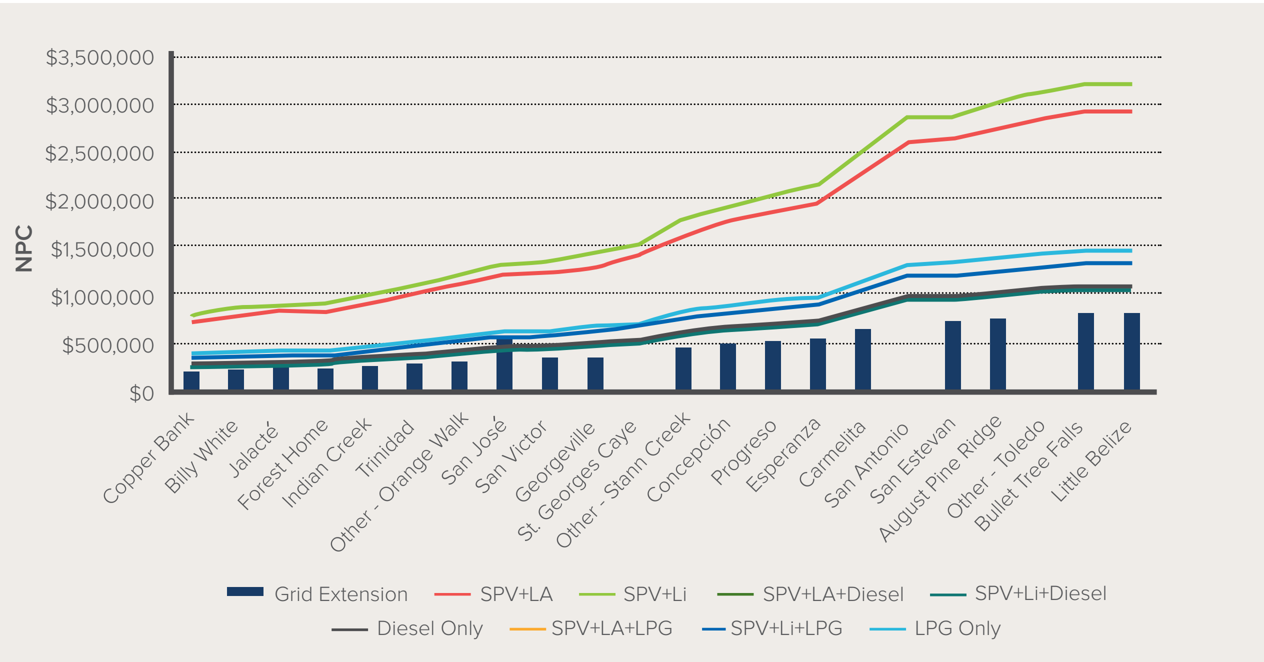


EXHIBIT 20

COST COMPARISON FOR GRID EXTENSION AND MICROGRID OPTIONS FOR 250 HH COMMUNITIES



prioritize when grants present themselves.

There are clear benefits and limitations to either approach to electrification. Grid extension offers more flexibility for growth while keeping the additional capital investment relatively low. Microgrids offer the benefits of reduced stress on the transmission and distribution network, avoiding right of way issues and land acquisition, reduced susceptibility to natural disasters with falling overhead lines, and reduced losses. These microgrids can be scaled up, as these decisions are community-specific and require project management. The CPP analysis provides a framework to make these decisions given initial insights. Ultimately the intent of this analysis is to equip Belize with the tools and knowledge to drive the optimal decisions for each community at the time when the electrification-approach decision needs to be made, based on the prevailing market conditions at that time.

For those communities that are best served by microgrids, the CPP analysis illustrates that microgrids that are purely renewable can cost 70 to 200 percent more than hybrid (solar, batteries, and diesel) systems. This is because they are sized to meet the peak load in a single day, in addition to providing spinning reserve. However, some grants require purely renewable systems, and in cases where installing distribution lines is prohibitive and poor roads provide a barrier to diesel delivery, 100 percent renewable energy systems are practical choices. Exhibits 21–23 show a comparison of net present cost for each microgrid configuration for the three community sizes that were modeled, along with the renewable energy (RE) penetration plotted on the right-hand axis.

When comparing energy storage options, lithium-ion (LI) batteries are more cost-effective than lead acid

EXHIBIT 21

SUMMARY OF NPC AND RE PENETRATION FOR MICROGRID OPTIONS FOR 50 HH COMMUNITIES

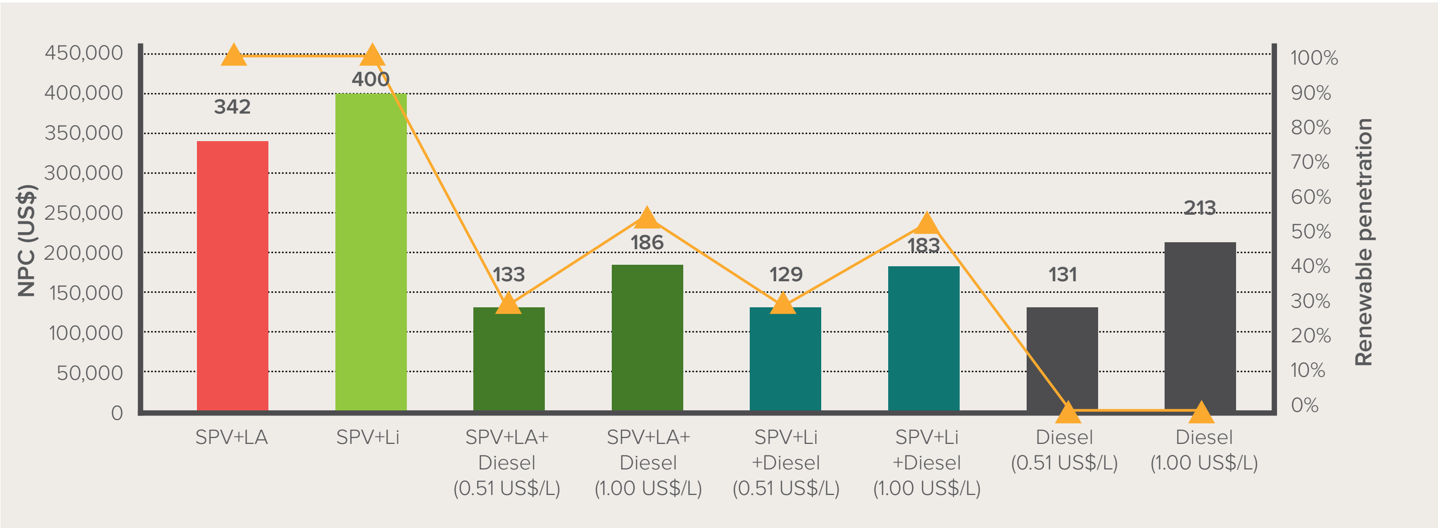


EXHIBIT 22

SUMMARY OF NPC AND RE PENETRATION FOR MICROGRID OPTIONS FOR 100 HH COMMUNITIES

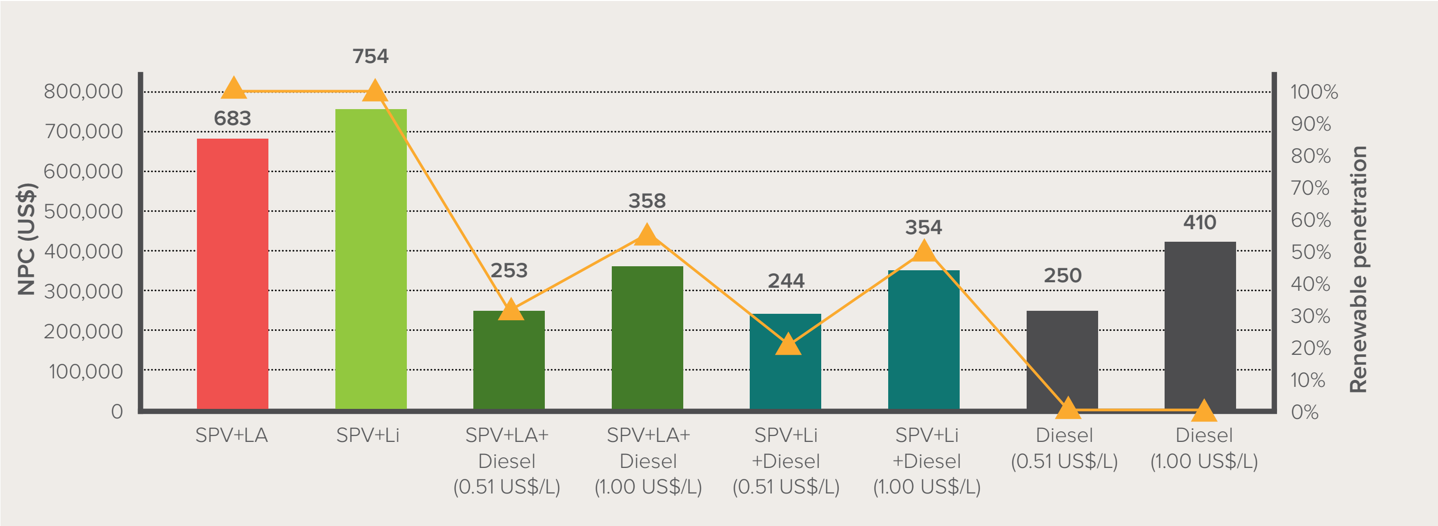
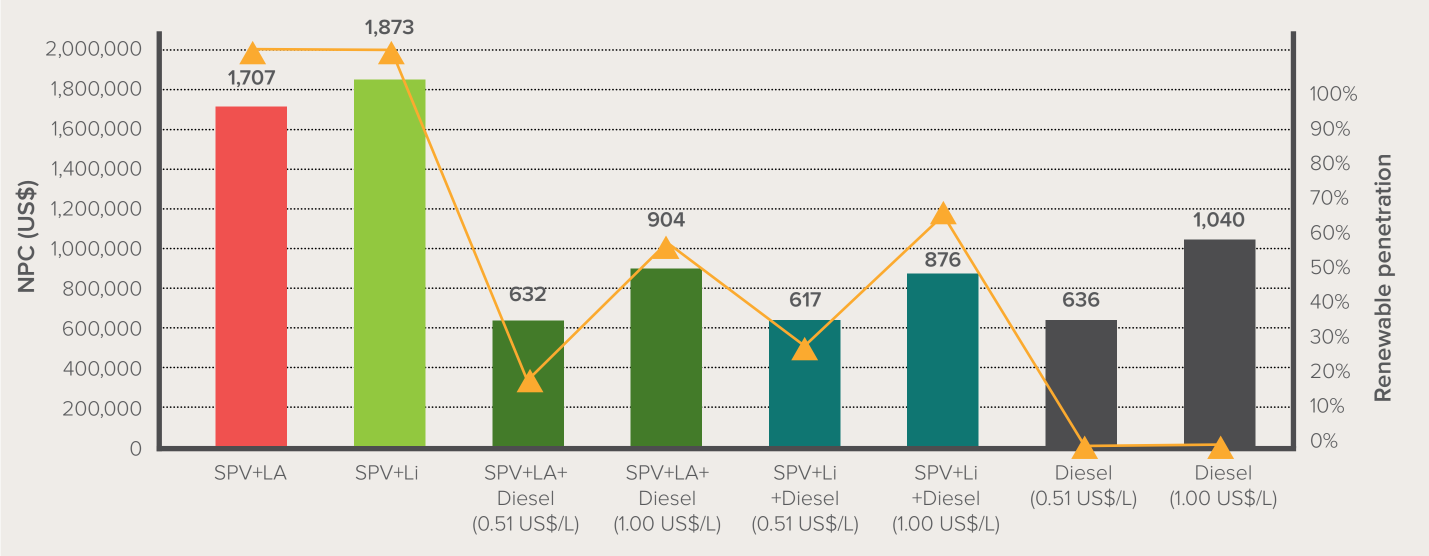


EXHIBIT 23

SUMMARY OF NPC AND RE PENETRATION FOR MICROGRID OPTIONS FOR 250 HH COMMUNITIES



(LA) batteries for hybrid remote microgrids due to longer life and lower cost of operation. While the initial investment for LA is half the initial cost of LI, the latter's cycle life is nearly triple that of the former, while also allowing for further depth of discharge within each battery unit. From a lifetime cost perspective, these characteristics make LI the economically preferable storage option. This is dependent on proper battery installation and management. Across all microgrid configurations with storage, the LI option proved to have a lower NPC, and thus a lower levelized cost of electricity (LCOE), than the LA option.

The levelized cost of electricity for communities served by microgrids is above the national tariff. The LCOE of a hybrid microgrid, for example, is at least 28 percent more than the national tariff (selecting the example of a generic 100 HH solar-LI-diesel microgrid, the LCOE is US$0.23/kWh, while the national tariff is US$0.18/kWh). That being said, in the cases outlined above, it is the lower-cost option compared to grid extension for at least six communities, and perhaps up to 13. Providing electricity for all, either via the central grid or through microgrids, carries a significant cost. Grants that are specific to microgrids provide the opportunity to electrify an even greater number of communities while freeing up more of BEL's capital. These cost-offsetting grants were not taken into account in this analysis, but their availability will change the economics and could allow more than 13 communities to be electrified via microgrids.

While a hybrid system is the most cost-effective microgrid option over 20 years, the conditions of certain grants (i.e., requiring 100 percent renewable energy) may dictate system characteristics. Even without firm guidelines, it is important to consider how grants can help cover the higher capital costs associated with increasing the percentage of renewable energy generation in the system while also securing benefits to the owner of the systems in the form of reduced operating costs. Bundling the design and procurement of microgrids can further reduce costs, reduce logistics, and allow for the availability of readily accessible spare parts (if all microgrids use the same equipment, an inventory can be kept in Belize which expedites replacement and repair).

3.2 GRID-SCALE ANALYSIS

The CPP analysis focused on grid-scale options leads to recommendations to implement a ten-year energy efficiency program to save 218 million kWh by 2036, and develop at least 5 MW of additional solar PV and 18 MW of wind resources through sound procurement processes following the implementation of the current planned projects, in order to support sustainable economic development, ensure security of supply, and supply least-cost electricity to Belizeans.

The resulting new resources included for development by 2036 for each scenario are shown in Exhibits 24 and 25. As discussed earlier, the 15 MW solar PV and 8 MW Santander 2 biomass projects included in the Reference scenario appear in all scenarios. It is important to note that the Reference scenario is only able to meet demand until 2034, requiring investment in an additional interconnection line with Mexico. After incorporating project-level interconnection costs into the model, projects with high infrastructure cost such as Hick's Caye offshore wind (which would require an undersea cable) are not selected often. Only one scenario, Hydro/Biomass, suggests pursuing additional hydropower resources beyond the 28.3 MW total nameplate capacity provided by Chalillo 2 and Upper Swasey, suggesting that new resources such as solar are beginning to outcompete resources such as hydro as the costs associated with further development increase.

Exhibit 26 shows the percent of electricity load met by CFE imports in each scenario for modeled year 2036. Scenarios recommending low levels of investment in additional domestic generation capacity, such as the Reference scenario, exhibit the highest levels of dependence on Mexican imports. Comparing the Reference scenario, which includes an additional interconnection line with Mexico, to the two Interconnection scenarios shows how the combination of additional interconnection with investments in domestic generation and energy efficiency can reduce the dependence on imports by almost 20 percent without sacrificing reliability. Another important note is that the PUC has suggested a goal of limiting imports

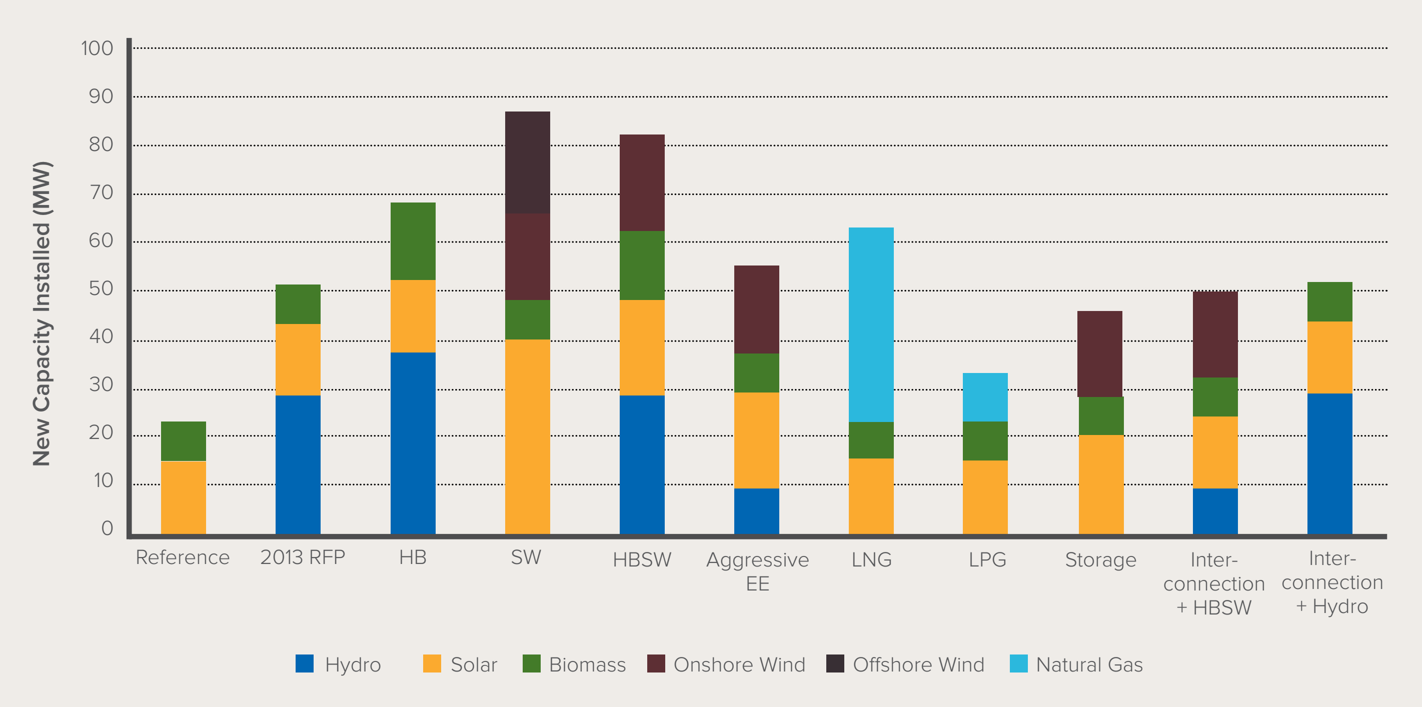
EXHIBIT 24

NEW INSTALLED CAPACITY BY SCENARIO BY YEAR 2036 (MW)

	REF	2013 RFP	HB	SW	HBSW	AGG. EE	LNG	LPG	STORAGE	INTERCONNECT + HBSW	INTERCONNECT + HYDRO
SOLAR PV PROJECT	15	15	15	15	15	15	15	15	15	15	15
NEW SOLAR PV	-	-	-	25	5	5	-	-	5	-	-
MASKALL I WIND	-	-	-	9	9	9	-	-	9	9	-
AMBERGRIS CAYE WIND	-	-	-	9	9	9	-	-	9	9	-
HICK'S CAYE WIND	-	-	-	21	-	-	-	-	-	-	-
CHALLILO 2 HYDRO	-	19.3	19.3	-	19.3	-	-	-	-	-	19.3
UPPER SWASEY HYDRO	-	9	9	-	9	9	-	-	-	9	9
NEW HYDRO	-	-	9	-	-	-	-	-	-	-	-
SANTANDER PHASE II	8	8	8	8	8	8	8	8	8	8	8
NEW BIOMASS	-	30	8	-	8	-	-	-	-	-	-
NATURAL GAS	-	-	-	-	-	-	40		-	-	-
LPG	-	-	-	-	-	-	-	10	-	-	-
NEW INTERCONNECTION	30	-	-	-	-	-	-	-	-	30	30
LI-ION (MWh)	-	-	-	-	-	-	-	-	34 MWh	-	-

EXHIBIT 25

NEW INSTALLED CAPACITY BY 2036 FOR EACH SCENARIO. NOTE THAT CAPACITY TO IMPORT FROM MEXICO IS NOT INCLUDED IN THIS CHART. THE STORAGE SCENARIO INCLUDES 34 MWH OF BATTERY STORAGE IN ADDITION TO THE NEW CAPACITY SHOWN HERE.



from Mexico to 30 percent of total electricity supply in Belize. The HBSW and Aggressive EE scenarios are the closest to achieving this target, with roughly 35 percent of total load met by imports in 2036 in these scenarios.

A central insight emerging from the modeling process is that a market-based RFP process in isolation does not always lead to the best-case investment plan for Belize's grid. Long-term energy planning at this level is necessary to ensure that proposed projects integrate such that the impacts of each new asset on the operation of the entire system are fully accounted for. When this systems-level approach is taken, certain projects from the 2013 RFP may not integrate well with other assets, lowering the competitiveness of this scenario.

As discussed above, the CPP analysis indicates that reinforcing the interconnection to Mexico alone is not the optimal solution for Belize's grid. Although the interconnection with Mexico allows Belize to purchase low-cost electricity and supports the reliable operation of Belize's grid, increased reliance on CFE also leads to several risks. While prices are low today, there is a persistent risk of price swings in the Mexican grid, which depends on fossil fuels to provide roughly 80 percent of its total generation. Historical fluctuations and future projections are discussed in more detail in the cost volatility section below. In addition to price volatility, increased reliance on CFE continues to leave a single critical point of failure for Belize's electricity system, lowering the resilience of the grid overall.

EXHIBIT 26

THE PERCENTAGE OF ENERGY IMPORTED FROM MEXICO IN EACH SCENARIO, IN MODELED YEAR 2036. NOTE THAT THE REFERENCE AND 2013 RFP SCENARIOS DO NOT INCLUDE ANY ENERGY EFFICIENCY MEASURES.

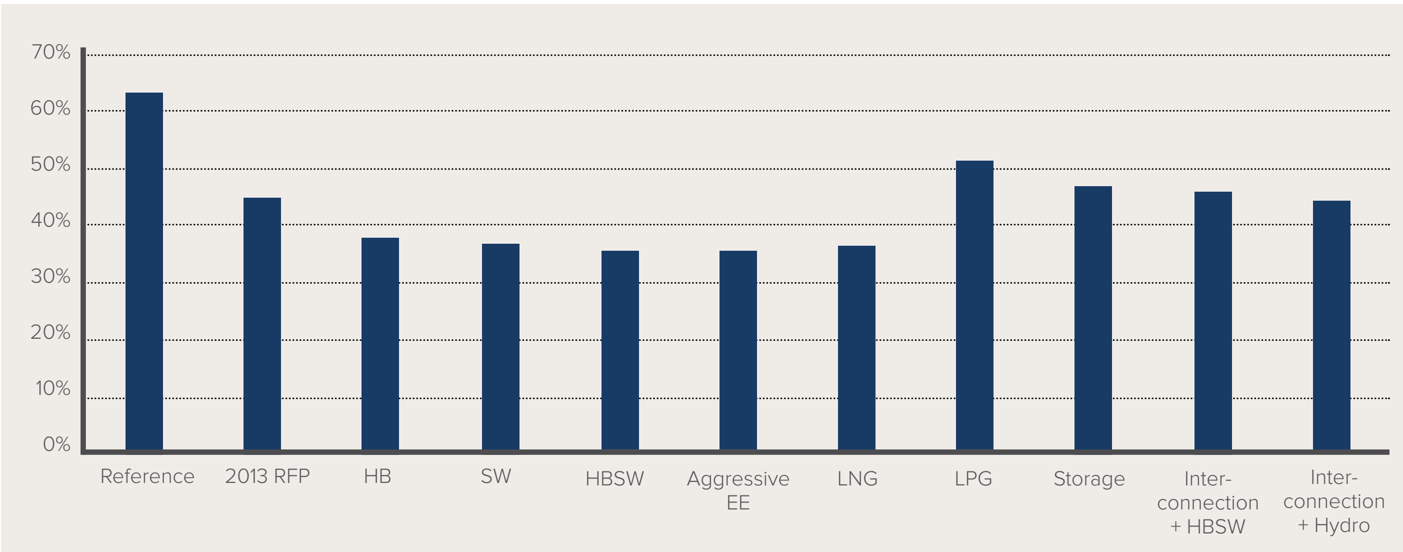


EXHIBIT 27

SUMMARY OF SCENARIO SCORES FOR SHARED GOALS

GOAL	POINTS POSSIBLE	REF	2013 RFP	HB	SW	HBSW	AGG. EE	LNG	LPG	STORAGE	INTERCONNECT + HBSW	INTERCONNECT + HYDRO
1. SUSTAINABLE ECONOMIC DEVELOPMENT	35	13.0	25.8	30.4	25.7	31.4	26.6	21.0	17.5	20.6	23.8	25.4
2. SECURITY OF SUPPLY	30	14.8	17.7	17.9	21.9	19.4	21.7	18.6	18.6	25.2	25.1	24.9
3. LEAST COST	35	33.0	31.1	32.7	33.9	33.2	35.0	30.3	27.3	33.4	33.9	33.2
TOTAL SCORE		**60.8**	**76.6**	**81.0**	**81.5**	**84.0**	**83.3**	**70.0**	**63.5**	**79.2**	**82.8**	**83.5**

The 11 total scenario scores for the three shared goals are shown in Exhibit 27. All scenarios score higher than the Reference scenario with the exception of the LPG scenario. This indicates that there are multiple feasible options that provide benefits beyond current plans. The scenario that scores the highest overall is HBSW, followed closely by Aggressive EE. Following the completion of current planned projects, the HBSW scenario calls for the construction of both the Chalillo 2 and Upper Swasey dams and 8 MW of new biomass (likely at the current Belcogen site) in addition to the 5 MW of new solar and 18 MW of wind recommended above. While it is not the highest scoring overall, Aggressive EE represents the least-cost scenario for Belize, highlighting an opportunity to capitalize on savings in the short term with potential to begin project implementation within the next two to three years. The two interconnection scenarios also receive high scores, highlighting the opportunity to consider coupling investment in an additional line to Mexico with other domestic generation resources.

The small margin in summary scores observed between some scenarios paints a more complicated picture of Belize's investment options, with various benefits distributed across scenarios. Despite these small margins, there are clear recommended actions that emerge from the CPP analysis. This section provides further detail on the metrics considered for each of the three goals, and the specific advantages certain scenarios offer for Belize.

3.2.1 SUSTAINABLE ECONOMIC DEVELOPMENT

The CPP recommendations lead to increased investment in Belize, an increase in the number of local jobs available, a reduction in expenditure on imported fuel and electricity, and an increase in both renewable penetration and the efficiency of end use. Exhibit 28 includes the key metrics and scores for each scenario under the sustainable economic development goal.

Increase Investments Occuring in the Country

To test the objective of increasing investments occuring in the country, the team calculated the total capital expenditure in each CPP scenario. The results are shown in Exhibit 29. Scores were determined by assigning the scenario with the most investment the maximum number of points (6.5), and calculating scores for the other scenarios based on the percentage difference in total investments compared to the maximum amount. In this metric, the team included the capital cost of every new project modeled in each scenario.

Capital expenditures are one indicator of investment in Belize. Scenarios including development of new, domestic projects such as the LNG and the HBSW scenarios score higher in comparison to scenarios such as the Reference scenario or Interconnection that double down on existing infrastructure-enabling electricity imports. The LNG, 2013 RFP, and HBSW scenarios all lead to increases in investment in the energy sector by greater than 200 percent compared

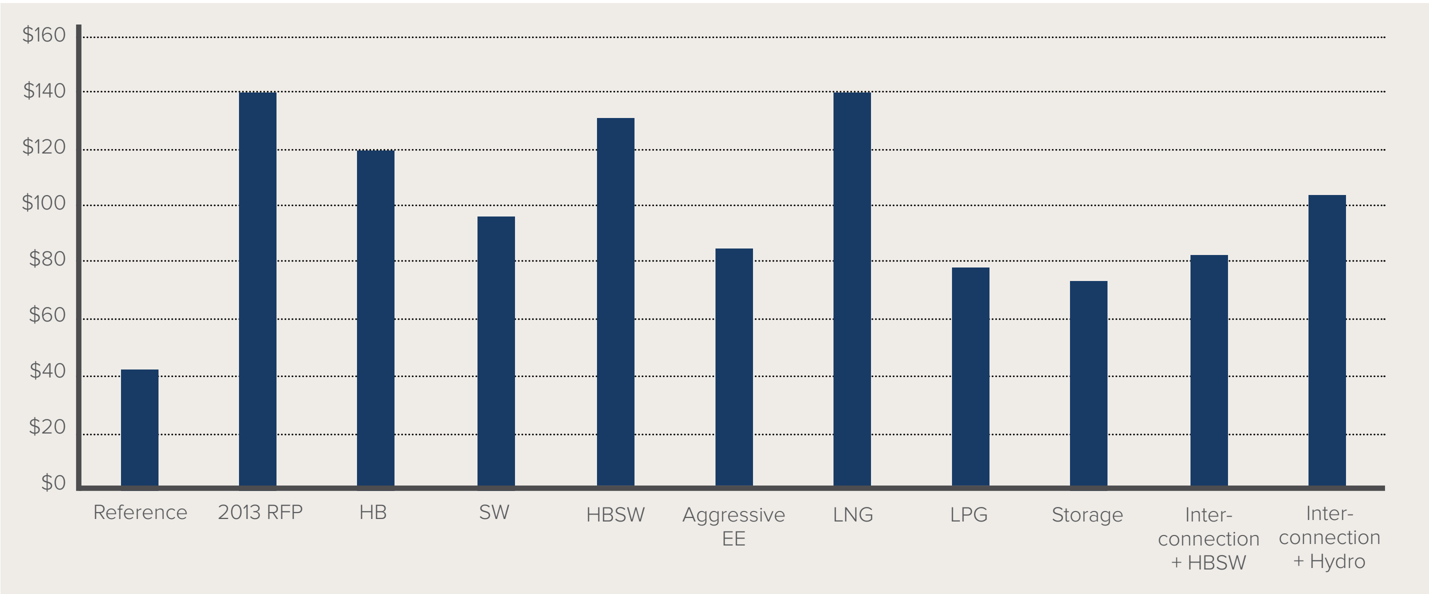
EXHIBIT 28

SUMMARY OF SCENARIO SCORES FOR SUSTAINABLE ECONOMIC DEVELOPMENT

METRIC		REF	2013 RFP	HB	SW	HBSW	AGG. EE	LNG	LPG	STORAGE	INTERCONNECT + HBSW	INTERCONNECT + HYDRO
TOTAL CAPITAL EXPENDITURE		$41.8M	$139.6M	$120.2M	$97.1M	$131.2M	$84.8M	$140.3M	$78.9M	$72.6M	$83.5M	$103.8M
POINTS	**6.5**	1.9	6.5	5.6	4.5	6.1	3.9	6.5	3.7	3.4	3.9	4.8
NUMBER OF NEW JOBS		3,500	9,200	12,400	8,400	12,300	6,700	2,700	2,000	4,900	7,900	7,900
POINTS	**9**	2.5	6.6	9	6.1	8.9	4.8	1.9	1.4	3.6	5.8	5.8
TOTAL DOLLARS SPENT ON IMPORTED FUEL FOR ELECTRICITY AND ON IMPORTED ELECTRICITY		$275.4M	$190.9M	$193.8M	$219.5M	$187.4M	$203.3M	$244.3M	$255.1M	$235.6M	$225.0M	$206.7M
POINTS	**6.5**	4.4	6.4	6.3	5.5	6.5	6	5	4.8	5.2	5.4	5.9
PERCENTAGE OF LOAD MET BY RENEWABLE ENERGY SOURCES IN 2036		35.19%	52.06%	50.73%	51.56%	53.97%	45.11%	35.18%	35.16%	41.63%	44.30%	45.74%
POINTS	**6.5**	4.2	6.3	6.1	6.2	6.5	5.4	4.2	4.2	5	5.3	5.5
AMOUNT OF ENERGY EFFICIENCY IMPLEMENTED (kWh) BY 2036		0	0	114.8M	114.8M	114.8M	218.2M	114.8M	114.8M	114.8M	114.8M	114.8M
POINTS	**6.5**	0	0	3.4	3.4	3.4	6.5	3.4	3.4	3.4	3.4	3.4
TOTAL POSSIBLE POINTS	**35**											
TOTAL SCORE		**13.0**	**25.8**	**30.4**	**25.7**	**31.4**	**26.6**	**21.0**	**17.5**	**20.6**	**23.8**	**25.4**

EXHIBIT 29

NET PRESENT VALUE OF THE TOTAL CAPITAL EXPENDITURE IN EACH SCENARIO (US$ IN MILLIONS)



with the Reference scenario. The HBSW scenario requires roughly US$90 million further investment in the energy sector compared with the Reference scenario. Further investment in domestic generation in Belize supports an expanding energy sector that can attract further investors and IPPs. Increased investment in Belize and increased competition among bidders for project PPAs can influence cost of service across the system and help BEL and other stakeholders obtain the lowest prices in future negotiations. The success of early projects in new technologies can also reduce the risk and uncertainty that serve as barriers for investors in underdeveloped resources. Beyond the results of the modeling, the CPP recommends that further development of a clean, efficient procurement process can solidify the regulatory framework and attract the most beneficial projects to Belize.

This approach allows for comparison of the direct investment associated with each scenario, but does not capture indirect investments occurring as a result of the overall benefits offered by the favorable scenarios. For example, the reduction in the cost of generation associated with the implementation of an aggressive EE program is not captured in this methodology, which values up-front capital investment rather than savings over the long run. Furthermore, energy efficiency brings stability to the electricity sector that could lead to lower prices and incentivize businesses to invest in Belize beyond the energy sector. This methodology considers aggregate investments under each scenario, assuming that the entire country is the beneficiary, with economic development gains spreading out across the population. It is likely that scenarios such as Aggressive EE that provide benefits directly to consumers over a long period of time provide a different type of economic value for Belizeans that is not completely captured in this framework. Despite these limitations, the economic benefits of the Aggressive EE scenario are accounted for in other metrics, such as the least-cost analysis, which is weighted almost 30 points higher than the investment metric.

Projects owned by Belizeans drawing on domestic financial resources and investment will carry greater benefit to the country. Each technology is subject to a specific set of characteristics and constraints that determine the mix of foreign and domestic financing. Certain scenarios, such as the Reference scenario or Liquified Natural Gas, increase the amount of control foreign entities (Mexico in this case) hold over the energy system and limit the ability of Belize to shape its own energy future. Technologies such as hydro or biomass managed by IPPs will likely rely on a mix of local and foreign capital that reduces the outflow of foreign currency from Belize while also providing opportunities to build capacity in-country. Due to incomplete information on the financial markets in Belize, these issues were not calculated within the CPP, but remain important factors differentiating each scenario and influencing long-term financial security and economic development.

The team notes that the current conditions in Belize are such that all equipment and the majority of materials required the construction of new renewable energy projects will be imported in the near future. This requires the use of foreign exchange, as purchases cannot be made in Belizean dollars. This condition remains the same for both domestic and foreign investors, and puts a similar strain on Belize's currency balance. Both local and foreign investors are also required to convert BZD to USD to repay loans and cover equity. However, domestic generation financed by foreign investors still offers economic gains for Belize where a portion of profits and revenues are reinvested in the country to cover operations costs, in particular, local labor costs. This benefit of local reinvestment does not occur with imported electricity. Several of the existing domestic generation assets including the BECOL dams reinvested Belizean dollars in the country to cover labor costs and local operations. Santander followed a similar strategy where local costs related to sugarcane cultivation were covered by local finance.

The CPP does not differentiate between local and foreign finance for three primary reasons. The first reason recognizes that local finance carries a higher risk premium, and is likely more expensive than foreign finance. This leads to the assumption that all new projects will seek a high proportion of foreign finance to lower costs, especially given the conditions stated above where all components must be imported. The second reason recognizes that if a foreign investment were to fail, the burden would fall on the foreign investor and losses could be recuperated outside of Belize. A failure of a locally financed project would put additional strain on the financial markets of Belize. The final reason is referenced above, and assumes that both local and foreign finance will generate similar levels of economic development as local finance can only be used for domestic labor and operations.

The CPP does differentiate between the sustainable economic development associated with domestic generation assets versus electricity imports. The Reference scenario, which includes a limited amount of investment in domestic generation and heavy reliance on imports, scores the lowest in increased investment in the country as none of the profits will be reinvested in Belize. Similarly, both of the interconnection scenarios score lower in terms of investment than scenarios with higher amounts of domestic generation such as the HBSW scenario. A similar pattern is reflected in the job creation metric as well as in the sustainable economic development category overall. Domestic generation also carries long-term economic benefits for Belize beyond the timeline of analysis for the CPP: Once the foreign investments are fully paid off, more profits and revenues can be reinvested in Belize and generation costs will decline as assets such as dams have longer lifetimes than their respective PPA contracts. To ensure that Belize is maximizing economic gains from foreign finance, stakeholders can negotiate with investors in the contracting process to secure contract lengths that are shorter and reflect the payback on the investment. When PPA terms are renegotiated, the capital investment that must be foreign is a very minor component, giving local stakeholders a chance to invest, and local banks can cover a higher percentage of debt due to a greatly de-risked project. Because the majority of the costs are operational and local, the demand for foreign exchange is greatly reduced as well.

Increase Number of Jobs Available

To test the objective of increasing the number of jobs available for Belizeans in the energy sector, the team drew on existing international models and reports on job creation across different energy technologies. Further investment in locally generated, renewable energy stands to produce higher job growth than fossil fuel-based technologies, across all assessed technologies. This is a trend that has been well documented by the United States Department of Energy (DOE) and other large organizations. The 2017 US Energy and Employment Report notes that in the United States, roughly five times as many people are employed in the renewable energy sector than in the conventional energy sector. While Belize is subject to a different set of constraints and opportunities in terms of job growth potential, this analysis utilized the best available data from the United States to accurately assess differences in job creation potential between scenarios. The analysis drew from the Jobs and Economic Development Impact (JEDI) models developed by the National Renewable Energy Laboratory (NREL) to estimate the potential for both temporary (construction) and permanent job growth. The JEDI model takes a wide set of inputs and metrics into consideration to estimate the amount of jobs that can be created per unit of installed capacity. For technologies and scenarios where the JEDI estimates were incomplete, this analysis drew on reports from the US DOE, the International Energy Agency (IEA), the Solar Energy industries Association (SEIA), and others to complete calculations. In the analysis, permanent jobs were weighted as 50 percent more valuable than all construction jobs. Construction jobs were also

EXHIBIT 30

SUMMARY OF TOTAL JOBS CREATED IN EACH SCENARIO BY 2036

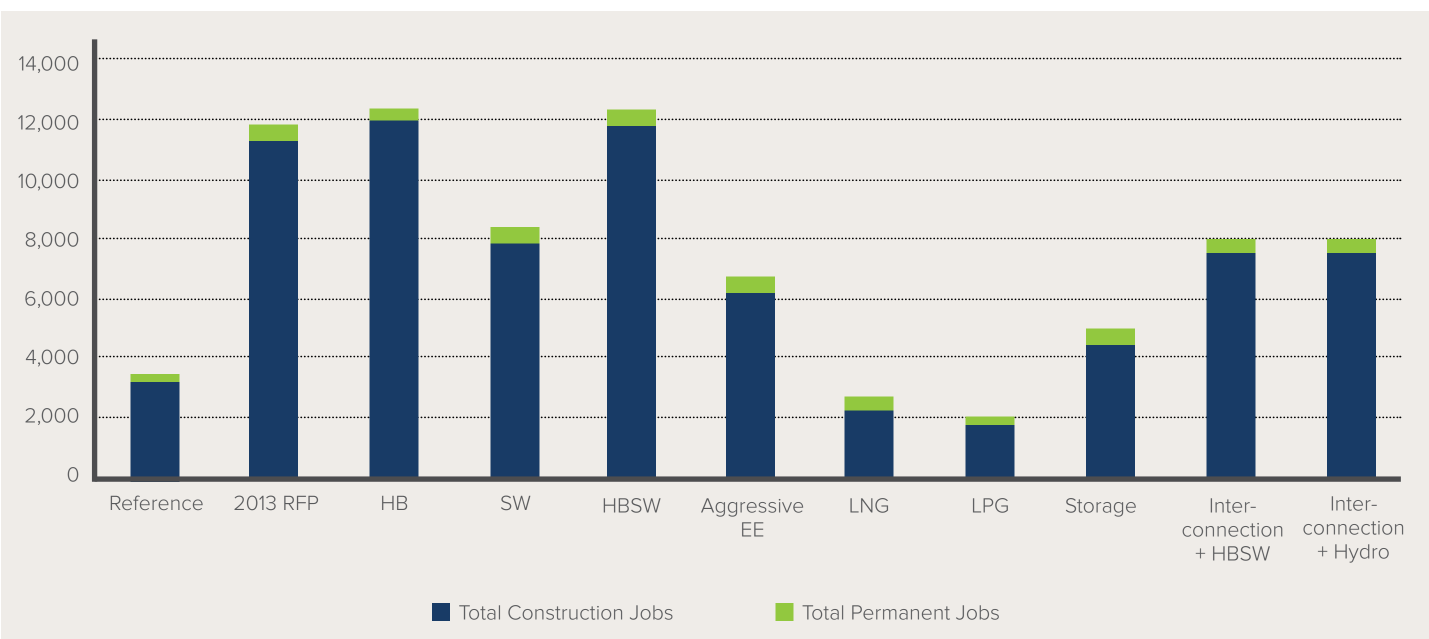
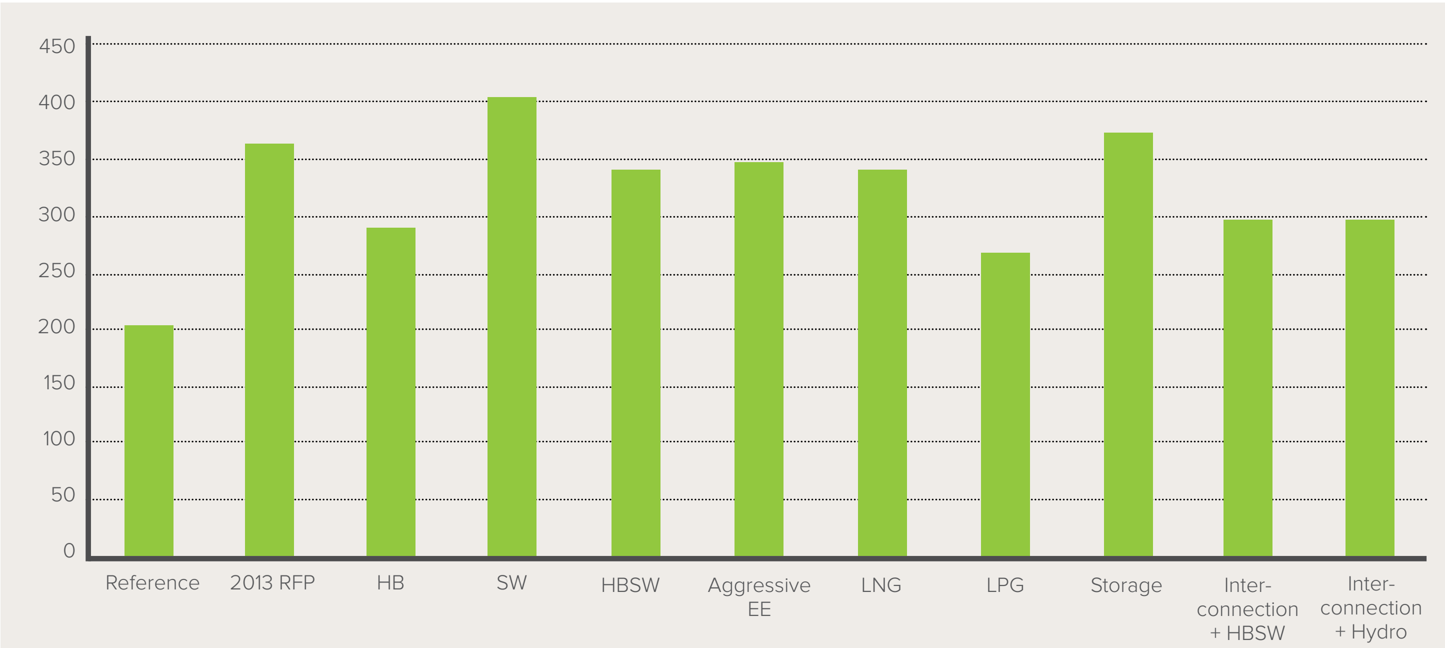


EXHIBIT 31

SUMMARY OF PERMANENT JOBS CREATED IN EACH SCENARIO BY 2036



weighted based on the duration of the construction time period. Exhibit 30 shows the total number of new jobs created per scenario over the 20-year modeling period, while Exhibit 31 zooms in to show the number of permanent jobs created per scenario.

As discussed above, scenarios with a higher proportion of renewable energy generation have the highest potential for total job creation. This analysis does not capture the residual job creation spurred by investment in renewable technologies such as biomass, which is likely significant in the context of Belize, with growth in the agricultural sector. The growth of the sugarcane industry in Belize has indicated early gains from investment in renewable technologies that depend on domestic resources and labor. For example, both the HB and HBSW scenarios generate over 8,800 more jobs than the Reference scenario (more than a 250 percent increase). When looking exclusively at permanent job creation, scenarios such as Storage, Aggressive EE, and LNG show similar levels of job creation as HBSW and HB. The large differentials seen when looking at total job production are partially attributable to the large number of construction jobs generated by hydro projects. Across all scenarios, the numbers of construction jobs far surpass the numbers of permanent jobs due to the presence of large, labor-intensive projects in most scenarios. Permanent jobs tend to be in operations and maintenance, either with BEL or an IPP. It is important to note that projected job creation for both the natural gas scenarios is lower than the projections for the Reference scenario due to the fact that natural gas infrastructure creates fewer jobs than interconnection infrastructure, according to NREL.

Reduce the Total Cost of Imported Fuel and Electricity

The value of fuel import expenditures was calculated by drawing on both historical data and future projections to evaluate each scenario against business-as-usual trends. Historical data and estimates from organizations such as the World Bank and the US Energy Information Administration (EIA) were inputs used to predict fuel prices through 2036. Information on the projected cost of electricity imported from Mexico was provided by BEL based on a cost forecast from CFE. With the projections of imported energy cost (both fuel and CFE imports) and energy generation associated with each resource, the team calculated the total cost of imports related to electricity. Exhibit 32 includes the total spending on electricity-related imports over the 20-year modeling period in each scenario.

The results from these calculations point to the HBSW scenario as the least import-intensive scenario, saving almost US$90 million in expenditure on imports compared to the Reference scenario. The Reference scenario has the highest cost for imports due to reliance on existing HFO and diesel generating assets to meet peak demand in later years. The Aggressive EE scenario assumes there will be a 20 percent reduction in energy consumption by 2036 and hence has the lowest level of generation attributable to these fossil fuel assets. Aggressive EE does not represent the lowest import cost option due to a heavier reliance on Mexican imports than scenarios such as HBSW. Scenarios with a higher proportion of domestic, renewable assets also have lower import requirements compared with the Reference scenario.

Import costs in the Storage scenario are higher than those in the Interconnection scenarios. This is due to less development of new capacity, which requires continued dispatch of the existing fossil assets and higher dependency on CFE than the more renewable-intensive scenarios. It is important to note that the impact on government revenues from a decrease in fuel imports for the grid-level recommendations will not be significant, as fuel imports for electrical generation represent a small proportion of total imports. Development of new technologies and efficiency programs also creates opportunities to explore new revenue streams such as tariffs on inefficient appliances.

Increase Renewable Energy Penetration

The percentage of total generation attributed to renewable energy was calculated from the total generation per technology modeled in 2036 across all scenarios. Generation totals in 2036 were used, due to the fact that all assets will be on line and operational by this time in the project cycle. Using 2036 data also shows progress from the Reference scenario. Exhibit 33 shows the RE penetration in each scenario in 2036; given the projected growth in electricity demand by 2036, the total renewable energy penetration is lower than today for many of the scenarios.

The HBSW scenario has the highest renewable energy penetration, with 54 percent of total generation coming from renewables in 2036. This represents an approximately 19 percent increase over the Reference scenario projections for 2036. The 2013 RFP and SW scenarios follow close behind, with 52 percent and 51.5 percent of generation from renewables in 2036, respectively. The Reference and Liquified Natural Gas scenarios score roughly the same in terms of renewable energy penetration. While it is understood that there is some renewable energy generation in the CFE mix, it is not significant at the interconnection node in Corozal and therefore is not counted as renewable in the analysis. The results of the CPP show that Belize has several viable options that allow the country to progress toward renewable penetration goals outlined in the 2015 NDC of reaching 85 percent RE penetration by 2030; fully achieving these goals would likely require adding considerable cost to the system.

Increase Efficiency of End Use

Energy efficiency implementation was estimated from a combination of savings potentials outlined in existing reports conducted by external consultants (including the Castalia 2014 report and the Econoler 2013 proposal), and comprehensive load growth studies confirmed by BEL. Specifically, the EE potential

EXHIBIT 32

TOTAL SPEND ON ELECTRICITY-RELATED IMPORTS IN EACH SCENARIO

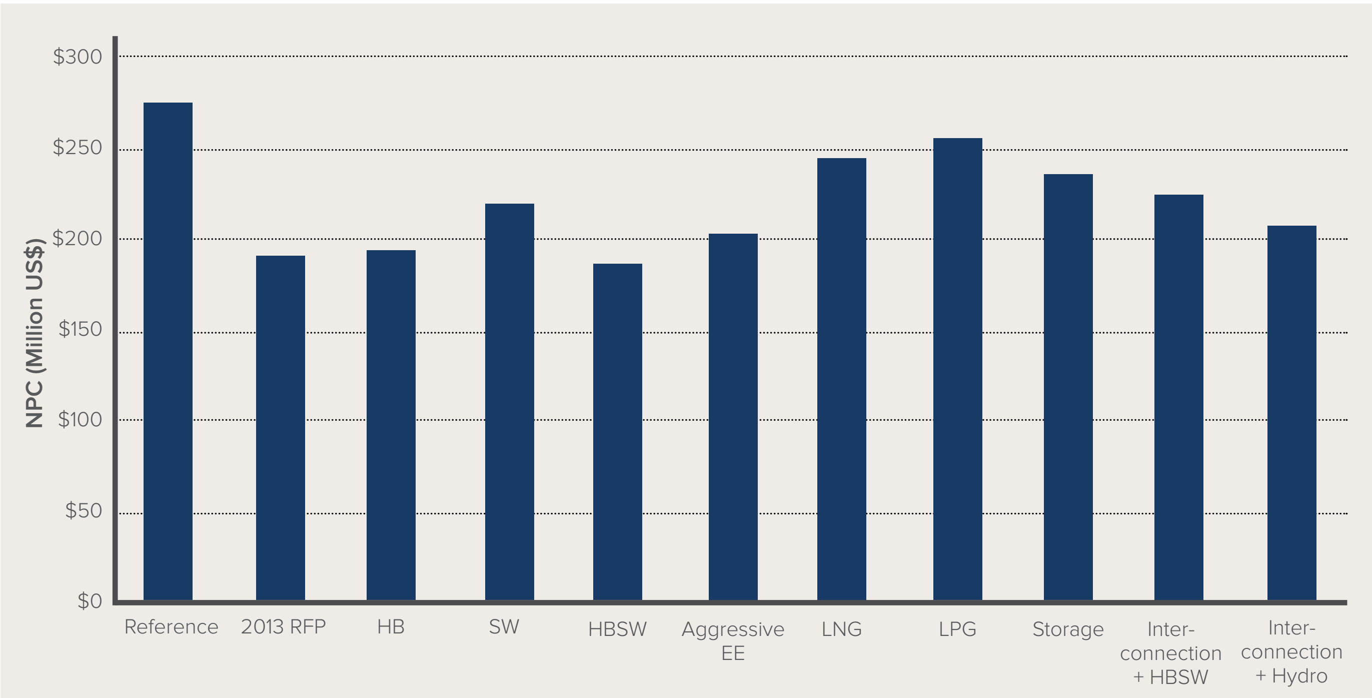
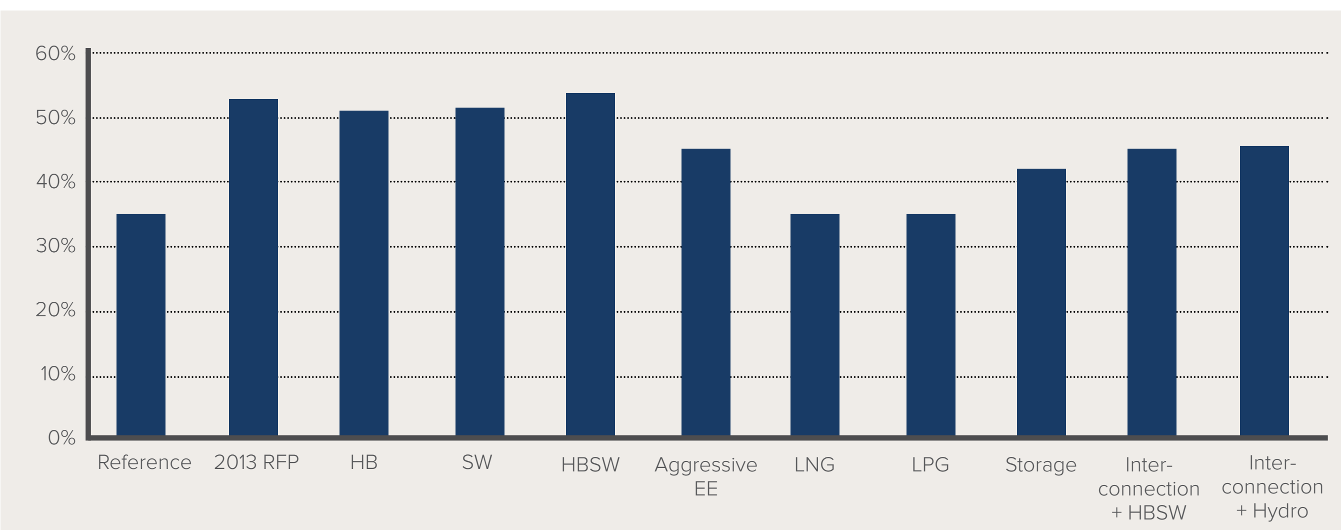


EXHIBIT 33

RENEWABLE ENERGY PENETRATION MODELED IN 2036 IN EACH SCENARIO



presented by Castalia assumes that within 10 years, 75 percent of all energy consumers will adopt all relevant EE measures. This results in a cumulative 24 percent energy savings from the baseline in 10 years, for a year-over-year savings of 1.8 percent of annual sales. These figures informed the CPP assumptions, but were modified following feedback from partners and insights from other case studies on what a realistic timeline (20 years versus the 10-year timeline suggested by Castalia) and savings potential (20 percent energy savings versus 24 percent) for an aggressive EE program implementation would look like. Castalia assesses the overall cost of all packaged recommended EE measures at approximately US$0.105/kWh saved. After adding an additional 15 percent to cover program administration costs based on case studies from Saint Lucia and Barbados, this figure is closer to US$0.121/kWh saved. The CPP drew on national energy roadmaps conducted in Saint Lucia which assessed a total cost of between US$0.05–$0.07 per kWh saved as a more accurate estimate for the potential program costs in Belize. While it is possible to see higher material and labor costs for a new market such as Belize, the CPP recommends revisiting the assumptions behind the costs of EE programs to obtain a more accurate picture of the cost of energy saved in Belize, as EE is typically the cheapest resource available.

Castalia identifies specific steps to ensure the success of an EE program, including decentralizing government payment for electricity, adapting and implementing a building code, developing financial mechanisms to invest in sustainable energy, developing and operationalizing a financial mechanism for the private sector, providing consumers more information on energy services and equipment, adopting certifications for energy services, adopting labeling for EE equipment, improving tariff structure for EE and distributed generation, improving the functioning of BEL's decoupled tariff structure, and revising BEL's efficiency incentives.

It is also possible for Belize to explore solicitation of energy service companies (ESCOs) as a performance-based, market-oriented mechanism to improve energy efficiency. These companies are remunerated based on the amount of energy they save, and offer guaranteed or shared savings with their client.

Additionally, we recommend that any EE program costs include total costs of program administration, as well as participants' costs, to assess the total cost of energy saved. For the CPP, these costs totalled approximately US$6 million, including all program costs and incentive costs. When considered as a resource, energy efficiency has one of the lowest "levelized costs" (approximately US$0.07/kWh saved), making it competitive with some of the cheapest resources available to Belize including CFE and hydro.

In total, the Aggressive EE scenario saves roughly US$42 million in comparison to the Reference scenario and US$88 million in comparison to the 2013 RFP scenario. Beyond the cost savings captured in the analysis, EE programs have a significantly higher proportion of permanent jobs than other technologies. The DOE *2017 US Energy and Employment Report* found that, of the 6.4 million Americans employed in the energy sector, 2.2 million are employed in energy efficiency. While this scenario does not score highest in terms of total job creation (primarily due to the high construction job creation associated with utility-scale projects), it is important to note that the cost per job created for energy efficiency is far lower than for any other technology.

3.2.2 SECURITY OF SUPPLY

The CPP recommendations lead to reduced cost volatility of electricity, while increasing electricity system reliability, resiliency, and adaptability. Exhibit 34 includes the key metrics and scores for each scenario under the security of supply goal.

EXHIBIT 34

SUMMARY OF SCENARIO SCORES FOR SECURITY OF SUPPLY

METRIC		REF	2013 RFP	HB	SW	HBSW	AGG. EE	LNG	LPG	STORAGE	INTERCONNECT + HBSW	INTERCONNECT + HYDRO
CHANGE IN MAX YEAR-TO-YEAR COST FLUCTUATION GIVEN A VOLATILE FORECAST FOR CFE, DIESEL, HFO, AND NATURAL GAS		$30.3 M	$19.5M	$17.9M	$17.3M	$16.6M	$17.0M	$18.7M	$24.1M	$22.7M	$21.9M	$21.1M
POINTS	5	2.7	4.3	4.6	4.8	5	4.9	4.4	3.4	3.6	3.8	3.9
SAIDI (INCREMENTAL OUTAGE DURATION)		1.96	1.40	1.51	1.47	1.49	1.11	1.50	0.74	0.40	0.35	0.33
POINTS	10	1.7	2.4	2.2	2.3	2.2	3.0	2.2	4.4	8.3	9.5	10.0
DIVERSITY OF TECHNOLOGIES; DIVERSITY OF LOCATION		25.1%	24.5%	24.4%	16.2%	21.3%	18.4%	20.9%	25.7%	18.6%	22.2%	24.2%
POINTS	10	6.4	6.6	6.6	10	7.6	8.8	7.7	6.3	8.7	7.3	6.7
QUALITATIVE, RELATED TO CONTRACTS AND SIZE OF INVESTMENTS IN RESOURCES AND OPTIONS FOR CUSTOMERS		4.15	4.24	4.50	5.05	4.66	5.24	4.49	4.76	4.82	4.66	4.46
POINTS	5	4	4.1	4.3	4.8	4.4	5	4.3	4.5	4.6	4.5	4.3
TOTAL POSSIBLE POINTS	**30**											
TOTAL		**14.8**	**17.4**	**17.7**	**21.9**	**19.2**	**21.7**	**18.6**	**18.6**	**25.2**	**25.1**	**24.9**

Meeting Load and Operating Reserves

As described in Section 2, the team used the HOMER Pro microgrid modeling software to model the hourly operation of the electricity system for Belize in each of the 11 scenarios. The model ensured basic security of supply requirements, including an ability to meet the load (today and in the future, based on the demand forecast) and an ability to meet operating reserve requirements.

Exhibits 35–37 illustrate examples of the hourly dispatch of Belize's resources as modeled in HOMER for year 2036 on June 7; the power supplied by each resource in each hour is shown. Three scenarios are shown here to demonstrate various options available for meeting electricity demand; all 11 scenarios ensure an ability to meet forecasted load and operating reserve requirements.

Reduce Cost Volatility of Electricity

To test for the objective of reducing the cost volatility of electricity, the team first established volatile price forecasts for diesel, HFO, natural gas, and CFE, in contrast to the generally smooth projections used in the overall scenario analysis. Exhibits 38-41 show the volatile forecasts for each resource, which are based on historical fluctuations.

EXHIBIT 35

HOURLY DISPATCH OF RESOURCES IN THE HBSW SCENARIO, FOR EXAMPLE DAY JUNE 7, 2036

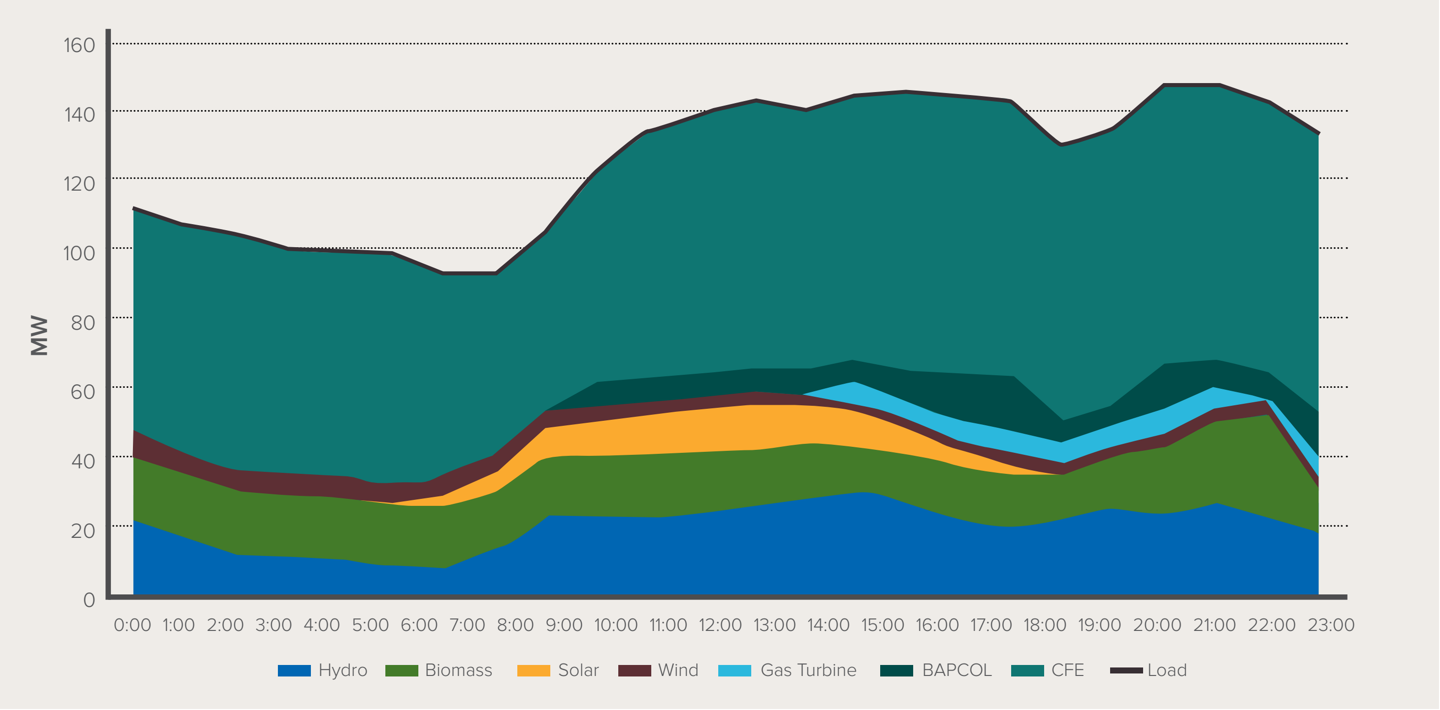


EXHIBIT 36

HOURLY DISPATCH OF RESOURCES IN THE AGGRESSIVE EE SCENARIO, FOR EXAMPLE DAY JUNE 7, 2036

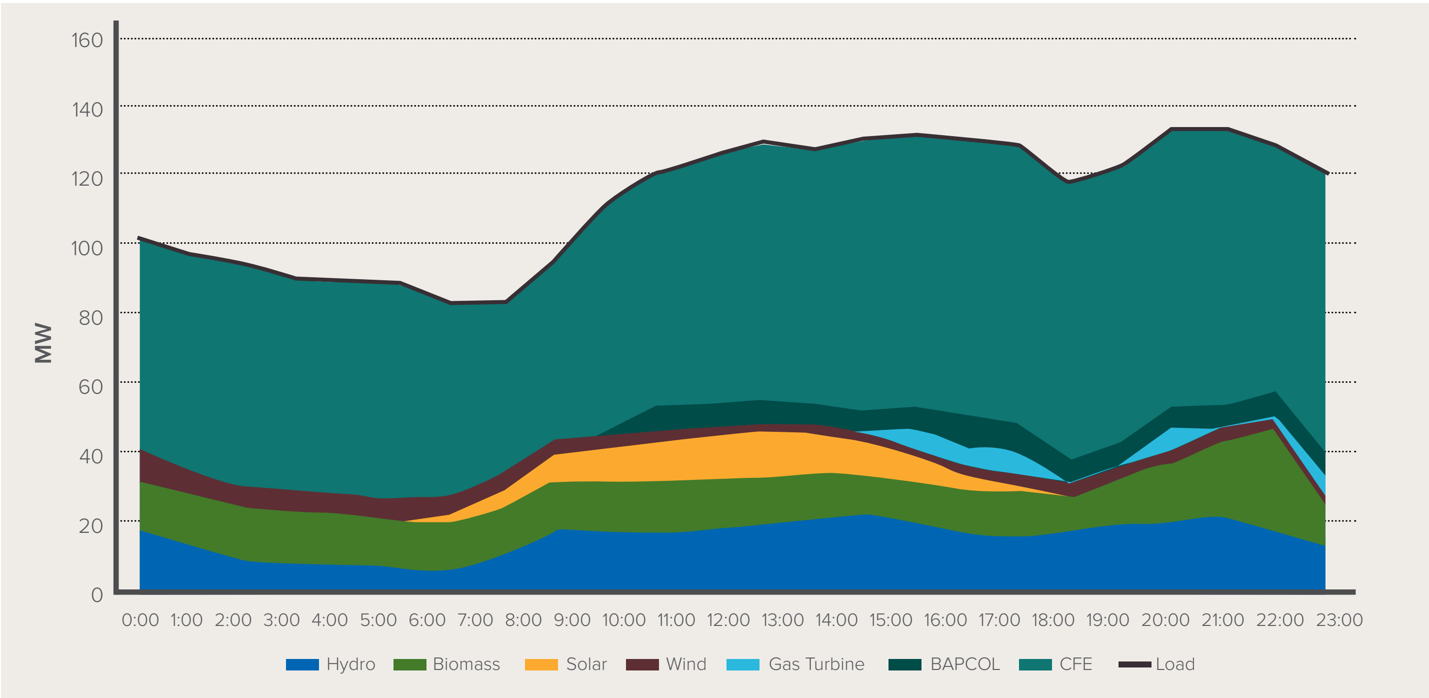


EXHIBIT 37

HOURLY DISPATCH OF RESOURCES IN THE INTERCONNECTION + HYDRO SCENARIO, FOR EXAMPLE DAY JUNE 7, 2036

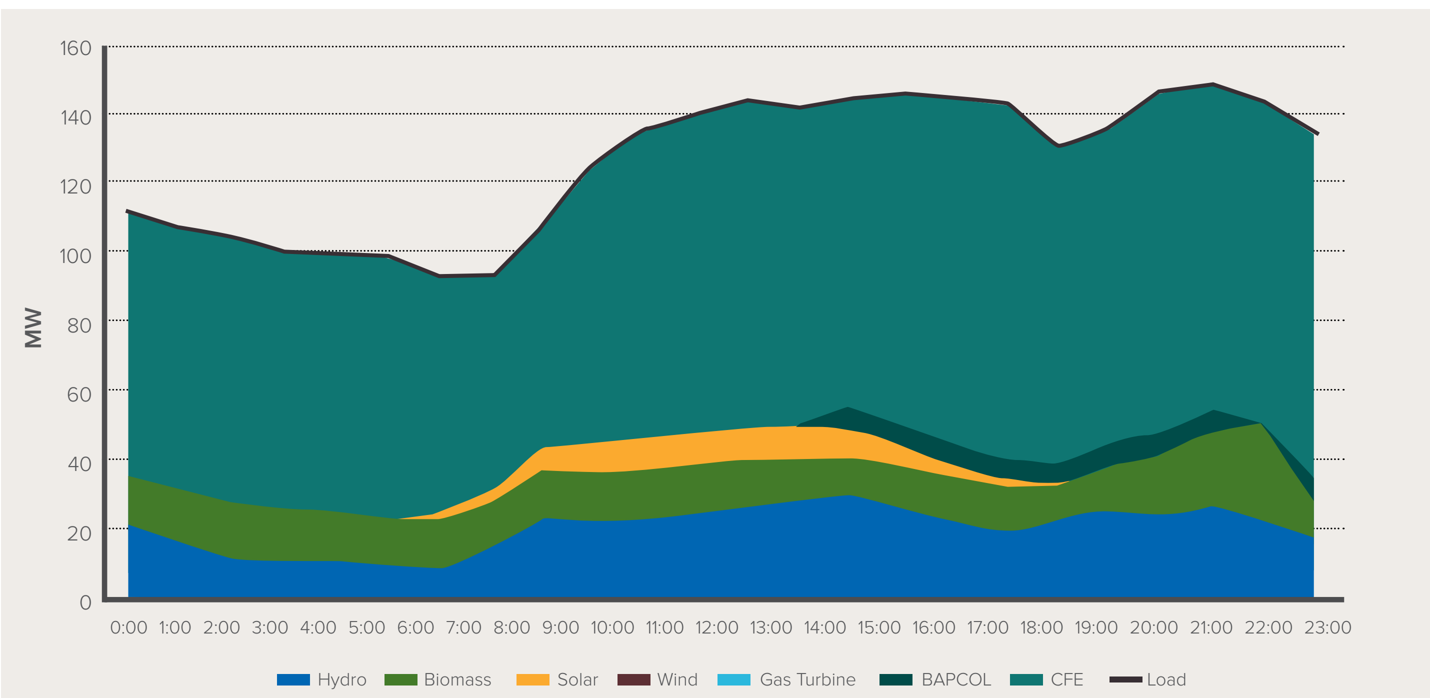


EXHIBIT 38

REFERENCE AND VOLATILE PROJECTIONS FOR DIESEL FUEL PRICE

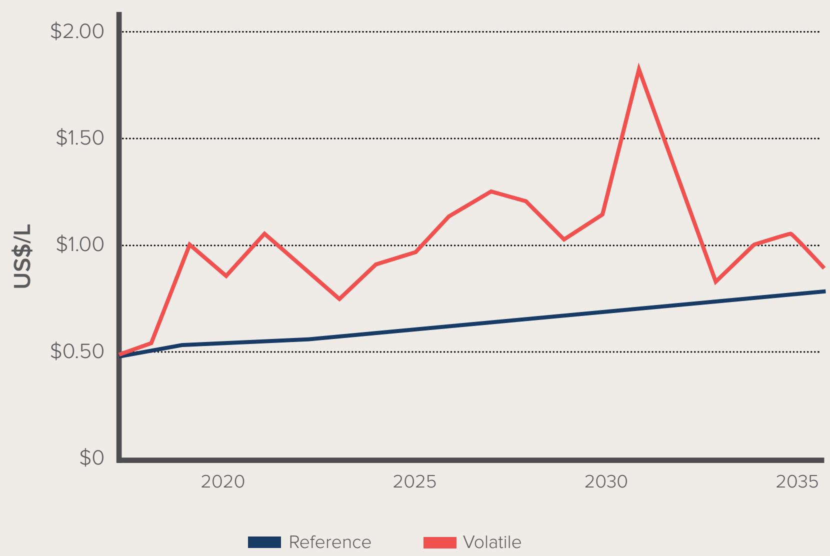


EXHIBIT 39

REFERENCE AND VOLATILE PROJECTIONS FOR HFO PRICE

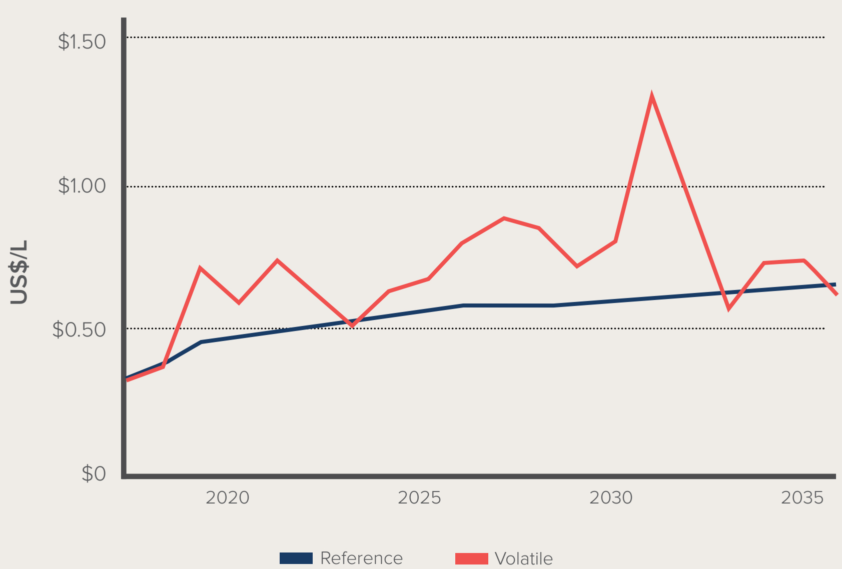
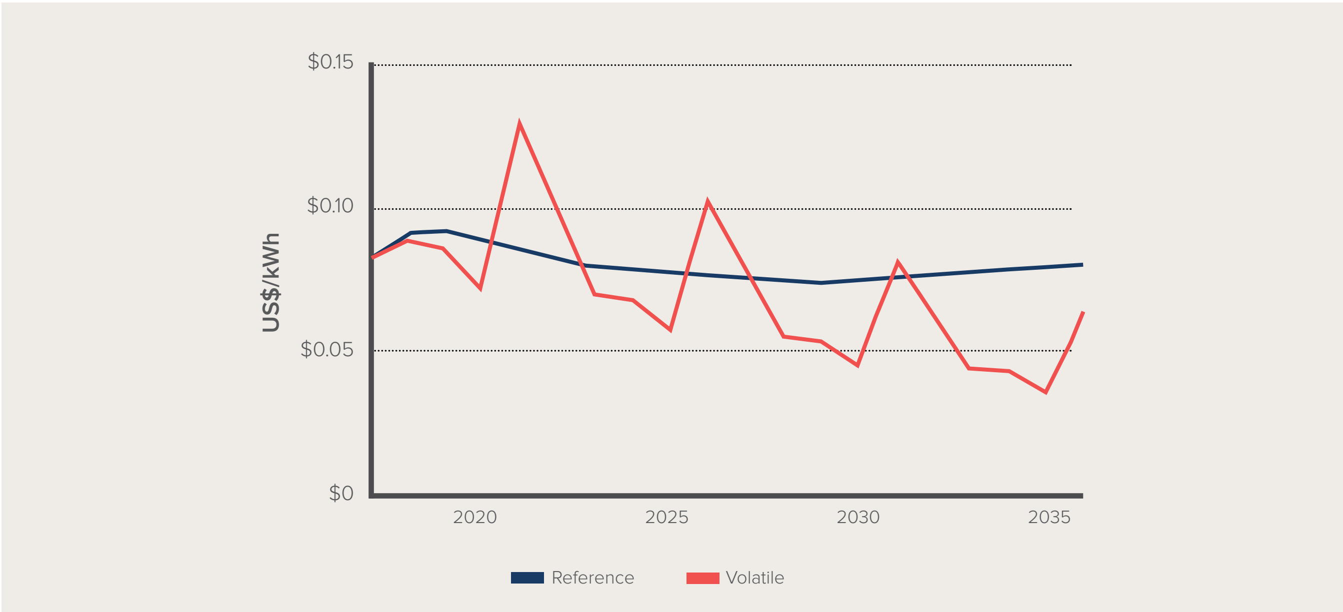


EXHIBIT 40

REFERENCE AND VOLATILE PROJECTIONS FOR NATURAL GAS PRICE

EXHIBIT 41

REFERENCE AND VOLATILE PROJECTIONS FOR CFE IMPORT PRICE



The team then used these volatile price forecasts to estimate how much would be spent on imported energy (both fuel and CFE imports) every year for each scenario. The team then compared the yearly volatile and the yearly nonvolatile cost estimates, and found the difference between the two estimates every year. The scores were based on the year with the maximum difference between the yearly volatile and the yearly nonvolatile cost estimates.

The strong dependence on CFE and the volatile nature of CFE pricing historically is a strong driver of volatility. As a result, we see that scenarios that are largely dependent on CFE are also ranked the most volatile. Resources that contribute to the best scores included energy efficiency and a range of domestic renewable energy projects. Opting for the HBSW scenario (the least volatile), lowers the volatility of the electrical grid by over 45 percent compared with the Reference scenario. Scenarios such as Aggressive EE and SW show similar gains in this facet of energy security. Scenarios that depend heavily on CFE also typically rely more heavily on volatile diesel and HFO generators to meet energy demand. Interestingly, the two Interconnection scenarios are less volatile than the Storage scenario due to a wider array of generation resources.

Increase Reliability

To investigate impacts on electricity system reliability for the 11 scenarios, technical experts at DNV GL completed grid integration studies. These studies included two steps; a power flow analysis to examine grid operation in each scenario, and calculation of projected future outage duration. The results show that all scenarios are operationally feasible for projected 2025 electricity demand, but all scenarios see potential grid operation issues as demand continues to grow (year 2035 was specifically tested in the models). In addition, there is minimal impact to projected electricity outage duration across the 11 scenarios.

The technical experts at DNV GL completed power flow analysis for each of the 11 scenarios for the day with the peak load (May 5) and the day with the minimum load (August 5) for modeled year 2025. First, the flow of power in the electricity grid was analyzed during normal system operation. Next, a contingency analysis was completed, removing one transmission line at a time from operation in the model. Each of the 115 kV, 69 kV, and 34 kV lines were removed one at a time, for a total of 51 contingency tests. For both normal and contingency operations, the analysis reveals any violations in terms of grid operation,

EXHIBIT 42

POWER FLOW RESULTS FOR ALL SCENARIOS

		NORMAL OPERATION						AGGREGATE OF CONTINGENCY OPERATION					
SCENARIO	Case	Under Voltage	Over Voltage	Thermal	Islanded Gen	Islanded Load	Unsolved	Under Voltage	Over Voltage	Thermal	Islanded Load	Islanded Gen	Unsolved
	Units	**#**	**#**	**#**	**MW**	**MW**	**#**	**#**	**#**	**#**	**MW**	**MW**	**#**
REFERENCE	**Peak**	23	0	6	0	0	N/A	215	26	4	104.05	169.69	4
REFERENCE	**Min**	4	1	0	0	0	N/A	160	83	7	21.24	43.01	0
2013 RFP	**Peak**	19	0	5	0	0	N/A	51	5	2	140.26	158.39	0
2013 RFP	**Min**	0	0	0	0	0	N/A	54	5	2	21.24	131.59	0
HB	**Peak**	22	0	5	0	0	N/A	331	12	16	140.26	176.81	0
HB	**Min**	0	0	0	0	0	N/A	0	3	0	10.18	55.2	0
SW	**Peak**	14	0	5	0	0	N/A	64	5	0	130.43	165.9	0
SW	**Min**	0	0	0	0	0	N/A	0	11	0	10.18	35	0
HBSW	**Peak**	14	0	5	0	0	N/A	104	0	3	130.43	160.6	0
HBSW	**Min**	0	0	0	0	0	N/A	0	12	0	9.23	36	0
Agg. EE	**Peak**	20	0	4	0	0	N/A	351	8	3	118.7	153.8	0
Agg. EE	**Min**	0	0	0	0	0	N/A	0	20	0	8.44	36	0
LNG	**Peak**	19	0	5	0	0	N/A	135	0	12	108.24	169.69	0
LNG	**Min**	3	0	0	0	0	N/A	90	10	7	21.24	43.01	0
LPG	**Peak**	11	0	6	0	0	N/A	156	0	4	108.24	169.69	0
LPG	**Min**	3	0	0	0	0	N/A	106	5	1	21.24	43.01	0
Storage	**Peak**	14	0	5	0	0	N/A	89	5	2	130.43	160.6	0
Storage	**Min**	0	0	0	0	0	N/A	0	8	0	9.23	36	0
Int+HBSW	**Peak**	14	0	5	0	0	N/A	111	4	3	130.43	148.6	1
Int+HBSW	**Min**	0	0	0	0	0	N/A	22	0	0	9.23	36	0
Int+Hydro	**Peak**	17	0	5	0	0	N/A	342	5	1	140.26	160.6	0
Int+Hydro	**Min**	0	0	0	0	0	N/A	0	2	0	11.19	35.6	0

including voltages below the allowable range (below 95 percent of nominal rating for normal operation, below 90 percent of nominal rating for contingency operation), voltages above the allowable range (above 105 percent of nominal rating for normal operation, above 110 percent of nominal rating for contingency operation), thermal overloads (above 100 percent of nominal rating), and generation or load that becomes islanded (disconnected from the remainder of the grid). Exhibit 42 summarizes the results of the power flow analysis, first for normal operation, and then summed across the 51 contingency operation tests that were modeled, for the year 2025.

All scenarios experience some under voltage violations on the peak day in 2025 under normal operation, ranging from 11 to 23 violations. All scenarios experience four to six thermal overloads during normal operation as well. Summing across the 51 contingency operation modes, all scenarios experience an increased number of under-voltage violations, some over-voltage violations, thermal overloads, and both load and generation that becomes islanded. In addition, the Reference and Interconnection + HBSW scenarios have instances of unsolvable power flow, meaning that the system would not be able to operate under that contingency condition (indicative of a potential system-wide blackout). These results indicate that all of the 11 scenarios are feasible for normal grid operations with the modeled electricity demand for 2025, with some degree of operational performance degradation.

The DNV GL team also completed power flow analysis for modeled year 2035; given the growth in demand projected by 2035, the current grid configuration is unable to operate successfully in these power flow models. As electricity demand grows in the coming years, Belize can consider options for adjusting the grid configuration to better utilize available generation to meet load, including adding a transmission loop to connect the 69 kV system back to the 115 kV system, upgrading the 69 kV line to the south to 115 kV, and strengthening the 115 kV transmission line in the north of the country.

Exhibits 43 and 44 show an example power flow result for the peak day in the HBSW scenario, for 2025 and 2035, respectively. The voltages throughout the Belize grid are shown with different colors; a voltage of 1.0 per unit (pu), meaning that the voltage matches the nominal rating for that line, is shown in green. Voltages above the lines' rated values are shown in yellow and red, with red representing 10 percent over rated voltage (1.1 pu). Voltages below the lines' rated values are shown in blue, with dark blue representing up to 20 percent below rated voltage (0.8 pu).

In the 2025 example case (Exhibit 43), voltages are within the allowable range for fluctuations throughout the grid. In the 2035 example case (Exhibit 44), the increased demand projected by that year results in significant undervoltages throughout the grid.

The technical experts at DNV GL then forecasted a common utility reliability metric for each of the 11 scenarios. System average interruption duration index (SAIDI) is a measure of how long electricity outages last, usually measured in minutes or hours and calculated by:

$$\textit{SAIDI} = \frac{\sum \textit{Customer Minutes Interrupted}}{\textit{Total Number of Customers}}$$

BEL measures and reports SAIDI annually, including differentiating between outages caused by issues on the transmission and distribution system, and those caused on the generation system. For 2016, BEL reported a total SAIDI of 43.7 hours, with 24.4 hours coming from generation-related outages and 19.3 hours coming from line-related outages.

DNV GL completed analysis for 2025 to forecast the incremental impact to SAIDI for each scenario. The team first created a probability density function (PDF) for the probability that the generation portfolio

EXHIBIT 43

POWER FLOW RESULTS FOR THE HBSW SCENARIO, PEAK DAY IN 2025

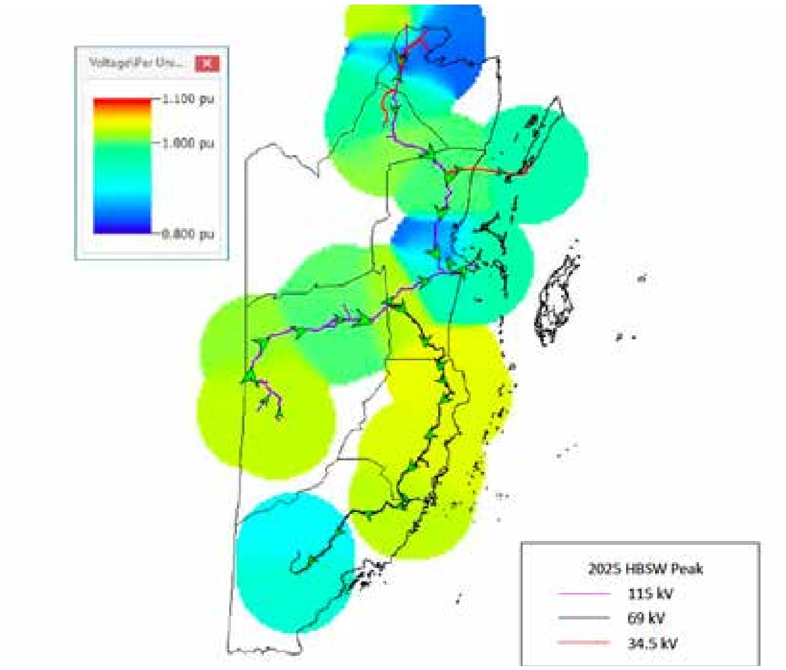
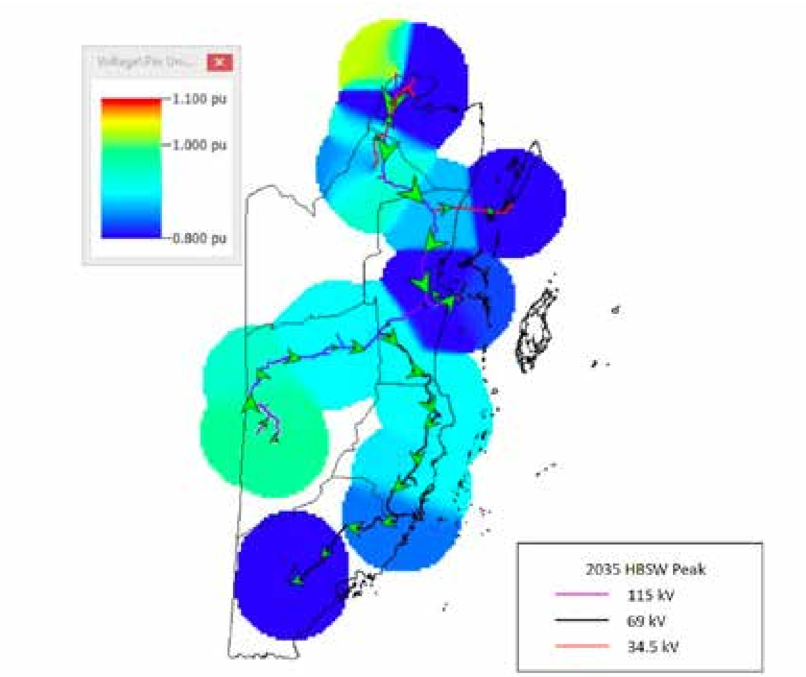


EXHIBIT 44

POWER FLOW RESULTS FOR THE HBSW SCENARIO, PEAK DAY IN 2035



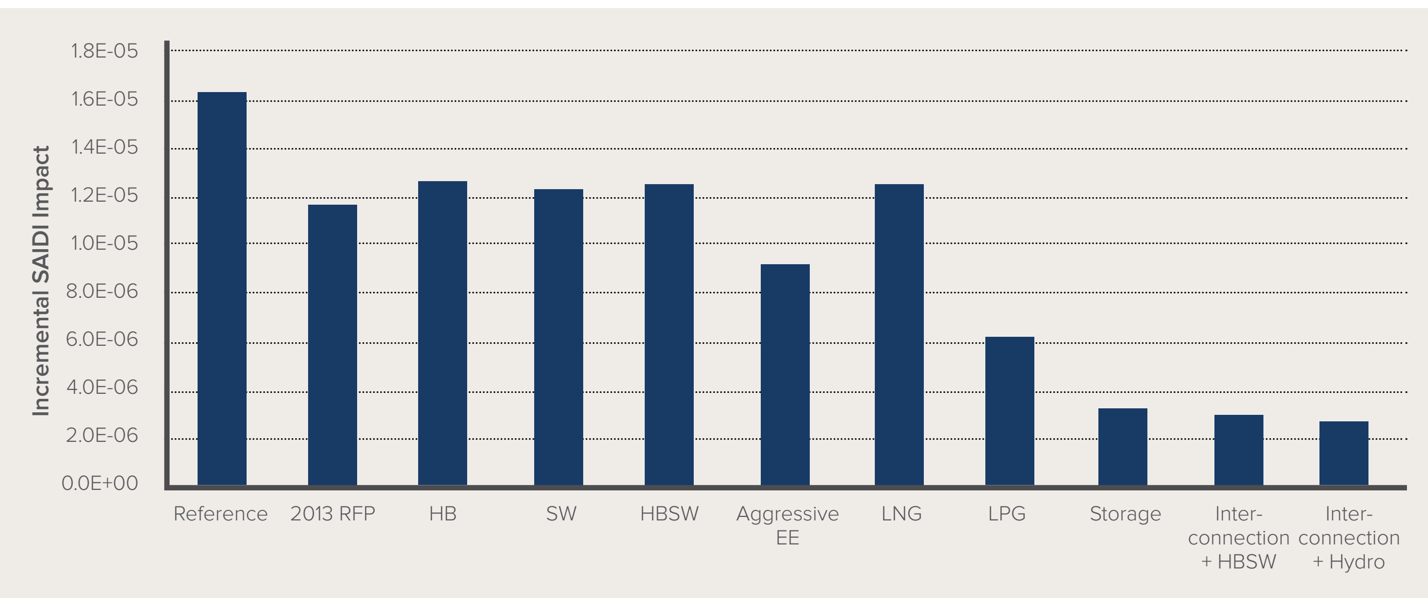
in each scenario can meet a particular load; this is based on the forced outage rate and capacity factor for each individual generation unit. On an hour-by-hour basis, the PDF was applied to the load, and the hourly results were aggregated for the whole year to get the projected generation outage hours. Finally, the number of outage hours was divided by the projected number of customers in 2025 to get the incremental SAIDI, which is the addition to SAIDI above the current system value.

The forecasted incremental addition to generation-related SAIDI for each scenario is shown in Exhibit 45. While the overall incremental addition is quite small, there are key differences across scenarios. The scenarios that increase the amount of flexible or dispatchable capacity, either in the form of battery energy storage or through additional interconnection to CFE, see the lowest incremental impact to SAIDI. The scenarios that add new generation capacity but not new storage see a similar incremental impact to SAIDI, which is about four times greater than that of the Storage and Interconnection scenarios. The Reference scenario, which adds the least new generation capacity to the system, results in the highest impact to forecasted outage duration.

In addition to completing power flow analysis and forward-looking SAIDI calculations, the DNV GL team also developed an approach to take a deeper look at dispatching of resources using the Pydome tool. Pydome (Python-based Dispatch Optimization Model for Electricity) is a DNV GL tool to model electricity systems and markets, using an industry-standard optimization formulation. Pydome finds the optimal unit commitment and economic dispatch of power plants, renewable resources, and storage based on minimization of overall system cost. The DNV GL team customized the Pydome tool for the Belize CPP in order to appropriately model the existing hydro units, given their locations on the same river system and the opportunity to make dispatch decisions by using the

EXHIBIT 45

INCREMENTAL SAIDI IMPACT IN 2025 FOR ALL SCENARIOS



reservoir at the Chalillo dam to store or release water. This adds a level of detail beyond the reasonable dispatch approximation in the HOMER Pro analysis of the CPP scenarios. The custom Pydome tool for Belize is available from DNV GL for continued use in examining options for dispatching existing and new generation resources.

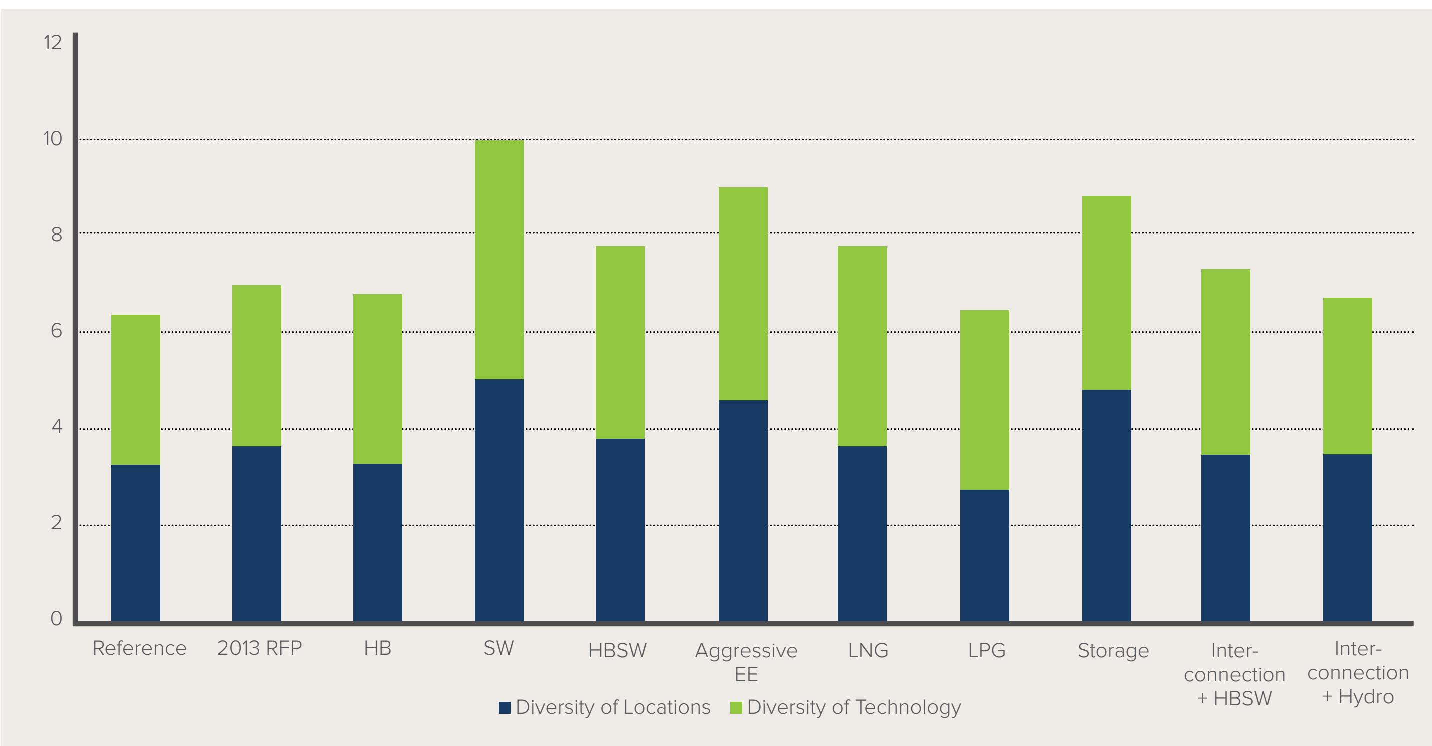
Increase Resilience

Resilience is a central topic of discussion in today's conversations around long-term energy planning. Resilience can be loosely defined as the ability of the grid and its operators to anticipate, prepare for, and adapt to changing conditions. This also includes the ability to recover quickly using comprehensive technical solutions. This differs from reliability (typically measured in the frequency and duration of outages) in that resilience typically refers to how the grid responds to external shocks as opposed to the more regular consistency of service. Resilience takes into consideration all sides of the system, including generation, transmission, distribution, and end use. For the purposes of the CPP, the team focused on the resiliency of different generation mixes, while providing some complementary analysis of issues related to the grid operation.

The resilience analysis focuses on two key metrics to quantify the resilience scores of each scenario: diversity of location of generation assets, and diversity of technologies in the 2036 generation profile. This approach makes two large assumptions. The first is that the most resilient system will have generation assets evenly distributed across the country. The

EXHIBIT 46

SUMMARY OF SCENARIO SCORES FOR RESILIENCE



second is that the most resilient system will have an even mix of technologies in the generation profile. While there are limitations to these assumptions, this approach avoids overweighting renewable technologies as more resilient and provides a baseline to which all scenarios can be compared. Exhibit 46 summarizes the resiliency scores for each scenario.

Results show that scenarios with a higher proportion of renewable technologies in the generation mix, which also tend to be more geographically distributed, tend to score higher for resilience in comparison with the Reference scenario. Scenarios such as LPG, which lead to further homogeneity in both diversity of location and technology, score the lowest for resilience. Scenarios such as HB, which double down on generation in the already concentrated Cayo region, also score lower in terms of resilience.

Beyond the scope of the CPP analysis, the US DOE uses case studies from extreme weather events to show that investments in resilient grid infrastructure such as distribution automation significantly reduce the intensity and duration of outages. Some report SAIDI and SAIFI improvements over 40 percent through resilience measures. Several reports claim approximately 90 percent of outages originate in the distribution system and, in the US, more than 70 percent of outages were weather-related. Beyond updating the transmission and distribution systems, a majority of Antigua and Barbuda's solar arrays remained online through the storm due to hurricane-proofing construction. While storage was not identified as an optimal choice for Belize, bringing on distributed generation and storage capacity can significantly reduce power loss and shorten grid downtime. Organizations such as NREL have begun to value resilience in nuanced ways that consider the willingness-to-pay of customers to avoid outages. Other factors that were outside of the scope of the CPP also influence resiliency. In general, a more resilient grid will experience a lower percentage of infrastructure damage than the Reference scenario grid in the case of an extreme event. A resilient grid will also experience lower power loss in the case of an extreme event and will be able to recover more quickly than in the Reference scenario.

Results from the CPP show that scenarios with a high proportion of renewables, especially the SW scenario, score the highest in the context of the resilience metrics used in this process. It is important to note that all technologies explored in the CPP are vulnerable to disruptions not fully addressed in this measuring framework. For example, wind turbines are susceptible to damage from strong hurricanes which could reduce system resilience in the face of extreme storms. Wind turbines currently being considered for utility scale projects on the Yucatan Peninsula in Mexico by the Chinese manufacturer Envision Energy are rated with a "survival wind speed" of 59.5 m/s (or 214 kmh/133 mph). These conventional 3-blade, land-based turbines perform well in the low-wind speed conditions of Belize but remain vulnerable to hurricanes greater than Category 4. Offshore, two-blade turbines developed by the same manufacturer do not have a listed “survival wind speed” due to their more stable design, and have survived storms with wind speeds greater than 50 m/s with no damage.[11] While certain aspects of wind turbine design increase vulnerability, it is important to note that undersea cables (such as for the Hicks Caye site) that require significant investment and raise overall costs also have a high resilience value that is not captured in the current methodology.

Solar PV is another technology that is vulnerable to extreme conditions. Solar arrays on the US Virgin Islands were destroyed by the Category 5 wind speeds of Hurricane Maria primarily due to improper installation and racking techniques. It is important that large, ground-mounted solar arrays be installed in ways that meet the requirements of intensified storms while also considering flood risk. An important note is that Belize’s solar resource is the most widely distributed around the country and has the potential to bring generation to districts such as Toledo that currently house very little of the overall total generation. The impact of distributed generation from solar technologies is also not captured in current resilience measurements. An important clarification is that, without investment in storage, solar PV (and all other renewables) are susceptible to the same types of resilience issues that face the T&D infrastructure of the grid. Despite this, solar PV can still be considered as a more resilient option than resources such as natural gas due to its dispersed nature and ability to operate in an islanded mode.

Storage is often considered one of the most effective ways to enhance system resilience and ensure operation if key generation assets are taken offline. As contextualized earlier, CPP resilience metrics rely on proportional generation attributable to each technology in 2036 to determine the mix of technologies in each scenario. The batteries are not dispatched in the same way as other generation resources and serve as a reserve, leading to marginally lower resilience scores under the current measurement framework. It is likely that this scenario would score higher in terms of resilience (and adaptability) if the methodology was adapted to consider the resilience advantages of storage technology beyond its actual contribution to total generation in a given year.

As referenced in Section 1, a World Bank report from 2016 concluded that recovery from Hurricane Dean, which struck Belize in 2007 and caused a near complete blackout, took nearly a week before service was fully restored. Hurricane Richard, which hit in 2010, cut off the main hydropower stations and interrupted service to 45 percent of the country for more than four days. Tropical storms, such as Alex in 2010, which cut off 10 percent of the grid, are more common, with outages ranging from two to nine hours. The economic impact of lost GDP from the unserved energy is estimated to be as much as US$3–$5 million for each hurricane (and around US$300,000 from Alex). The report concludes that only an estimated 18

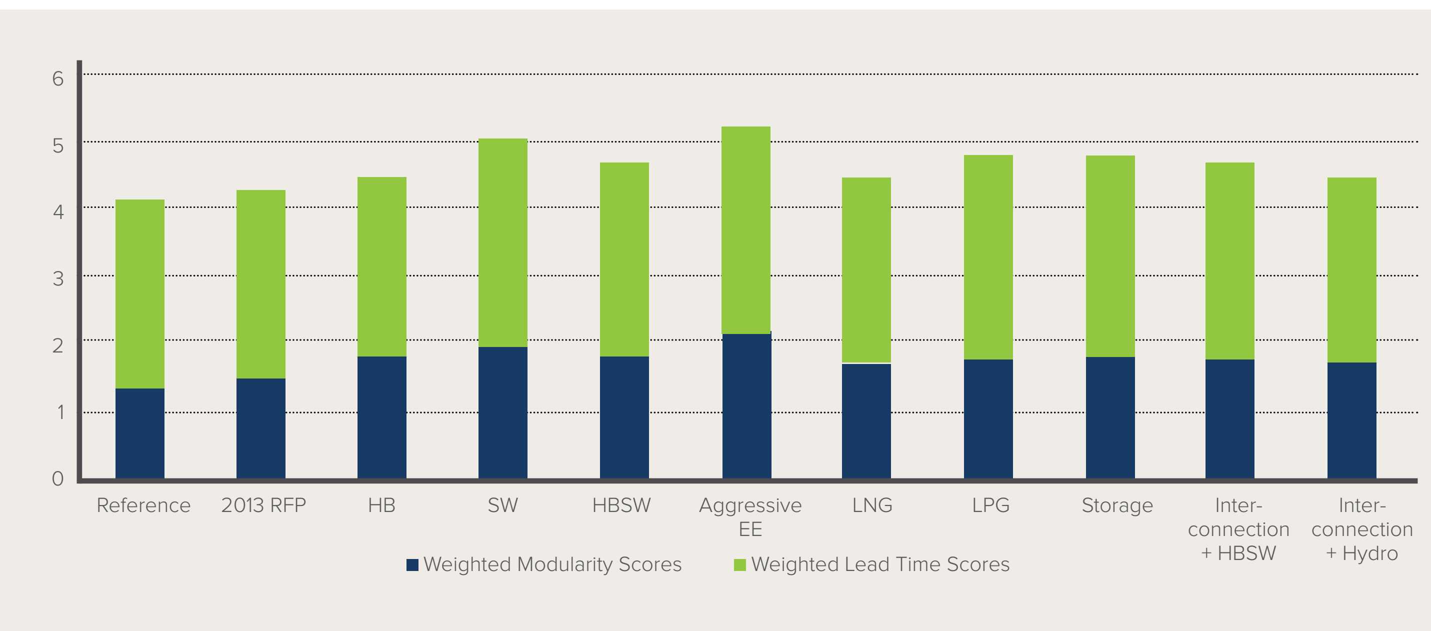
percent of BEL customers would have been impacted if the transmission lines were segmented, compared with the 88 percent that were actually affected. Almost 23 percent of the customers that were affected could have been spared if the western transmission line connecting the 51.5 MW BECOL hydro plants was segmented with circuit breakers. Case studies from the US DOE around electrical islands established in the wake of Hurricane Gustav in 2008 indicate resiliency can be increased with each islanded component, with systems remaining operational due to “smart” grid control that would have otherwise been nonfunctional.

Increase Adaptability

Adaptability is typically measured qualitatively, and is loosely defined as how well an energy system is able to respond to shifting demands and needs from consumers. Highly adaptable systems are able to absorb these fluctuations quickly and ensure that other system elements such as reliability and resiliency are prioritized. For this analysis, the CPP considered two key variables applied to each technology to calculate a score for adaptability: full project lead time and the modularity of the technology. For project lead time, the team consulted with experts in the project development field as well as external reports to determine an approximate lead time from early project implementation to commercial operation. Modularity scores relate to how easily a certain technology can be implemented and scaled to meet flexible needs. Technologies with high modularity scores, such as solar, tend to have low lead times, as they are able to be deployed more quickly and at variable quantities. Technologies such as hydropower have low modularity scores, as they require a certain level of installed capacity and typically have long lead times due to more intensive construction processes. Both modularity and lead time were weighted based on the proportion of generation attributable to each technology in 2036, and the results are shown in Exhibit 47.

EXHIBIT 47

SUMMARY OF SCENARIO SCORES FOR ADAPTABILITY



Results show that adaptability is the highest in the Agressive EE scenario. This is due to the high level of modularity and very low lead time of EE measures, as well as the fact that EE programs reduce overall strain on the system and allow for flexibility in response to shifting demand. While scenarios with higher levels of capital expenditure and more fixed infrastructure, such as Liquified Natural Gas, score lower in terms of adaptability, the overall range of adaptability scores is narrow (4 for the Reference scenario is the lowest while 5 for Aggressive EE is the highest). This is likely the case because of the presence of technologies with low adaptability, such as hydro, in all scenarios.

Adaptability can also be considered against long-term shifts that influence the electricity sector. According to the NDC, Belize expects national rainfall averages to decrease up to 10 percent by 2100. This figure exists within the range of predictions identified in other reports on the conservative end of the spectrum. Fluctuations have been observed in the recent past where electricity generation costs increased by 16 percent following particularly intense drought conditions in 2010 and 2011. Diversifying the domestic electricity generation mix so it is not entirely dependent on hydro will enhance the adaptability of the grid to climatic shocks. Developing mixed generation will further reduce dependence on imports from Mexico as well as fluctuating oil prices, which contributed to the increased cost during the droughts.

3.2.3 LEAST COST

The CPP analyzed the net present cost of each system to determine systems with the least cost over the full time span of the CPP. Most of the resources modeled in the analysis are represented as PPAs, which are assumed to reflect the levelized cost of electricity of the system plus a margin of profit for the IPP. The LCOEs incorporated in the PPAs capture the full range of costs for each aspect of the system over the full lifetime of each asset. A summary of scenario scores for the least-cost goal is included in Exhibit 48.

For new projects, PPA prices were estimated by taking the LCOE outputs from HOMER models and adding an assumption of 15 percent profit margin to the IPP. It is important to note that the 15 percent value was used as a consistent estimator for the purposes of these calculations alone and does not serve as a recommendation when pursuing negotiations with IPPs. For resources that may not be structured as a PPA (such as natural gas and storage), a 70/30 debt to equity split was assumed with a 20-year loan repayment timeline and a 6 percent annual interest rate. Costs to connect with existing grid infrastructure were also applied to each project to more accurately assess the full NPC of each scenario. The total NPC for each scenario is shown in Exhibit 49.

Results support findings in existing external reports that the Aggressive EE scenario represents the

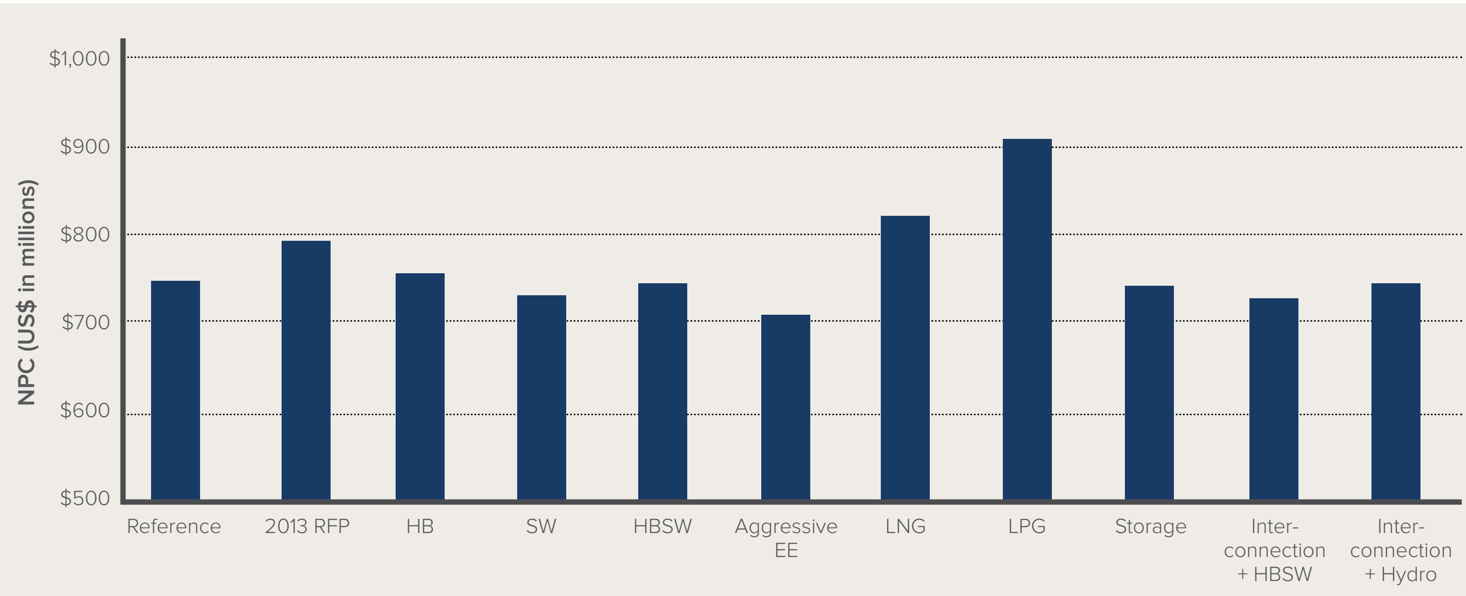
EXHIBIT 48

SUMMARY OF SCENARIO SCORES FOR LEAST COST (NPC, US$ IN MILLIONS)

REF	2013 RFP	HB	SW	HBSW	AGG. EE	LNG	LPG	STORAGE	INTERCONNECT + HBSW	INTERCONNECT + HYDRO
$747.4	$793.2	$754.4	$729.0	$743.2	$705.5	$815.1	$904.9	$739.9	$727.8	$744.1
33	31.1	32.7	33.9	33.2	35.0	30.3	27.3	33.4	33.9	33.2

EXHIBIT 49

TOTAL NET PRESENT COST BY SCENARIO



least-cost option for Belize. This is due to the fact that greater reductions in consumption by 2036 require less capital investment in large-scale infrastructure projects and less overall dependence on fuel and electricity imports compared with the Reference scenario and other scenarios. Overall, the Aggressive EE scenario saves almost $42 million in comparison to the Reference scenario and almost US$88 million in comparison to the 2013 RFP scenario. LPG represents the most expensive scenario in terms of NPC primarily due to the large investment required to develop the necessary infrastructure to support the fuel supply chain and high fixed hourly generation costs. When individual project interconnection costs are accounted for fully, the divergence in NPC between scenarios is not as high as initially predicted, given the diverse mix of technologies in most scenarios. This can also be attributed to the investment requirements of new projects in almost every scenario. While these metrics reflect the most accurate cost estimates for the timeline of the CPP, it is important to note that the long-term benefits of capital-intensive projects such as offshore wind that come on line in later years are not fully captured by the CPP end-year of 2036.

04 SENSITIVITY ANALYSIS

SENSITIVITY ANALYSIS

The team conducted a sensitivity analysis to test the robustness of the CPP solution, exploring sensitivities that could result in a different optimal mix of new resources. Three main sensitivity variables were tested: electricity demand growth, CFE electricity prices, and rainfall (which impacts the electricity generation from hydro and biomass resources). The change in each sensitivity variable, and its impact on the optimal mix of resources in scenarios where new renewable resources are optimized, are discussed in this section.

Overall, the sensitivity results show that solar and hydro are the most sensitive resources, and that demand growth is the most sensitive input. Demand growth is also the input where changes would be most able to be predicted; a slowing or increase in demand growth rate would likely be observed, and plans could be adjusted. Changes in CFE prices or rainfall would likely be harder to see coming. The modularity of solar PV technology means that project sizes could be increased or decreased easily given a change in observed trends compared to predicted; hydro is less modular, due to the time and investment required for new large hydro projects.

4.1 SENSITIVITY INPUTS

In previously completed electricity demand forecasts, the baseline forecast includes a growth in sales of 3.4 percent per year. The low- and high-sensitivity forecasts include sales growth of 2.3 percent and 4.5 percent, respectively. Projections for electricity system losses were kept the same in each sensitivity case, resulting in total electricity use in modeled year 2036 of -18 percent and +22 percent from the baseline. While the electricity demand forecast was based on projections for population and GDP growth, two additional factors that may contribute to lower or higher demand growth include customer adoption of distributed generation (DG) and of electric vehicles (EV). Appendix J includes an initial assessment of transportation sector options, including EVs, in Belize. Although the CPP analysis focuses on the electricity sector, Appendix J also includes a broader overview of the transportation sector and opportunities to improve it beyond EVs.

Along with the baseline price forecast that was used in the core scenario analysis, CFE prices 25 percent lower and 25 percent greater were tested. As discussed in Section 1, CFE prices have historically been volatile, so testing higher and lower average projections to understand the impact on optimal resource mix is important.

The final key sensitivity tested was rainfall, since this variable will impact the electricity production of both hydro and biomass resources. Historical high- and low-production years for each resource were used to estimate the potential increase and decrease in production from the baseline models. This resulted in a range of hydro production from -25 percent to +9 percent, and a range of biomass production from -80 percent to +6 percent.

4.2 SENSITIVITY RESULTS

Exhibit 50 shows the results of the sensitivity analysis for the HB scenario. When these two resources are the only option for new investments, a change in CFE price has limited impact on the optimal amount of hydro, and causes no change in the optimal amount of biomass. A decrease in rainfall matching historical low years leads to 150 percent more new biomass being optimal, and 72 percent more new hydro; more installed capacity is required to meet electricity demand when there is less rainfall and therefore less production from each hydro and biomass plant. A change in load growth either higher or lower than the baseline forecast results in a 70 percent change in the optimal amount of hydro in either direction.

Exhibit 51 shows the results of the sensitivity analysis for the SW scenario. When these two resources are the only options for new investments, only an increase in CFE price results in more solar PV being part of the optimal resource mix. A scenario relying on only new solar and wind is not able to meet the higher growth in demand or greater reduction in hydro and biomass production simulated here. Additional resources, either beyond the three specific wind projects, or beyond these two technologies, would be required to fill this gap. A reduction in either CFE price or demand growth results in 54 percent less new wind being optimal, and a reduction in demand growth results in 63 percent less solar PV being optimal.

EXHIBIT 50

SUMMARY OF SENSITIVITY RESULTS FOR THE HB SCENARIO

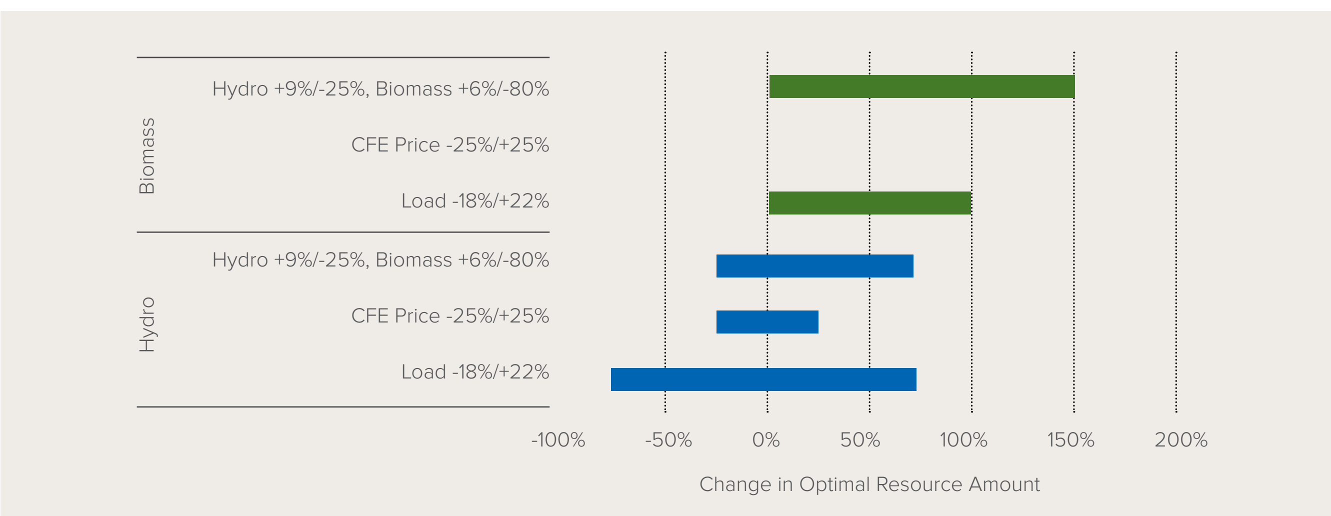


Exhibit 52 shows the results of the sensitivity analysis for the HBSW scenario. When all four resource options are available for new investment, we see the biggest changes in the optimal amount of new hydro (127 percent increase when rainfall decreases or load increases), and an increase of 117 percent in optimal wind capacity for all three sensitivity variables (the addition of the Hicks Caye offshore project).

Exhibit 53 shows the results of the sensitivity analysis for the Aggressive EE scenario. The biggest change is seen with hydro, with the optimal new amount changing by over 300 percent with either an increase in demand growth or a decrease in rainfall.

Exhibit 54 shows the results of the sensitivity analysis for the Interconnection + HBSW scenario. With the second interconnection line to Mexico providing generation to the system, there are fewer new in-country resources in the baseline scenario. The only sensitivity that results in fewer new resources being optimal is a reduction in CFE price of 25 percent, which removes wind completely from the optimal mix. The other changes are seen when sensitivity variables change in the positive direction; a 22 percent increase in demand by 2036 results in twice as much solar and over 200 percent more hydro being optimal, while a 25 percent increase in CFE prices by 2036 results in the Hicks Caye offshore wind project being part of the optimal mix. A reduction in rainfall resulting in lower hydro and biomass production results in 114 percent more hydro capacity and 33 percent more solar capacity being optimal.

EXHIBIT 51

SUMMARY OF SENSITIVITY RESULTS FOR THE SW SCENARIO

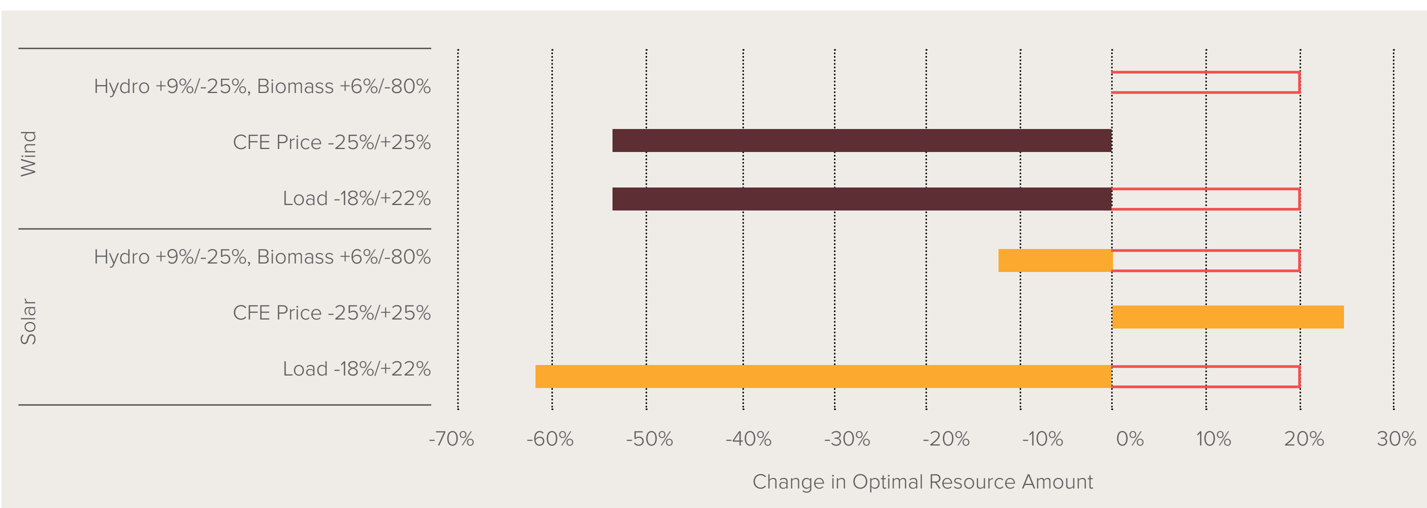


EXHIBIT 52
SUMMARY OF SENSITIVITY RESULTS FOR THE HBSW SCENARIO

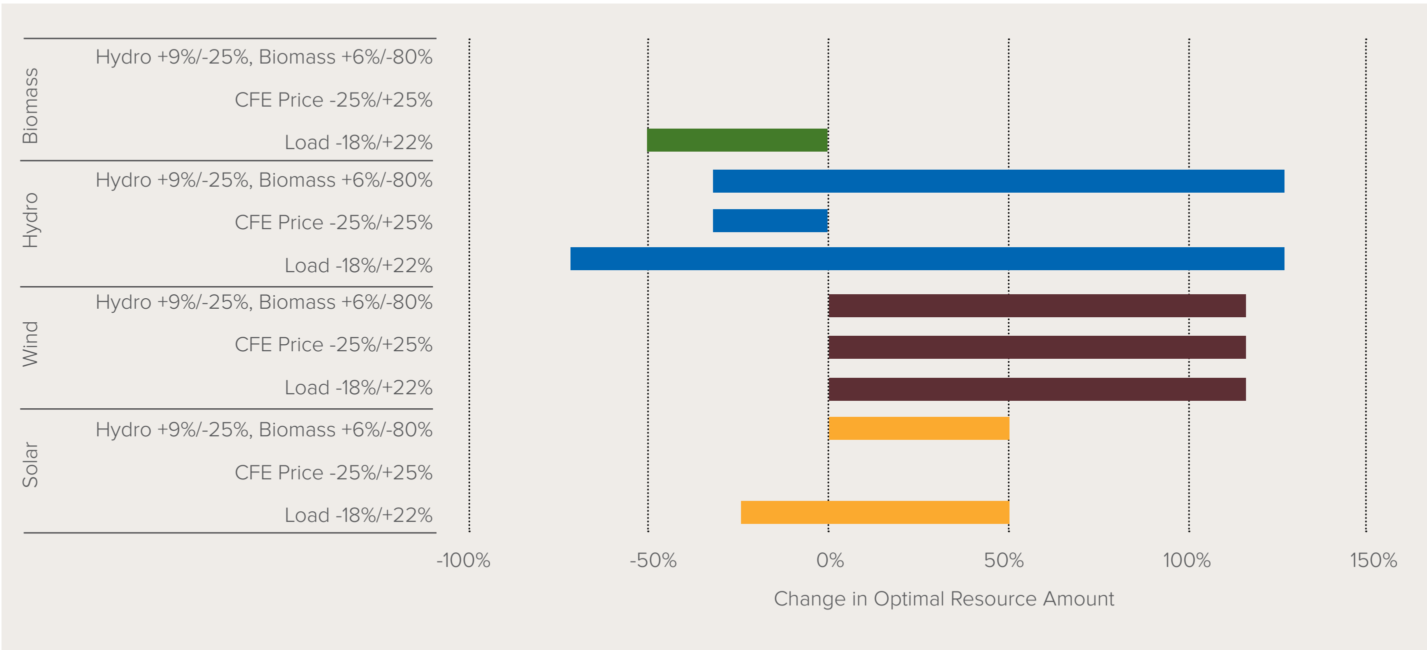


EXHIBIT 53
SUMMARY OF SENSITIVITY RESULTS FOR THE AGGRESSIVE EE SCENARIO

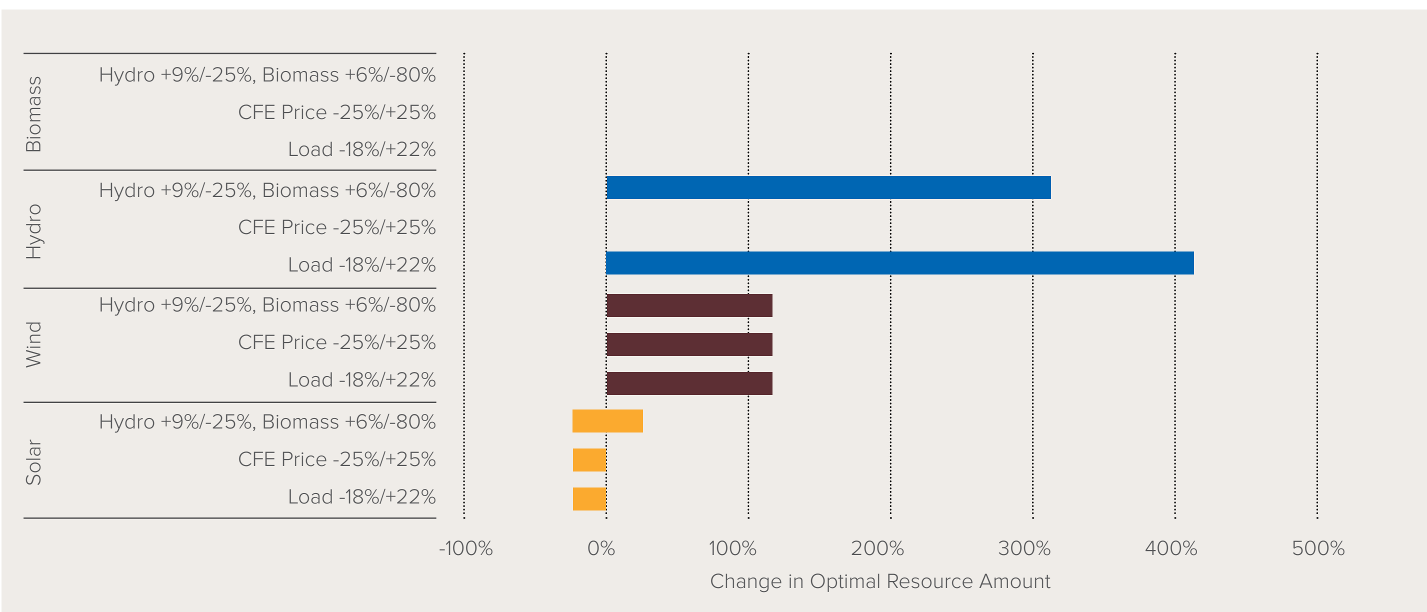
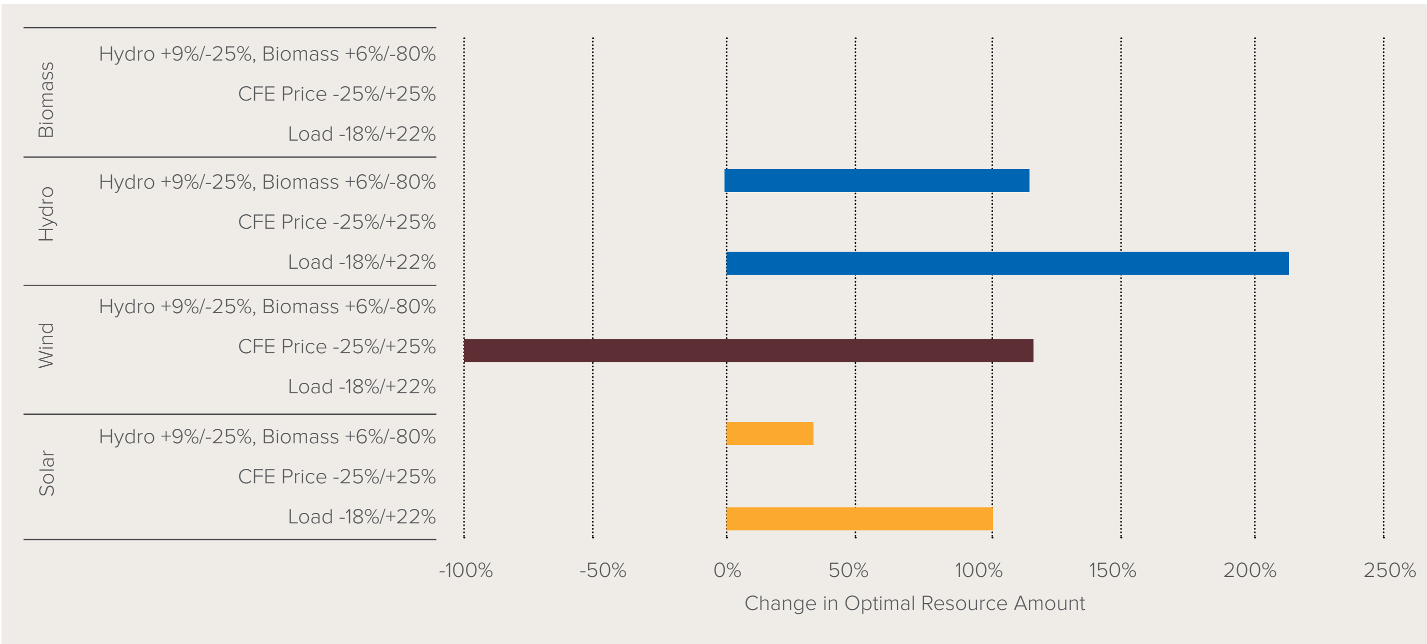
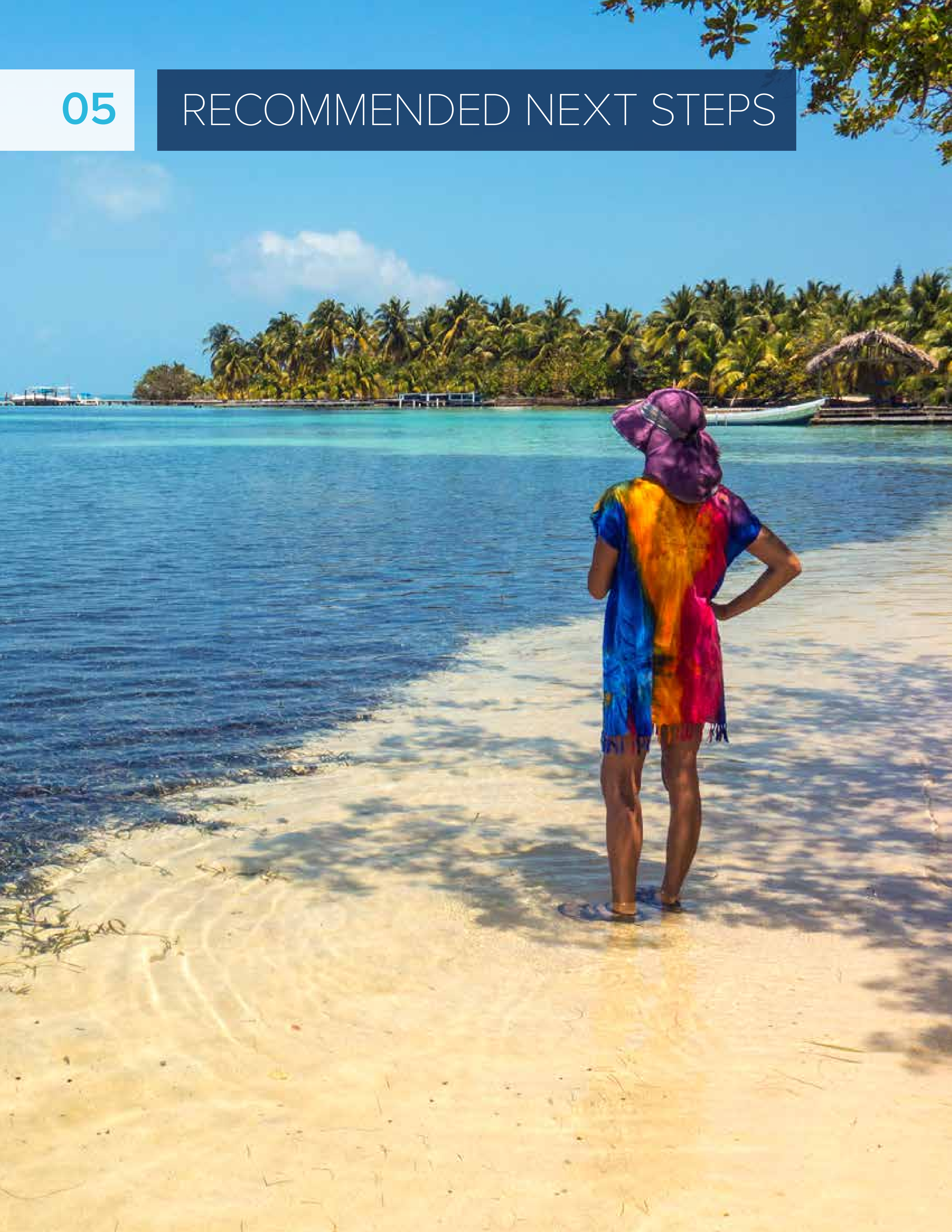


EXHIBIT 54

SUMMARY OF SENSITIVITY RESULTS FOR THE INTERCONNECTION + HBSW SCENARIO



05 RECOMMENDED NEXT STEPS



RECOMMENDED NEXT STEPS

The CPP process results in a set of clear recommendations for Belize to take action and continue progress toward its shared energy sector goals of sustainable economic development, security of supply, least cost, and energy access. Belize should implement energy efficiency, advance its plans to achieve 100 percent energy access, and consider the next procurement for grid-scale resources to include solar and wind.

5.1 ENERGY EFFICIENCY

Pursuing a dedicated energy efficiency program can increase total energy efficiency savings from an assessed 10 percent savings to 20 percent, and provide a cost-effective component of the overall energy strategy, while building local investment and job creation. Energy efficiency poses some challenges to the billing strategies in Belize and the revenues different entities derive from the electricity sector. Energy savings potential could increase economic activity and interest in Belize, drawing support from the economic ministries of the government while challenging the revenue collection of BEL. Furthermore, a centralized energy efficiency program reduces dependence on fuel imports, a vital funding stream for the Ministry of Finance and the government as a whole. The process of developing the CPP with input from the regulator, government, and BEL provides a model through which Belize can harmonize differing priorities while developing new policies and business models to capture the economic benefits of energy efficiency without sacrificing revenue. The CPP included an independent review of existing energy efficiency studies and the results concur that pursuing energy efficiency is a no-regrets option that allows Belize to pursue its shared goals for the electricity sector in the short term.

Across many markets, energy efficiency is often found to be the least-cost resource, including in Saint Lucia, where a recent national planning process found energy efficiency costs between US$0.05 and $0.07 per kWh. In Belize, many energy conservation measures are cost-effective versus the average tariff,

but uptake with customers continues to be slow. Therefore a programmatic approach should start with careful consideration of the barriers to energy efficiency adoption identified by Castalia and included in the National Sustainable Energy Strategy (NSES), as well as further data collection on current supply chains for equipment. With the right pilot funding allowed by the regulator for an efficiency program, the utility can sponsor these investigations, and then staff an initial program to offer incentives to customers for installing efficient equipment. Based on the total savings potential identified in the NSES, this program should start with residential and commercial customers. While it is not the largest energy user, street lighting constitutes a significant portion of the government's electricity bill and should be targeted simultaneously as it only requires coordination between the government and the utility.

Belize's electricity use by sector is shown in Exhibit 55. Scaling up existing lighting programs organized by the government could also lead to significant savings in electricity use for lighting purposes. Targeting the replacement of inefficient refrigerators and freezers through the implementation of limited subsidies will help to speed up the adoption of efficient appliances in the residential sector. As one of the largest loads on the system, large institutions such as hotels should

EXHIBIT 55

ELECTRICITY USAGE BY SECTOR IN BELIZE (CASTALIA, 2014)

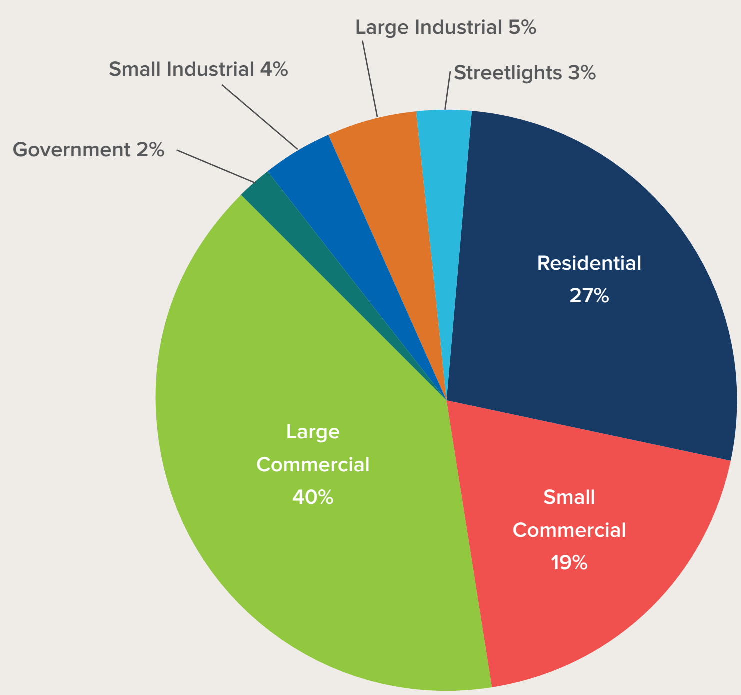


EXHIBIT 56

PROPOSED APPROACH FOR EE PROGRAM IMPLEMENTATION IN BELIZE

MAIN ACTIONS	SUPPORTING ACTIONS OR CONSIDERATIONS
PUC to provide an incentive for BEL to encourage EE among customers	Determine structure, most likely in the form of an authorized program cost and an incentive cost
BEL to establish the EE program, including hiring and training staff	Decide on target EE level for the program Decide on target sectors Decide on what appliances to encourage, and other eligible EE upgrades for the program
BEL to determine incentives to customers for participating	Determine specific incentives; rebates are most common Determine eligibility criteria to participate
BEL to market the program and communicate with customers	
BEL to offer incentives	Could be considered a pilot phase
BEL and PUC to track program progress	Most likely through evaluation, measurement, and verification (EM&V)
BEL and PUC to revise and refine the program approach	Based on initial results

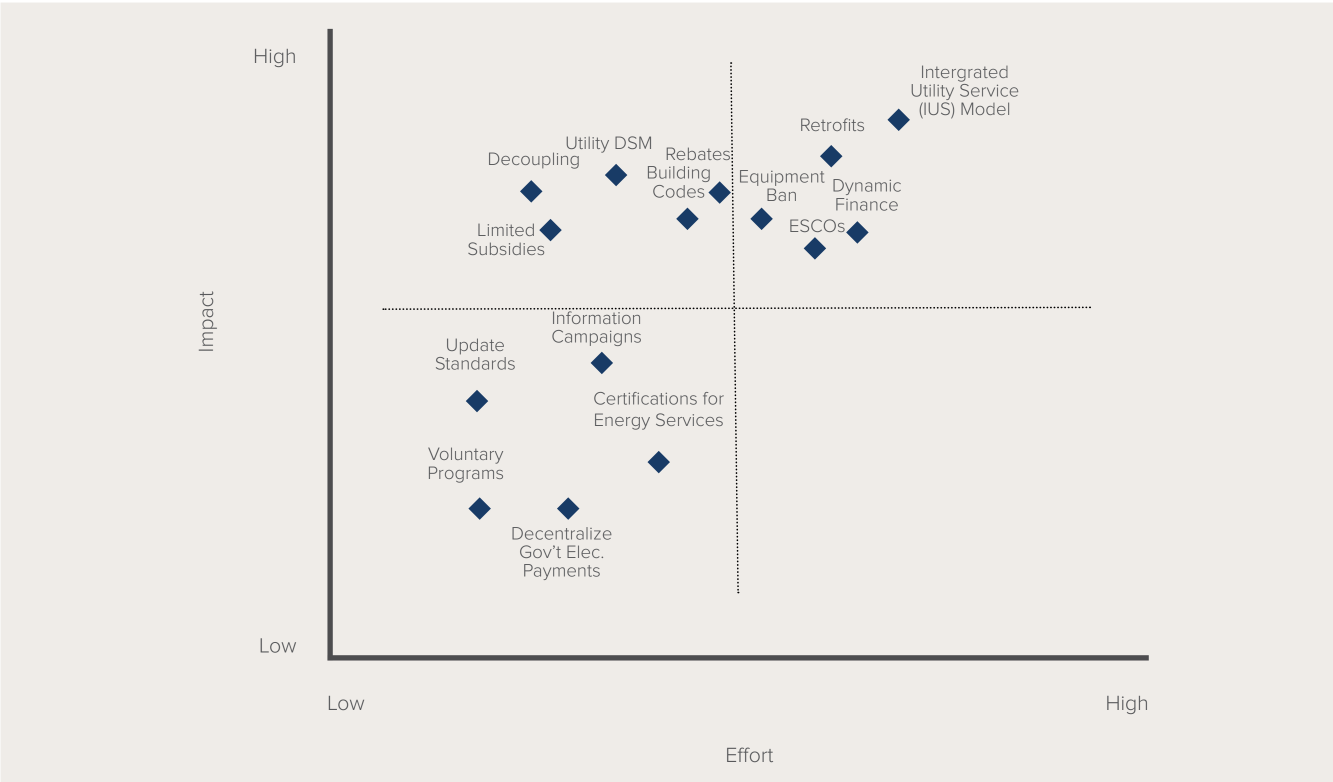
be a primary target of efficiency programs through the application of a suite of programs ranging from air conditioning system upgrades to best practices from the widespread adoption of solar water heating seen in Barbados. Such an application has the potential for efficiency gains across sectors in Belize.

Operationalizing this incentive program will require additional staff in the engineering, finance, and customer service departments at BEL. Exhibit 56 outlines a proposed structure for implementing an EE incentive program in Belize.

Following the initial phase, the program can then be refined, and may evolve to include additional interventions including incentives in the supply chain to offer more efficient products, appliance ratings, and increased tariffs on inefficient equipment. Moving to more advanced programs can provide greater savings but increase program costs, and will require an expanded oversight role from the regulator. Exhibit 57 begins to compare the effort of potential interventions against their relative impact in terms of overall efficiency savings. These comparisons can help to inform Belize's approach to structuring its EE program. After establishing a first incentive program as described above, the government and PUC can examine and authorize a pilot of either an energy service company (ESCO) or integrated utility service (IUS) model to provide more customized and thorough energy efficiency interventions versus an incentive program; both increase the impact and lead

EXHIBIT 57

ENERGY EFFICIENCY APPROACHES, CATEGORIZED BY IMPACT (TOTAL SAVINGS) AND EFFORT REQUIRED



to higher EE savings, while requiring increased effort to implement.

Per the proposal submitted by Econoler, Belize should explore solicitation of ESCOs as a performance-based, market-oriented mechanism to improve energy efficiency following the implementation of incentives to capitalize on low-hanging fruit and organic adoption by consumers. Given the experience of BEL working with independent companies to provide electricity generation, mobilizing EE programs to be administered by ESCOs is a promising option for Belize.

The concept of the integrated utility service (IUS) model was first examined by Rocky Mountain Institute and Fort Collins Utilities, a municipal utility in Colorado. The core concept involves the utility taking an active role in not only incentivizing the efficient use of electricity among its customers, but directly auditing homes, assessing efficiency measures, performing upgrades, and offering financing. These roles greatly expand the traditional value proposition of an electric utility.

The option of the IUS would require BEL to encourage EE, including interventions on the customer side of the meter, and thereby develop new revenue streams that decouple utility revenues from electricity sales. Leadership from BEL in this area will not only serve to enhance the financial health of the utility, but will also prepare the utility for the future energy needs of the country while lowering total electricity

bills for the average customer. This IUS model has been preliminarily explored in other regions and has potential to yield the highest impact, although at higher costs than other programs.

Either variety of program would depend on skilled contractors and equipment installers, who can be identified during the initial incentive program phase. Any pilot program should specifically test:

1. The interest and engagement from customers with these custom solutions
2. A sales process that attracts and screens customers to produce the right projects (energy efficiency upgrades)
3. An engineering process to determine the right interventions for the customer
4. Prequalified installers of equipment
5. Methods of financing, including but not limited to on-bill financing (where efficiency upgrades are paid for through a line item on a customer's electricity bill)

This process will build capacity in the utility, and can particularly be a way to engage with large commercial users, especially the tourism sector, given its needs for periodic facility upgrades and low electricity bills.

5.2 ENERGY ACCESS

There are six communities where the cost of a solar-storage-diesel microgrid is markedly less than that of grid extension; San Carlos, Pine Hill, Otoxha, Crique Sarco, San Vicente, and San Benito Poite. To advance toward providing energy access in these communities, Belize should assess the expected electricity needs of these communities in further detail, continue to pursue funding for microgrid development to offset capital costs (and thus keep the rate base additions due to energy access at a minimum), and aggregate procurement of microgrids where possible.

The first step toward total energy access is to pursue specific and detailed load analysis for each particular case, where uncertainty could be reduced if the GOB jointly with PUC and the Bureau of Standards define a minimum level of energy access. Such regulatory practice would enable all energy access projects to be developed under the same framework, where the installed capacity per number and type of facility for each specific solution would remain consistent, and thus scaling up would become more cost-effective.

The Energy Access tool developed as part of the CPP process will allow stakeholders in Belize to develop initial load profiles for specific communities, and compare estimates for microgrid and grid extension costs. The tool can be used as a first step in developing proposals for funding to implement microgrids in communities where that is the least-cost option.

Belize can benefit from economies of scale by grouping communities where remote microgrids are the least-cost option and issuing consolidated procurements. With a single, competent entity being selected to design, procure, and install multiple microgrids in a given timeframe, the unit cost of each system will go down. This also makes it simpler when replacement parts are needed, in that only one brand of inverter needs to be stocked in-country, for example.

Grant funding is currently secured to support the implementation of microgrids in three initial communities. Through this process, GOB and BEL should focus on equipment selection and monitor logistical challenges of building remote microgrids to gain useful learnings for future projects. As more microgrids are built, the process can become smoother and more efficient by using best practices from these first projects, and the performance of each set of equipment should be monitored to note the actual performance in the Belize climate compared to the theoretical or expected performance put forth by the manufacturer. This will guide future procurement and equipment selection.

5.3 GRID-SCALE RESOURCES

The CPP analysis showed the benefit of continuing to diversify energy resources in Belize, specifically by pursuing new investments in solar and wind. Following the completion of the currently planned projects, Belize should issue a procurement for specific solar and wind projects that contribute to achieving the country's shared energy priorities. Exhibit 58 summarizes the recommended next steps for Belize related to grid-scale resources.

As an initial step, continued resource data collection is required to ensure the optimal solar and wind projects are pursued. There is an ongoing solar and wind resource assessment being undertaken by the US Trade and Development Agency (USTDA) and its consultants DNV GL, which will yield bankable resource data at high-potential locations. Ambergris Caye and Maskall have been identified as promising onshore wind locations, and the preliminary estimates from DNV GL at these sites, using V136 Vestas turbines in the models, are 9 MW at each site. Solar data is also being collected at specific sites in Belize, and similar to wind, de-risking of identified sites must occur in order to build thorough tender documents and ensure the best price for Belize.

EXHIBIT 58

RECOMMENDED NEXT STEPS FOR GRID-SCALE RESOURCES

ACTION	KEY PARTY RESPONSIBLE
Complete current USTDA-funded solar and wind resource assessments	BEL
Begin procurement process for specific projects: - Ambergris Caye and Maskall wind projects (up to 18 MW total) - Solar up to 5 MW	BEL
Complete a two-phase procurement process, with a request for qualifications (RFQ) followed by a request for proposals (RFP)	PUC
Structure the RFP as an open process so all who qualify can bid, with clear guidelines for each resource type being pursued, and a pre-established evaluation committee with agreed-upon metric	PUC
The growth of EVs can be hard to predict; however, if load grows faster than expected due to EVs, solar is a good generation asset that is scalable and complements EV load.	BEL

AP APPENDICES

APPENDICES

APPENDIX A: BELIZE CURRENT ELECTRICITY SYSTEM

EXHIBIT A1

INSTALLED ELECTRICITY GENERATION CAPACITY IN BELIZE

POWER PLANT	RESOURCE	TECHNOLOGY	CAPACITY (MW)
CHALILLO	Hydro	Francis turbines	7
MOLLEJON	Hydro	Francis turbines	25
VACA	Hydro	Francis turbines	19
HYDRO MAYA	Hydro	Run-of-river	3.5
BAPCOL	HFO	Internal combustion	23.8
SANTANDER	Biomass	Steam CHP	16
BELCOGEN	Biomass	Steam CHP	27.5
	HFO	Internal combustion	4
WESTLAKE	Diesel	Gas turbine	22.8
CAYE CAULKER	Diesel	Internal combustion	4

Note: Santander and Belcogen capacities refer to the total installed capacity, however, the PPA of these two assets only considers 8 MW and 13.5 MW, respectively.

APPENDIX B: LIST OF COMMUNITIES FOR ENERACCESS ANALYSIS

EXHIBIT B1

LIST OF COMMUNITIES IN BELIZE WITH NO OR PARTIAL ENERGY ACCESS AS OF 2018

CITY, TOWN, OR VILLAGE	NO. OF HH	DISTRICT	ELECTRIFIED N = NO P = PARTIAL	PLANNED ELECTRIFICATION YEAR	PLANNED ELECTRIFCATION COST (US$)
SAN CARLOS	29	Orange Walk	N		$-
LOWER BARTON CREEK	30	Cayo	N		$-
MEDINA BANK	34	Toledo	N	2020	$306,391
CONEJO CREEK	34	Toledo	N		$-
MABILHA	34	Toledo	N		$-
RINGTAIL	35	Cayo	N		$-
MONKEY RIVER	37	Toledo	N		$-
SANTA ELENA	37	Toledo	N		$-
CORAZÓN	39	Toledo	N		$-
PINE HILL	39	Toledo	N		$-
SELENA	40	Cayo	N	2017	$223,377
SPRINGFIELD	40	Cayo	N		$-
SAN PABLO	40	Toledo	N		$-
MIDWAY	42	Toledo	P	2017	$46,781
LAGUNA	46	Toledo	P	2017	$46,419
SANTA ANA	48	Toledo	P	2017	$73,144
MIDDLESEX	51	Stann Creek	P		$-
YEMERY GROVE	51	Toledo	P	2017	$47,841
GOLDEN STREAM	52	Toledo	N	2019	$300,021
OTOXHA	52	Toledo	N		$-
SUNDAY WOOD	52	Toledo	N		$-
UPPER BARTON CREEK	54	Cayo	N		$-
LOS TAMBOS	55	Cayo	P	2017	$308,332
SAN FELIPE	59	Toledo	P	2017	$90,631
SANTA TERESA	61	Toledo	N		$-
CRIQUE SARCO	64	Toledo	N		$-
HICATTEE (SOUTHERN HIGHWAY)	65	Toledo	P	2017	$61,983
SANTA CRUZ	67	Toledo	N		$-
SAN ISIDRO	73	Toledo	N		$-

CITY, TOWN, OR VILLAGE	NO. OF HH	DISTRICT	ELECTRIFIED N = NO P = PARTIAL	PLANNED ELECTRIFICATION YEAR	PLANNED ELECTRIFCATION COST (US$)
DUCK RUN 3	76	Cayo	P	2017	$296,520
SAN VICENTE	77	Toledo	N		$-
JACINTO/ WESTMORELAND	78	Toledo	P	2020	$78,790
PUEBLO VIEJO	78	Toledo	N		$-
DUCK RUN 2	79	Cayo	P	2017	$13,950
DOLORES	81	Toledo	N		$-
OTHER - COROZAL	82	Corozal	P	2020	$86,068
SAN BENITO POITE	91	Toledo	N		$-
MANGO WALK	93	Toledo	N		$-
SEVEN MILES	96	Cayo	N	2018	$325,473
COPPER BANK	104	Corozal	P	2020	$42,010
BILLY WHITE	113	Cayo	P	2018	$83,246
JALACTÉ	119	Toledo	N		$-
FOREST HOME	120	Toledo	P	2020	$47,401
INDIAN CREEK	134	Toledo	N	2019	$346,482
TRINIDAD	145	Orange Walk	P	2020	$17,530
OTHER - ORANGE WALK	161	Orange Walk	P	2020	$68,525
SAN JOSÉ	175	Toledo	N		$-
SAN VICTOR	179	Corozal	P	2020	$26,188
GEORGEVILLE	190	Cayo	P	2017	$110,782
ST. GEORGES CAYE	204	Belize	N		$-
OTHER - STANN CREEK	237	Stann Creek	P	2020	$52,121
CONCEPCIÓN	257	Corozal	P	2018	$56,440
PROGRESO	273	Corozal	P	2018	$30,169
ESPERANZA	286	Cayo	P	2017	$37,426
CARMELITA	335	Orange Walk	P	2020	$44,195
SAN ANTONIO	381	Cayo	P	2018	$90,121
SAN ESTEVAN	385	Orange Walk	P	2020	$19,076
AUGUST PINE RIDGE	400	Orange Walk	P	2019	$121,473
OTHER - TOLEDO	416	Toledo	N		$-
BULLET TREE FALLS	426	Cayo	P	2018	$237,742
LITTLE BELIZE	427	Corozal	N	2019	$346,627
ROARING CREEK	449	Cayo	P	2018	$42,662
SHIPYARD	621	Orange Walk	N	2018	$477,396
DANGRIGA	2,572	Stann Creek	P	2020	$68,415

APPENDIX C: SOLAR RESOURCE ASSESSMENT

SOLAR PV RESOURCE POTENTIAL

The CPP team recognized that a detailed solar resource assessment is underway in Belize, with specific measurements being taken at identified and promising sites. To complement that detailed analysis, the CPP included development of a GIS-based web tool called SpatialEdge, created by consultants NepCol International. The tool provides an overview of total solar PV potential in Belize based on **ground-mount**, **carport**, and **rooftop** locations; information on more than 13,000 potential sites is included, showing their size, susceptibility to landslides, and how much PV could potentially be installed. By filtering sites with the tool, this information can be aggregated at levels determined by the user. An overview of the number of roofs, amount of space available, and potential PV capacity is shown in Exhibit C1.

In this assessment, solar PV potential is defined as the amount of space available (in m^2) multiplied by 130 W/m^2. The potential capacity calculated here represents the theoretical maximum, which will likely need to be reduced by partners to account for the following factors:

- **Shading:** The output of PV systems goes down significantly when whole panels or even individual cells are shaded. Other buildings, trees, obstructions on the roof itself, etc. need to be considered when siting a PV system to avoid any reduction in production from an installed system due to shading.

- **Structural issues:** PV panels add about 10 kg/m^2 of weight if attached to the roof, and even more weight when using a ballasted system. Not all roofs are sturdy enough to support this amount of additional weight.

- **Building age:** The age of some roofs may also make it inadvisable to install a new PV system, as PV systems are designed for a 25+ year life. Replacing a roof that has PV installed adds cost and time to remove and re-site the solar PV, and therefore placing solar on aging roofs is rarely recommended.

- **Roof orientation:** Steeply-sloped roofs that face north should be avoided due to their lower potential for electricity output.

- **Roof size:** Some of the buildings included in this analysis may be too small to cost-effectively install PV systems. While PV systems can be very small (e.g., a single-panel, 250 W system), there are economies of scale in design, installation, financing, etc. that result in larger systems generating better financial returns.

- **Policy limitations:** Modifying policy to set an overall PV-system size limit for residential properties, regardless of their roof size, can limit the amount of distributed solar PV deployment.

The software tool developed for this analysis allows the user to apply certain filters to narrow down the number of sites. The available filters (some of which may be more useful when evaluating land for ground-mount systems) are:

- Roof size

- Landslide susceptibility

- Distance to grid

- Distance to road

Access to the full tool is available at http://belizesolar-analysis.spatialedge.net/. To view the tool for Belize, log-in information is required.

EXHIBIT C1

SUMMARY OF SPACE AVAILABLE FOR SOLAR PV IN BELIZE

DISTRICT	ROOFTOP SOLAR POTENTIAL (MW)	CARPORT SOLAR POTENTIAL (MW)	GROUND-MOUNT SOLAR POTENTIAL (MW)
BELIZE	341	1	
CAYO	366	<1	
COROZAL	124	<1	
ORANGE WALK	258	<1	
STANN CREEK	290	0	
TOLEDO	17	<1	
TOTAL FOR BELIZE	**1,395**	**1**	**1,558,551**

Exhibit C2 is a screenshot showing the main SpatialEdge page, with a view of the whole country. On the left side of the screen, the user can select which district(s) to view. The total solar potential results on the right side of the screen will update to show the totals for only the portion of the map that is currently visible.

Along with selecting a specific island view, the user can use additional filters on the left side to view buildings within a certain size range, within certain distances from main roads, on land within certain slope ranges, varying liquefaction potential, and susceptibility to landslides.

Zooming in on a specific area allows the user to view individual buildings, as shown in Exhibit C3. Clicking on a building brings up a summary box listing the rooftop size and potential for solar PV, as well as an estimate of the building's suitability for solar PV. A number was assigned for each of the suitability parameters (roof size, distance to roads, landslide susceptibility, etc.) to give an overall estimate of each building's suitability for solar PV. Each building has a unique identification number, allowing for easy referencing of specific buildings between users of the tool.

The additional options on the left side, shown in Exhibit C4, allow the user to examine additional details within the tool. For example, the second option is the Datasets, which allows the user to view key infrastructure such as roads and electric lines, as well as landslide susceptibility areas, liquefaction potential, and slope maps.

The SpatialEdge tool allows the user to view the total space potential for solar PV in Belize, and to filter the results based on several criteria.[iv] The tool can be utilized beyond the CPP to identify top potential sites for rooftop PV installations. Solar PV is included in many of the scenarios investigated as part of the CPP.

[iv] For questions or technical support on SpatialEdge, please contact Kaitlyn Bunker at kbunker@rmi.org.

EXHIBIT C2
MAIN SPATIALEDGE PAGE

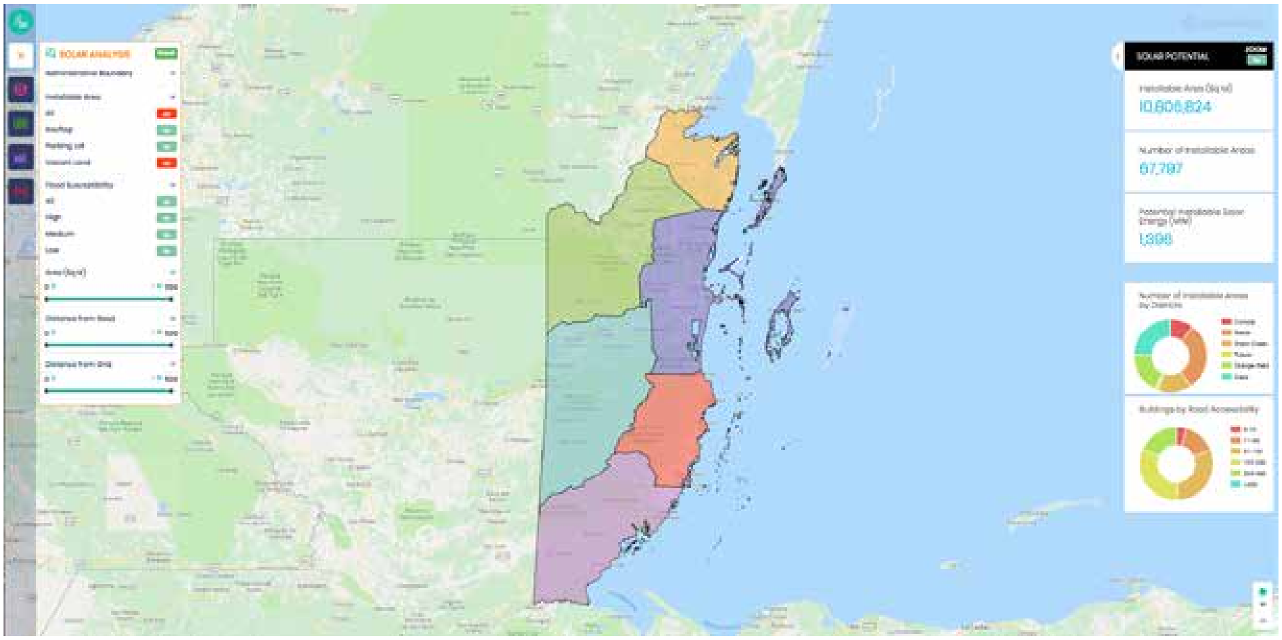


EXHIBIT C3
EXAMPLE OF ZOOMING IN TO VIEW INDIVIDUAL BUILDINGS IN SPATIALEDGE

EXHIBIT C4
DATASETS AVAILABLE TO VIEW IN SPATIALEDGE

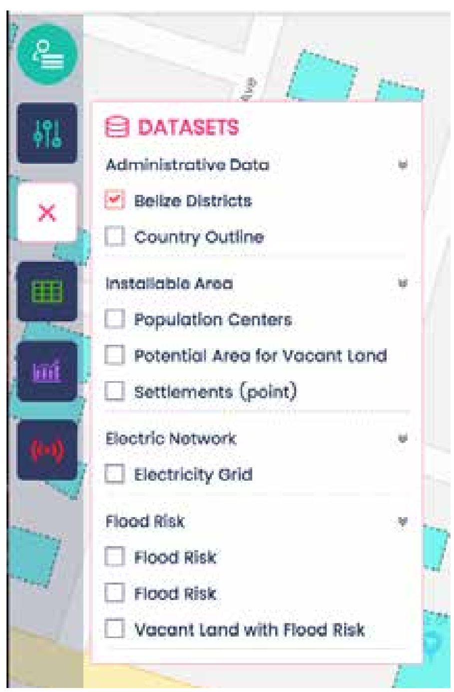


EXHIBIT C5

EXAMPLE SUMMARY CHARTS IN SPATIALEDGE

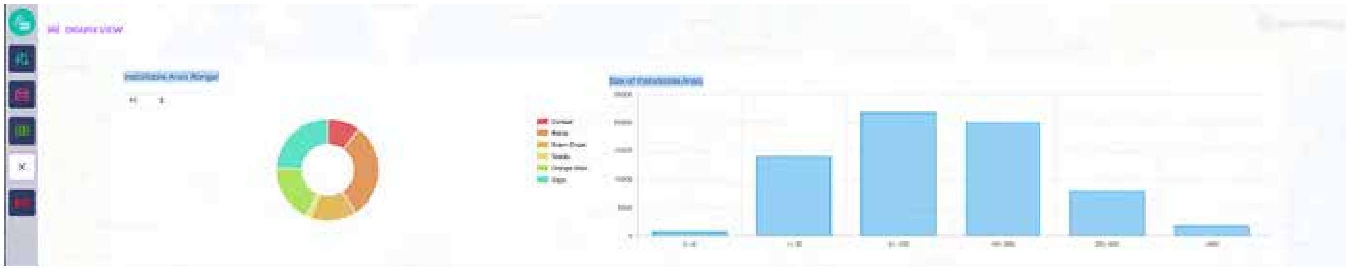


EXHIBIT C6

PROJECTED SOLAR PV CAPITAL COST (US$/WAC)

INSTALLATION TYPE	2017	2018	2019	2020	2021	2022	2023
Ground Mount (2 MW average)	$2.25	$2.16	$2.08	$1.99	$1.91	$1.84	$1.76

SOLAR PV COSTS

The CPP team, in consultation with developers of recent projects in the Caribbean and Central America, considered ground-mount solar PV installation, and made a projection for capital costs (development, engineering, construction) and total operating costs based on experience in the region and recently achieved project costs. The projections were tailored specifically for the CPP based on recent project pricing, and using an average total cost reduction of four percent per year based on industry projections. The solar PV installed cost projections through 2023 are included in Exhibit C6.

For solar operating and maintenance costs, the team included the costs of regular maintenance as well as inverter replacement and insurance costs. This results in an O&M cost estimate of **US$0.05 per Watt per year**.

APPENDIX D: WIND RESOURCE ASSESSMENT

Wind turbines harness the wind's natural and variable kinetic energy for electricity generation. The power that a wind turbine generates is proportional to the rotor diameter and the cube of the wind speed.[v] As a result, wind speed at the rotor is the critical factor in assessing wind potential. Wind energy is a market-proven renewable technology that emits nearly zero greenhouse gases during generation because it is harvesting natural kinetic energy.

One of the CPP objectives is sustainable economic development, of which job creation is an important component. Wind creates a ripple effect of job creation (see Exhibit D1). These jobs span from on-site construction jobs, to induced jobs that contribute to the local economy and persist well into the operation phase of the project.

In Belize, the CPP team considered both **onshore** and **offshore** wind infrastructure. For onshore installations, foundation requirements are determined on a site-specific basis, as well as different installation techniques. Offshore technology is complex and more expensive to install and maintain; however, the benefits sometimes outweigh these challenges. Offshore wind tends to be stronger and more sustained than wind resources that are inland. Furthermore, offshore technology allows for larger wind turbines that are usually more cost-effective per unit of energy and can be deployed in shallow offshore locations more easily than they can be deployed onshore. Offshore wind turbines can sometimes offset contention with communities that may oppose the noise, shadow effects, general aesthetics, and right-of-way issues that can arise with onshore wind.[12]

Wind Resource in Belize

Land areas are divided into seven classes based on wind speed, and therefore generation potential. Lands with wind class 1 or 2 are considered to have poor or marginal wind resources. Locations with wind class of 3 and above are considered areas with moderate to excellent wind resources. There is currently limited information about Belize's wind resource, with a detailed assessment now underway at specific sites.[vi] However, the National Renewable Energy Laboratory's wind assessment of Central America (see Exhibit D2) shows moderate to good wind potential in Belize in open areas of elevated terrain, in extreme coastal northern areas, and in some of the northern offshore islands.

Overall, Belize has approximately 700 km^2 of land with moderate to good wind resource (class 3 or higher). Assuming an array power density of 3 MW per km^2 and a hub height of 50 m, this roughly results in a gross onshore wind capacity of 2,200 MW. These figures are gross installed capacity potential without accounting for availability of land. Belize also has significant offshore potential with about 9,065 km^2 of offshore area with moderate to excellent wind resource.[vii] Of this area, about 23 percent is between the coast and the barrier reef and has moderate wind potential (class 3), and 25 percent is beyond the barrier reef and has good wind potential (class 4). Assuming the same array power density of 3 MW per km^2, this results in a total gross offshore wind potential of 27,000 MW. While

[v] $P = ½ * \rho * A * v^3 * Cp$ where ρ is the air density, A is the area swept by the rotor, v is the wind speed, and Cp is the turbine's power coefficient.

[vi] Typically, before a major wind project, 12 or 18 months of site-specific data from a meteorological tower (at 50 or 80 meters) is required to prove the resource.

[vii] Area up to 112 km off the coastline.

EXHIBIT D1

CHARACTERIZATION OF THE ECONOMIC RIPPLE EFFECT OF A WIND FARM[13]

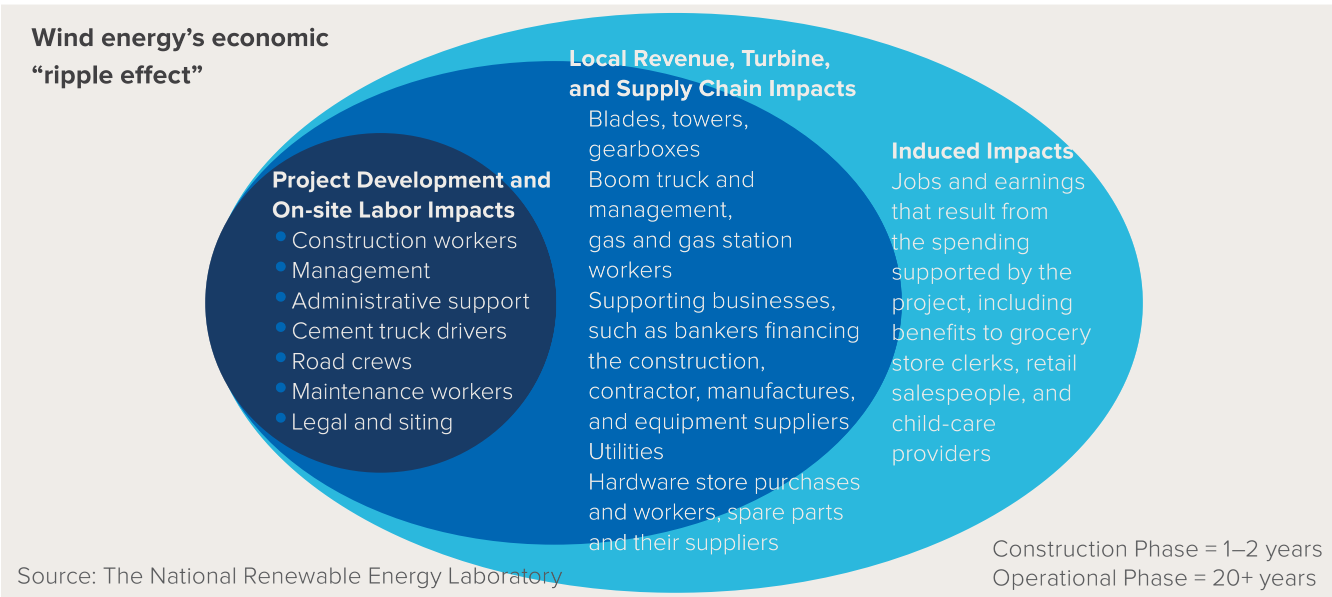
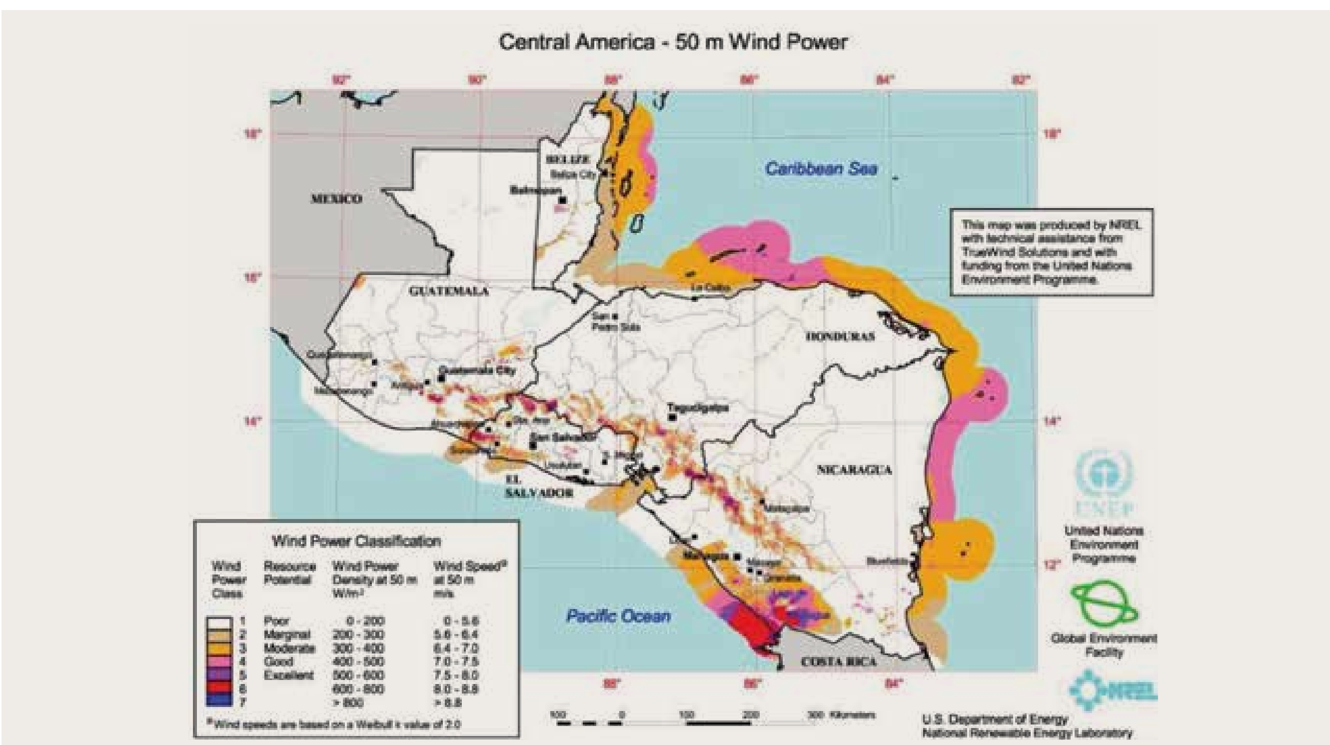


EXHIBIT D2

50 M WIND POWER DENSITY (W/M²) MAPS OF CENTRAL AMERICA[14]



these estimates far exceed any reasonable need for power generation in Belize, they reinforce the importance of screening sites.

In order to realistically assess the wind potential in Belize, RMI and CCI worked with BEL and technical experts at DNV GL to understand the sites of promising potential. Once three promising sites in Belize were identified, the team received hourly production forecasts based on the Vestas V136 3 MW turbine for the three locations. This turbine model was chosen since it is commonly used in low-wind speed environments.

DNV GL assumed a 100-meter hub height for all three locations, and included air speeds, number of turbines (based on the interconnection limit of the nearest substation), turbine layout, and loss factor assumptions appropriate for each. These are summarized in Exhibit D3 below.

Windpower Costs

Each potential wind site has specific considerations that would impact installation cost. The complexity of design, procurement, and infrastructure varies depending on whether one is considering a project in Maskall, one on Ambergris Caye, or a near-shore project at Hick's Caye. The technical experts at DNV GL again provided estimates of both capital and operating expenses for each of these three sites in Belize, which are shown in Exhibit D4. The additional cost of transmission lines to connect each of the Ambergris Caye and Hick's Caye projects to the Belize grid were considered separately in the CPP analysis.

EXHIBIT D3

WIND FARM ASSUMPTIONS USED BY DNV GL TO CALCULATE HOURLY ENERGY PRODUCTION AT THREE SITES

LOCATION	MASKALL I	AMBERGRIS CAYE	HICK'S CAYE
SITE DESCRIPTION	Onshore	Hybrid	Near Shore
NUMBER OF TURBINES	3	3	7
WIND FARM SIZE	9 MW	9 MW	21 MW
TURBINE LAYOUT	Single Row	Single Row	Two Rows

EXHIBIT D4

WIND FARM COST ESTIMATES FOR THREE SITES

LOCATION	MASKALL I	AMBERGRIS CAYE	HICK'S CAYE
CAPITAL EXPENSE (US$/kW)	$2,400	$2,550	$2,800
OPERATING EXPENSE (US$/kW/y)	$25.00	$27.50	$32.50

APPENDIX E: HYDRO RESOURCE ASSESSMENT

OVERVIEW OF CURRENT HYDROPOWER CAPACITY

In 2016, 42.2 percent of Belize's electricity was generated using hydropower. The current installed capacity of hydropower generation in Belize is 51.5 MW. Current hydropower capacity is distributed between 25.5 MW at the Mollejon Hydro Plant, 7.0 MW at the Chalillo Hydroelectric Dam Plant, 19.0 MW at the Vaca Hydroelectric Facilities, and 3.5 MW at the HydroMaya Dam. The power purchase agreements for each dam are BZ$0.175/kWh for the Mollejon and Chalillo Dams, BZ$0.151/kWh for the Vaca Dam, and BZ$0.135/kWh for the HydroMaya Dam.[15]

In 2016, these four dams in total produced approximately 260,200 MWh, with considerable variation between the wet and dry seasons. The Mollejon dam alone produces roughly 160 percent more power during the wet season (21 MW on average, versus 8 MW on average in the dry season).[16] These seasonal variations were incorporated into the CPP scenario modeling efforts, using the historic hourly generation data provided by BEL.

OPPORTUNITIES AND CHALLENGES FOR HYDROPOWER EXPANSION

As Belize seeks to aggressively reduce GHG

emissions and transition to a more resilient energy sector, strengthening and expanding current hydropower capacity is feasible in the short to medium term. The operation of existing dams has already reduced the country's dependence on electricity imports from Mexico, and potential development of 13 additional sites has been documented.[17] Hydropower continues to play a significant role in the government's plans, as outlined in the 2012–2017 Strategic Plan, to turn Belize into a net energy exporter by 2020.[18] In 2006, external consultants found that the total undeveloped hydropower potential beyond current capacity is between 75 and 100 MW. Assuming a capacity factor of 40 percent and the 75 MW prediction, the IEA estimates that Belize could roughly double the current annual generation from hydro and meet almost all electricity demand if the remaining resource were developed.[19] Business-as-usual strategies presented in BEL's 2009 expansion plan also call for a large expansion of hydropower, adding 70 MW in capacity by 2033.[20]

While significant opportunities exist to expand hydropower use in Belize, climate change poses risks for the security of the country's freshwater resources. According to the recent Nationally Determined Contribution, Belize expects national rainfall averages to decrease up to 10 percent by 2100.[21] Increasing stress on freshwater resources from expanding development in human settlements and the tourism sector pose a risk to the future reliability of sufficient flow for hydroelectric generation. As the likelihood of extreme weather events such as El Niño and La Niña increases, hydropower is vulnerable to volatile changes in resource availability. Increases in the demand for electricity and periods of low rainfall can strain hydroelectric power generation. A rainfall shortage in 2011 reduced reservoir and head levels, and lowered generation capacity. This shortage led to increased electricity imports from CFE, which coincided with higher oil prices. This combination of events led to a 16 percent increase in average generation costs from 2010 to 2011.[22] Beyond fluctuations in freshwater resources, rising sea levels and an increase in the frequency and intensity of storms threaten coastal transmission facilities and infrastructure.[23]

The recent Castalia report argues that Belize has a considerable amount of small hydropower sites that are not tapped yet, as well as medium to large sites (>10 MW). A challenge facing this technology, as well as other renewables, is the absence of standard offer contracts (SOCs) for grid-connected generation. The 2014 report argues that BECOL must resolve licensing issues with regards to the Upper Macal River to assess further potential in that region.[24] To accurately assess the full potential to develop additional hydropower, updated hydrological reading stations are necessary. The 2011 Integrated Water Resource Management Act must also be updated to ensure that all of the systems dependent on reliable freshwater are served. This requires additional focus on environmental impact assessments to ensure that vital ecosystems that mitigate the impacts of climate change are not threatened by hydroelectric development.[25]

As stated in this appendix, various studies have highlighted the potential for expanding the use of hydropower in Belize. It is likely that the overall physical space available for new hydro in Belize is greater than the economically or technically optimal amount to connect to the electricity system. The CPP includes new hydro resources in select scenarios, including the option for the proposed Chalillo 2 and Upper Swasey dams, and at least one additional hydro project beyond those.

APPENDIX F: BIOMASS RESOURCE ASSESSMENT

BIOMASS USE TODAY FOR ELECTRICITY GENERATION

In 2016, biomass provided 12.9 percent of electricity in Belize, with an installed capacity of 31.5 MW and energy sold to BEL at a price of US$0.0812/kWh.[26] Beyond electricity generation, various biomass resources including firewood and sugarcane products are used for different applications including cooking and industrial uses. Firewood usage is focused in the residential sector, in cooking practices that include inefficient open-fire schemes. In addition, the use of bagasse occurs in the industrial sector, where sugarcane by-products are harnessed for heat and power generation; the major players are Belize Sugar Industries from the ASR Group and the Santander Group, both private stakeholders that currently hold power purchase agreements.

QUANTIFICATION OF BIOMASS RESOURCES

Several resource types are available for a potential expansion in the use of biomass for electricity generation in Belize, including sugarcane, rice husk, and biogas.

Sugarcane

Similar to other Central American countries, the cane industry in Belize is highly relevant to the nation's economy; according to the ASR group, over recent years it represents 8–10 percent of Belize's GDP and has boosted foreign direct investment by 75 percent. The importance of the sugarcane industry is further emphasized by the existence of the Sugar Act 2001, a legislative tool that seeks to secure a framework to improve productivity, field efficiency, and cane quality. From 2000 to 2010 the cultivated extension of sugarcane in Belize grew from 23,067 ha to 24,281 ha.[27] Further statistics indicate 27,126 ha in 2014;[28] these values result in an average annual growth rate (AAGR) equivalent to 1.12 percent. However, the registered productive yield in Belize is 42 ton/ha in comparison to the subregional average yield of 79.3 ton/ha; neighboring Guatemala registered the highest yield at 102 ton/ha.[29]

Exhibit F1 describes the electricity generation potential from sugarcane in Belize where two cases are described—case (A) assumes that crop yield in Belize will grow at the average subregional annual rate (i.e., 2.15 percent) registered between 2012 and 2014. Case (B) assumes an updated Sugar Act that "enables stakeholders to manage the industry effectively on a commercial basis"[30]—the net effect of which would be a progressive improvement of the crop yield to 100 ton/ha by 2030. Both cases describe two options where 50 percent or 75 percent of the straw is collected in the field depending on the level of mechanization applied, which would result in additional electricity generation of 8.44 and 12.65 MWh/ha per year,[31] respectively.

As shown in Exhibit F1, the potential for electricity generation from sugarcane in Belize depends on the field practices, fluctuating between **17 to 28 MW for 2017 and 26 to 67 MW for 2030**. These results are comparable to those presented by NREL (i.e., < 40 MW biomass potential).[32]

Rice Husk

At present, most of the consumed rice in Belize is imported; in fact, it appears that rice companies in Belize are experiencing difficulties in competing with international rice producers on prices.[33] Between 2000 and 2010, the cultivated extent of rice grew at an annual average of 2.03 percent. Statistics suggest a prominent yield improvement from 2.71 ton/ha (2000) to 4.61 ton/ha (2010),[34] where the later value is comparable to the average yield of countries above the equator.[35] However, countries should have a target of at least 7 ton/ha to be able to supply rice at a competitive price.[36] Exhibit F2 evaluates energy potential from rice where the husk of the rice is harnessed through gasification technology for electricity generation purposes. Accordingly, the energy potential is evaluated through two cases where both assume that the cultivated extent has continued to grow at the same average annual rate as the one indicated in the Environmental Statistics Report (2012). However, case (A) describes a situation where Belize's crop yield is kept constant (i.e., 4.62 ton/ha) while case (B) considers that Belize progressively achieves the minimum competitive crop yield suggested by the FAO (7 ton/ha). Both cases explore the energy potential by considering a gasifier's performance of between 1.75 and 1.85 MWh/ton.[37]

Based on the morphology of the rice crop, the above results assume that 20 percent of the paddy rice constitutes the husk. Overall, the rice-husk energy potential in Belize fluctuates between **1.35 to 2.65 MW for 2017 and 1.75 to 4.94 MW for 2030**.

Biogas

Various parties in Belize have recently shown a significant interest in processing agricultural residues for energy recovery. The Caribbean Community Climate Change Center (the 5Cs) has taken a lead on quantifying the country's "waste to energy" potential by harnessing the organic waste from municipal solid waste (MSW), banana plantations, shrimp farms, and animal manure. A recent study has identified relevant sites with biogas potential in Belize, as shown in Exhibits F3 and F4.[38] Given these potential sites and the analysis completed by the 5Cs, the electricity generating potential from biogas in Belize in **approximately 3.4 MW**.

EXHIBIT F1

PROJECTED CROP YIELD OF SUGARCANE AND ENERGY POTENTIAL

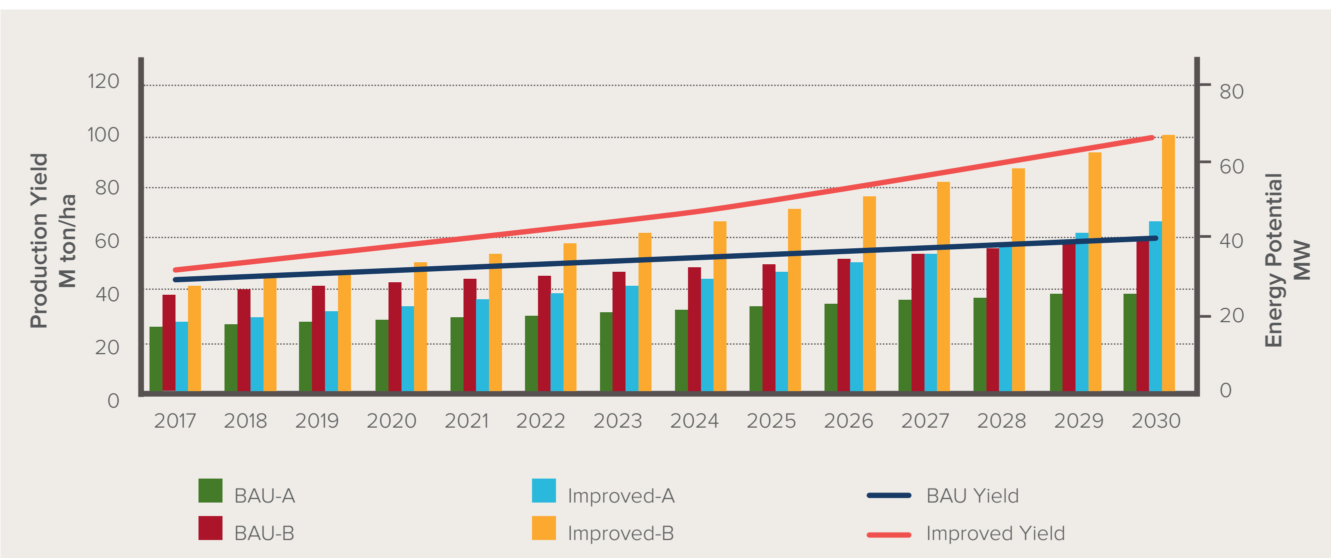


EXHIBIT F2

PROJECTED CROP YIELD OF RICE AND ENERGY POTENTIAL

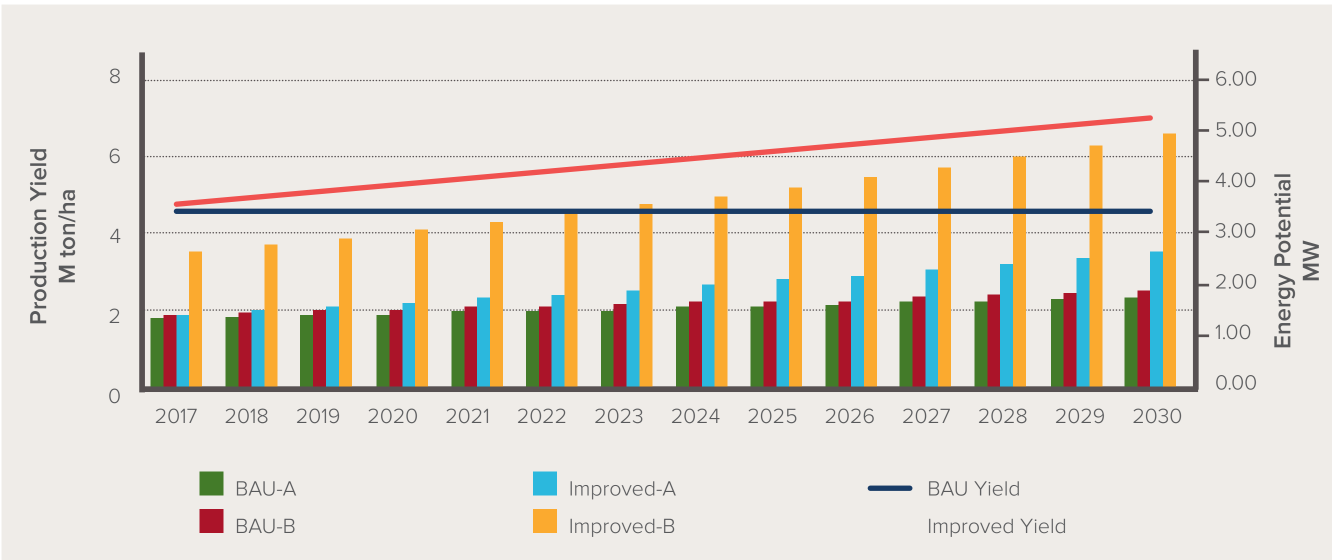


EXHIBIT F3

POTENTIAL SITES TO HARVEST BIOGAS FOR ELECTRICITY GENERATION

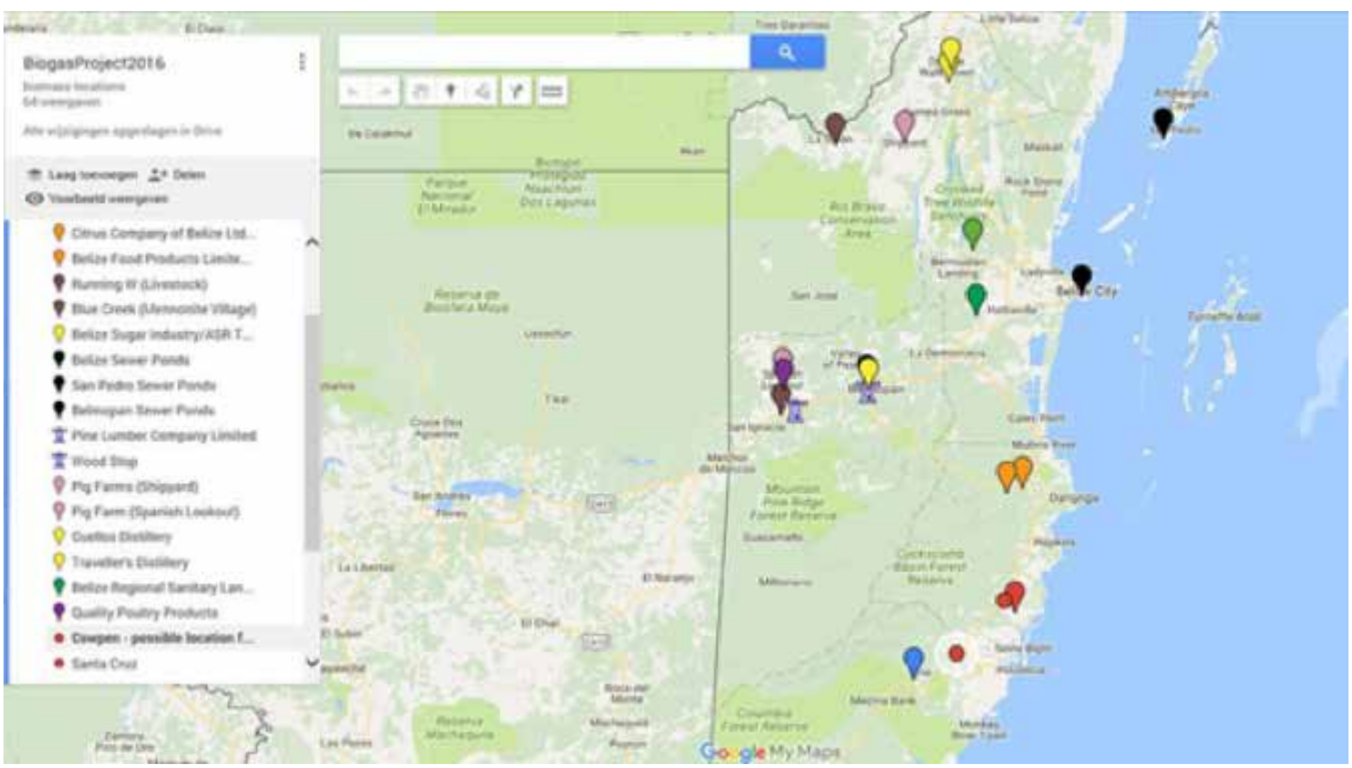


EXHIBIT F4

POTENTIAL LOCATIONS AND SOURCES TO HARVEST BIOGAS FOR ELECTRICITY GENERATION

LOCATION	BIOMASS SOURCE	POTENTIAL (MW)
BELIZE CITY	Sewer effluent	0.11
SAN PEDRO	Sewer effluent	0.01
BELMOPAN	Sewer effluent	0.02
HAMLAND PIGGERY	Pig manure slurry	0.01
PIG COUNCIL	Pig manure slurry	0.04
MOUNTAIN VIEW	Bananas and banana stems	0.01
BANANA GROWERS ASSOCIATION	Bananas and banana stems	0.11
BELIZE AQUACULTURE LTD.	Shrimps heads and shells	0.35
CITRUS PRODUCTS OF BELIZE LTD.	Solid waste stream of citrus, peel, pulp, rags, and seeds	1.36
TRAVELLER'S DISTILLERY	Vinasse	0.03
BELIZE SOLID WASTE MANAGEMENT AUTHORITY	MSW	0.37
	Food scraps	0.50
QUALITY POULTRY	Chicken manure	0.54
TOTAL BIOGAS POTENTIAL FOR ELECTRICITY GENERATION		**3.46**

TECHNOLOGY COSTS

This section describes the cost of biomass power generation technology as indicated in the 2014 report *RFPEG2013 1st Phase Bid Evaluation*, a work jointly prepared by the Ministry of Energy, Science & Technology, and Public Utilities (MESTPU); PUC; and BEL. Based on this report, during the initial phase of the RFPEG2013, five biomass project proposals were presented; Exhibit F5 summarizes the costs associated with the bids.[39]

The above technology costs are comparable to those presented by the US Whole Building Design Guide (WBDG), which indicates that in the US, small-

EXHIBIT F5

SUMMARY OF TECHNOLOGIES AND COSTS FROM INITIAL RFPEG2013 BIDS

RESOURCE AND TECHNOLOGY	AVAILABLE CAPACITY (MW)	CAPITAL COST (BZD/KW)	LCOE (US$/KWH)	HIGHLIGHTS
Sugarcane bagasse – steam turbine	8 (2016) 8 (2018)	7,047 6,807	0.13	Generation of electricity for sale to the BEL grid is only anticipated for four months of the year in the dry season when cane is being milled.
Sugarcane bagasse – steam turbine	16 (2018)	9,550	0.095	Project involved the development of a facility for the production of ethanol and electricity. The project was found to be technically feasible, but certain aspects related to the project's financial performance were unclear.
Cohune nuts kernel shell - gasification	4.20 (2018)	7,250	0.125	The proposal document included several flaws related to the technical and financial feasibility. One of the primary concerns was whether the project would have sufficient biomass availability throughout the year. The report concluded that it is not recommended to consider the proposal for further dispatch-simulation analysis.
Wood/eucalyptus/ cohune nuts - gasification	30 (2016)	11,190	0.145	Developer did not demonstrate clearly that fuel for the project would be available. The availability of funding was also a major flaw with the project proposal. The developer also raised environmental concerns, since eucalyptus trees are invasive and known to be dominant, which may cause permanent damage.
Eucalyptus - gasification	22 (2022)	9,564	0.14	

scale biomass electric plants have installed costs of US$2,891 to US$3,854 per kWe with an LCOE of between US$0.144 and US$0.769 per kWh.[40] Another report from the IEA et al., (2015) indicates average capital costs of between US$3,906 and US$4,278 per kWe for general biomass and biogas technologies, and between US$2,815 and US$4,354 per kWe for all types of combined heat and power (CHP) plants.

CONNECTION TO TRANSPORT SECTOR

While this portion of the CPP analysis focuses on scenarios for the future of the electricity sector in Belize, electricity and transport are related in multiple ways. Earlier insights outlined key opportunities in the transport sector including electrification and the use of natural gas. An alternative use for biogas, discussed above, is in the transportation sector, where the gas is used as fuel without going through the intermediary step of electricity generation. Additional agricultural by-products such as ethanol and biodiesel are also suitable fuels for ground transportation.

The CPP team analyzed two cases where ethanol and biodiesel displace 5 percent and 10 percent of the final energy needs of gasoline and diesel by 2030, and calculated the land required to produce this fuel. For this purpose, conventional biofuel consumption for the year 2030 was projected by analyzing the historical data between 2005 and 2015 through a linear logarithmic approach. In relation to Belize's use of biofuels in the transport sector, the production and use of ethanol and biodiesel are not part of Belize's energy system today. The importance of the sugarcane industry in Belize suggests an adequate potential for the production of ethanol, where the Caribbean Basin Initiative, which concedes preferential export terms for Belizean biofuel to the US, may boost ethanol production in the medium and long terms.

In relation to the use of biodiesel, the potential of *Jatropha Curcas* has been investigated by various organizations including the European Union, the Organization of American States, and the Energy and Environmental Partnership for Central America.[41] However, the team's analysis shows that production of biodiesel from palm oil would require less land.

A comparison of the biofuel analysis and the cultivated land reported in the Environmental Statistics Report (2012) suggests that it is possible to displace 10 percent of conventional transport fuels by ethanol and biodiesel. However, it would be important to ensure that the above results do not breach the National Lands Act (1992, revised 2003), Land Utilization Act (1981, revised 2009), or Environmental Protection Amendment Act (2009).

RECOMMENDATION

Belize's bioenergy potential could vary significantly depending on field practices, where enhancing the agricultural sector and achieving optimal crop yield would boost the biomass energy potential. Exhibit F6 presents specific biomass potential that could be found in Belize.

Although it is possible that Belize has further biomass potential, the latest available statistics—published in 2012 by the Ministry of Natural Resources and Agriculture—show that the most relevant crops are sugarcane and rice. Other potential biomass resources (e.g., eucalyptus and cohune nuts) were not justified as readily available in recent project proposals. The use of biogas was studied by the 5Cs. However, the successful production of biogas may be significantly limited by the production dynamics of different agricultural businesses, waste treatment practices, and

EXHIBIT F6

SUMMARY OF BIOMASS POTENTIAL IN BELIZE

	SUGARCANE BAGASSE	RICE HUSK	BIOGAS
LOW-POTENTIAL CASE	30 MW	2 MW	0 MW
HIGH-POTENTIAL CASE	70 MW	5 MW	3.4 MW

APPENDIX G: STORAGE RESOURCE ASSESSMENT

OVERVIEW OF ENERGY STORAGE

Storing energy can be accomplished through various means, for example: electrochemical (batteries), thermal (compressed air energy storage [CAES]), potential (gravity), kinetic (flywheel), and electromagnetic (supercapacitors). Exhibit G1 summarizes various technology options for energy storage, along with their typical sizes, time periods for use, and main services they can support.

Batteries are commercially available, and are modular options for storage that can provide multiple stacked value streams. Pumped storage is a form of bulk energy management that can only be used where the geography permits, and there has been a study on its potential in Belize showing a suitable site. For these reasons, we suggest a focus on electrochemical (batteries) and gravity (pumped-storage) technology options within the CPP.

ENERGY STORAGE VALUE

Energy storage can provide a range of different values to an electricity system and, in some cases, different values can be provided at different times to increase the overall benefit of including energy storage; examples include frequency regulation, voltage support, and enabling higher penetration of renewable energy resources. Energy storage, when deployed at strategic locations on the distribution network, can be a cost-effective solution for managing constraints and deferring investments. The main values provided by energy storage depend on the application; both grid-connected and remote applications are considered here.

Remote Microgrids

Where grid extension is prohibitively costly, alternative options are available for supplying electricity to villages in rural Belize. This can take the form of a community microgrid or stand-alone solar home systems. Including energy storage in these remote electricity systems is required to ensure a consistent supply of electricity to residents and businesses. Electricity from variable sources can be stored in batteries when it is produced and released when it is needed. The primary benefit of energy storage in this application is to maximize the electricity generation from solar PV during the day, and make it available in the evening to power lighting and other electricity needs in the community. The capability of the selected inverters can allow for the storage asset to cover small fluctuations in electricity generation throughout the day to maintain grid integrity and stability. For example, an inverter with control software optimized to meet a community's objectives can allow battery charging from solar PV when the solar irradiance is high, and control the batteries to discharge with passing cloud cover.

Grid Scale

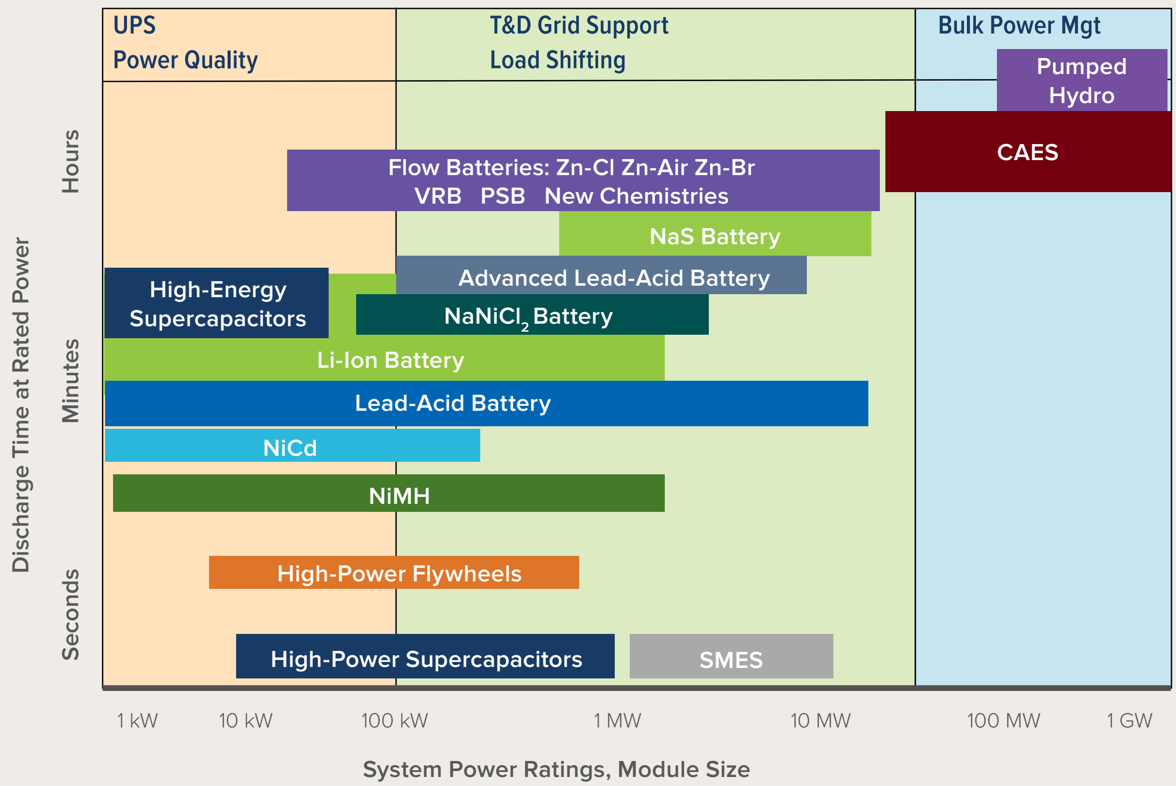
Along with storing electrical energy when it is generated in excess and releasing when there is a higher demand, energy storage at the grid scale can offer a spectrum of stability and management benefits. Energy storage can be placed at strategic points in the distribution network, and some of the potential benefits include:

- **Long-term fluctuations:** Placed near the load centers, storage resources can respond to fluctuations over time in electricity demand, placing less stress on the generation assets to adjust their output on the time scale of minutes. They can also be used to meet the load during peak hours, avoiding the need to use peaking resources and saving both fuel and operational costs for fossil-fuel generators.

- **Short-term fluctuations:** For shorter-term fluctuations in either electricity demand or generation output on the order of milliseconds, storage resources can offer frequency and

EXHIBIT G1

DIFFERENT TECHNOLOGIES HAVE DIFFERENT RESPONSE TIMES AND DISCHARGE RATES. TECHNOLOGY OPTIONS ARE GROUPED HERE ACCORDING TO THE GRID SERVICES THEY BEST PROVIDE



Legend: UPS: Uninterruptible Power Supply, NiCd: Nickel Cadmium, NiMH: Nickel Metal Hydride, VRB: Vanadium Redox Battery, PSB: Polysulfide Bromide Battery, SMES: Superconducting Magnetic Energy Storage

voltage support to the grid, avoiding the need for generators to continuously adjust their output on this small time scale.

- **Increased use of RE:** Storage resources can support the use of larger amounts of variable renewable resources by ensuring that available electricity generation is stored and able to be used to meet electricity demand. This results in less curtailment of available renewable energy resources.

ENERGY STORAGE TECHNOLOGIES AND COSTS

As described above, this assessment will focus on opportunities to utilize battery energy storage and pumped-hydro storage.

Batteries

While many battery chemistry options exist, two that are most commonly used both in remote microgrid and grid-connected applications are advanced lead acid and lithium ion. Exhibit G2 compares and contrasts these battery types.

EXHIBIT G2

COMPARING LITHIUM-ION AND LEAD-ACID BATTERY TECHNOLOGIES

	LITHIUM ION	ADVANCED LEAD ACID
PROS	Expected life of 10 years	Most-affordable option below 100 kWh
	Very good at dealing with frequency regulation (small-amplitude charging and discharging)	Proven technology with manufacturers with long track records
	Little requirement for manual maintenance	Absorbent glass mat (AGM) lead-acid batteries require little maintenance or thermal control
	High depth-of-discharge capability	
CONS	Expensive below 100 kWh	Maximum depth of discharge about 50%
	Manufacturers have not been in business for very long—this is a new and evolving technology	Five- to six-year lifetime (if managed properly). Can be much lower if management is not controlled
	Needs thermal management	Low energy-to-weight ratio
		Slow charge cycles

EXHIBIT G3

COMPARING LITHIUM-ION AND LEAD-ACID BATTERY CAPITAL COSTS

	LITHIUM ION	ADVANCED LEAD ACID
REMOTE MICROGRID SCALE (<100 kWh)	1,800–2,800 BZ$/kWh	700–1,000 BZ$/kWh
GRID-CONNECTED SCALE (>500 kWh)	1,400–2,000 BZ$/kWh	1,000–1,500 BZ$/kWh

EXHIBIT G4

COMPARING LITHIUM-ION AND LEAD-ACID BATTERY OPERATING AND MAINTENANCE (O&M) COSTS

CHEMISTRY	APPLICATION	O&M COST
LITHIUM ION	Remote Microgrid	BZ$370/kW/y[48]
	Grid Connected	BZ$180/kW/y[49]
ADVANCED LEAD ACID	Remote Microgrid or Grid Connected	BZ$30/kW/y[50]

In this appendix, we compare batteries based on the capital cost per storage capacity in kWh. We compiled information from recent research by RMI experts as well as experience with recent energy storage projects in the Caribbean, and Exhibit G3 includes a summary of estimated capital costs for these two battery types at two different scales.

Once installed, there is an ongoing cost to maintain the batteries, including thermal and environmental control, grid interconnection, replacement, and disposal costs. Most chemistries of lithium-ion batteries need to be in a thermally controlled environment, otherwise their lifespan will be shortened. In the tropics, this means an air-conditioned space. Thus, the annual operating costs of lithium-ion batteries are very dependent on the cost of electricity in the system, as this electricity will be used to thermally manage the environment of the batteries. Advanced lead-acid, in particular the absorbent glass mat (AGM) batteries, are sealed batteries where the electrolyte is a gel and is thus spill proof, requiring little maintenance. The cost of maintenance depends on the cost of personnel visits when required.

In addition, batteries must be replaced at regular intervals, typically three to 10 years. Disposal costs and proper procedures for both chemistries described here are concerns and difficult to predict, since it is uncertain what the facilities in place in Belize will be at the end-of-life of these batteries and, should export be needed, what the cost would likely be. Disposal and replacement cost estimates are included in the CPP analysis; the batteries themselves require replacement, but not the housing, controls, and other equipment.

Estimated operating costs per year for each battery type are included in Exhibit G4, which include regular maintenance, thermal control, and environmental control.

Pumped Storage

Pumped hydro storage can only be located where the geology allows for it, specifically with both a higher-altitude and lower-altitude reservoir available to store a large amount of water. Previous studies done in Belize indicate potential in the Challilo region. Two sites were identified, as shown in Exhibit G5 below.

Pumped storage is excellent for storing energy when there is excess generation from renewables at a low cost. When electricity is not being generated or is being generated a high cost, then gates are opened from the high reservoir and the water spins a turbine and generates electricity from the stored potential energy. Pumped storage can provide a continuous supply of energy for many consecutive hours, depending on the reservoir volume and rate of flow. This is best used for load management/load smoothing and peak shaving, but is not fast-acting enough for frequency and voltage regulation.

The capital cost of pumped hydro was estimated by NORPLAN for a system of Antigua's Public Utilities Authority at BZ$46 million to BZ$60 million for a 10 MW at 15 MWh facility. Pumped hydro involves hillside construction, large volumes of concrete, and tunneling. The time required to develop and install a pumped-hydro storage system is significantly longer than electrochemical energy storage alternatives.

[viii] Calculated with a 250 kWh 4:1 power/energy ratio battery, with an 80% depth of discharge. Assuming one full cycle per day and a grid electricity cost of $0.75BZ/kWh (The mid-range of kWh costs for an initial St. George's Caye microgrid design).

[ix] Calculated with a 250 kWh 4:1 power/energy ratio battery, with an 80% depth of discharge. Assuming one full cycle per day and a grid electricity cost of $0.36BZ/kWh.

This appendix outlines the energy storage technologies that are most relevant to Belize, their estimated costs, and ancillary benefits and value that can be unlocked with the use of appropriate inverters. Energy storage was included in the CPP analysis in two ways—in investigation of the technology and system-sizing options for electrifying remote communities, and secondly in evaluating solutions for grid-connected resources. For the second application, energy storage was included in one CPP scenario along with new generation options, and the hourly operation of the electricity system given the resource mix was modeled.

EXHIBIT G5

OPTIONS STUDIED FOR PUMPED-HYDRO STORAGE IN BELIZE

CHARACTERISTICS	PINE RIDGE TO CHALILLO	SOUTH SIDE TO CHALILLO
POWER (KW)	20,307	20,601
EFFICIENCY	0.75	0.75
HEAD (M)	120	200
GRAVITY (KG-M/S^2)	9.81	9.81
FLOW (M^3/S)	23	14
WORKING VOLUME (M^3)	120,000	80,000
ENERGY STORAGE (MWH)	29.43	32.70
DISTANCE (KM)	0.5	0.48
DIAMETER AT 5 M/S (M)	2.42	1.89
RISE ANGLE (DEGREES)	13.9	24.6

APPENDIX H: NATURAL GAS RESOURCE ASSESSMENT

Natural gas has become a valuable component of many continental energy systems. The vast reserves for natural gas in countries such as the United States (bolstered by shale gas production) allow it to compete with oil as a resource for various energy needs. Analyzing possible natural gas supply pathways for Belize is useful to view a full picture of electricity options, given its potential to offer firm capacity, a lower emissions index, and a lower and more stable cost than oil. The purpose of this assessment is to inform stakeholders about the feasibility and implications of investing in natural gas for electricity generation. Two main options are considered here: importing liquefied natural gas via ship, and importing compressed natural gas (CNG) via pipeline. The import infrastructure required under each option, the cost of the gas itself, and the necessary investment in new generation resources are explored.

LIQUEFIED NATURAL GAS IMPORT OPTION AND COST

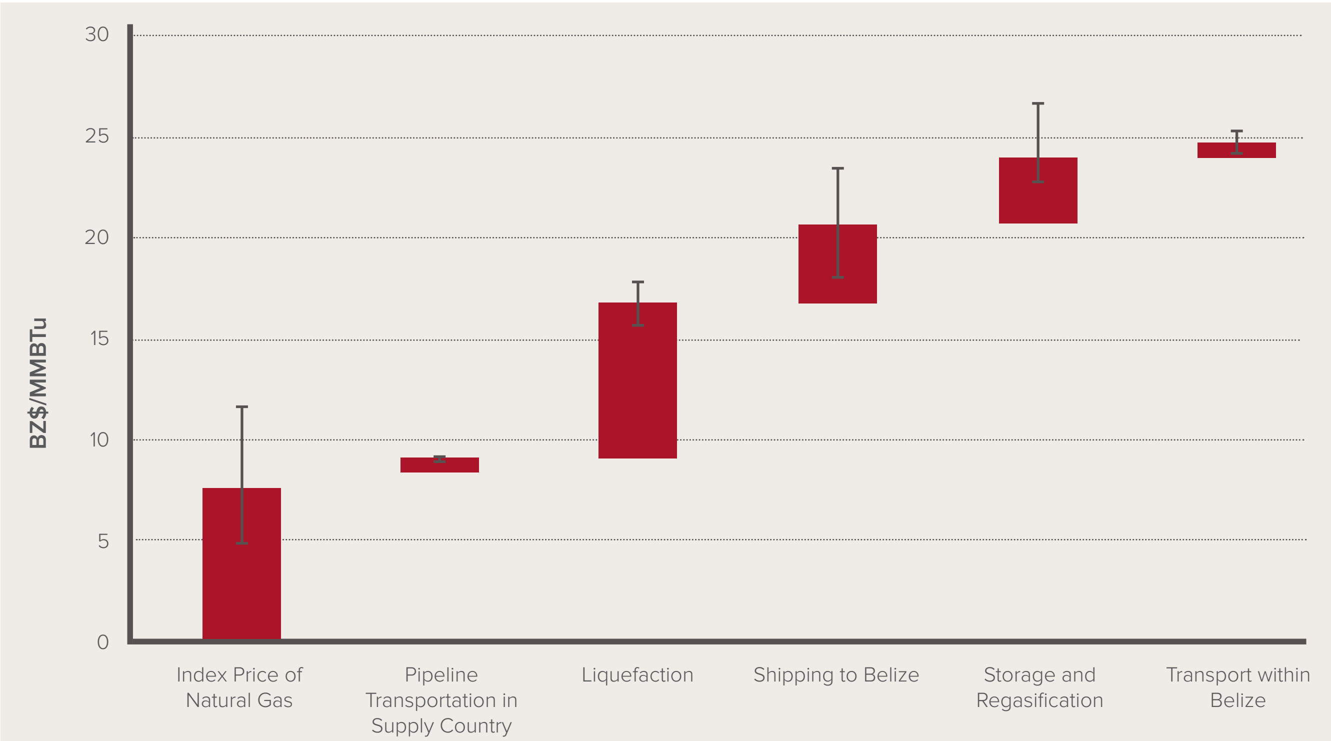
To explore the opportunity for importing LNG, the team interviewed US-based natural gas suppliers, although other countries such as Colombia, Venezuela, and Trinidad and Tobago also offer natural gas exports. Panama is also currently constructing an LNG facility with the intention of becoming a natural gas hub for Central America.[43] Several steps are required for Belize to receive LNG and prepare it for use in electricity generation, as outlined here:

1. Purchase the gas, under a specific volume contract (discussed further below).
2. Transport that gas to an export facility (perhaps from major LNG ports in the US, Panama, Colombia, or Trinidad and Tobago).
3. Liquefy the gas (by compressing it and cooling it to -161 degrees C) to decrease the volume.
4. Transport the LNG to the port of Belize, in a specialized container ship.
5. Store the LNG, either onshore in vacuum-insulated tanks or offshore.
6. Regasify the LNG at an import facility (receiving terminal) that is likely onshore (or potentially offshore in a floating storage and regasification unit, FSRU), but requires specialized super-cold infrastructure. This facility could have a capital cost between BZ$220 and BZ$440 million, and could also be financed and operated by a supplier with a long-term contract to supply gas to Belize.
7. Transport the gas to the generation facility (either with trucks or pipelines).

Each of these steps includes a cost, either variable with the price of gas or related to the cost of investment in new infrastructure. Exhibit H1 provides an estimate of the cost for each step of the process, per unit of fuel received in Belize.

EXHIBIT H1

COST STRUCTURE FOR POTENTIAL LNG IMPORT VIA SHIP TO BELIZE



For several of these steps, additional considerations that can impact the cost include:

1. The optimal storage tank size is a large factor in making an investment decision. There is a trade-off in cost between increased investments in land and tanks versus the frequency of LNG cargo arrivals.
2. Suppliers often encourage use of a dedicated ship, in which case, it is best to maintain a high utilization factor (i.e., frequent trips and minimal storage space).
3. Regional collaboration might drive shipping costs down further, resulting in a decrease of up to two-thirds for the shipping component of the overall cost.

In consideration of risks, LNG is not flammable or toxic (when in the liquid form), and accidental discharge does not pose significant environmental hazard. However, a leak can create a gaseous cloud that is highly flammable and dangerous. LNG ships are often considered safer than diesel tankers, but storing LNG in highly pressurized containers (at sea or on land) requires constant oversight. In the US, The Federal Energy Regulatory Commission requires safety exclusion zones near LNG facilities, with the exact sizing being open to interpretation. Offshore facilities could mitigate this risk, but carry unique costs and risks of their own.

COMPRESSED NATURAL GAS IMPORT OPTION AND COST

To explore the opportunity for importing CNG, the team reviewed current use of natural gas and stated strategies for other Central American nations, including Mexico, Guatemala, Honduras, and El Salvador. Their interest creates a potential collaboration between several countries in the region for natural gas supply through Mexico. Mexico currently imports natural gas via pipelines from the US, and in 2014, one-third of the Mexican natural gas national demand was satisfied by imports.[44] With growth expected in both natural gas demand in Mexico and imports to the country,[45] there is an opportunity for regional collaboration by extending pipelines from Mexico to other nearby countries, including Belize.

Mexico's gas pipeline network extends from Reynosa in the north to Valladolid in the south, on the Yucatan Peninsula. For Belize to access natural gas from Mexico, it would mean extending this pipeline and negotiating an agreement with Mexico to purchase CNG. Natural gas purchase from Mexico means that Belize would also be dependent on Mexico's relations with its suppliers. Exhibit H2 shows the existing natural gas pipelines in Mexico, highlighting the existing pipelines connecting to the US and those near the border of Belize.

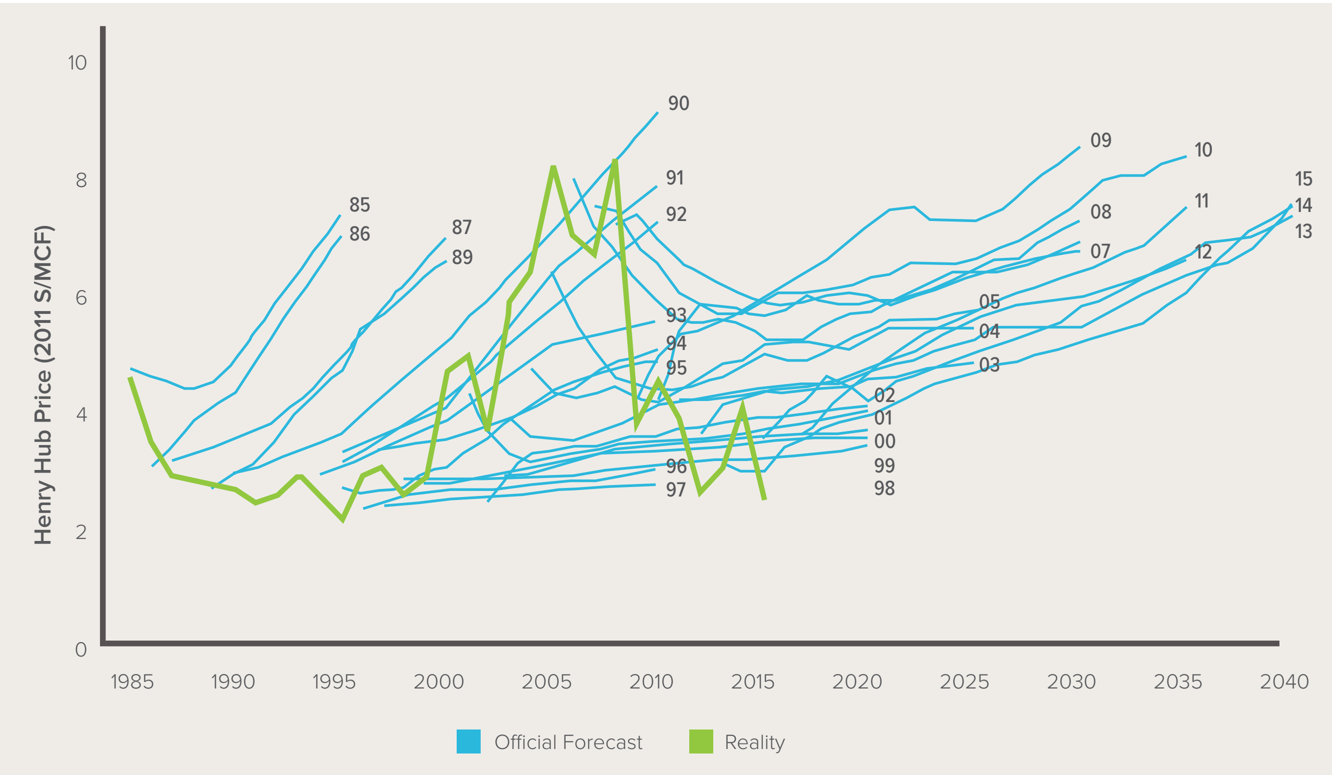
Receiving CNG from Mexico would require an extension of the existing pipeline by approximately 100 miles toward Estero Franco for a border crossing to Belize. Cost estimates for building gas pipelines vary greatly depending on the size of the pipe, the location for construction, the terrain, and

EXHIBIT H2

NATURAL GAS AND OIL PIPELINE NETWORK IN MEXICO[46]

EXHIBIT H3

US NATURAL GAS PRICES VS. PROJECTIONS, 1985–2015



the population density, among other things. Land ownership and right-of-way considerations can also impact the cost of pipeline construction. Estimates for total pipeline construction cost range from US$100,000 per mile,[47] to US$1,000,000 per mile.[48]

As with LNG, the physical risks of CNG can be mitigated through optimal design and operation of equipment. Typically, transmission pipelines carrying CNG are routed across land not owned by the pipeline company, and the hazard distance to people and property can range from under 20 m for a smaller pipeline at lower pressure, to over 300 m for a larger one at higher pressure. The most challenging gas pipeline accident would be a jet-fire type where leaked natural gas with high pressure would be released as a jet flow from a split in the pipeline. If the leaked gas is lit at the split, the jet fire would damage peripheral personnel and buildings.

FUEL COST AND ADDITIONAL RISKS

While the discussion above described physical risks with the use of both imported LNG and CNG, perhaps the most significant risk or limitation of a strategy that relies on natural gas is that Belize would likely be asked to sign a long-term agreement for receiving natural gas, committing the country to a commodity with high historical price volatility (large swings). High volatility of prices means that natural gas may not be a true hedge, or a contributor to a lower-cost electricity system. While the price of natural gas is typically lower than that of oil, the price has fluctuated significantly in the past 30 years. Being limited to a volatile fuel source for a term of 10 to 20 years (necessary for infrastructure investment) can restrict any cost saving for ratepayers and adds additional risk. Exhibit H3 shows the recent volatility in natural gas price, in comparison to various projections.

GENERATION INFRASTRUCTURE COST

With either import option for natural gas, additional investment would be required in generation infrastructure to utilize the fuel, although the existing BEL back-up gas turbine would be an initial point of use. To provide a larger scale of use required to justify the import of natural gas, it is likely that new generation resources would be required. For new generation, the average capital cost for new combined cycle gas turbines (CCGT) is US$1,200/kW with an operating and maintenance (O&M) cost of US$10/kW/year.[49]

Based on the initial cost estimates presented here, and discussion at the December CPP meeting, the import of LNG via ship was the option put forth to be explored within the CPP. The scenario analysis tested for the established CPP goals of sustainable economic development, security of supply, energy access, and least cost, so that the option for natural gas was compared against other resource options being explored in the CPP.

APPENDIX I: CFE MODELING ASSUMPTIONS

Purchases of electricity from Mexico (CFE) account for a significant portion of Belize's electricity supply today, and this resource plays an important role in all scenarios investigated through the CPP. As with other resource options, the team projected costs into the future to use as modeling inputs. This appendix outlines the CPP assumptions related to CFE.

To project CFE prices into the future, the team used near-term forecasts provided by BEL, and worked with technical experts at DNV GL to create a reasonable forecast for the next 20 years. Exhibit I1 shows the projection for annual CFE price in US dollars per kWh purchased.

In addition, the team used a daily price profile in the CPP dispatch modeling, where the CFE purchase price changes each hour. Exhibit I2 shows the daily profile of CFE prices.

EXHIBIT I1

ANNUAL CFE PRICE PROJECTIONS OVER CPP ANALYSIS PERIOD

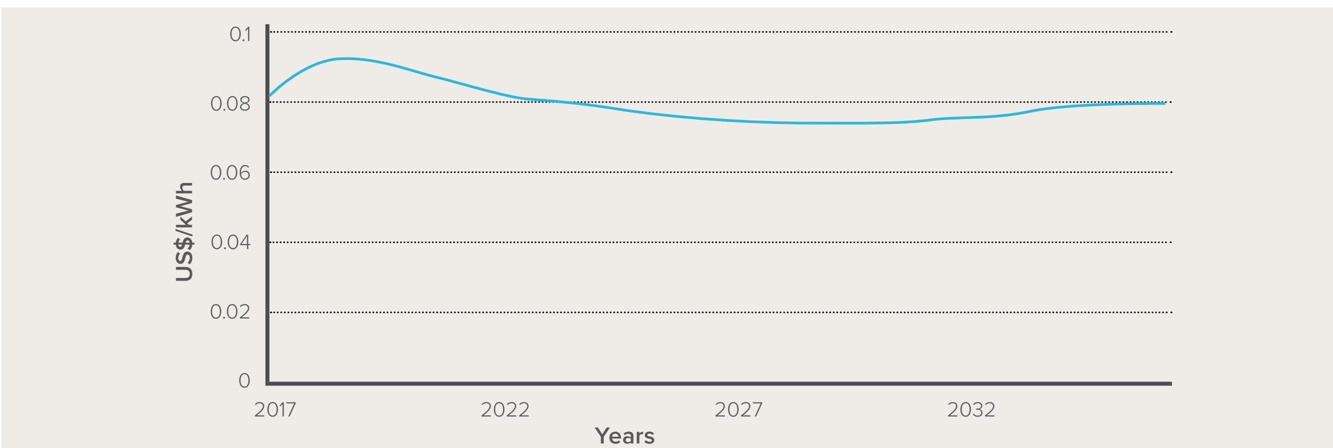
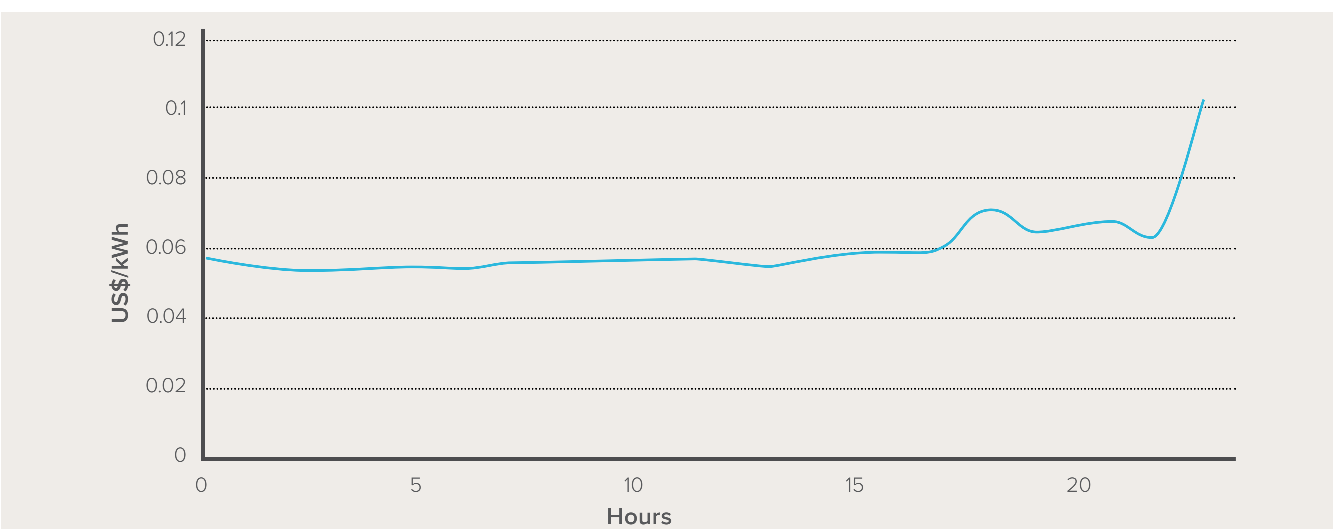


EXHIBIT I2

DAILY CFE PRICE PROFILE USED IN CPP DISPATCH MODELING



APPENDIX J: INITIAL TRANSPORTATION OPTION OVERVIEW

The CPP stakeholders indicated an interest in improving the transportation sector in a wholistic manner. In order to help address some of the key questions regarding the transportation sector, this overview was prepared to outline some of the key characteristics of the current transportation situation in Belize and present opportunities for improvement.

The team identified that Belize has an opportunity to transition its transportation system to one that addresses access, accommodates the least cost for customers, promotes sustainable economic development, and increases the security of energy supply. Currently, ground transportation accounts for the largest consumption of energy in the transportation sector in Belize and presents the largest opportunity for decarbonization in this sector.[x]

As it stands, Belize's ground transportation sector is growing, depends on fossil fuels, and is expensive for Belizeans. Personal vehicles will be the fastest-growing vehicle type in Belize, projected to grow at a rate of 4.25 percent per year until 2035. The dependence on fossil fuels in the industry negatively impacts the country's ability to reduce greenhouse gas emissions. The high tax on fuel (43 percent in 2016) and high import tax (up to 67 percent for a 6-cylinder personal vehicle) make transportation expensive for both private vehicle owners and public transportation users. Although high fuel taxes decrease total demand for fuel, the revenue from fuel taxes makes up about 10 percent of the government's revenue.

There are many viable options for reducing the ground transportation sector's dependence on fossil fuels. Two potential opportunities include: (1) an electric bus fleet, and (2) a compressed natural gas bus fleet. Both projects would serve as a model for green transportation deployment while also reducing the fleet's operating cost, dependence on imported fossil fuels, and environmental impact. Promoting electric vehicles through the deployment of electric buses has the added benefit of providing a revenue stream for BEL, while also using the transportation sector to facilitate electricity sector transition (through grid balancing). An electric bus saves 93 percent in fuel cost and 81 percent in emissions compared to a typical bus used in Belize today. Electric buses require a high up-front cost to purchase the vehicles, typically carry higher first costs for customers, and require a charging infrastructure to provide reliable long-distance travel. The CNG bus option, on the other hand, comes with high up-front costs for infrastructure to produce and distribute CNG. A transition to CNG vehicles would, however, stimulate a new local industry while also reducing fossil fuel imports to Belize. In the short term, Belize should identify a pilot project that is able to both reduce the dependence on fossil fuels while also providing affordable transportation options for Belizeans.

CURRENT SITUATION

In 2010, the main consumer of energy in Belize was the transport sector (47 percent of total energy consumption) followed by the industrial sector (27 percent of total energy consumption).[50] Within the transportation sector, the biggest consumption of energy by BTU came from the consumption of gasoline—accounting for 47 percent of all transportation consumption—the others were diesel for 37 percent, and kerosene (primarily used as aviation fuel), crude oil, and LPG for the remaining 16 percent.[51] The large consumption of gasoline and diesel is mostly the result of Belize's ground transportation. Given the relative importance of

[x] Assuming that gasoline is used only for ground transportation.

ground transportation in Belize and the limited scope of our project, we will be limiting the analysis of this memo to ground transportation, a growing fossil fuel-dependent and expensive sector in Belize.

PROJECTED GROWTH

The most recent accounting of vehicles in Belize was completed in 2007. More recently, studies analyzing the relationship between the country's vehicle fleet and its GDP help us estimate the size of the current fleet and predict how the number of vehicles will change over time. A study by Egis-Transconsult found an elasticity ratio between the number of vehicles and GDP of 1.5 for all vehicles in the country. Stated another way, a 1 percent increase in GDP causes a 1.5 percent increase in the number of vehicles. The relationship between vehicle number and GDP is shown in Exhibit J1. An analysis of private vehicle ownership shows an elasticity ratio of 1.7, illustrating an even faster increase of private vehicles as GDP grows. On the other hand, public transport vehicles have an elasticity of 0.5, suggesting a slower increase in public transportation vehicles compared to the country's GDP growth.[52]

Given the country's historical and projected GDP and vehicle growth rates, total vehicles in the country are expected to increase at a rate of 3.75 percent per year (as shown in Exhibit J2), and personal vehicles are expected to increase at a rate of 4.25 percent per year until 2035. If this growth rate of personal vehicles continues, the number of personal vehicles in the country would more than double by 2035.

Although this study provides a good prediction of long-term growth in vehicle ownership, historical records show that the actual number may be much higher. Based on the most recent vehicle statistics available in Belize, from 2001 to 2007, imports of new and used vehicles increased by 51 percent. Within this time period, the numbers of almost every type of vehicle grew dramatically, as seen in

EXHIBIT J1

RELATIONSHIP BETWEEN VEHICLE FLEET AND GDP

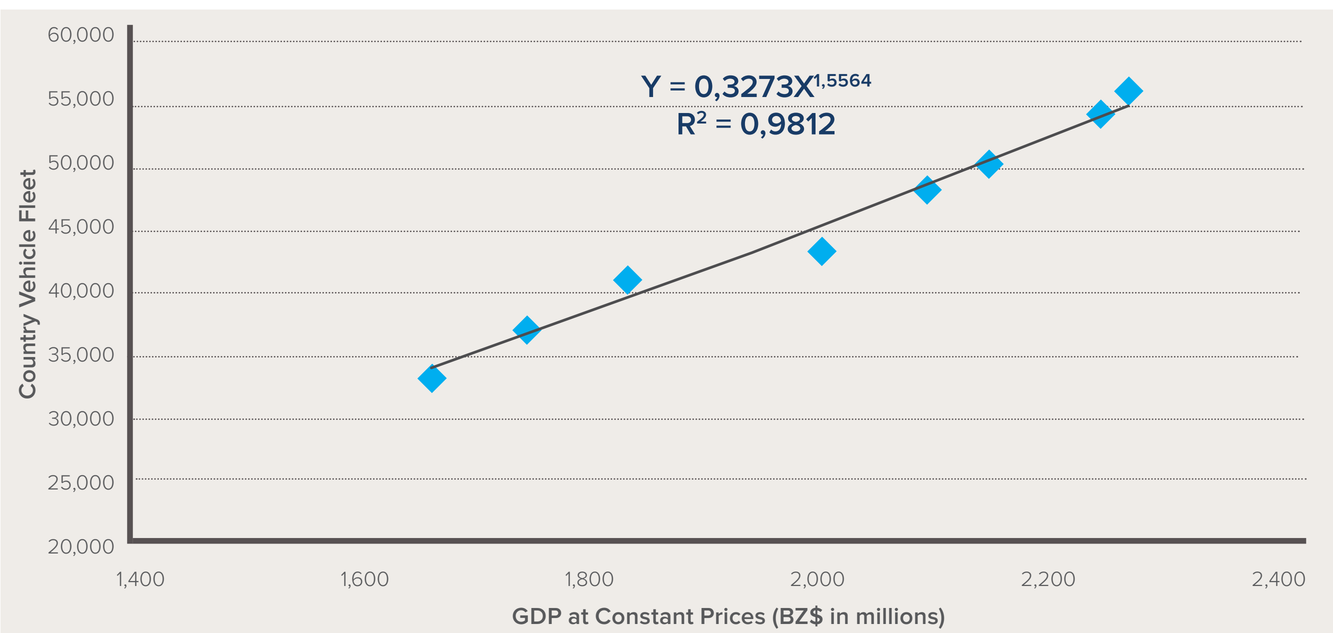


EXHIBIT J2

PROJECTED INCREASE IN THE NUMBER OF LICENSED VEHICLES IN BELIZE

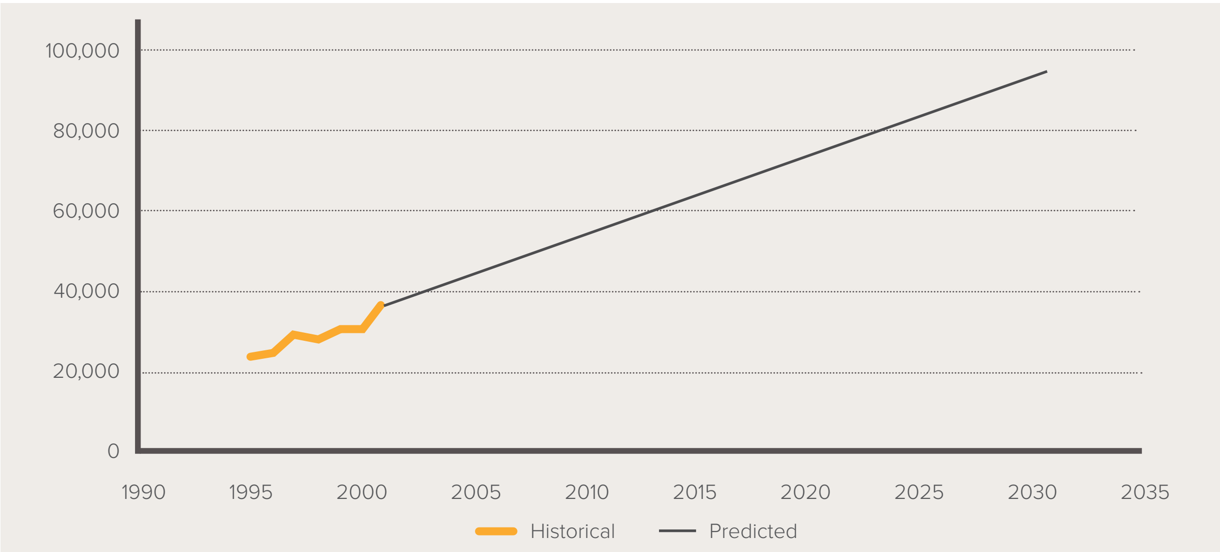


EXHIBIT J3

NUMBER OF VEHICLES IMPORTED, BY TYPE, BETWEEN 1995–2007

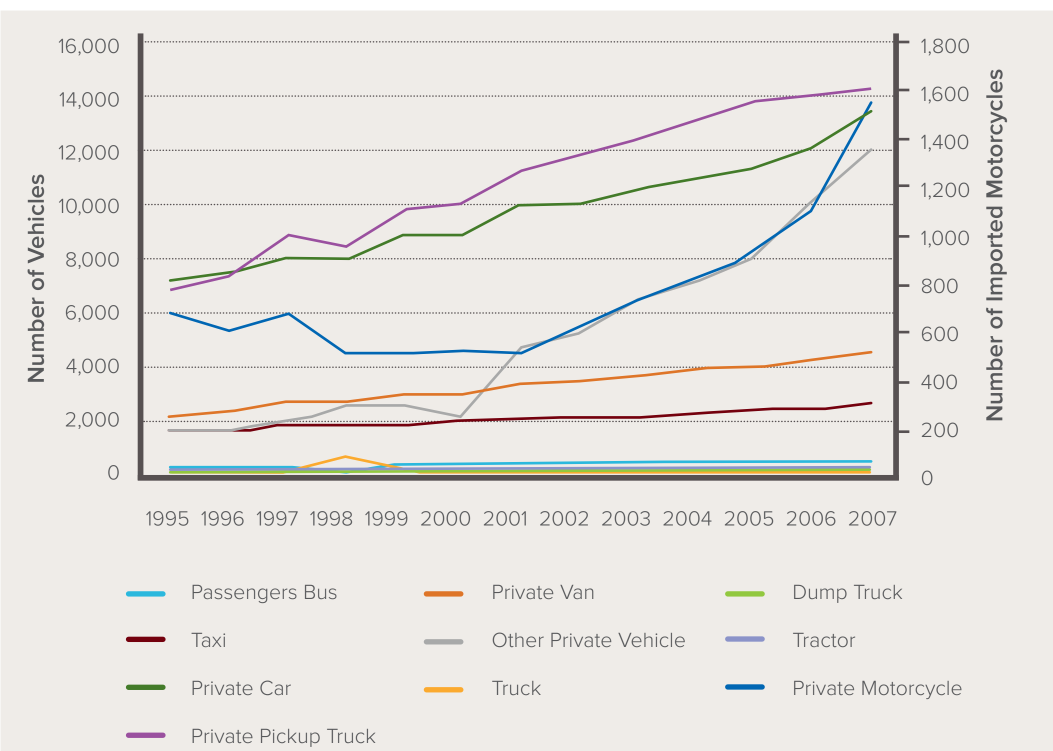


Exhibit J3. Motorcycles saw the largest percentage increase in purchases, growing 198 percent during that time period.[53]

This rapid increase in personal vehicles may strain Belize's transportation infrastructure, increase traffic congestion, and contribute to local air pollution. Furthermore, the increase in personal vehicles without a shift away from internal combustion engines would increase the country's dependence on fossil fuels and increase its greenhouse gas emissions (GHG). In the year 2000, Belize's transportation sector released 428,900 tons of CO_2, of which 330,550 tons of CO_2 corresponded to ground transportation.[54]

DEPENDENCE ON FOSSIL FUELS

Currently, 100 percent of the fuels used in the transportation sector in Belize are imported.[55] The dependence on fossil fuels represents a significant economic risk for Belize, since all of the country's refined oil products used for transportation come from Venezuela under the Petrocaribe Agreement.[56] Given the political instability of Venezuela, the dependence on fossil fuels from Venezuela represents a potentially destabilizing force to the transportation sector.

In addition to price instability, the dependence on imported fuel in the transportation sector strains the country's ability to regulate its currency. Since 1976, Belize has pegged its exchange rate to the US dollar at a rate of BZ$2.00 to US$1.00. In order to maintain this exchange rate, the IMF Country Report of 2008 recommended that the country target having monetary reserves equivalent to three months of imports.[57] Currently, refined petroleum imports represent 12 percent of the total imports of Belize,[58] increasing the amount of required monetary reserves.

Belize has already set objectives to reduce the amount of imported fossil fuels. The Ministry of Energy, Science & Technology, and Public Utilities, for example, set a national objective to "reduce the country's dependence on imported fuels by 50 percent by 2020, from one million barrels to one-half million barrels by increasing the production of modern energy carriers from domestic renewable energy resources, coupled with improving energy efficiency and conservation. The ultimate goal is for Belize to become a net exporter of biofuels well before 2033." Despite the country's goal, in 2016, Belize imported 3.4 million barrels of refined oil products. This means that instead of reducing fuel imports by half, Belize has increased its import of refined oil by three times.

HIGH COSTS

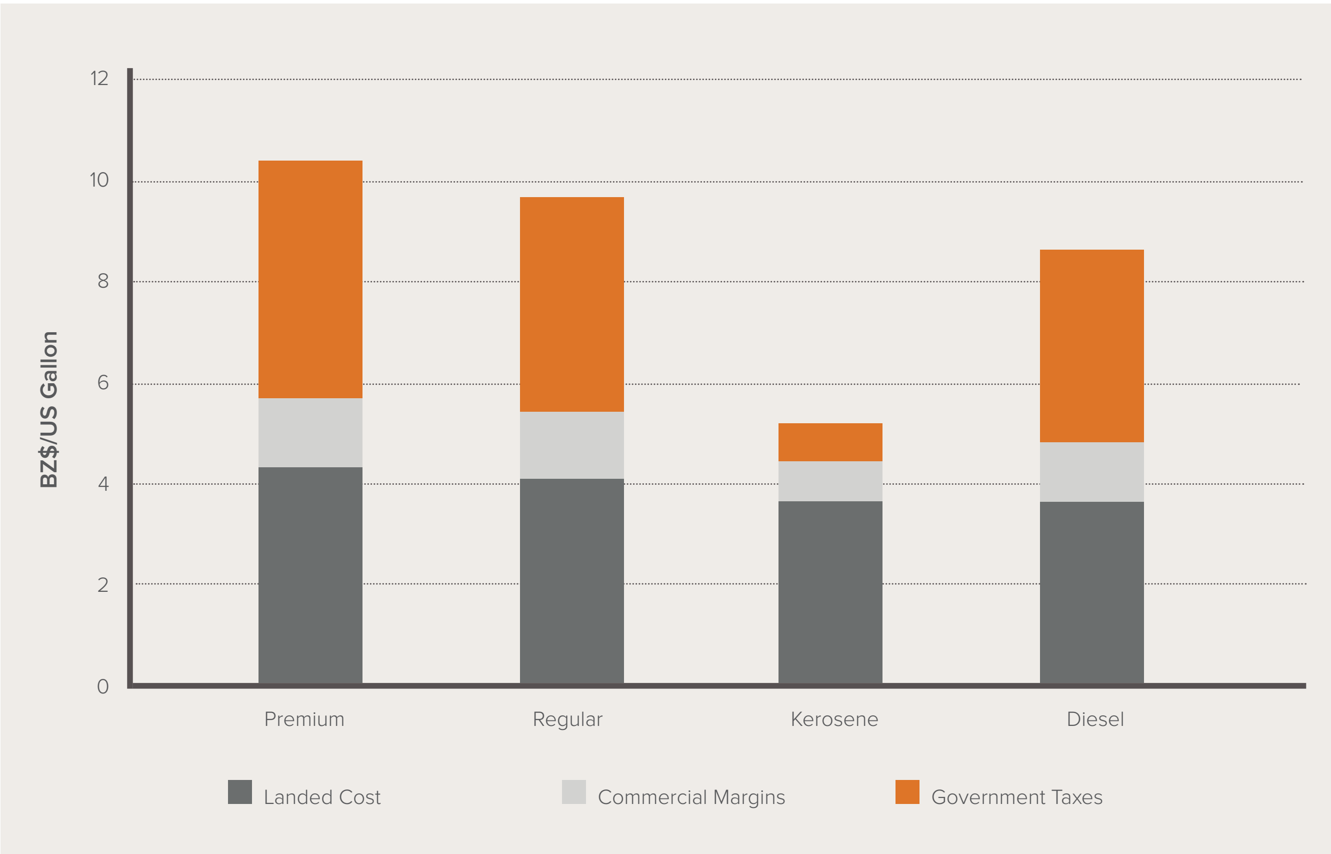
Owning a car in Belize is prohibitively expensive for most Belizean households. A government worker, for example, who lives in Belize City and commutes to Belmopan daily on the bus, would be spending BZ$68 a week. On an average annual salary of about BZ$21,900 a year, transportation to work alone would soak up about 15 percent of the worker's pre-tax salary just going to and from work. The same worker, were she to own a 2007 Honda Civic and drive an average of 54 miles a day, would spend BZ$108 each week on gasoline alone.

The high cost of car ownership is largely a product of the high import tax on vehicles and high fuel costs. Since 2000, the import tax on vehicles has been charged based on the type of vehicle and size. Cars are considered luxury items in Belize and are taxed at higher rates than other types of vehicles. A six-cylinder car, for example, is taxed at 76 percent, whereas a six-cylinder truck is taxed at 47 percent of the customs value (cost, insurance, freight-CIF).[59]

Refined petroleum products in Belize are heavily taxed to the consumer, as shown in Exhibit J4. The high proportion of taxes is used to buffer against the international fluctuations in the oil market.[60] Despite the relatively stable fuel prices, the high tax on fuel represents a large economic markup for a consumer. For example, in 2016, the average percentage of the retail price for regular gasoline that was government taxes was 46 percent. Although fossil fuel imports

EXHIBIT J4

COST TO THE CONSUMER OF REFINED PETROLEUM PRODUCTS IN BELIZE (JULY 2016)[63]



pose challenges to the environment and currency stability and taxes on those imports increase total cost of transit, taxes on refined oil products make up a significant portion of the country's revenue.[61] In the 2011–2012 fiscal year, for example, taxes and royalties from the oil sector accounted for approximately 10 percent of government revenues.[62]

Most of the public buses in Belize are retired school buses from the US that are approximately 15 to 20 years old, and generally have been driven more than 500,000 miles. About 80 percent of these vehicles are diesel buses with a high fuel consumption of about 4 mpg. Given the high cost of diesel and the low fuel efficiency for these vehicles, some companies report that 75 percent of their operational costs go toward buying fuel. Even though there are many people in Belize that depend on buses, the average occupancy of a bus is 54 percent.[64]

The government plays a regulating role for the public transportation industry even though it is privately run. The government sets the bus fares, administers licenses, and determines the bus routes. Drivers of public buses have to pay to renew their licenses every two years. This represents instability for public transport companies since there is no guarantee that they will be able to renew their license every two years, and likely discourages investments in their vehicles.

According to the latest figures released by the Statistical Institute of Belize, the price of transportation continues to rise. On average, consumer price increases for transportation surpassed the national average for consumer price increases. National consumer prices rose 1.3 percent between November 2015 and November 2016, whereas the transport index increased 9.4 percent. In particular, fuel prices rose 22.1 percent for gasoline, 18.4 percent for premium gasoline, and 25 percent for diesel, and prices for new motor vehicles were also up, rising by an average of 4.3 percent. Even public transportation users saw a 5.6 percent increase in cost in November 2016.[65]

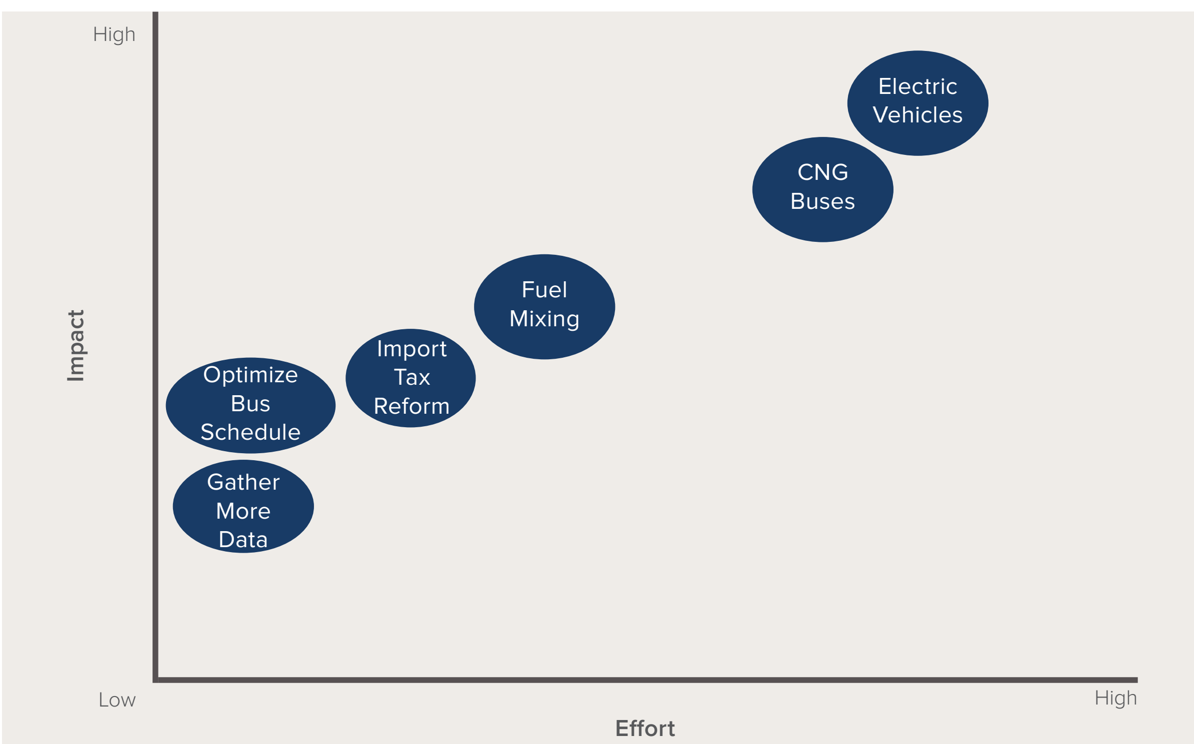
Given the high cost of importing and operating a car, it should be no surprise that nearly 65 percent of households do not own a vehicle.[66] Those that can't afford cars mainly use taxis, public minivans, or buses as their primary form of transportation. Because public transportation is such an important source of mobility, special attention should be paid to its efficacy. In summary, transportation costs are high for Belizeans, and disproportionately impact low- and middle-income residents.

OPTIONS

Given that the vehicle fleet is currently growing, dependent on fossil fuels, and expensive, there is an opportunity for Belize to shift its transportation system to one that addresses access, is least-cost, promotes sustainable economic development, and increases the security of energy supply. Although there are many options for improving the transportation sector, select options are described here, and Exhibit J5 shows the relative potential impact of each, along with the effort required to implement it. Two options, transitions to electric vehicles and to compressed natural gas

EXHIBIT J5

SELECT OPTIONS, THEIR RELATIVE IMPACT, AND THE RELATIVE EFFORT REQUIRED TO IMPLEMENT THEM



vehicles, are explored in more detail since they have the highest potential for impact in the transportation sector toward the shared CPP goals. This list of options is not exhaustive, but is intended to provide an early overview of several potential options to consider.

IMPROVING THE CURRENT PUBLIC TRANSPORTATION FLEET

Opportunities for improving existing public transportation include:

- **Improved maintenance of bus fleets:** Increased frequency of maintenance reduces buses' operational cost in the long run, and may lead to higher mileage and cleaner exhaust.

- **Improved bus scheduling:** Optimized routes and schedules can increase bus ridership.

- **Collection of better data:** GPS trackers added to buses would be a low-cost way to establish some basic data on public transit, and allow more-informed decision-making.

IMPORT TAX REFORM

Import taxes for cars could be modified to incentivize the importation of cleaner, newer, and smaller vehicles. Belize has the potential to improve fuel efficiency to 20 miles per gallon if 25 percent of its gasoline-powered vehicle fleet is replaced with smaller vehicles. This could lead to a reduction in total gasoline imports of approximately 3.8 percent, saving BZ$4.2 million. Replacing 25 percent of gasoline-powered vehicles with hybrid-electric vehicles would lead to a reduction in gasoline imports of 5.34 percent, saving BZ$6 million annually.[67] Furthermore, Belize could restructure vehicle import taxes to account for a vehicle's age and the number of miles on it.

BIOFUEL MIXING

Based on an Organization of American States study, cellulosic ethanol production has the potential to meet and even surpass total gasoline demand.[68] Belize could begin to transition its vehicles toward using biofuels by gradually mixing ethanol into the vehicle fuel supply. In most cases, an E10 fuel blend (10 percent ethanol blended with gasoline) is deemed viable without the need for retrofits of vehicles and without losing engine or vehicle warranties. More ambitious targets could be set for E20 or E30; however, further detailed analysis is required to determine ethanol's technical potential in Belize. A biofuel fuel mix would decrease the amount of gasoline Belize would have to import while galvanizing

EXHIBIT J6

EXAMPLES OF CNG AT A FUELING STATION (LEFT) AND A CNG BUS AT DENVER INTERNATIONAL AIRPORT (RIGHT)

the local biofuel market. To use cellulosic ethanol for transportation, Belizeans could ferment agricultural, forestry, and municipal wastes as feedstocks for conversion to ethanol, as well as use dedicated feedstocks that do not compete with food products.

COMPRESSED NATURAL GAS

Compressed natural gas vehicles are becoming increasingly popular alternatives to diesel vehicles around the world. CNG vehicles are a proven technology that have been successful in the United States, especially as buses and trucks.[69] Although CNG vehicles are more expensive than comparable diesel vehicles, the low price of CNG compared to diesel makes for relatively short payback periods (a little over three years)[70] in the United States. It is difficult to estimate the potential cost savings from a CNG vehicle at this stage of the analysis since it is highly dependent on the source of CNG, fueling station arrangement, and number of fleet vehicles. Yet, we can look to some case studies for an overall idea of how much a CNG bus fleet can save. Denver Airport's bus fleet, for example, was changed to CNG in 1998. Every year, they save about US$136,458 in fuel costs per bus leading to a simple payback period of seven years.[71] Given the high cost of diesel and the desire to reduce fossil fuel imports, Belize could benefit from the conversion of part of its vehicle fleet to CNG technology. However, it is difficult to predict the cost of producing CNG locally without an assessment of the potential for Belize to produce its own CNG.

Total wells-to-wheels GHG emissions (g CO_2e/mi) for modern buses are generally slightly higher from CNG buses than from diesel buses, due primarily to the upstream impact of methane emissions from natural gas production and processing. The increase in total annual GHG emissions from operating new CNG buses instead of new diesel buses could be as high as 13.3 tons CO_2e per bus.[72] However, if CNG is coming from a local source that would otherwise simply release methane to the air, a CNG bus could lead to significant emissions savings. Furthermore, CNG buses will always have particulate matter and toxic emission benefits over diesel buses because natural gas combustion inherently produces lower levels of these emissions.[73]

Perhaps the largest possible benefit from the development of CNG bus technology is the development of a CNG industry within Belize, potentially large enough for exports. The CNG used to power these buses could come from landfill gas or other agricultural waste products already available in the country. A successful CNG bus pilot could pave the way for a transportation industry primarily powered by CNG. A transportation sector primarily run on local CNG could provide new jobs to generate the fuel, and would allow gas station workers a new avenue of

EXHIBIT J7

EXAMPLES OF AN ELECTRIC BUS (LEFT), AN ELECTRIC CAR (CENTER), AND AN ELECTRIC CHARGING STATION (RIGHT)

income. However, in case producing CNG locally is not economically feasible, Belize could import liquefied natural gas and gasify it in country. Because public transit is such a critical part of the country's mobility system, a pilot project for CNG buses could be a good starting point for the development of this industry.

ELECTRIC VEHICLES

Electric vehicles can be used as a tool to reduce emissions relating to transportation, cost relating to transportation, and Belize's dependence on fossil fuels. EVs can also help facilitate the grid's transition to renewables by providing a variety of grid services. The following are potential pilot projects for EV development in Belize:

- **BEL vehicle fleet:** A utility fleet would be a good initial fleet to target; utilities have an incentive to learn more about the technology since its success would affect their future operations.

- **Private resort:** An all-inclusive resort would be a good fleet to target because it has vehicles that travel long distances. Furthermore, these resorts have an incentive to convert their cars for publicity reasons, and have available capital to invest in EVs.

- **Government fleet:** The government fleet may be good to start with because it would allow the government to lead by example. Furthermore, a successful experience with EVs may convince the government to put favorable policies in place for EVs.

- **Golf cart electrification:** The electrification of golf carts in Belize's small islands would improve the country's sustainability image. The islands that have golf carts likely have the capital to invest in a technology change. This initiative could be paired with a pilot battery-recycling project to ensure the safe disposal of electric golf cart batteries.

- **Public buses:** A public transportation fleet would be a good candidate for electrification given its current high operating costs, the high mileage of the vehicles, and the ability to control charging.

Given the significant opportunity available for **electrifying public buses**, we focused on this option. The low fuel-efficiency of the existing buses and the high diesel prices in Belize lead to very high operational costs. To explore the operational differences between the current diesel buses and electric buses that might be switched to, the team investigated the operational cost of a bus route between Belize City and Santa Elena, shown in Exhibit J8. This route is approximately 84 miles one-way on generally flat terrain. Given an average range for an electric vehicle of 120 miles, an electric bus could, at most, run two round trips per day, given enough time to recharge before each leg of the journey. For every round trip between Belize City and Santa Elena, it would cost BZ$52 to fuel the electric bus at today's electricity prices. With current diesel prices, the electric bus's fuel price is **93 percent less expensive** than the diesel alternative. In a single day, that would lead to a savings of BZ$686 in fuel. Every year of operation would lead to a savings of over BZ$250,000.[xi]

Despite the significant savings in operational costs, the up-front cost of an electric bus is a major hurdle to widespread electric bus adoption. A used diesel bus can be purchased from the US and imported to Belize at less than BZ$20,000. A new electric bus and its equipment, on the other hand, can generally cost between BZ$220,000 and BZ$1.5 million.[74] Although the large capital investment will be prohibitive for

[xi] Not accounting for days the vehicle is out of service, or for changes in prices of diesel or electricity.

EXHIBIT J8

SAMPLE BUS ROUTE FOR COMPARISON OF DIESEL AND ELECTRIC BUSES

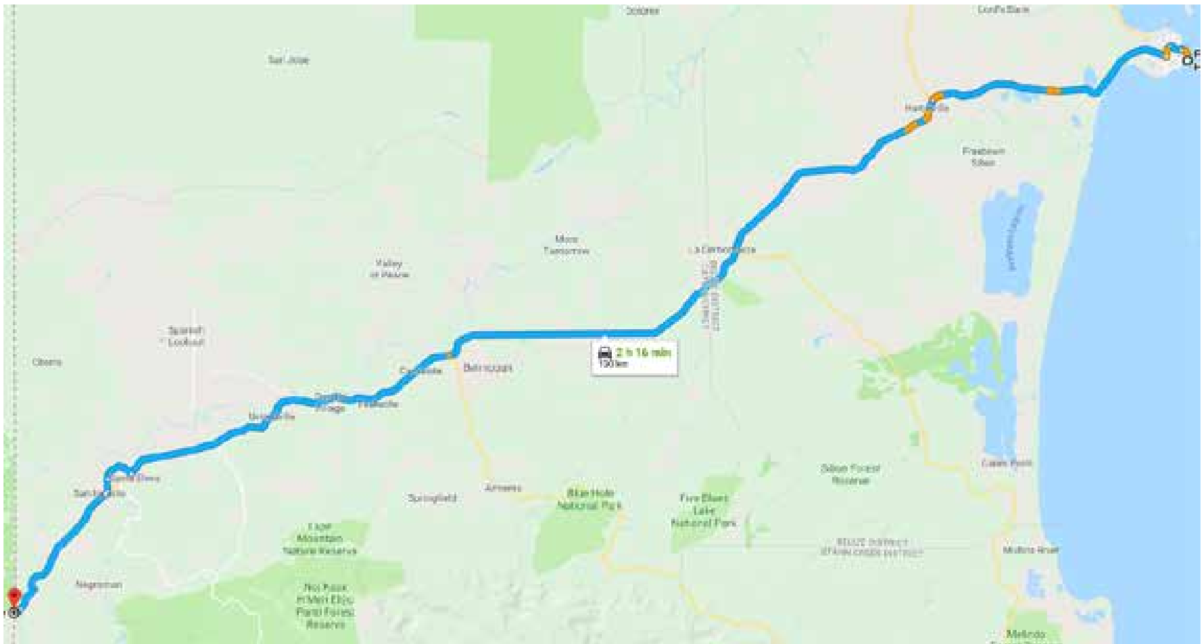
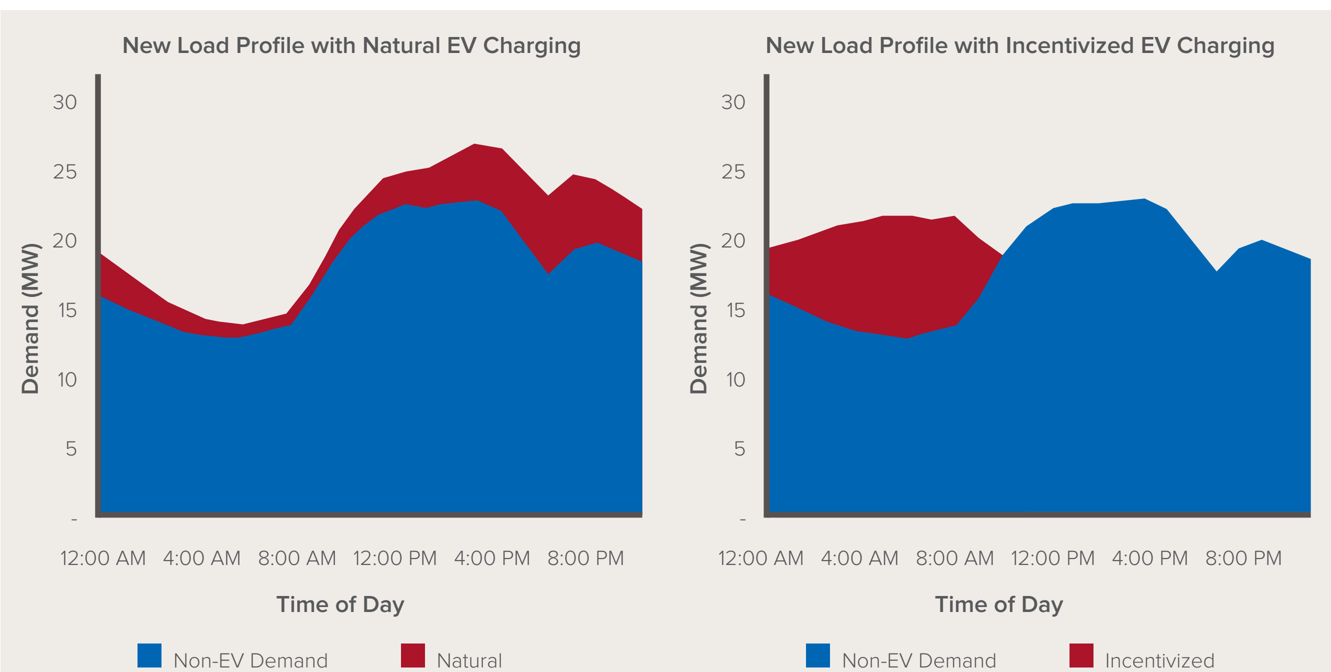


EXHIBIT J9

TWO POTENTIAL IMPACTS OF ELECTRIC VEHICLE CHARGING ON A SMALL EXAMPLE GRID



some, the fuel savings can lead to a payback in two to six years. Even for someone with the capital necessary to buy an electric vehicle, regulatory changes will have to be made to make an electric bus fleet feasible. The license renewal process for public buses, for example, will have to be extended for electric vehicles.

The increased load from EV charging is not only an added revenue stream for BEL, but can also be used to manage a highly renewable grid. The charging load of electric buses, for example, can be used as a way to soak up renewables on the grid that would otherwise be curtailed. However, the utilization of renewable energy depends on whether EV charging is natural or incentivized.

Exhibit J9 shows the change in load profile for a small example grid on a day when EV charging is added to the demand of electricity. The EV demand, shown in red, represents the hypothetical electricity demand of 5,300 personal EVs, each driving 20 miles a day. The area in blue represents the existing grid load. Graph 1 models the charging pattern in a scenario where there are no incentives in place to direct EV charging. Graph 2 models a scenario where all the EV charging is optimized to eliminate curtailed renewable generation.

Along with their operational cost reductions and grid benefits, EVs could reduce the emissions related to transportation significantly. Even when compared to newer and cleaner diesel buses, an electric bus on the current Belize electricity grid mix emits **81 percent less g/CO_2e per yea**r. These emissions savings should only improve as more renewables are added to the grid.

SUMMARY: COMPRESSED NATURAL GAS AND ELECTRIC VEHICLES

Exhibit J11 summarizes the opportunities available from EVs and CNG vehicles in relation to the shared CPP goals. EVs provide an added revenue stream for BEL that could help minimize the impact on their business model of distributed generation and energy efficiency, provide the best environmental impact, and also bring an added benefit of utilizing the transportation sector to facilitate electricity sector transition. EVs include an expensive up-front cost, while the CNG option comes with high up-front costs for infrastructure to produce and distribute CNG. A transition to CNG vehicles would, however, stimulate a new local industry while also reducing fossil fuel imports to Belize.

EXHIBIT J10

EXAMPLES OF ELECTRIC (LEFT) AND CNG (RIGHT) BUSES

EXHIBIT J11

SUMMARY OF OPPORTUNITIES AND IMPACT ON CPP GOALS FOR BUS PILOTS

	ACCESS	LEAST COST	SUSTAINABLE ECONOMIC DEVELOPMENT	SECURE ENERGY SUPPLY
ELECTRIC BUS PROJECT	Reduce the operational cost of bus	93% reduction of fuel cost for an electric bus	- Reduction in emissions by 81% - New high-tech industry - Support management of a highly renewable electrical grid - Decrease in fossil fuel imports liberates availability of foreign currency	- 20 electric buses could reduce total diesel use by 1% - Additional load increases BEL's revenue 30% in an optimistic scenario - Provide grid stabilization
COMPRESSED NATURAL GAS BUS PROJECT	Reduce the operational cost of bus	Reduction of cost dedicated to fuel over the lifetime of the vehicle for a bus	- New jobs from development of new industry - Reduction in emissions from transportation - Decrease in fossil fuel imports liberates availability of foreign currency	Reduction of imports if local resources are used

EN

ENDNOTES

ENDNOTES

[1] Arlet, Jean. *Electricity Tariffs, Power Outages and Firm Performance: A Comparative Analysis*. The World Bank. 2017. http://pubdocs.worldbank.org/en/444681490076354657/Electricity-Tariffs-Power-Outages-and-Firm-Performance.pdf

[2] Navarrete, Manuel. *Estadísticas del subsector eléctrico de los países del Sistema de la Integración Centroamericana (SICA)*. CEPAL. 2016. https://repositorio.cepal.org/bitstream/handle/11362/42720/1/S1701275_es.pdf

[3] *CARICOM Countries Renewable Energy/Energy Efficiency Data Collection Survey Final Report*. CARICOM. 2015. http://open_jicareport.jica.go.jp/pdf/12185096.pdf

[4] Esquival, Maricarmen et al. *Vulnerability for Climate Change of Hydroelectric Production Systems in Central America and their Adaptation Options*. OLADE. 2016. http://biblioteca.olade.org/opac-tmpl/Documentos/cg00341.pdf

[5] *Second National Communication to the United Nations Framework Convention on Climate Change*. Government of Belize. 2011. http://unfccc.int/resource/docs/natc/blznc2.pdf

[6] *The Power System in the Storm: The Call for Energy Resilience and Climate Adaptation in Belize*. World Bank. 2016.

[7] Rodriguez, Enrique et. al. *The Energy Sector in Belize*. IADB. 2014. https://publications.iadb.org/bitstream/handle/11319/6742/The-Energy-Sector-in-Belize.pdf?sequence=1

[8] World Bank, 2016.

[9] Inter-American Development Bank, 2014.

[10] *2017 U.S. Energy and Employment Report (USEER)*. US Department of Energy. 2018. https://www.energy.gov/sites/prod/files/2017/01/f34/2017%20US%20Energy%20and%20Jobs%20Report_0.pdf

[11] Dvorak, Paul. "Envision Energy 3.6 MW Two-blade Offshore Turbine." Wind Power. 2016. https://www.windpowerengineering.com/featured/envision-energy-3-6-mw-two-blade-offshore-turbine/

[12] http://www.iea.org/media/pams/belize/EnergyPolicyFramework.pdf

[13] https://www.energy.gov/sites/prod/files/WindVision_Report_final.pdf

[14] https://openei.org/doe-opendata/dataset/80043f89-ef6c-42fd-8366-f4838e046b2c/resource/ef3c1642-0b5c-4efe-afe0-aafa94e43bcf/download/camwindreport242.pdf

[15] http://www.puc.bz/index.php/publications/electricity-sector/others/87-rfpeg-2013-official-document/file

[16] http://www.smallhydroworld.org/fileadmin/user_upload/pdf/2016/Americas_Central/WSHPDR_2016_Belize.pdf

[17] http://unfccc.int/resource/docs/natc/blznc2.pdf

[18] https://publications.iadb.org/bitstream/handle/11319/6742/The-Energy-Sector-in-Belize.pdf?sequence=1

[19] https://www.iea.org/media/pams/belize/EnergyPolicyFramework.pdf

[20] Castalia Strategic Advisors, Final Report: Overcoming Barriers to Belize's RE and EE Potential (Vol.1), Inter-American Development Bank, 2014.

[21] https://unfccc.int/files/focus/ndc_registry/application/pdf/belize_ndc.pdf

[22] https://publications.iadb.org/bitstream/handle/11319/6742/The-Energy-Sector-in-Belize.pdf?sequence=1

[23] http://www.bz.undp.org/content/dam/belize/docs/UNDP%20BZ%20Publications/Belize-and-Climate-Change-The-Costs-of-Inaction.pdf

[24] Castalia Strategic Advisors, Final Report: Overcoming Barriers to Belize's RE and EE Potential (Vol.1), Inter-American Development Bank, 2014.

[25] http://unfccc.int/resource/docs/natc/blznc2.pdf

[26] Indicated tariff in the Exhibit 11 Part (3) for the period 01 January 2008–31 December 2017. Power Purchase Agreement between BEL Ltd. and BELCOGEN (February, 2007).

[27] Ministry of Natural Resources and Agriculture - Lands and Surveys (2012). Environmental Statistics for Belize.

[28] Food and Agriculture Organization of the United Nations (2017). *FAOSTAT.*

[29] USDA Global Agricultural Information Network (2014). USDA Global Agricultural Information Network, Consejo Salvadoreño de la Agroindustria Azucarera, and anecdotal information.

[30] ASR Group (2015). *Sugar Industry of Belize - Transforming Sugar Production in Belize into a Modern, Sustainable, Green Model, Contributing to Jobs, Growth and Energy Security.*

[31] Carvalho et al., (2017). *Analysis of energy consumption in three systems for collecting sugarcane straw for use in power generation.*

[32] National Renewable Energy Laboratory (2014). *Energy Initiative Transition – Energy Snapshot Belize.*

[33] Centaur Communications Corporation Ltd. (2011). *Largest Rice Producer In Belize Shuts Down His Business.*

[34] Ministry of Natural Resources and Agriculture - Lands and Surveys (2012). *Environmental Statistics for Belize.*

[35] Food and Agriculture Organization of the United Nations (2017). *Rice Market Monitoring Report.*

[36] Calvert, L. Sanint, M. Châtel and J. Izquierdo (2006). *Rice production in Latin America at critical crossroads.* FAO Regional Office for Latin America and the Caribbean (RLC), Santiago, Chile.

[37] Shekhar Das et al., (2014). *Electricity from Rice Husk: A Potential Way to Electrify Rural Bangladesh.*

[38] Marco Linders (2016). *Potential study on producible biogas and renewable energy from biomass and organic waste in Belize.* Caribbean Community Climate Change Center.

[39] MESTPU, PUC & BEL (2014). *RFPEG2013 1st Phase Bid Evaluation.*

[40] US Whole Building Design Guide - National Institute of Building Sciences (2016). Biomass for Electricity Generation. https://www.wbdg.org/resources/biomass-electricity-generation

[41] CCaricom Climate Change Centre. (2008). *Biofuels in the Caricom Region. San Salvador.*

[42] http://www.eprg.group.cam.ac.uk/wp-content/uploads/2016/10/1626-Text.pdf

[43] Newspaper – *La Estrella de Panamá* (23, December, 2016). First natural gas plant in Central America, with 25% progress.

[44] Mexico Energy Secretariat (2015). Electricity Sector Forecast 2015–2029.

[45] FTI consulting (2017). *Outlook for Natural Gas in Mexico*.

[46] https://www.theodora.com/pipelines/mexico_pipelines.html

[47] Energy Secretariat of Mexico (2016). *Five-Year Plan for the Expansion of the National Integrated Natural Gas Transportation and Storage System 2015-2019*.

[48] http://www.beg.utexas.edu/energyecon/accra_july_07_workshop/Accra%20workshop%20Jul07_Topic%201.pdf

[49] Energy and Environmental Economics Inc. (2014). *Capital Cost Review of Power Generation Technologies - Recommendations for WECC's 10- and 20-Year Studies*.

[50] IDB – The Energy Sector in Belize; 2012.

[51] Government of Belize – National Energy Policy Framework; 2012.

[52] Egis-Transconsult – Travel Demand Model; 2017.

[53] Organization of American States, Department of Sustainable Development, *Toward a National Energy Policy Assessment of the Energy Sector in Belize*, 2011.

[54] Ministry of Public Service, Energy, and Public Utilities, *Capacity Development in Renewable Energy Policy and Mapping in Belize*, 2016.

[55] Ibid.

[56] Inter-American Development Bank, *The Energy Sector in Belize*, 2014.

[57] International Monetary Fund, *Belize: 2008 Article IV Consultation-Staff Report and Public Information Notice on the Executive Board Discussion by the Executive Director*, 2008.

[58] Egis-Transconsult, *Preparation of a Comprehensive National Transportation Master Plan for Belize-Baseline Analysis Report*.

[59] Belize Customs & Excise Tax Department; website accessed September 2017.

[60] Ministry of Energy, Science & Technology, and Public Utilities, *Strategic Plan, 2012-2017*.

[61] Calculated using Ministry of Finance historical fuel data document; 2017.

[62] Inter-American Development Bank, *The Energy Sector in Belize*, 2014.

[63] Ministry of Finance, Effective prices; 13 July 2016.

[64] Egis-Transconsult, *Preparation of a Comprehensive National Transportation Master Plan for Belize*, 2017.

[65] Ibid.

[66] Ministry of Public Service, Energy, and Public Utilities, *Capacity Development in Renewable Energy Policy and Mapping in Belize*, 2016.

[67] Ministry of Public Service, Energy, and Public Utilities, *Capacity Development in Renewable Energy Policy and Mapping in Belize*, 2016.

[68] Organization of American States, *Feasibility Study on the Cellulosic Ethanol Market Potential in Belize*, 2009.

[69] US Department of Energy Office of Energy Efficiency and Renewable Energy, *National Gas Buses: Separating Myth from Fact*, 2000.

[70] Ibid.

[71] Colorado Energy Office, *Experience with Compressed Natural Gas in Colorado Vehicle Fleet*s, 2012.

[72] M.J. Bradley & Associates LLC, *Comparison of Modern CNG, Diesel, and Diesel Hybrid-Electric Transit Buses: Efficiency & Environmental Performance*, 2013.

[73] US Department of Energy Office of Energy Efficiency and Renewable Energy, *Natural Gas Buses: Separating Myth from Fact,* 2000.

[74] Judah Aber, *Electric Bus Analysis for New York City Transit*, New York City Transit and Columbia University, 2016.

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