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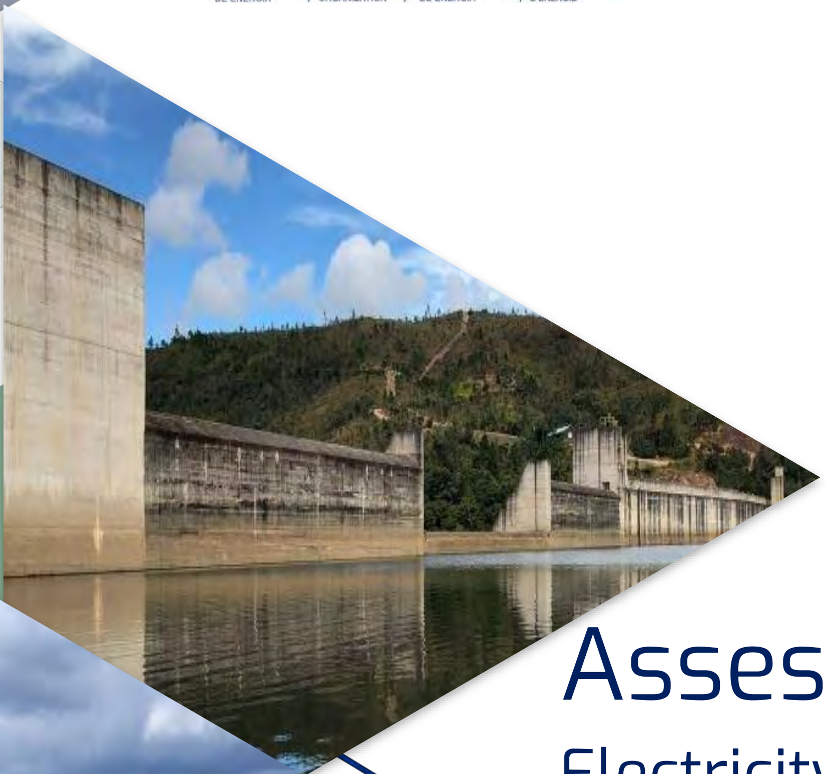

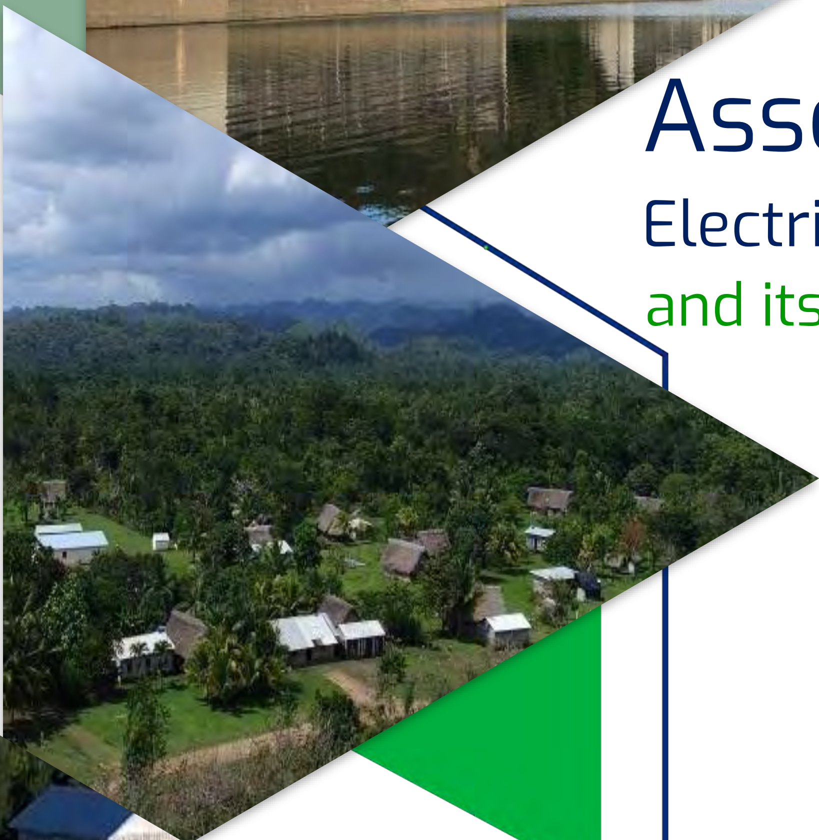

Assessment of the Electricity Generation System and its Investment Alternatives of Belize

Electricidad

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The photographs were made by Gabriel Castellanos and are published with his authorization. From top to bottom: (i) Chalillo Power Plant Dam, Macal River, San Ignacio, 7 MW, (ii) Golden Stream, Hellgate & Indina Creek, Orange Walk, (iii) La Gracia Project, Cayo District, PV rural electrification project in Belize.

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Table of Contents

Executive Summary

In order to develop a generation expansion plan for Belize a reference scenario was devised on the following premises:

- Hydroelectric and Biomass projects and their associated technologies have already been identified, thus no additional projects of these types are being considered;
- A strong AC interconnection with CFE México that is currently used to supply the Belize system with significant amounts of imported energy, also provides the capability to export excess renewable energy and will also serve as system backup and second order regulation when intermittent power is deployed, thus playing the role of energy storage;
- The additional future expansion of the generation system will be based on certain standard generation technologies for the following energy sources:
- Renewables: Wind and Solar energy
- Oil Fired Backup Thermal Generation to provide the necessary firm power that the combined system will require.

Bearing this in mind, the technologies being used as standard "building blocks" for the present Generation Expansion Plan are based on fully proven, state of the art solutions, as per the following:

- Solar: Photovoltaic (PV) panels.
- Wind: Size of windmill on the higher end of the commercially available models (~3 MW).
- Conventional Backup Thermal using fuels already available in the country:
  - Reciprocating internal combustion engines (RICE) or piston engines, running on heavy fuel oil (HFO) and/or diesel oil (DO). Two different models were considered: a larger one, of around 8 MW capacity, and a smaller one, of about 2 MW capacity, the latter in two different configurations, fixed and mobile, as per the following:
    - "Large" Size: ~8 MW dual fuel diesel engine, running on heavy fuel oil (HFO) with diesel oil (DO) as backup fuel, similar to the Wärtsilä 18V32 model;
    - "Small" Size: ~2 MW diesel engine, running on DO only, similar to the Caterpillar 3516B or Cummins KTA50-G3 models;
      - Fixed
      - Mobile, similar to the Caterpillar CAT XQ2000 or Cummins C1250 D6 (see 6.3.1 below for more detail)
  - Gas turbines (GT) in open cycle configuration, running on DO, based on the aeroderivative type and with a capacity of 25 - 35 MW (similar to the GE LM2500 in Westlake).

PV Solar

As it is explained in the following chapters, PV systems are especially well suited for small sized systems and will thus be used in this study as the reference technology for the utilization of solar energy in the Belize Generation Expansion Plan. Regarding investment cost, a reference value of about 2500 USD/kWp (kWp = kW of peak capacity) for utility-scale PV systems without storage can be considered reasonable.

Wind Energy

State of the art windmills currently stand in the 2.5 to 4 MW range and feature three blades, horizontal axis and rotor diameters of more than 120 meters, utilizing doubly fed asynchronous generators. For these machines, a specific investment cost of 1500 USD/kW installed capacity can reasonably be expected.

Conventional Backup Thermal Generation

Regarding environmental impact and assuming SO2 emissions are kept under control by using low sulphur fuels in all cases, GTs present significantly lower NOx and Particulate Matter (PM) emissions than RICE. However, low load factors usually observed in backup thermal generation operating in systems with a broad renewable base allow for a certain relaxation of the environmental requirements –for instance with respect to the International Finance Corporation (World Bank Group) Environmental, Health, and Safety Guidelines for Thermal Power Plants, henceforth the “WB’s EHS Guidelines” or simply “WB’s guidelines” (see 6.2.3 below)– in favour of cost efficiency without significantly compromising the environment, thus reducing the disadvantage of RICE before GTs in this respect.

By way of summary, and in general terms, the main advantages of GTs over RICE are the significantly lower variable O&M costs, as well as lower contaminating emissions, specially NOx and PM, while on the other hand the advantages of RICE over GTs are their higher efficiencies (lower heat rates) and fuel flexibility which in combination result in lower fuel costs. Regarding specific investment cost, there is not a significant difference between GTs and large sized RICE in the smaller range of capacities, though a slight advantage in favor of GTs can normally be observed.

The following table presents the relevant features of these backup thermal technologies:

Basic Generation Modules, Thermal Generation

Technology	Specific Investment Cost (USD/kW)	Fuel	Heat Rate, LHV* (MJ/MWh)	Fixed O&M Cost (USD/yr)	Variable O&M Cost (USD/MWh)	Emissions requirements (WB's Guidelines)	
						NO_x (mg/Nm^3)	PM (mg/Nm^3)
GT	1000	DO	10000	400000	5.00	150	50
RICE							
Large	1100	HFO/DO	7700	400000	10.00	1460	50
Small (fixed)	1200	DO	9200	170000	12.00	1460	50
Small (mobile)	1300	DO	9200	170000	13.00	1460	50

**LHV = Low Heat Value of fuel*

Sample calculations to evaluate the variable fuel cost of generation from the fuel price and the heat rate is presented below.

Geothermal

Due to the lack of clearly identifiable geothermal resources in Belize, no significant potential for any Enhanced Geothermal System (EGS) was analyzed in the present study. However, if future developments were to be considered on this area, it seems reasonable to assume that they would be implemented by means of small sized Binary Cycles based on the Organic Rankine Cycle (ORC) concept.

Relevant drivers in the selection of proposed technologies for the Belize Generation Expansion Plan:

- Fuels, Infrastructure and Logistics: Petroleum-derived liquid fuels currently used in the country: Diesel (DO) and Heavy Fuel Oil (HFO)
- Cost: In this respect, the size of the individual piece of equipment becomes significant in the determination of both investment and operational costs:
  - Investment costs: usually affected by economies of scale.
  - Fuel costs: result from the thermodynamic efficiency of the equipment and the fuel price; should account for exhaust gas treatment variable costs when these mitigation measures are required.
  - O&M costs:
    - Variable: includes lubricants, other consumables, spares;
    - Fixed: personnel, security, "balance of plant" power (controls, communications, lighting, etc.)
  - Electric system operation costs: related to ancillary services that can be provided by the power plant, such as frequency and voltage regulation, short term reserve, system stability support, etc.
- Environmental Requirements: Local regulations are to be observed, unless funding from international development institutions is sought, in which case more stringent specific requirements from these institutions may have to be followed. Such is the case with the International Finance Corporation (IFC) of the World Bank Group (WB), that will be discussed with more detail in 6.2.3 below.

Investment Alternatives

In order to analyze the possibilities of financing an expansion plan, it is necessary to differentiate between the power generation projects that will be carried out through PPA contracts and the expansion and improvement of the transmission and distribution network.

To finance PPA contracts, the usual Project Finance mechanisms can be used. Depending on the quality of the project, it may be necessary to incorporate guarantees from the shareholders or from the company's own balance sheets.

For str ucturing the financing, some provisions of the contracts are important in terms of technical requirements, the strength of the commitment to purchase energy by the offtaker, payment guarantees, termination events and dispute resolution mechanisms.

The credit rating of BEL, and the fact of having secure collection of electricity customers, also allows to eventually manage additional guarantees of repayment of the energy supplied by the PPA contracts.

For structuring the financing of transmission works, the multilateral development banks must be included in the portfolio: WB, CAF, IDB, etc.
In general, generation and transmission assets require long repayment periods, and at the same time, they have a low performance risk. The multilateral banks have the possibility to go longer and have within their policy the financing of basic infrastructure of their member countries. Additionally, compared to commercial banks, multilateral banks have a risk assessment structure that is more favorable to grant loans, even with credit risks that do not reach the Investment Grade category.

It is important to incorporate into the analysis that multilateral banks, in addition to providing financing, can provide guarantees that mitigate risks to facilitate the funding of projects by commercial banks. In any case, multilateral banks have financing windows for both, the public and private sectors. The support to private developments has been growing, while projects with PPA contracts have increased in the region.

The multilateral banks also finance generation projects, especially they have focused on supporting the incorporation of non-conventional renewable energies that are key factor in the mitigation of climate change (mainly wind and solar photovoltaic).
Consistent with this policy, the requirements of both, multilateral and commercial banks, make special emphasis on protecting the environment, not affecting ecosystems and minimizing the impact on local communities.

Credit quality, a consistent expansion plan and the management capabilities of both the developer and offtaker, are essential to obtain financing and improve commercial conditions. In addition to traditional financing, concession mechanisms associated with a fee can be developed for the expansion of networks; operational leasing format and others that simplifies the financing of the works by the companies responsible for the construction.

Finally, the repayment capacity is related to BEL's revenues, which is why a relevant aspect of the financing agencies' analysis will be regarding the tariff structure and its capacity to repay the effective costs of providing the services. The mechanisms for adjusting and updating them are included in the analysis.

In parallel with the definition of the generation and transmission expansion plan, it is required to develop a plan of financing sources, in order to have an acceptable diversification that allows obtaining an adequate portfolio of terms, interest rates and guaranteeing conditions.
Special consideration should be had on the negotiation deadlines and the sources that best suit the characteristics of the projects.

The analysis should not ignore the flexibilities that contracts may have (important in projects with very long terms) and the mitigation of financial risks that contracts allows (e.g. interest rate risk coverage).

Chapter 1

Power Generation Survey and Proposed Expansion Scenarios

1.1 Availability of Primary Energy Resources

In this First Chapter the objective is to define the framework for the system expansion plans that is the ultimate goal of the assessment. To do so it starts describing the primary resources available and the actual situation of the existing generation plants and grid. After that, it goes into the main issue, that is the possible expansion plans, and the different demand scenarios and supply alternatives that should be considered. Finally, the main variables and decisions that define the alternative expansion scenarios are presented, setting a frame for the discussion with Belize´s officials that should determine the specific scenarios to be simulated.

1.1.1 Hydro

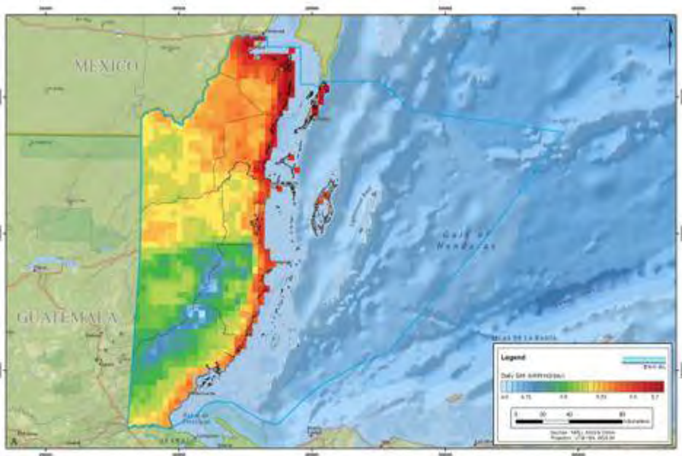
Hydro power is relevant in Belize, but its expansion possibilities are limited. Two new projects have been assigned in the 2013 RFP, and BEL officials believe there are no other new relevant alternatives. However, in the documentation received Clerk do not find studies ratifying this view, and the possibility should not be turned down completely until new studies or a new RFP are carried out.

The report works on the primary hypothesis that hydro power does not have expansion possibilities additional to the past RFP 2013.

1.1.2 Non- Conventional Renewable Energy: Wind and Solar PV

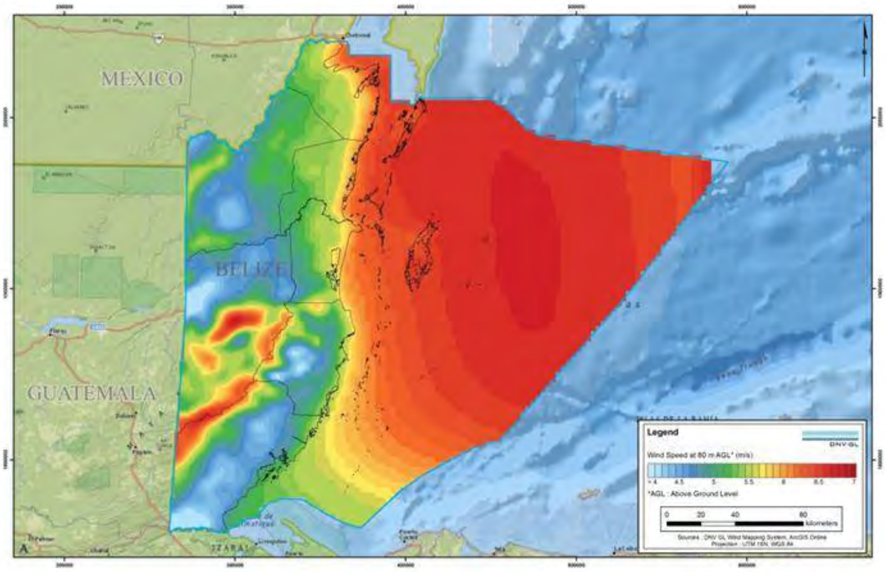
Considering the studies/information provided (Site selection ranking matrix provided by BEL) and the renewable resources maps (http://globalsolaratlas.info/; DNV GL maps provided by BEL), both wind and solar power can be developed in Belize.

Map 1.1. Belize Solar Global Horizontal Irradiation



Source: DNV GL, provided by BEL

Map 1.2. Belize Wind Speed



Source: DNV GL, provided by BEL.

In relation to wind, the characteristics of the resource are:

- Average onshore wind speed, at 80m above ground level: 4.5 – 7 m/s
- Average offshore wind speed, at 80m above ground level: 5.5 – 7 m/s
- Considering the values mentioned, an onshore wind generation project would have a capacity factor of approximately 33 - 35%.

With respect to solar, the characteristics of the resource are:

- Average Global Horizontal Irradiation: 1600 – 2000 kWh/m2/year
- Photovoltaic power potential: 1300 – 1700 kWh/kWp
- Which lead to a capacity factor of approximately 17 - 19%.

In both cases, considering CLERK's experience, solar and wind onshore generation could be developed at competitive prices.

Regarding offshore wind generation, CLERK considers it as a second stage, once onshore generation has already been developed. On the other hand, there are complementary issues that must be considered:

- Connection to network
  - Radial system
  - Voltage issues
- Hurricane/flood risk
- Terrain complexity
- Site remoteness

Considering the matrix provided by BEL (BEL Site Selection Ranking Matrix 1706021.xlsx), the issues mentioned before may define the feasibility of a project. For example, the following projects proposed have a good renewable resource but aren't feasible due to various reasons:

- Corozal II. Good wind resource but considerable flood risk
- Chan Chen site. Good solar resource but too far from electrical grid
- Consejo site. Good solar resource but too far from electrical grid
- Corozal I. Good wind resource but too far from electrical grid

However, there have been advances among which it can be highlight the supply contract of Bapcol Solar of 15 MW, which would be in service between 2019 and 2020.

Nevertheless, other projects like Ambergis Cay (wind), Guacamallo (wind), Maskall I (wind), Airport site I (solar PV), Ladyville I (solar PV), Belcogen III (solar PV) seem to be feasible.

As a result, the development of both solar and wind generation should be seriously considered within the system expansion plan. However, eventual network constraints should be taken into account and the resulting reinforcement costs should be considered in the whole equation.

In addition to the available resources that were evaluated; Belize has comparative advantages for the incorporation of significant amounts of non-conventional renewable energy, because of the capacity of the interconnection with a very large market, like Mexico, which can be thought to operate as a "storage capacity" equal to the power of the interconnection. In addition, the limited impact that the interconnection has on the Mexican market, makes the probability of supply constraints practically zero, except for the case of the event of a large fault.

If plans were designed with the restriction that the system should to be able to support the contingency of a cut off from the Mexican grid, related to a fault in the interconnection, the wind and solar power penetration should be restricted to relatively low numbers, maybe less than 15% installed capacity.

However, complementing wind and solar power with storage, this limit can be increased. And in Belize's case, where hydro power is already present and has some impact, it could be interesting to optimize the wind and solar power plants with the existing hydro to limit the need of large new storage or new backup plants.

Wind and solar power provides a stable average generation capacity on a medium-term basis, but it fluctuates in an hour by hour basis. The combination with storage seems optimal, but pump storage is expensive, and battery technology is still not mature for big storage needs. As said, existing hydro reservoirs may be a good storage option, during the rainy season but not during the dry season.
Also, wind and solar power provides an interesting energy package, intermittent but very predictable in annual average, that can be sold to neighbors over the interconnection. In addition, this interconnection will also serve as system backup and second order regulation when intermittent power is deployed.

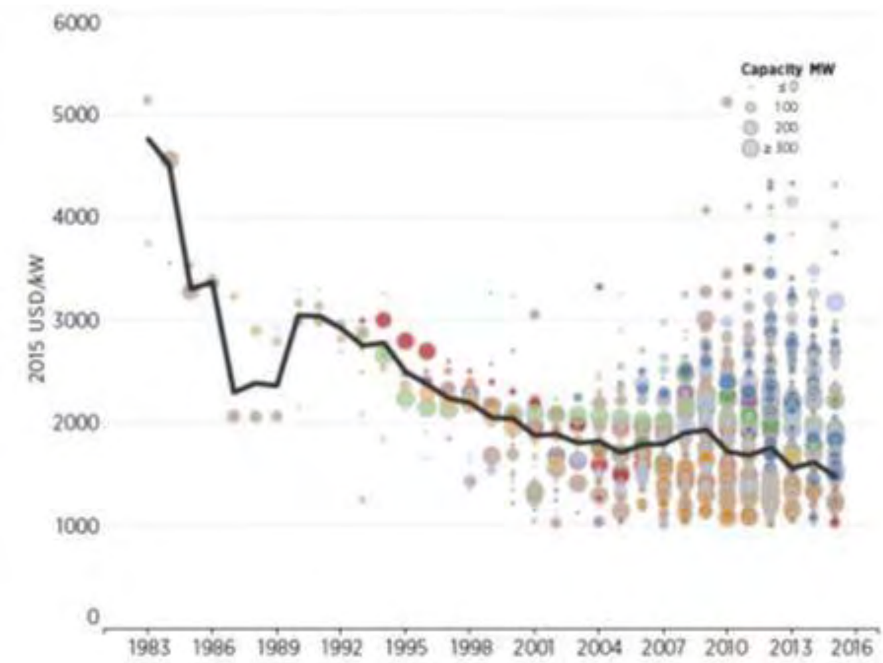
Summing up, wind and solar generation is an option that can be included in the plans, taking care of the contingencies and the need for backup and regulation.

The inclusion in the system of significant amounts of intermittent energy (solar photovoltaic or wind power), requires spinning power and storage capacity. On the other hand, Belize has hydraulic storage capacity of many hours, during long periods of time in the year, which would operate as spinning power to cover short-term deficits. Also, to be noted, the demand curve of the Belize electricity system has its peak during daytime hours, creating synergy with solar PV generation.

In relation to prices, technological progress has pushed them down, especially in solar power and wind power. The prospective studies Clërk have consulted, indicate that this process will continue during the planning period.

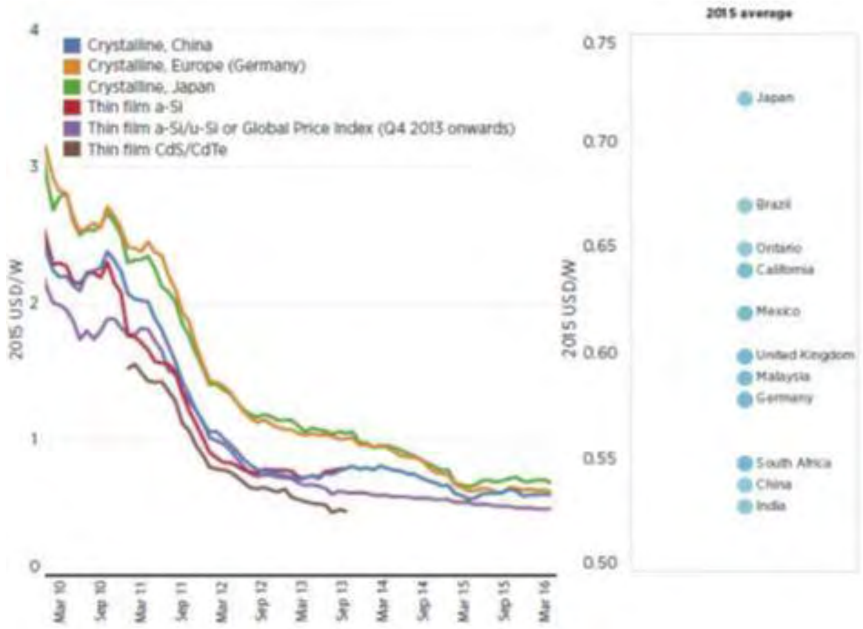
Below is a detail of the past evolution of prices, both of installed MW of wind generation; and the price of photovoltaic solar generation modules. The price decline has been constant and has consolidated in a very competitive values.

Graph 1.1. Total Installed Costs of Onshore Wind Projects by Country 1983-2014 / 2015 US$/kW



Source: Irena Renewable Cost Database

Graph 1.2. Global PV Module Price Trends 2009-2016 / 2015 US$/kW

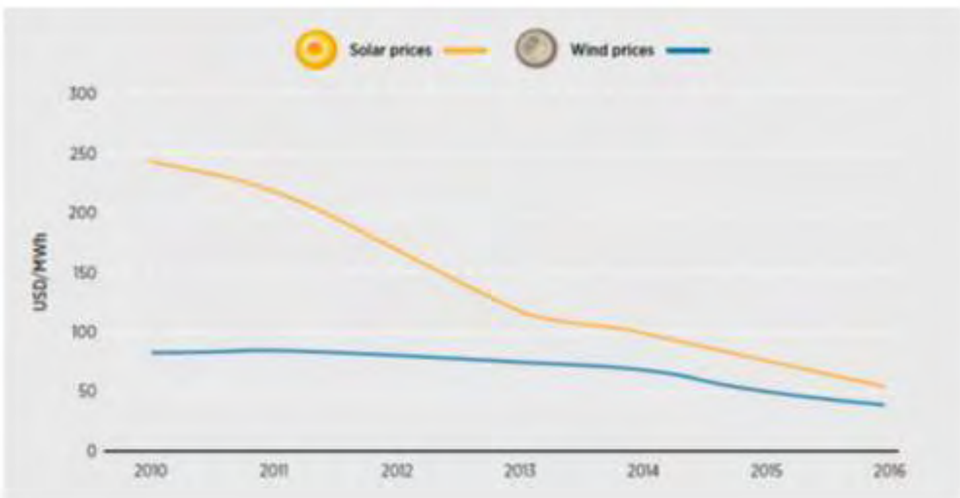


Source: GlobalData.2014; pvXchange.2016; Photon Consulting. 2016

This situation has been transmitted almost directly to the price of PPA auctions in the global average.

However, it is important to point out that prices reflect local conditions, especially those related to investment financing. Many of the projects are carried out under the Project Finance format, and therefore the credit quality of the off taker is decisive.

Graph 1.3. Average Prices resulting from auctions 2010-2016 US$/MWh



Source: IRENA. 2017

1.1.3 Biomass

Biomass generation is already being exploited in Belize (BELCOGEN is an important plant, and Santander is also an interesting experience). Revenue from the energy chapter of an agro-industrial project is always important to make the investment sustainable. Belize government, which probably is – as in many countries – interested in stimulating investment in productive projects, may be occasionally willing to accept special conditions from investors that want to complement their business with generation. However, it is always an issue to privilege a specific project with special benefits, such as tax exemptions, special dispatch modes, etc. As a rule, the benefits related to the energy generation business should be carefully tailored to harmonize with Belize's electric system, prices should be in line with the market and dispatch conditions should be adequate to the general dispatch rules.

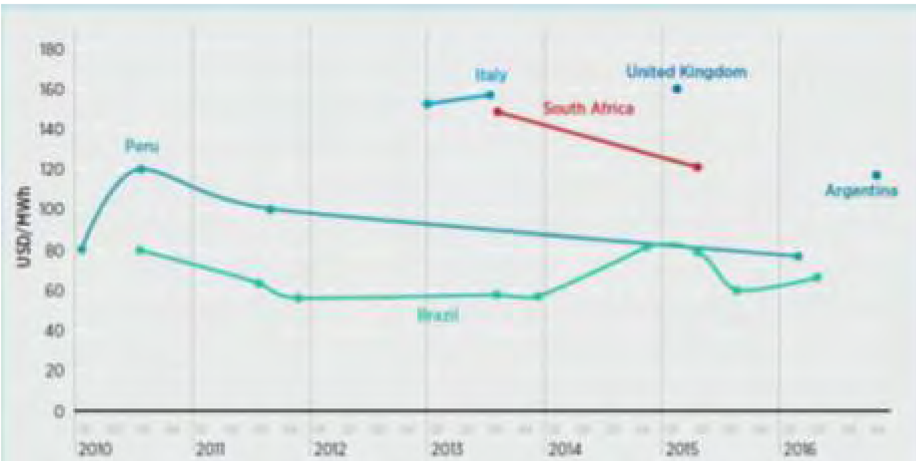
It should be noted that in 2017, 8 MW of the SEEL Biomass project will enter into service and an additional 8 MW will be incorporated in 2020

In this development process, there is no doubt that a future for biomass cogeneration exists, closely related to agroindustry operations such as sugar production and other endeavors.

In Graph 1.4 is shown a detail of the past evolution of prices of biomass auctions between 2010 and 2016.

The prices of auctions in Brazil, a competitive and open market can be a good reference to evaluate prices of transfer of the biomass cogeneration to the electric market.

Graph 1.4. Evolution of average biomass prices in auctions January 2010-July 2016 / US$/MWh



Source: IRENA.2017 (forthcoming)

1.1.4 Fossil fuels

Belize has a small on shore oil field in operation, and the country does not have refinery. Therefore, diesel oil and HFO for power plants, as well as the rest of the liquid fuels the country uses, are imported, mostly under de Petro Caribe agreement with Venezuela.

BEL owns and operates a Gas Turbine near Belize City, which runs on diesel oil, and serves as backup, with less than 5% uptime, and BAPCOL, a 22 MW IPP in the South, operates on HFO, serving also as backup and voltage regulator with very little operation.

There are no known gas reserves in Belize, and the investment to connect to the Mexican gas network would be important. However, news about the discovery of important gas reserves across the border to the West, in nearby Guatemala, has been made public recently. It is a forest area with important restrictions from an environmental point of view, and it will surely take some time for the country to exploit it. The distance to Belize's main demand points is apparently not large, so, if it proves to be an interesting gas reserve, surely in the mid to long term, gas would be available for electricity generation. On the other hand, the country's size does not allow mounting a viable LNG operation to feed Belize´s power generation.

Summing up, fossil fuels do not seem to be a choice for the short and midterm expansion and depending on the eventual new gas field in Guatemala, it could be used in the long term for backup. It is estimated that the only use of fossil fuels in the medium term would be as back up for biomass power plants in the event of limitations in the amount of bagasse.

Having analyzed existing resources and specially the interconnection expansion alternatives, the best recommendation for the short and medium term is not to include in the national expansion plan costly and complex alternatives, such as "pump storage" and off shore wind power. Storage in existing hydro reservoirs should be the option for many years.

Regarding energy efficiency, of course it is an important complement to the expansion plan, slowing the growth rate of electricity demand and therefore providing with a significant way to lower the investment that the system will need. However, Clerk experts strongly believe that the projections in the Castalia report, which announce a 24% economy at the end of the period, are far too optimistic. In energy efficiency it is important to distinguish between low cost actions, which may have significant effects, and long term, heavy investment alternatives, that may not be convenient or effective. Tariff incentives, mostly through different time – of – day prices, should be considered, to achieve adequate peak shaving. Other measures such as appliance labeling, and quality minimums should be also applied. However, the savings that could be achieved are expected to be less than 15%.

Although, as mentioned above, local conditions have a significant impact on prices; it is important to visualize the trend of the prices of the different technologies and their comparison in relevant markets. In particular, the US EIA report is one of the best international benchmarks.

The levelized cost of electricity (LCOE) is shown in Table 1.1 for all technologies that come into operation in the year 2022.

Table 1.1. Estimated LCOE (weighted average of regional values based on project capacity additions) for new generation resources, plants entering service / 2022

U.S. Capacity-Weighted[1] Average LCOE (2016 $/MWh) for Plants Entering Service in 2022

Plant Type	Capacity Factor (%)	Levelized Capital Cost	Fixed O&M	Variable O&M (including fuel)	Transmission Investment	Total System LCOE	Levelized Tax Credit[2]	Total LCOE including Tax Credit
Dispatchable Technologies								
Coal 30% with carbon sequestration[3]					NB			
Coal 90% with carbon sequestration[3]					NB			
Natural Gas-fired								
Conventional Combined Cycle	87	14.0	1.4	42.0	1.1	58.6	NA	58.6
Advanced Combined Cycle	87	14.0	1.3	37.5	1.0	53.8	NA	53.8
Advanced CC with CCS					NB			
Conventional Combustion Turbine	30	36.8	6.6	54.3	3.0	100.7	NA	100.7
Advanced Combustion Turbine	30	22.8	2.6	58.8	3.0	87.1	NA	87.1
Advanced Nuclear	90	70.8	12.6	11.7	1.0	96.2	NA	96.2
Geothermal	90	29.2	13.3	0.0	1.5	44.0	-2.9	41.1
Biomass	83	47.2	15.2	34.2	1.2	97.7	NA	97.7
Non-Dispatchable Technologies								
Wind – Onshore	41	39.8	13.1	0.0	2.5	55.8	-11.6	44.3
Wind – Offshore					NB			
Solar PV[4]	25	59.8	10.1	0.0	3.8	73.7	-15.6	58.1
Solar Thermal					NB			
Hydroelectric[5]	60	54.1	3.1	5.2	1.5	63.9	NA	63.9

[1]The capacity-weighted average is the average levelized cost per technology, weighted by the new capacity coming online in each region. The capacity additions for each region were based on additions in 2018-2022. Technologies for which capacity additions are not expected do not have a capacity-weighted average, and are marked as "NB" or not built.
[2]The tax credit component is based on targeted federal tax credits such as the production or investment tax credit available for some technologies. It only reflects tax credits available for plants entering service in 2022. Not all technologies have tax credits, and are indicated as "NA" or not available. The results are based on a regional model and state or local incentives are not included in LCOE calculations. See text box on page 2 for details on how the tax credits are represented in the model.
[3]Due to new regulations (CAA 111b), conventional coal plants cannot be built without CCS because they are required to meet specific CO_2 emission standards. Two levels of CCS removal are modeled, 30% and 90%. The coal plant with 30% removal is assumed to incur a 3 percentage-point adder to its cost-of-capital to represent the risk associated with higher emissions from a plant of that design.
[4]Costs are expressed in terms of net AC power available to the grid for the installed capacity.
[5]As modeled, hydroelectric is assumed to have seasonal storage so that it can be dispatched within a season, but overall operation is limited by resources available by site and season.

Source: U.S. Energy Information Administration, Annual Energy Outlook 2017 , January 2017, DOE/EIA-0383 (2017)

1.2 Inventory of generation plants

It was realized an identification and general description of the facilities that power the electricity system in Belize. The generation system comprises a fairly balanced mix of hydroelectric (54 MW installed), fossil fired (50 MW installed) and biomass fired (50 MW installed) power plants. Most of them are privately owned and supply energy to the grid by means of PPAs with BEL, as it is the case for all the hydro and biomass plants, as well as one diesel plant, with the remaining two fossil fired plants owned by BEL.

In the present chapter it is provided a summary list of the Belize generating plants, indicating their main characteristics and ownership, followed by a brief description of each plant with their more relevant features.

Table 1.2. Belize Power Plants 2017

Name	Owner	Type	Fuel	Rating (MW)	Year of construction	Location (Approx. coordinates)
Westlake	BEL	GE LM2500 Gas Turbine	DO ASTM N°2	22.8		17°28'2.66"N 88°17'44.17"W
BELCOGEN	IPP	Steam CHP	Biomass (bagasse)	12.5 (bp)/ 15.0 (cnd)		18° 2'31.82"N 88°33'28.04"W
		IC Engines	HFO	4.0 (2x2)		
		PPA		13.5 PPA		
Santander	IPP	Steam CHP	Biomass (bagasse)	2 x 8.0	2017	17°20'21.88"N 88°44'40.39"W
		PPA		8.0		
BAPCOL	IPP	IC Engines	HFO	23.5 (3x7.8)	2005	16°40'19.92"N 88°23'26.85"W
Mollejon	IPP	Hydro (Macal River)		25.0		16°57'18.43"N 89° 2'43.33"W
Vaca	IPP	Hydro (Macal River)		19.0 (2x8+1x 1)		17° 1'12.26"N 89° 3'29.75"W
Chalillo	IPP	Hydro (Macal River)		7.0		16°51'44.53"N 89° 0'48.80"W
Hydro Maya	IPP	Hydro (Rio Grande)		3.5		16°19'7.06"N 88°56'6.08"W
Caye Caulker (isolated)	BEL	IC Engines	Diesel	4.0		17°44'36.41"N 88° 1'33.83"W (approx.)

Source: Clërk Survey

1.2.1 Fossil Fueled Power Plants

1.2.1.1 Westlake[1]

Owner: BEL
Generating equipment:

- x 22.8 MW, Diesel oil (ASTM N°2) fired GE LM2500 Gas Turbine. Woodward Atlas control system.
- Unit Operating Hours: 13,700 (not reached running hours for major overhaul).
- Last borescope inspection: November 2016.

1.2.1.2 BAPCOL

Blair Athol Power Company Limited[2]
Owner: Belize Aquaculture, Ltd.
Generating equipment[3]:

- x 7.8 MW HFO fired Wärtsilä 18V32 engines (23.5 MW in total).

1.2.1.3 Caye Caulker (isolated)[4]

Owner: BEL
Generating equipment:

- Caterpillar 3516 Mobile Generator - these have been on the island for about 17 years. They were originally being rented from the CAT dealer, Gentrac, then BEL decided to purchase.
- Running Hours: 42,092 hours; 44,491 hours; 39,719 hours
- 1 Caterpillar 3512 Generator - this was purchased used Easter 2016. Since under BEL's ownership unit has run 6,234 hours. Seller was unable to provide BEL with previous running hours.

1.2.2 Biomass Power Plants

1.2.2.1 BELCOGEN LTD.

CHP plant supplying a Power Purchase Agreement (PPA) with BEL and an Energy & Steam Purchase Agreement (ESPA) with the Belize Sugar Industries Ltd. (BSI) Tower Hill sugar mill. The plant consists of a bagasse fired steam CHP plant and an HFO fired IC engine power plant.

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[1] Files "BEL Power System.pptx", July 14th 2017, and "Caye Caulker_ West Sub- Energy Study.docx", Sept 19th 2017

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

[3] File "IPP Plant Descriptions.pdf"

[4] Files "BEL Power System.pptx", July 14th 2017, and "Caye Caulker_ West Sub- Energy Study.docx", Sept 19th 2017

Owner: Belize Sugar Industries Limited (BSIL)[5]
Plant Equipment Description
Steam CHP:

- x 90 t/h bagasse & HFO boilers (64 bar / 485°C)
- 1 x 12.5 MW back pressure (bp) turbo-generator
- 1 x 15 MW condensing (cnd) turbo-generator
- Diesel engine generation:
- x 2 MW medium speed HFO engines

Environmental parameters[6]

The Belcogen facility has been specified to meet the appropriate international environmental standards as generally specified in World Bank Group Pollution Prevention and Abatement Handbook - new thermal plant (July 1, 1998). During the two main operating regimes the plant can achieve the key environmental performance parameters set out below:

	Value	**Unit**
Boiler operation on bagasse		
Boiler stack particulate emission	≤ 100	mg/Nm3, dry at 11% O2
Boiler stack NOx	≤ 750	≤ 750 mg/Nm3, dry at 11% O2
Boiler Stack SOx	n/a	
Boiler operation on HFO		
Boiler stack particulate emission	≤ 100	mg/Nm3 , dry at 3% O2
Boiler stack NOx	≤ 750	mg/Nm3 , dry at 3% O2
Boiler Stack SOx	≤ 2000	mg/Nm3 , dry at 3% O2
HFO engine generation		
Exhaust stack – particulate emission	≤ 100	mg/Nm3 , dry at 15% O2
Exhaust stack – NOx	≤ 2000	mg/Nm3 , dry at 15% O2
Exhaust stack SOx	≤ 2000	mg/Nm3 , dry at 15% O2
Co-generation facility		
Noise	≤ 70	dBA

1.2.2.2 SANTANDER

CHP plant supplying a Power Purchase Agreement (PPA) with BEL and Energy & Steam to the Santander Sugar Mill.
Owner: Santander Sugar Group[7]
Plant Description[8]
Bagasse fired steam CHP plant consisting of:

- 1 x 120 t/h bagasse & HFO boiler (41 bar / 400°C)
- x 16 MW condensing / extraction turbo-generators

5 http://www.booker-tate.co.uk/project/belcogen-cogeneration-central-america/

6 File "IPP Plant Descriptions.pdf"

7 http://www.santandersugar.com

8 File "IPP Plant Descriptions.pdf"

1.2.3 Hydro Power Plants

1.2.3.1 Mollejon

Plant Description[9]
Hydroelectric plant situated at the Macal River near its confluence point within the Mollejon Creek, in Cayo District, rated at approximately 25 MW.
Generating equipment[10]:

- x 8.4 MW Francis turbines (25.2 MW in total).

1.2.3.2 CHALILLO

Plant Description[11]
Hydroelectric plant situated at the Macal River 16 km upstream of the Mollejon hydro plant in Cayo District, rated at approximately 7 MW. It provides additional water storage to the Chalillo / Mollejon hydro complex.
Generating equipment[12]:

- x 3.5 MW Francis turbines (7 MW in total).

1.2.3.3 VACA

Plant Description[13]
Hydroelectric plant situated on the Macal River downstream of the Mollejón hydro plant in Cayo District, rated at approximately 19 MW.
Generating equipment:

- x 9 MW Vertical Francis turbines (18 MW in total) for normal flows.
- 1 x 1 MW Horizontal Francis turbine for minimum flow operation

9 File "IPP Plant Descriptions.pdf"

10 Filehttp://www.cneec.com.cn/english/productsandservices/OurBusiness/Energy/HydraulicPowerGeneration/200903/t20090301_76727.html; "IPP Plant Descriptions.pdf". http://library.bfreebz.org/Threats/Electrowatt-Ekono AG for Belize Electric Company Ltd., Hydroelectric Potential Assessment, 2006.pdf

11 File "IPP Plant Descriptions.pdf"

12 File "IPP Plant Descriptions.pdf"

13 File "IPP Plant Descriptions.pdf"

1.2.3.4 HYDRO MAYA

Plant Description[14]
A run of the river 2.2 to 2.6 MW hydroelectric plant located on the Rio Grande River approximately three kilometers north of the village of San Miguel, in the Toledo District of Southern Belize, developed and designed especially for the Toledo District power grid Generating equipment:

- One large turbo-generator, 1600 – 1800 kWe
- One small turbo-generator, 600 – 800 kWe

1.2.4 Inefficient and polluting power units

According to the primary analysis performed, none of the plants can be considered obsolete and therefore should not be replaced. The only exception is the Caye Caulker plant which is isolated and the connection to the interconnected system would allow its replacement.

In relation to the problems of pollution and the impact on the environment; It should be noted that the use of HFO and diesel may be polluting. However, the impact is extremely low, since thermal plants have, on average, very few generation hours per year. They are basically used as backup.

1.2.5 Recommendation for replacement

In view of the current situation and different expansion plans being evaluated, which include possible addition of renewable sources and the development of international interconnection links and network expansions, it was not proposed the replacement of fossil fueled generation equipment in the short term, unless dictated by economic reasons exclusively. In fact, Clerk experts trongly recommend keeping an adequate availability of such equipment by continuing with normal maintenance activities, including preventive and predictive, in order to maintain a firm backup thermal generating basis. This will allow the optimization of the renewable resources and interconnections while ensuring the continuity and quality of the power supply at all times and with a minimum cost.

It is made a special point in this respect regarding the Caye Caulker diesel engine plant which should be kept in good operating condition as backup of the planned interconnection of the main system to the island by means of a submarine link, in case of a failure of the said interconnection facility.

In relation to this, the following table shows the relevant weight that the interconnection has for the security of supply and the stability of the system.

[14] File "IPP Plant Descriptions.pdf"

Table 1.3 Relevant weight that the interconnection has for the security of supply and the stability of the system

	2015	2016	Average
Power Purchased	kWh	kWh	2015-2016
Power Purchase - CFE	54.857.688	243.559.509	41%
Power Purchase - BECOL - Mollejon & Chalillo	151.666.768	165.011.818	26%
Power Purchase - BECOL - Vaca Only	74.103.980	82.003.415	13%
Power Purchase - Hydro Maya	10.220.100	13.491.000	2%
Power Purchase - BELCOGEN	83.174.842	79.043.744	13%
Power Purchase - BAPCOL	11.933.645	17.567.416	2%
JICA (UB Solar)	421.600	450.000	0%
Diesel Generation (GT grid and isolated Caye Caulker)	15.500.945	13.542.686	2%
	601.879.568	614.669.588	100%

Source: Clërk Survey

1.3 Other system components

1.3.1 Transmission grid and system operation

The transmission network voltage levels used in Belize are 115 kV and 69 kV. A preliminary assessment of the network indicates that the general condition is very good.

Belize uses American Standards. The support structures/columns for overhead lines are made of treated pine wood imported from USA. This regulation ensures reliable, economical and technically adequate installations, which are essential requirements to optimize the network development.

On the map, marked in red, the 115 kV lines are shown, in blue the 69 kV lines and in green the 34.5 kV circuits. It is important to note the interconnection with CFE México on the northern border.

Map 1.3. Belize Transmission Network

Source: Bel

Nowadays, imports are steadily around 50 MW, and the injection to the Belize system is done in the North end, while the demand is mostly concentrated towards the center of the network.

In order to supply the demand, which at present reaches a peak of 90 MW, and also for voltage regulation, the hydraulic power plants of Cholillo-Mollejón-Vaca and Hydro Maya must be operated.

When there is little generation from these hydro plants, the BEL turbine near Belize City and the Bapcol plant in the southern end are needed. The latter is used for voltage regulation at the southern end of the 69 kV line. The steam plants burning bagasse, Santander and Belcogen, are seasonal and contribute during the sugar cane harvest.

The distance of the 115 kV stretch to the interconnection with Mexico, is approximately 150 km, while the stretch to the power plants, passing through Belmopan, exceeds 100 km.

The 69 kV line to the south is also about 140 km. With these distances, the design constraint is the voltage drop, which can be mitigated with compensation or generation.

Considering that during demand peaks, now 90 MW, the interconnection alone fails to supply demand within the technical required parameters, generation fulfills these two functions.

It should be noted that the output medium voltage busbars of transformer 115 kV / MV and 69 kV / MV have capacitive compensation. This configuration is correct because it helps to control voltage close to the customers, and after the transformers, with its inductive impedance, maximizes the regulating capacity.

1.3.2 Network Expansion Plans

The Map 3 shows the grid expansion options in purple.

Map 1.4. Belize
Grid Expansion Options

Source: BEL

To fix ideas, it is referred to 50 MW as the capacity of the 115 kV line, and 20 MW as the capacity at 69 kV. Under these conditions, the second interconnection with Mexico at 115 kV, which would connect to the Belmopan region, would optimally increase the capacity to 100 MW, and improve voltage regulation in the Belmopan zone at the end of the 115 kV network. It should be noted that the voltage regulation within certain limits is strictly linked to the reduction of losses in the network, which produces a positive externality.

The 34.5 kV extensions of a second cable to Cayo San Pedro and the connection to Caye Caulker, would meet the growth of demand and would allow the Caye Caulker diesel plant to be put out of service.

A second stage international interconnection, linked to future demand growth over the next 10 years, would include SIEPAC, where the interconnection modality in the South should be carefully evaluated.

This solution is more expensive and strongly depends on international agreements, thus it should be analyzed strategically. The idea of continuing to strengthen the interconnection with Mexico in a third stage cannot be ruled out, as well as the possibility of even connecting Belize system to the Central American system through Mexico, assessing the prospect of a future regional market.
The network and substations expansions in the North and Center are justified to meet the demand with an adequate safety operation.

These expansions, mainly of the 115 kV system, allow to adequately optimize imports, and also enable BEL to make occasional exports in the future.

In summary, the planned network expansions correctly solve medium-term needs in both transmission capacity and voltage regulation and prepare the system for all the future scenarios.

As it will be seen further on in generation planning, given the seasonality of the bagasse and hydroelectric plants, the need for 115 kV works will emerge more clearly, particularly the line between Mexico and the Belmopan region.

Additionally, due to risk of supply and the need of voltage regulation, it will be necessary to increase backup generation power. This expanded system will meet these minimum requirements to mitigate adverse effects in the medium term.

Finally, and reinforcing the idea, any scenario of generation expansion to supply the demand with high levels of reliability must always be associated to a transmission network that allows the flows with an adequate voltage regulation in all the nodes and consequently lower the losses.

1.3.3 Losses and service universalization

Losses percentages were calculated related to different bases of incoming energy. Usually, distribution losses are calculated as a percentage of incoming energy from the grid. Losses calculations are a result of energy balance, with three metering frontiers:

- Generation
- MV feeders
- Consumption points (Commercial metering)

Generation and MV feeders have tele-metering, consequently the energy can be registered simultaneously. For consumptions, except big consumers, the commercial metering/reading is done by routes of lecture in different days each month. For this reason, the balance needs to be done taking into account the delay between generation/feeders metering and consumption metering. Additionally, commercial metering has different periods each month, consequently it is necessary to consider averages in periods of some months to mitigate this effect.

Considering the information provided by BEL, a first overview from 2000 to 2016 is shown in Graph 5.

Graph 1.5. BEL Losses-Twelve-Month Moving Average 2000-2016 % losses

Source: BEL

For commercial metering, a twelve-month moving average is assumed, comparing in the same period with generation and feeders metering. From Graph 1.5 it can be derived the following conclusions:

- Total losses decreased slowly, in the last years it is close of 12%
- Transmission losses grew from 2% to 5 - 6%.
- Distribution losses decreased from 10% to 6%.

In the period 2000 – 2016, total generation plus importation grew from 262 to 615 GWh, 2.35 times in 16 years. Transmission losses grew approximately with the same ratio. Distribution losses have had the opposite behavior that could be explained by the following reasons:

- Improvements in the MV network, such as substitution of cables for greater section and new circuits.
- Increase in the number of transformers MV/LV, monophasic in MV and biphasic in LV, with lower losses.
- Consequently, transformers being closer to consumptions and shorter LV circuits

Currently distribution losses are low if compared with typical levels of losses in distribution systems.

From another point of view, it has been analyzed the correlation between total losses and two other magnitudes:

- Total generation plus importation.
- CFE importation.

Results are shown in Graph 6.

Graph 1.6. Belize Generation and Losses, Energy KWh, 2015-2016

Source: BEL

It is evident from Graph 1.6, that there aren't significant variations in total losses amount, although the demand points are further away from the interconnection point than from the generation sites. This could be explained mainly by the use of generation at the center and south power plants in periods of peak demand to get better voltage control, which improves losses in the worst scenario, remembering the fact that losses follow a square law correlation with demand.

In opposite, total losses show an important correlation between total generation plus importation, and total demand, which is an expected result.

Lastly, the amount of distribution losses reflects the inexistence of commercial losses, such as metering errors or illegal connections to the network. This situation could be explained by two factors:

- Harsh collection policy: If customers' don´t pay the bill, BEL cuts the service.
- Low exposure of the LV network, circuits are short and directly to the houses.

For energy forecast, it can be assumed the hypothesis that the losses level will be kept within the current levels, this is 11-12% total for the whole system, 5 - 6% in transmission related incoming energy from generation and interconnection, and 6% in distribution related to incoming energy to the distribution system. This hypothesis implies that the current policy of cutting consumers who do not pay the bill will continue, and that the improvements of distribution network will develop with the demand growth.

Finally, it should be noted that the entry of the transmission lines for a second interconnection with Mexico will lead to a transmission loss reduction, but will grow again with the growth of demand, so the suggested values for the projections are average values.

1.3.4 Rural Electrification Plan

BEL presented a list of electrification projects to serve consumers not connected to the grid. There is a total of 218 projects, which comes out from a census recorded in 2010. From these projects, 154 have already been executed, and another 37 with an amount of BLZ 9.34 million are being implemented with the objective of ending until 2020.

This situation, as well as the degree of electrification is shown in Table 1.4.

Table 1.4. Degree of Rural Electrification, 2010 Census Analysis

Total Households	79.492
Fully Electrified	68.192
Partial Electrified (1/2 assumed)	3.873
Total Households electrified	72.065
% Electrified	90,66%
Unelectrified Households	7.428
% Unelectrified	9,34%
Households Planned for Electrification to 2020	5.251
Total Planned Electrified by 2020	77.316
% Electrified by 2020	97,26%
% Unelectrified by 2020	2,74%

Source: Rural Electrification Belize_2017.xlsx

With the above-mentioned plan, population with electric service will go from 90% in 2010 to 97% in 2020. As for all electrification expansions, the more distant households are from the grid, the more expensive the connection costs, and thus the process usually slows down. In this final stage, autonomous solutions, for example with solar panels, are always considered as part of the solution. It is pending to re-register the remaining homes and update the electrification plan with the new data.

With the projections for the incorporation of new home consumers, it is quite feasible to sustain the hypothesis that the remaining 3% of householders will be electrified within 10 years.

The advances of electrification considering connection to the network can be observed in Map 5. Clearly, the concentration of the households, and by consequence the medium voltage (MV) network, follows the axes and population.

There are important areas that are evidently of very low population, where the electrification of the missing 3% should be developed.

Map 1.5.
Households Concentration

Source: BEL

1.4 Quality of service – SAIDI SAIFI

Quality of electric service for final customers is characterized by the following attributes.

- Continuity of electrical service, measured as average times and individual interruption times, and the interruption frequency.
- Voltage drops, first as a network design variable and then verified in measurements in medium voltage buses, and measurements on final customers.
- Wave quality, measured as disturbances to the sine wave, such as flicker, harmonic distortion, etc.

In order of importance, continuity of service is the most critical, in second term voltage drop, and finally wave quality.

In this chapter, continuity of service is approached, and some considerations are made about voltage regulation.

The metering of continuity of service is done by indicators; the most relevant is the SAIDI. The SAIDI, System Average Interruption Duration Index, is the sum of the interruption times per consumer divided by the total of consumers, which results in the average time of interruption per consumer.

In Table 6, the evolution of BEL SAIDI is shown:

Table 1.5. Evolution of BEL SAIDI 2011-2015

	SAIDI				
	2011	2012	2013	2014	2015
Total System	**28.00**	**24.09**	**21.03**	**23.80**	**19.64**
CFE & Local IPPs	2.78	0.81	0.67	3.93	3.40
Hurricane	0.00	0.50	0.00	0.00	0.00
Vandalism	0.68	0.02	0.35	0.00	0.09
Total (Less IPPs, Hurricane, Vandalism)	**24.54**	**22.76**	**20.01**	**19.88**	**16.14**
Planned	**12.73**	**8.86**	**11.51**	**10.41**	**7.09**
Distribution	4.44	3.13	6.23	3.41	3.46
Transmission	3.08	2.91	2.17	2.15	1.55
Substation	5.21	2.81	3.11	4.85	2.03
Generation	0.00	0.00	0.00	0.00	0.06
Unplanned	**11.81**	**13.90**	**8.56**	**9.47**	**9.05**
Distribution	6.37	4.30	3.94	4.57	5.81
Transmission	0.66	3.25	2.85	3.03	1.21
Substation	4.76	3.67	1.43	1.75	1.61
Generation	0.02	2.68	0.35	0.11	0.42

Sources: generation & network

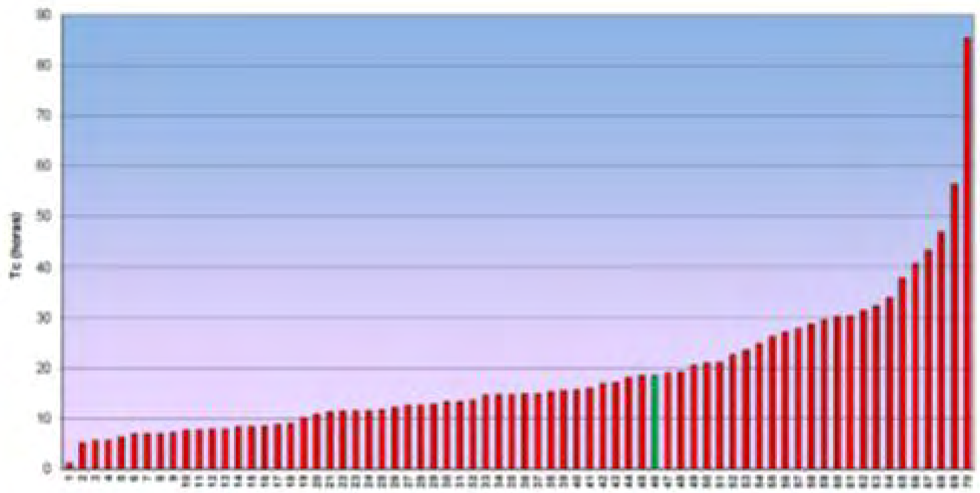
The annual values in all the components of the indicator show improvement. The values of average time of interruptions correspond to a radial (means no meshed) structure of the transmission and distribution network. This topological structure cannot be avoided because of the geographical distribution and the low density of the consumers.

The weight of planned interruptions in distribution network is high, 36% of total in 2015. This high value is consequence of the network structure and a hard maintenance plan, reflected in a good condition of the installations.

The good level of SAIDI depends of good practices in operation response, preventive and corrective maintenance, and good standards in projects and construction. From all points of view, BEL shows good technical level, correct practices and is reasonably rigorous, once taken in account the size of the company and the resources available.

In Graph 7, BEL SAIDI is compared with values obtained in CIER companies.

Graph 1.7. Number of interruptions experienced per customer 2016, Tc Hours



Source: CIER – SAIDI 2016 (Tc=SAIDI)

It can be observed that SAIDI is very sensitive with the consumer density, mainly with MV km per consumer, thus it is necessary to make the comparison showing this parameter. With 3000 km of network extension and 80.000 customers, there is an average of 40 meters of MV network per costumer.

This density is low and corresponds to the last third part of CIER Table. Consequently, BEL shows a good relative position compared to CIER companies, taking into account the density of consumers in the medium voltage network. The expected value of the SAIDI would be around 20 hours per year, consistent with what is being verified.
In relation to voltage drop, the control in HV and MV circuits up to feeders in substations is done by the Control Center placed in Belize City. For this purpose, the Control Center has the follows tools:

- Generation voltage control.
- Tap changers of HV/MV transformers.
- Connectable capacitors in the MV substations bus.

The radial structure of the network makes it difficult to perform voltage regulation, whereby BEL needs frequently to use all the available resources, mainly with high demand and high power in CEF interconnection.

As next step, BEL could implement the registration of final consumers´ voltage, in MV and LV. This registration can be done in one week per consumer, with registration of average values each 10 or 15 minute. The values obtained are classified in three groups, between limits, out of limits but not critical, and out of limits but critical. Depending on the quantity of values registered in each group, it is defined if it is acceptable or not.

Finally, BEL engineers mentioned the problem of non-equilibrium voltage between phases. This problem has two sources, the absence of transpositions in the 115 kV network, and the distribution monophasic transformer connection. At 115 kV level, transpositions could be solved by special structures in two points of each line. Connection of monophasic transformers in MV network requires a general revision and registration of the connection phases for each distribution transformer.

1.5 Generation Expansion Plans

From the generation point of view, some expansion actions are needed. The supply from Mexico has been growing steadily, and in a few years, will achieve the maximum contractual levels, creating an issue that must be attended. Also, the strategic concerns arise because of the high dependency from this interconnection.

The awareness of these issues has driven the efforts of the Ministry of Energy and the Public Utilities Commission, and, even though an official expansion plan is not yet available, the reports emerging from different consulting projects (Siemens Power Transmission & Distribution, Inc., 2009) (Castalia, 2014) (Estudios Energéticos Consultores/Grupo Mercados Energéticos, 2016) have served as guidelines. MEPSPU_2016-10-28.pptx, based on the mentioned documents, shows the possible actions in all fields for the period 2015-2030. Initiatives to strengthen generation capacity are being carried out, a request for proposals has been issued in 2013, with 4 new IPP contracts being under way. These contracts are based on different sources, capacities and forecasted start-up dates.

The energy sources prioritized in the RFP were renewable, mainly biomass, hydro, and some solar. This is compatible with the country’s resource profile, which was previously commented in this report.

At the same time, Energy Efficiency has been included as a strategic priority, with an ambitious plan being designed to achieve a reduction in the demand growth ratio of more than 1% per year, accumulated. The plan addresses specific issues, such as appliance labeling and fiscal incentives, central government accountability for its electricity consumption and new building codes. However, it is not still being deployed and it is optimistic.

In parallel with the generation expansion initiatives, the exploration of new international interconnections has been part of the recent analysis, with a complete report submitted by a consulting firm (Estudios Energéticos Consultores / Grupo Mercados Energéticos, 2016) as the result of a project financed by the IDB. In that study, different alternatives are evaluated, specifically a new interconnection with Mexico, in two alternative points, an interconnection with Guatemala, and a submarine interconnection with Honduras. The possibility to integrate SIEPAC, through these alternatives, is also analyzed.

As a general idea, the situation can be described as follows:

- Actual growth rate of electricity demand poses the question of how to develop supply infrastructure to meet the challenge, as actual facilities will find their limits in a few years.
- To do this, Belize is interested in expanding its own generation capabilities, especially if they are synergic with local industrial investment projects (specifically in sugar, forestry, or other agroindustry endeavors), but also if they allow to exploit its natural renewable resources, provided the environmental issues remain acceptable.
- Energy Efficiency should be complementary, allowing the demand growth to moderate, so an ambitious EE program should be part of the effort.
- International interconnections, for a small country such as Belize, should always be part of the plan, as they enable the access to virtually infinite sources at convenient costs. Also, for geopolitical reasons, the diversification should be valuable, and specially the affiliation to SIEPAC.
- However, even if renewables can supply interesting energy blocks, they cannot guarantee the necessary power, because of their intermittent or seasonal nature. The need for backup should be carefully evaluated and integrated into the plan.
- Finally, contingency plans that consider eventual interconnection failures should also be incorporated.

In the IDB-ME document, scenarios of demand growth are evaluated with alternative sources, in particular interconnections. In order to evaluate the interconnections, a ranking based on difficulty is established, assigning weight to each type of difficulty and then the difficulty score for each case. The weighted rank is shown in Tables 7 and Map 6.

Table 1.6. Score matrix of affection on infrastructure and geographic features

Weight	Criteria	MX1	MX2	MX3	MX4	GU1	GU2	HO1	HO2
100%	Infrastructures	3,12	2,34	2,14	2,17	3,18	2,72	3,58	3,58
1%	Crossing with existing overhead distribution lines	5	4	4	4	1	1	1	1
4%	Crossing with existing transmission lines	3	5	1	3	3	3	5	5
25%	Accesibility and maintenace	1	3	3	3	2	1	5	5
15%	Distance from other lines	5	2	2	2	4	3	2	2
22%	Connection of new power generation	5	1	1	1	3	3	3	3
10%	Influence with major infrastructures (Airports and Airfields)	2	2	5	4	4	4	4	4
10%	Distance to urban centers	5	5	1	1	3	3	3	3
6%	Elevation	1	1	2	2	4	3	5	5
5%	Crossing of Rivers	1	1	1	2	5	5	2	2
2%	Crossing with main roads	2	1	1	1	5	5	3	3

Source: IDB-ME document

Map 1.6. Rank of alternatives according to their impact on infrastructure and geographic features

Rank	Alternative	Score
1st	MX3 Xulha to Camalote	2.14
2nd	MX4 Xulha to Camalote (Through La Democracia)	2.17
3rd	MX2 Xulha to La Democracia	2.34
4th	GU2 La Democracia to Río Dulce (Through Mullins River)	2.72
5th	MX1 Xulha to West Lake	3.12
6th	GU1 La Democracia to Río Dulce	3.18
7th	HO1 La Democracia to Dangriga, then to Monkey River, then submarine Cable route A to Puerto Cortés	3.58
8th	HO2 La Democracia to Dangriga, then to Monkey River, then submarine Cable route B to Puerto Cortés	3.58

Source: IDB-ME document

The IDB-ME study emphasizes interconnections as a solution and, depending on demand projections and expansion strategies, includes, in a great or less extent, thermal generation, in particular diesel, to match the supply in the long term. The most aggressive behavior is to support the growth of demand with the interconnections with Mexico, Honduras and Guatemala, thus achieving integration with SIEPAC.

In SIEMENS study of 2009 appears some actions of the plan already in service, but in general it recommends expansions in all generation technologies and interconnections. As for hydro, it suggests extensions in the already exploited basin, but with reversible pumping stations. Wind generation is included as an additional source. In addition, regarding the interconnections, apart from expanding the capacity with the CFE, the interconnection with Guatemala appears.

The emphasis of the study, and the tools used, are oriented to the economic optimization of the expansion in generation.

The study of Castalia 2014 is already more comprehensive, referring not only to the expansion of generation, but also to a general plan in the field of energy expansion and other actions such as energy efficiency. It poses particular emphasis on comparing prices from different sources but has the difficulty that at the time of such comparison the oil costs were high, so the same logic today would not necessarily lead to the same results.

In summary, the referred studies are valuable antecedents, due to the scope and depth of the analysis performed. As a result, they should be taken into account as good references, but with the necessary corresponding updates of information and further analysis.

1.5.1 IPP Projects

There are five contracts to provide energy and power from independent producers which are in different stages of development.

As mentioned, they have different energy resources (hydro, biomass and solar) and installed capacity.

In Table 8 these projects are shown, as well as their year of commissioning, contract prices and their Levelized Cost of Electricity (LCOE).

Table 1.7. Belize Energy Projects Planned 2016-2022

Project	Planned Capacity (MW)							Total Capacity MW	Starting Energy Charge USD/MWh	LCOE USD/MWh	Contract Signed? (Y/N)
	2016	2017	2018	2019	2020	2021	2022				
SSEL - biomass		8,0	8,0	8,0	16,0	16,0	16,0	16,0	90,0	90,0	Y for Phase 1
SREL - Hydro Chal						19,3	19,3	19,3	109,0	101,2	N
SREL - Hydro-U- Swasey							9,0	9,0	114,0	105,9	N
Bapcol Solar				5,00	14,95	14,85	14,85	15,0	80,0	96,5	N

Source: BEL

This expansion is from renewable sources, which improves Belize emissions profile.

On the other hand, the power to be installed (59.3 MW) is significant in relation to the size of the system, even taking into account that they are variable and seasonal sources. It is important to note that most of the contracts have not been signed yet and they are under negotiation

The prices of the contracts and the LCOE, adjusted for the availability of the source, are within the international standards of each technology.

In addition, it is important to observe that the implementation of IPP projects will give the electrical system more resources for voltage regulation.

These projects are incorporated into the projection scenarios with the capacity, costs, and date of commissioning that are planned by Belizean authorities.

1.5.2 Expansion Hypothesis 2020-2035

In this chapter, it is explained the main decisions involved in the planning of Belize's electricity expansion. In this phase, it will be proposed and validated with BEL several scenarios. For the construction of these alternative system expansion scenarios, different dimensions have been analyzed. Among others it is point out these relevant issues, dimensions that shall be used to evaluate and compare the scenarios:

- System costs should be minimized, analyzing the LCOE of the different technologies available considering Belize's primary energy resources.
- Analysis of the generation / import combination, together with an adequate and efficient development of the transmission grid.
- System reliability and the need of backup power.
- Flexibility and diversification of the supply portfolio
- Sustainability and reduction of emissions of greenhouse gases

On the other hand, the set of proposed alternative solutions should incorporate decisions on different aspects relevant for both socioeconomic and energy policies:

- The level of failure admitted for the design of the system.
- The desire for the use of available primary resources, and the interaction with other productive developments (e.g. biomass).
- The desired degree of integration with other countries.
- Energy efficiency and environmental policies.
- Land use and water resources. Protected areas.

1.5.2.1 Interconnection and synergy with grid development

For network decisions associated with supply, it is also essential to evaluate new possible interconnections and the expansion of existing ones. Specifically, the planning of the transmission system can include expanding the interconnection capacity with Mexico to 100 MW through a new 115 kV line from Belmopan. This solution, besides increasing the exchange capacity with Mexico, allows an improvement of voltage regulation in the Belmopan area.

The interconnection with Guatemala will not be developed in the short term. It is an investment that could be considered only after the development of commercially viable gas in Guatemala near the border with Belize, which could then be associated with a thermal power station with lines to the SIEPAC. Therefore, this interconnection will not be incorporated in the projection period.

1.5.2.2 Non-conventional Renewable Energy

As mentioned, productive projects of national interest should be incorporated into the study. In particular, the projects related to the development of sugar cane and other agribusiness with associated electricity co-generation, which may have a significant weight. It is necessary to give these projects strategic priority, while at the same time it is important to ensure an adequate transfer price to the electricity market, and to manage eventual impacts on the electricity dispatch and storage operation.

Belize has potential for the development of non-conventional renewable energy, in particular solar photovoltaic and wind power. Both are generation technologies with significant levels of variability that would increase the variability and uncertainty of the whole system, a situation that the power system operator will have to manage. However, as Belize has this potential, which can achieve both environmental and cost benefits, variable energy should be incorporated in future planning portfolios.

In order to be able to compare portfolios, with and without variable generation, it is necessary to set the acceptable annual risk level of the system. When significant amounts of variable energy are incorporated into the system, it is necessary to ensure adequate backup levels to fulfill demand and maintain network security. In the international market there is already a lot of accumulated experience in incorporating important amounts of energy with high short-term variability in the energy matrix.
Experiences such as the Uruguayan and Danish electricity systems, with high penetration of wind energy, can be used to understand the requirements for the safe operation of such a system. In addition, Belize's electrical system has starting conditions that allow the incorporation of significant amounts of variable energy: the existence of spinning power of hydroelectric plants and a strong back-up of power in the interconnection with Mexico. There is also the possibility of incorporating thermal generation with quick response. In conclusion, the incorporation of variable resources should be considered.

1.6 Construction of the expansion scenarios

In the construction of the planning scenarios of the system, different hypotheses will be used on three main areas: Supply alternative portfolios, Demand evolution and Oil prices.

1.6.1 Alternative Supply Portfolios

Although the demand projection will be revised, DNV projection is taken as a reference, in which demand grows approximately 50% in 10 years. Consequently, in all cases the interconnection with Mexico is necessary extended as minimum to 100 MW.

a. Maximization of integration. Use of the interconnection and its contract as much as possible, minimizing the installation of new generation plants.
b. Medium integration. Find a mix of expansion with contribution of the interconnection and own generation.
c. Greater National Support. Define a maximum energy of the interconnection (for e.g. 30%) and the rest is covered with new local generation.

1.6.2 Demand alternatives

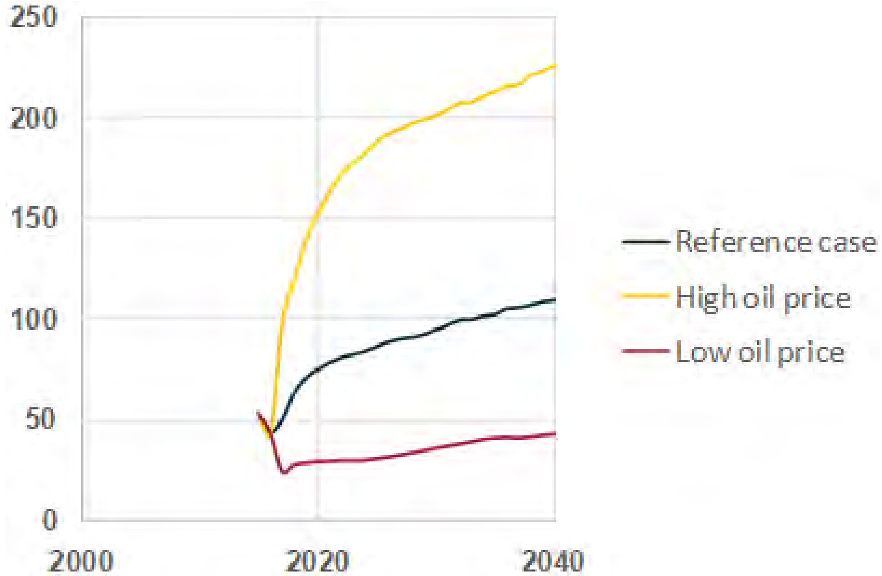
a. Historical evolution - Business as usual
b. Evolution with improvements (EE - loss reduction - etc.)

1.6.3 Oil prices

The projection scenarios of the EIA will be used:

a. High
b. Reference Case
c. Low

Graph 1.8. Crude Oil Prices Dollars per Barrel, 2016



Source: IEA, 2016

It is important to consider oil price projections, since there are generation costs that will be linked to these prices. In particular, thermal generation with HFO or gas, and the interconnection with Mexico have prices linked to oil costs, while hydro, wind, solar PV, and biomass are not influenced by the price of oil. Different future values of oil prices can lead to different combinations of generation sources.

This is seen in the studies of Castalia (2014, oil USD 100) and the studies of IDB-Mercados Energéticos (2016, oil USD 50).

Chapter 2

Demand Forecast and Generation Portfolios

2.1 Demand forecast 2020 - 2035

Chapter two starts reviewing the demand forecasts available for the timespan that is the objective of the study, and then propose other version for demand evolution. Then it gets into the Generation Expansion Plan, evaluating those available, including the information submitted by BEL and Belize authorities, and the decisions that have been made lately that influence the expansion trend for electricity generation in some way. The hypotheses were reviewed for each expansion plan and go on to formulate Clerk's own scenarios, which could alternatively be implemented, based and depending on a few strategic decisions, mainly the degree of dependency with cross border interconnections that is considered acceptable by Belize officials.

Finally, forward recommendations are done, regarding electricity generation expansion and interconnection in Belize, for the period 2020-2035.

2.2.1 DNV forecast

The Final Report of COST OF SERVICE & TARIFF STUDY, produced by DNV for BEL, is dated in April of 2017. In what follows, summarily some of its conclusions are presented, relevant to the study.

This Report included several tasks, two of them related to demand forecast and investments plans.

Task 2: Demand Analysis and Forecast
Analysis of existing customer demand
Demand Forecasting: Conceptual Background
Demand Forecast Results

Task 3: Cost Review and Projections
Review of BEL financial performance
Review of Investment plans and Cost projections

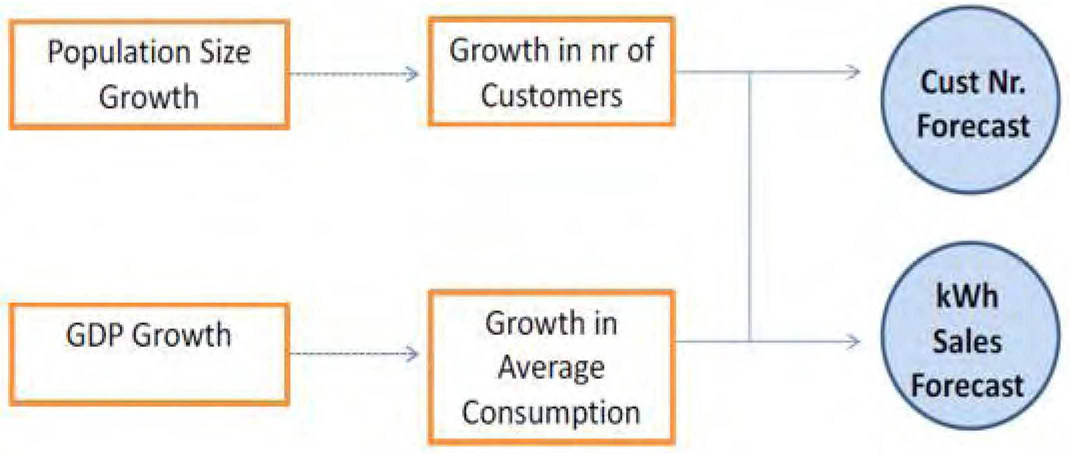
Tasks 4, 5, 6 refer to tariffs allocation and related issues.

As typically used for demand forecast, DNV applied the following criteria:

"For the demand forecasting an economic methodology has been adopted. In particular, two key economic variables namely population growth and Gross Domestic Product (GDP) growth are used as primary drivers for demand growth."

Figure 2.1 shows the methodology adopted by DNV.

Figure 2.1. Overview of Demand Forecast Methodology



Source: DNV

The customers forecast is applied to each category of customers separately. The growth in the number of costumers is assumed correlated with the growth of population.

To determine the correlation between population and customer growth, the elasticity is calculated with recent historic data (2000-2014) that represents the increase in the number of customers, referred to the annual increase of population. This elasticity is used to forecast the number of costumers based on population quantity.

For energy consumption per costumer, the elasticity between average consumption and GDP per capita is calculated, using recent historic data (2000-2014). This elasticity is then used to forecast the average consumption per costumer, based on GDP per capita forecast.

The elasticities calculated by DNV are showed in Table 2.1.

Table 2.1. Overview of Elasticity Factors Computed

Customer Category	ε_{kWh}	ε_C
Industrial & Commercial	0.98	1.27
Residential	0.98	1.27
Street Lighting	0.98	1.27

Source: DNV

The population growth shows stable rates in the analyzed period (2001-2013), situated from 2.5% to 2.7% per year.

GDP growth is positive in the analyzed period (2004-2014), but variable from 1% to 5%. Consequently, with the uniform growth of population, the GDP per capita shows positive and negative performances, from -2% to +2%.

- With those considerations, DNV constructed three scenarios, Low, Base and High, showed in Table 2.2.

Table 2.2. Summary of Scenarios Adopted in the Forecasting

Scenario	GDP/Capital growth	Population Growth
Low	-0.9%	2.5%
Base	0.1%	2.6%
High	+1.1%	2.7%

Source: DNV

The resulting growth rate for annual sales in MWh is 3.4% for the Base Scenario. For the Low Scenario it is 2.3% and for the High Scenario it is 4.5%. Energy sales and customer forecasts are show in the following Tables.

Table 2.3. Demand Forecast Results (Base Case)

	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Nr customers											
Social	6,448	6,660.45	6,879.89	7,106.57	7,340.72	7,582.58	7,832.41	8,090.47	8,357.03	8,632.38	8,916.79
Residential	62,737	64,804.05	66,939.20	69,144.70	71,422.86	73,776.09	76,206.85	78,717.69	81,311.27	83,990.29	86,757.59
Commercial 1	16,205	16,738.92	17,290.43	17,860.11	18,448.56	19,056.40	19,684.27	20,332.82	21,002.74	21,694.74	22,409.53
Commercial 2	1,330	1,373.82	1,419.08	1,465.84	1,514.14	1,564.02	1,615.56	1,668.78	1,723.77	1,780.56	1,839.23
Industrial 1	4	4.13	4.27	4.41	4.55	4.70	4.86	5.02	5.18	5.36	5.53
Industrial 2	5	5.16	5.33	5.51	5.69	5.88	6.07	6.27	6.48	6.69	6.91
Streetlight	54	55.78	57.62	59.52	61.48	63.50	65.59	67.76	69.99	72.29	74.68
BEL Own usages	57	58.88	60.82	62.82	64.89	67.03	69.24	71.52	73.88	76.31	78.82
Total	**86,840**	**89,701**	**92,657**	**95,709**	**98,863**	**102,120**	**105,485**	**108,960**	**112,550**	**116,259**	**120,089**
Sales (kWh)											
Social	3,244	3,354	3,468	3,585	3,707	3,833	3,963	4,098	4,237	4,381	4,530
Residential	178,211	184,263	190,521	196,991	203,681	210,597	217,749	225,144	232,790	240,695	248,869
Commercial 1	87,789	90,770	93,853	97,040	100,335	103,742	107,266	110,908	114,675	118,569	122,595
Commercial 2	187,197	193,554	200,127	206,923	213,950	221,216	228,728	236,496	244,527	252,831	261,417
Industrial 1	10,085	10,427	10,781	11,147	11,526	11,917	12,322	12,741	13,173	13,621	14,083
Industrial 2	40,467	41,841	43,262	44,731	46,250	47,821	49,445	51,124	52,860	54,655	56,511
Streetlight	26,238	27,129	28,050	29,003	29,988	31,006	32,059	33,148	34,273	35,437	36,641
BEL Own usages	2,474	2,558	2,645	2,735	2,828	2,924	3,023	3,126	3,232	3,342	3,455
Total	**535,705**	**553,897**	**572,707**	**592,156**	**612,265**	**633,057**	**654,555**	**676,784**	**699,767**	**723,531**	**748,101**

Source: DNV

These forecasts do not include hypothesis about Energy Efficiency, autogeneration (as for example solar photovoltaic in customer premises), or new consumption drivers such as electric vehicles.

Comments on DNV forecast

The methodology applied is the one typically used for energy sales forecast, where the projections are based in GDP and population growth. In this case, the correlation with GDP was done by GDP per capita and population, while it would be also valid using general projections of GDP directly.

The international and local sources of information were incorporated, using all the available information. The results are consistent as expected. The only comments, therefore, is that the study did not take into account future possible changes in the consumption behavior, introduction of own generation by customers, energy efficiency, and new consumptions such as electric vehicles.

2.2.2 Mercados Energéticos (ME) Forecast

ME Group produced in October 2016 a report called "Belize Interconnection I Phase_V3.2" and annexes "*Belize Interconnection I Phase_Appendix_V3.2*", studies financed through IDB.

In the Executive Summary of the main report, "Chapter 3 - Projected Demand", they describe what was done for forecasting electricity demand, and the results obtained.

"Two regression models were built to reasonable project demand growth in Belize. One is based on the GDP and population growth as explanatory variables and the second one is based only on GDP growth. It was observed that the model with two variables better represents the two main aspects that are present in the demand growth of developing countries: macroeconomic growth and degree of electrification and is the model chosen to project the demand in Belize.

- For projecting the demand for electricity for the next 15 years (2016-2030) two scenarios were used. The first one corresponds to a Business as Usual Case (BAU) where basically the demand growth continues to respond to economic and population growth. In the low growth scenario, the introduction of energy efficiency measures and distributed generation is assumed (EE&DG).
- Demand projection for the BAU assumed GDP growth and population growth in the short term (2016-2020) according to FMI projections of April 2016. From 2021 onwards, it was assumed for the population, the average growth of the last ten years (2.0 %) and for GDP growth the average of the short-term growth forecast (2.3 %).
- The projected demand for the BAU case presents a Compound Annual Growth Rate (CAGR) of 4.4%, which is similar to the historic value.
- Demand projection for the low case (EE&DG) was built based on the assumption that there is room for efficiency gains and energy savings, including distributed generation, so a 15 % of energy savings by 2033 is achieved. The resulting savings in the annual demand growth rate with respect to base case are approx. 1 percentage points. The regression model for this case uses GDP only as explanatory variable as it was found to be a better fit.
- The peak demand was projected, based on the relation between the energy demand and the peak demand through the Load Factor.

For the BAU case, it was assumed that the peak demand growth follows the historical trend (last five years) of 3.1% until 2020 and then follows the growth rate of the energy demand.

For the EE+DG case, it was assumed that the peak demand growth follows the historical trend (last five years) of 3.1% until 2018 and then follows the growth rate of the energy demand minus 1%.

Given the high cost of electricity in Belize as compared to other countries in the region, its high growth of expected electricity demand when compared to other neighboring countries highlights the need to secure the supply of cheap electricity to the country while developing economically-feasible renewable energy options and fostering increasing energy efficiency measures."

In the extended report, Chapter 3 Projected Demand, it is exposed detailed of the methodology applied, data inputs and results. Regression models for GDP+Population and GDP were adjusted with data inputs of the period 1992-2014. Table 2.4 represents the estimated growth with GDP and Population drivers.

Table 2.4. BAU Case – projected Demand and Explanatory Variables

Year	Population		GDP (at market prices)		Demand	
	000 inhab	%	constant $	%	GWh-year	%
2010	324	2.7%	2,451	3.3%	426	2.1%
2011	332	2.6%	2,502	2.1%	428	0.5%
2012	341	2.6%	2,596	3.7%	462	7.9%
2013	350	2.6%	2,630	1.3%	484	4.7%
2014	359	2.6%	2,737	4.1%	498	2.9%
2015	368	2.6%	2,771	1.2%	536	7.6%
2016	371	0.7%	2,839	2.5%	555	3.7%
2017	379	2.2%	2,910	2.7%	579	4.3%
2018	386	1.8%	2,982	2.6%	603	4.1%
2019	394	2.1%	3,055	2.5%	628	4.2%
2020	402	2.0%	3,131	2.4%	654	4.2%
2021	410	2.0%	3,209	2.0%	682	4.2%
2022	420	2.5%	3,288	2.3%	712	4.5%
2023	430	2.5%	3,370	2.3%	744	4.5%
2024	441	2.5%	3,453	2.3%	777	4.5%
2025	452	2.5%	3,539	2.3%	812	4.5%
2026	463	2.5%	3,627	2.3%	848	4.5%
2027	475	2.5%	3,716	2.3%	886	4.5%
2028	486	2.5%	3,809	2.3%	925	4.5%
2029	498	2.5%	3,903	2.3%	966	4.5%
2030	510	2.5%	4,000	2.3%	1,010	4.5%
2031	523	2.5%	4,099	2.3%	1,055	4.5%
2032	536	2.5%	4,200	2.3%	1,102	4.5%
2033	549	2.5%	4,304	2.3%	1,151	4.5%
2034	563	2.5%	4,411	2.3%	1,202	4.5%
2035	577	2.5%	4,520	2.3%	1,256	4.5%

Source: Mercados Energéticos Forecast

These results correspond to the Basic Scenario, without other considerations, as could be the case of expected gains in Energy Efficiency. Once the modification of consumption behavior is considered, the growth of demand decreases, with a hypothesis to reduce 15% up to 2033.

With these hypotheses the demand growth rate decreases close to 1% per year and ends in a difference of approx. 200 GWh/year in 2035, 1256 GWh (BAU) compared to 1043 GWh (EE&DG).

Additionally, evolution of Peak Demand was analyzed, key to determine power requirements in the System, generation plus imports to warrant energy supply. These projections were done in two scenarios, BAU and EE&DG.

Table 2.5. Projected Peak Demand- Both Scenarios

	BAU Scenario		EE&DG Scenario	
	Peak Demand	Load Factor	Peak Demand	Load Factor
	MW	%	MW	%
2016	95.3	66.5%	95.3	66.5%
2017	98.2	67.3%	98.2	67.3%
2018	101.2	68.0%	101.2	68.0%
2019	104.3	68.7%	104.3	68.1%
2020	107.5	69.5%	106.7	68.8%
2021	110.8	70.2%	109.2	69.4%
2022	115.4	70.4%	111.7	70.1%
2023	120.6	70.4%	114.3	70.8%
2024	126.0	70.4%	116.9	71.4%
2025	131.6	70.4%	119.6	72.1%
2026	137.4	70.4%	122.3	72.8%
2027	143.6	70.4%	125.2	73.5%
2028	150.0	70.4%	128.0	74.2%
2029	156.7	70.4%	131.0	74.9%
2030	163.7	70.4%	134.0	75.6%

Source: Mercados Energéticos Forecast

Comments of ME/IDB forecast

In this report, demand means exactly sales of energy. Long period of data inputs were used to adjust regression models (1992-2014).

Typical forecast based directly in GDP+Population correlation with energy consumption growth was used, with a result of annual growth between 4.1% and 4.5%, average of 4.4% in the period 2016-2035.

Additional hypothesis about Energy Efficiency were introduced, with an effect of minus 1% in annual energy consumption. Final analysis of demand peak (MW), critical to define generation power to install and plus import capacity, was included in both scenarios.

2.2.3 CLERK Revision and Proposal

The demand studies carried out by DNV and Mercados Energéticos Consultores, with different methodologies, provide very good information to prepare the demand scenarios that will be used in the simulations of the Belize electricity system.

DNV and ME use similar methodologies, but in different ways. GDP and Population based forecast were done in both studies. DNV added an intermediate step, introducing kWh/customer as a variable to project, while ME projects directly using the correlation demand vs. GDP/Population. Another difference is in the period taken in account to define the correlation with the drivers. DNV uses the period 2000-2014 for both drivers, while ME uses different criteria to select these base periods. All of them explain values of forecast demand ratios. In summary, the comparison of results is as following

- DNV High Scenario is similar to BAU (base without EE) ME Scenario (approx. 4.4%).
- DNV Base Scenario is similar to BAU minus EE&DG ME Scenario (approx. 3.1%-3.8%).
- DNV Low Scenario doesn´t have a similar one in ME projections (approx. 2.3%).

In the projections made by Clerk the growth resulting from the Business as Usual scenarios of both consultants was used.

Based on the real demand of 2016, the average growth of the period used was 3.4% for DNV and 4.42% for Mercados Energéticos Consultores.

To build demand at the generation level, it was assumed, in the BAU scenarios, that transmission and distribution losses remain constant during the analysis period. Given the volatility of the transmission losses, the 2007-2016 average was used for the projections.

Table 2.6. Demand Grow – Generation Level

		BAU
	DNV Average	Mercado Energéticos
	3,40%	4,42%
Changes and improvements	2,85%	3,84%

(*)The growths shown as a summary are the averages of the period

Source: Own elaboration

To complete the analysis, changes and improvements were made to the Business as Usual projections.

Four changes or improvements to the system were defined between 2018 and 2035.

1. Improvements and energy efficiency programs will allow to reduce the demand to 2035 by 15%. This value is in line with the analysis conducted by Mercados Energéticos Consultores. The assumption used is slightly lower than that of Mercados Energéticos since the decrease is proposed to 2035 instead of 2033. This is an improvement that can be achieved as planned changes are carried out.
2. Incorporation to the electrical system of new demands that represent a growth of 5% in the total of the years of the projection. It is a limited growth that must be seen together with the improvement of efficiency. International trends indicate a continuous "electrification" of energy demand; and also, specifically, an important entrance of electric vehicles to the auto market is estimated in the period.
3. The reduction of transmission losses was defined in two categories. One related to different improvements in the network; and the other specifically with the new interconnection line with Mexico. The improvements are described in the Transmission System chapter. This 15% improvement occurs linearly between 2018 and 2022, taking the transmission losses from 5.19% to 4.53%.
4. The commissioning of the second interconnection line with Mexico, allows an additional reduction of 5% in the year 2023. The transmission losses go down to 4.30% and remain constant until 2035.

Table 2.7. Changes and Improvements

Changes and improvements	%
Eneergy Efficiency to 2035	15%
New demands to 2035	5%
Reduction of transmission losses to 2035	15%
Reduction of transmission losses - Second line of Interconnection	5%

Source: Own elaboration

In summary, from the studies conducted by DNV and Mercados Energéticos Consultores; plus, the review and incorporation of improvement strategies carried out by the Clerk professional team, it is understood that an evolution of the demand at the generation level varying between 2.85% and 4.42% in the period, will adequately represent the possible future conditions of the Belize electricity system.

The different scenarios of evolution of the energy demand also define different scenarios of power peaks in the network.

To estimate the load factor of the system, the historical energy and power data of the Mercados Energéticos report were used.

The load factors were calculated for each year between 2012 and 2016. As there is little dispersion in the values, the average load factor was used.

Table 2.8. Changes and Improvements

Year	Grid Energy Supply	Peak Demand	System Load Factor
	MWh	MW	%
2012	528,172,489	81.1	74.34%
2013	550,952,578	83.3	75.50%
2014	566,018,720	85.6	75.48%
2015	601,879,568	92.5	74.28%
2016	614,669,588	95.3	73.63%
	Average		74.65%

Source: Own elaboration

This average load factor was then used to calculate the monthly peak for each energy demand projection. It was assumed that there is no improvement of the load factor in the period of the study.

2.3 Oil and natural gas prices projections

To build the oil prices projection scenarios, three cases of the EIA[15] Annual Energy Outlook 2017 were used. The reference case and the two extreme scenarios were used: high and low oil prices.

As mentioned, the objective of the projections is not to effectively forecast the future, but to model what the behavior of the system would be in different situations.

Clerk understands that, with these three scenarios, all future possibilities are included in the analysis; therefore, the behavior of different options of expansion of the energy supply can be evaluated adequately.

According to what the EIA report makes explicit, the Reference case assumes the crude oil prices (Brent Spot 2016), as is shown in Graph 1.8.

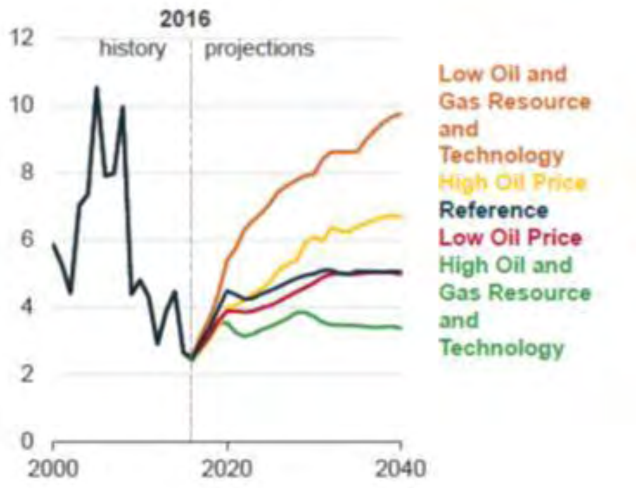
Although the Belizean market does not use natural gas, this fuel is very relevant for the simulation of the prices of the interconnection with the CFE.

The changes foreseen in the supply portfolio from Mexico include a high participation of combined cycles with natural gas. EIA projections were also used for natural gas prices.

For the simulations, the scenarios of high, low and reference oil prices were correlated with those of natural gas.

[15] United States Energy Information Administration

Graph 2.1. Henry Hub Natural Gas Price, 2016, dollars per million Btu



Source: EIA Report

The EIA report explains some conceptual foundations of the projections:
"…

- Trend improvement in known technologies, along with a view of economic and demographic trends reflecting the current central views of leading economic forecasters and demographers.
- Current laws and regulations affecting the energy sector, including sunset dates for laws that have them, are unchanged throughout the projection period.
- The potential impacts of proposed legislation, regulations, or standards not reflected in the Reference case.

…"
In general, and on the other cases, the EIA report indicates that oil prices are driven by global market balances that are mainly influenced by external factors to the NEMS model. In the High Oil prices case, the Brent crude in 2016 dollars reaches $226 per barrel by 2040, compared to $ 109/b in the Reference case and $ 43/b in the Low Oil Price case.

2.4 Generation Expansion Plan

To propose a Generation Expansion Plan, the different scenarios presented in the existing documentation must be considered first:

- DNV and ME reports are recent, 2016-2017.
  - DNV, however, is focused on demand forecast and tariffs, and does not get into generation expansion.
  - ME, even though it is focused on interconnections, to fulfill their objective included demand forecasts and possible scenarios of local generation to combine with complementary import scenarios.
- A third study, Castalia, was done in 2014, and its conclusions were provided to us by Belize authorities.

So, there are two precedent reports on generation expansion available, ME and Castalia. In what follows, those reports are reviewed and, based on the available information and on Clerk's own elaboration, alternatives will be proposed.

2.4.1 Mercados Energéticos Scenarios

The main conclusions of the report referring generation plus import scenarios were explained in the Executive Summary of the ME Report (hereof, in italics what belongs to the ME Report).

"....

ENERGY SUPPLY OPTIONS

- The most recent RFPEG launched in 2013 provided a set of more than 60MW of firm and partially firm renewable energy projects with competitive prices.
- The LCOE of biomass and hydro-ROR projects observed in the RFPEG are consistent with other bids of similar technologies of recent tenders in the Latin America region.
- When considering imports, the ranking of options according to LCOE clearly puts Mexico (63 US$/MWh) and Guatemala (87 US$/MWh) ahead of other indigenous firm sources in Belize that range between 101 and 113 US$/MWh

..."

Related to the Optimal Generation Expansion Planning the report indicates:

- The expansion possibilities of the system were analyzed under two scenarios of demand growth (average and low).
- Sources of supply consisted of Belize's own renewable sources and the expansion of the interconnection capability with neighboring countries (Mexico and Guatemala -MER) while meeting a set of planning criteria for a study horizon of 15 years (2016-2030).
- Six (6) scenarios were defined. The no-interconnection case for the system expansion using only local sources, the reinforcement of interconnection with Mexico to 100 MW and the building of a new interconnection with Guatemala (100 MW). Each of these 3 cases was analyzed for the two (2) demand scenarios.
- Existing PPAs were represented in terms of costs in accordance to the existing contracts.
- Energy from local renewable energy sources is dispatched with priority over thermal plants or imports.
- The interconnection capacity is considered as a firm source of power.
- The total costs for the cases with interconnection with Mexico or Guatemala are lower than the cases without interconnection, for both demand cases. This clearly shows that the interconnection presents a benefit to the system as the increase in transmission costs is less than the benefits due to savings of operation and investment cost when importing.

The report details the technical options of different interconnection alternatives and their costs. Clerk understands that because of the objective of the ME studies, they were focused on the development of interconnection solutions to attend demand growth, comparing with base scenarios without any increase of import capacity. All alternatives were analyzed for the BAU Scenario and the BAU minus EE Scenario.

For local generation, they assumed existing generation and new PPI generators that were already committed. The Executive Summary continues evaluating other issues, as environmental and social, economic evaluation of interconnections, risk analysis of interconnections and recommendations.

The report concludes that the best options of interconnection are the ones with Mexico, and it would be advisable to keep open the option with Guatemala. While this is less economically attractive, with more regulatory challenges; on the other hand, it presents the long-term benefits associated with the integration with the rest of Central America.

It must be highlighted that the power peak in 2035 will reach approximately 200 MW in the most optimistic scenario (163 MW in 2030). This means an approximate increase of 100 MW in the period, where 50 MW of this peak power increase would be covered with a second transmission line with Mexico Interconnection, and the rest should be covered with local generation or eventually, partially, with a new Guatemala Interconnection. PPIs in course provide 77 MW to be put in operation up to 2022.

In Clerk's opinion, a second stage of generation capacity expansion not yet planned, to be introduced after the second line to Mexico and the new PPIs, could introduce more renewables, wind and solar photovoltaic. This is feasible in sizes compatible with low system operation risk, so that it should be considered. Eventually some extra MW in power back up could be considered.

2.4.2 Castalia Scenarios

The summary of the Castalia study focuses on generation expansion, new renewable generation and energy efficiency. The rationale of the study is to compare costs between different power sources. The main issue to observe is that the work is of 2014, when the oil price was over 100 USD/bbl. Other sources are compared in cost of generation, particularly import cost, indexed with oil prices. In these comparisons, solar photovoltaic, wind, biomass and alternatives combined, were cheaper than interconnection prices. Under this hypothesis, as expected, expansion of generation results in the mentioned sources as the most convenient.

Regarding demand forecast, the results were similar in DNV and ME reports (ME was done two years later), reaching approximately 1500 GWh/year in 2035. Referring saved energy, EE and others, the Castalia conclusions were, in Clerk's opinion, too optimistic, sized in 24% up to 2035, compared with BAU projection. In summary, conclusions on the ranking of generation costs depend heavily of oil prices, considering that some generation and imports are indexed in oil prices, while other as hydro, solar, biomass and wind, and are not indexed in these prices. This issue will be considered in the proposal review.

2.4.2 Clërk Revision and Considerations

CLERK has started this work with the revision of all the available studies done from 2009 to 2016, incorporating critical information given by BEL, in order to have a consistent and updated start point for the new projections performed in this work.

In particular, CLERK considers as a fundamental hypothesis the construction of a second line of interconnection with Mexico and the elimination of isolated systems in the Cayes by submarine cables. As will be shown, this second line with Mexico in 115 kV solves the supply of demand up to 2035. Only with high demand growth, over 4%, this expanded interconnection with CFE (two lines 115 kV) will be saturated after 2030. Although it will be explicit in the analysis of the transmission network (Section 7), it must be highlighted that it also provides many advantages to the stability of the system.

In this Report, the internal load flows in the transmission network is not analyzed, but it is assumed that the future power backups (GT+Motors) will be localized conveniently close to the major demand buses. Likewise, and as it emerges from the analysis, the prices of imports from Mexico are very competitive compared to local generation options, considering the reference or the low scenarios for oil and gas prices, For the high price oil and gas scenario, CFE prices are close with local hydro and biomass generation, but they remain lower than GT/Motors generation.

The relative size of both markets (CFE-BEL) has also been considered in the portfolio construction process; together with the need for Belize to have an adequate level of autonomy. In this sense, the criterion assumed is to maintain the national power capacity near the peak demand, so that BEL can buy energy normally from CFE, but, in the event some difficulty should appear in any future period, it could supply the national demand.

From point of view of the energy supply, the criterion adopted is to keep the imports from CFE below 40% of the annual demand, except for Portfolio 3. After these basics portfolios considered, one sensitivity evaluation was performed, were new renewables sources are delayed and therefore imports from CFE results over 40% of participation in the mid-term.

Generation can be dispatched with different criteria, In BEL case, dispatch is done following the rules below:

- Hydro Generation, existing (Chalillo, Mollejon, Vaca) and future (New Makal, Suasey), is dispatched using all the possible generation, but they are administrated so that they can supply energy in the dry and the rainy season. All possible energy generation is bought by BEL.
- In the case of bagasse Generation (Belcogen, SSE), all the energy produced is bought by BEL. The production is associated with season production of bagasse, with the characteristics of each plant.
- In the case of renewable Generation, Solar PV and Wind Power, the production is totally dispatched, and all is bought by BEL.
- CFE currently completes the gross energy supply to the demand. Same criteria are applied to future growth of power contracted from CFE up to 100 MW.
- Backup Generation, (GT, Bapcol, and future GT + Motors), is only used to regulate voltage at peak demand and supply zone deficits in emergencies.

2.4.3 Methodology

The construction of possible scenarios of generation expansion and costs of supply is developed in the following steps,

- Demand forecast, in four scenarios, based in DNV and ME forecast, with particular consideration of issues regarding losses and energy efficiency.
- Projection of demand of power and monthly energy of existing generation, based on historic information given by BEL.
- Incorporation of new IPPs, currently in contract negotiation stage, with corresponding power and energy contribution, based information given by BEL.
- Projection of gradual Incorporation of new power and energy generation, including renewables and backup power, to maintain national power backup and energy supply in the parameters already commented.
- Verification of possible outage of service of old generators.
- Cost calculation for each generation source, of existing ones supported in Siemens Report for existing hydros, for CFE – BAL – SSE – BELCOGEN - GT and for the IPPs in negotiation from data supplied by BEL, and for the new generation facilities, using criteria from international references and local conditions.
- Valuation of total cost of supply in each scenario.

The methodology used implies for each one of the defined cases, to calculate in each year the total Cost of Supply of the demand; and then get the Net Present Value (NPV) of each of the solutions using an appropriate discount rate

Obviously, the ones with lower NPVs would be considered more valuable. However, this should be considered a starting point, from where the Belize energy authorities must also assess the risks of each solution and the contribution of different generation options to other governmental projects and objectives.

A discount rate of 10% was used. It should be noted that the 10% discount rate was also used in the study conducted by Mercados Energéticos Consultores.

The rate should have been technically calculated using the capital asset pricing model (CAPM). However, Clerk professionals consider that in this case it could give incongruent results considering the country risk of Belize.

Clerk considers that the 10% rate is adequate to remunerate the weighted capital (own capital + financing) of the generation projects. However, in order to check the consistency of the results, the calculations were also made with rates of 8% and 12%. In all cases the results are stable and the NPV ranking does not change at different rates.

The Levelized Cost of Energy (LCOE) was also calculated for all Cases, considering the total supply costs of the demand and the total energy to the network for each year. The same discount rate of 10% was used for the calculations

The study was conducted in parallel with two tools, on the one hand, a model of analysis prepared for the case by Clerk; and on the other the SimSEE energy simulation tool for some cases as a reference. The SimSEE is the simulator used by the electricity market administration in Uruguay (ADME) for the operation and analysis

The first model is based on average values and has been developed in a spreadsheet considering all the information and hypothesis, as well as current engineering practices for economical dispatch.

Being a small electricity system and considering the high participation of self-dispatched energy under contracts, a model using average values allows a good representation of the system behavior.

On the other hand, SimSEE allows the representation of the stochastic behavior of some variables, such as generation availability, intermittent generation (i.e. wind and solar), rains, stochastic variations of oil prices around average expected values, etc.
As a result, not only average values may be obtained from SimSEE simulations, but also values with specific probabilities of occurrence, such as renewable generation with 50 % probability or 90 % probability, loss of load probability of the system, supply failure, etc.

Of course, the more information that is available from the system to program SimSEE, the more accurate the results obtained.

For this work, it was not in Clerk's scope to develop a complete and detailed parametrization of Belize electrical system in SimSEE, because, in particular, not all the required information was available. However, it is useful to show some results, such as system failure and exceedance probabilities that cannot be obtained from the spreadsheet model.

In addition, Clerk aimed to show the potential of this tool, which has open access and proven effectiveness in the operation and planning of the Uruguayan electrical system.

Clerk's Model

The model for the calculation of energy supply from different sources was developed on a monthly basis, using the past seasonality of the different power plants, and projecting a similar seasonality for the new IPPs, depending on each technology. The peak power was also projected using the existing calculated power factor.

With that basis, it continues filling the different energy blocks using normal practices, that is, local IPPs enter first, and then imports from Mexico. The fossil fuel plants are used only to stabilize voltage and compensate transmission losses, or, very rarely, if there are specific power peak needs.

To size the energy needs and to size the new generation requirements, the local generation objective must be defined or, conversely, the percentage of imported energy that is strategically acceptable. In that way, the needs of local energy supply to be added to the system in the future, over new IPPs can be determined. Non-conventional energy sources are selected to fulfill these needs (wind and solar power).
Finally, to calculate the system's backup power needs, the intermittent generation facilities (i.e. wind and solar) are not taken into account, in order to size the interconnection and eventually new turbines to be put in operation.

Once having projected the energy and power needs, the cost of supply for the whole system can be calculated on a monthly and yearly basis, as well as the required investments.

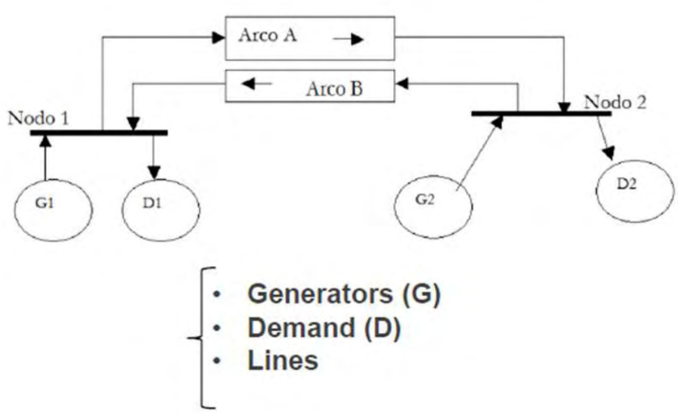
In addition, as mentioned before, a second tool was used to produce detailed information for each of the cases studied, SimSEE.

The SimSEE tool is an open source software produced by the Institute of Electrical Engineering, at the School of Engineering in the University of the Republic of Uruguay.

SimSEE consists on a platform for the simulation of electric energy systems, developed to facilitate the construction of electrical energy simulators in order to analyze different operation alternatives through the simulation of different scenarios, which allows calculate the future costs for each of the possible operation paths, and then try and study the consequences of different possible decisions.

As shown in the next figure, SimSEE allows to represent nodes and branches between nodes. At each node, it is possible to connect generators or demands. Each branch may be modeled with a maximum capacity and losses.

Figure 2.2. SimSEE Representation

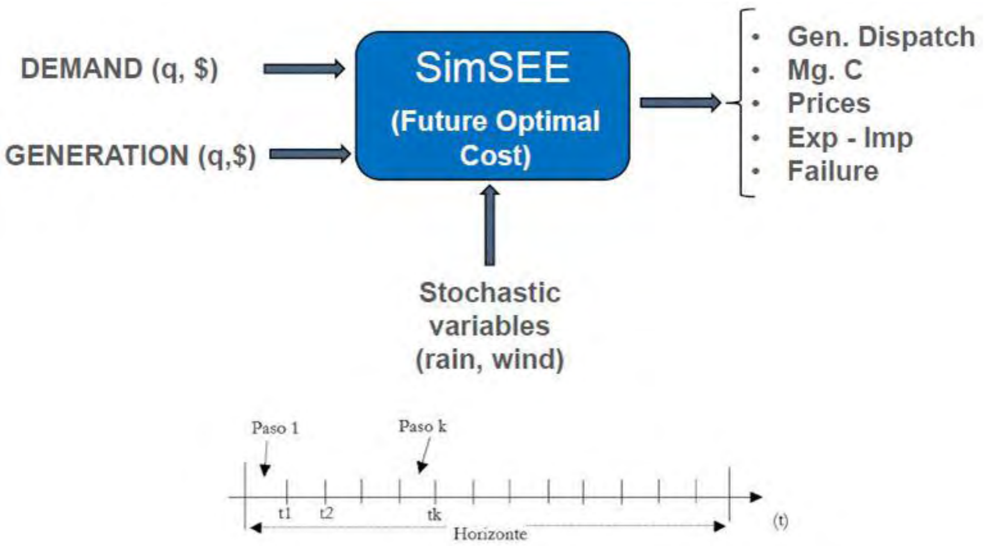


Source: SimSEE

In terms of variables, future demand may be modeled, indicating values for each time step, considering particular scenarios of growth. In addition, generators may be added specifying capacity, variable cost and maintenance program. Variables costs may be linked to other specified variables such as oil prices.

Moreover, SimSEE is able to consider stochastic variables, such as rains, wind or solar resources. For these cases, the stochastic nature of the resources may be modeled and calibrated for particular geographical conditions. Once all the relevant data is introduced, simulations can be performed specifying time step and time horizon. Figure 2.3. shows a diagram for SimSEE, which indicates inputs and outputs.

Figure 2.3. SimSEE Inputs and Outputs



Source: SimSEE

SimSEE allows to obtain the generation dispatch for all the resources, marginal cost of the system, prices, amounts of energy dispatched, imports and exports, and total cost of supply.

2.5 Scenarios Evolution

For the analysis of generation scenarios, evolution for each demand projection is divided in three groups:

Existing generation

- Existing generation put in service up to 2017
- Existing (modified) contract with CFE, 50 MW power
- New Generation
- New IPP in negotiation, that it will be in service from 2018 to 2022
- New generation not planned yet, mainly it incorporates backup power and renewables
- Increase gradually power contracted with CFE, up to 50 MW in addition

Existing generation, currently contract with CFE, and IPP in negotiation, are projected with historic or expected generation, for all the period analyzed. Generation not planed, area increased for goal power backup, national power and energy demand, follow the criteria exposed before.

2.5.1 Generation Evolution

In the following sections, a resume of generation evolution with demand growth is shown. Together is analyzed the duty life and possible replacements in the studied period.

2.5.1.1 Existing Generation in 2017

The following power generation plants are in service up to 2017, dates of in service are also indicated:

Fuel: GT (2003)
Isolated generation (Cayes)
Hydro: Chalillo (2005) + Mollejón (1996) + Vaca (2010) + Hydro Maya (2006)
Bagasse: Belcogen (2009), SSE (2017)

2.5.1.2 New IPP´s 2018-2022

The following power generation plants are through the negotiation process, the expected dates for its operation are indicated:

IPPs 2018-2022:
Hydro: New Macal (2020), Hydro Suasey (2022),
Solar PV: Solar South (2018)
In the sensitivity analysis, these dates are delayed, New Macal (2023), Hydro Suasey (2026), Solar South (2020).
GSR biomass is considered an unfeasible project.

2.5.1.3 New IPP from 2023

New IPP´s will be needed to supply the demand growth after 2022. Clerk considers new IPPs will go into service gradually from 2023 to 2026, depending on demand growth and renewable policies.

After the construction of SREL Suasey, Belize won´t incorporate new Hydro Generation, as there are no new feasible projects in sight. Wind Power and Solar PV are therefore considered to complete the supply of energy demand growth, as these technologies offer competitive prices, and the prevision is that these prices will decrease in the future. Environmental advantages are an important benefit to justify the use of renewables.

Wind Power and Solar PV are not considered firm power; consequently, the firm backup power will also have to grow. This backup can be provided by CFE, but in some scenarios, the need for new local GT and motors is seen.

2.5.2 Possible Generation Replacement

For Hydro plants, 40 years of duty life is usual if they had good maintenance. Habitually, after 40 years in hydro generators, the electric power parts, such as rotor and stator are replaced, and all the speed and voltage control are updated. This kind of upgrade sometimes also allows increasing the power.

The oldest hydro plant is Mollejón, which was put in service in 1996. The other plants were put in service after 2000. Consequently, in the period of the study, it isn´t necessary to upgrade these plants. Gas Turbines have a shorter duty life, of 20-25 years if they are used with intensity. Duty life depends mainly of hours of utilization. The West Lake GT is used only as backup; consequently, the duty life could pass to 2035 if it is maintained as today. Same situation for the Bapcol motors, it can be assessed that they reach 2035 without problems. However, in the new contract the power will be updated to three engines.

Belcogen probably will need a refurbishment before 2035, taking in account it was installed in 2009. All the new IPPs will have been in service less than twenty years, so they won´t be replaced up to 2035. GT, Motors, Wind Power and Solar PV have duty lives of more than 20 years in all technologies.

2.5.3 Portfolios

The construction of the supply portfolios was carried out considering the decisions that have already been taken by the authorities of Belize and the restrictions imposed by the current contracts with their respective maturity dates. In the three portfolios that were simulated, with the available information, Clerk seeks to minimize the generation costs and the investments associated with the transmission network. As it was exposed before, four demand scenarios were considered, the annual values are shown in the following table:

Table 2.9. Demand Scenarios 2017-2035

ENERGY	DNV BASE	ME BASE	DNV LOW	ME LOW
YEAR	MWh	MWh	MWh	MWh
2017	635,568	641,100	635,568	641,100
2018	657,178	667,385	653,162	665,219
2019	679,522	695,416	670,969	689,964
2020	702,625	724,623	689,288	715,656
2021	726,515	755,057	708,134	742,333
2022	751,216	789,035	727,522	770,034
2023	776,758	824,541	746,728	798,006
2024	803,167	861,646	768,194	828,886
2025	830,475	900,420	790,277	860,960
2026	858,711	940,939	812,995	894,276
2027	887,907	983,281	836,366	928,881
2028	918,096	1,027,529	860,409	964,824
2029	949,311	1,073,767	885,143	1,002,159
2030	981,588	1,122,087	910,588	1,040,939
2031	1,014,962	1,172,581	936,764	1,081,219
2032	1,049,471	1,225,347	963,693	1,123,058
2033	1,085,153	1,280,488	991,396	1,166,515
2034	1,122,048	1,338,110	1,019,896	1,211,655
2035	1,160,198	1,398,325	1,049,214	1,258,541

Source: Own elaboration

The Base Scenarios are with growth based in GDP and Population growth. The Low scenarios were built from the Base scenarios adding improvements of energy efficiency and changes on the modality of consumptions. Annual energy is distributed monthly, based in the monthly average distribution of 2015 and 2016 (Source: "Belize - Net Generation by Source 2015 and 2016.xlsx").

Table 2.10. Belize Annually Energy Supply - Monthly Distribution, %

JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
7.35 %	6.76 %	8.30 %	8.63 %	9.10 %	8.67 %	8.97 %	8.99 %	8.58 %	8.54 %	7.92 %	8.19 %

Source: Own elaboration

Table 2.11. Belize Monthly Power Peak – MW 2017-2035

PEAK DEMAND	DNV BASE	ME BASE	DNV LOW	ME LOW
YEAR	MW	MW	MW	MW
2017	115	116	115	116
2018	119	120	118	120
2019	123	126	121	125
2020	127	131	124	129
2021	131	136	128	134
2022	136	142	131	139
2023	140	149	135	144
2024	145	156	139	150
2025	150	163	143	155
2026	155	170	147	161
2027	160	177	151	168
2028	166	185	155	174
2029	171	194	160	181
2030	177	203	164	188
2031	183	212	169	195
2032	189	221	174	203
2033	196	231	179	211
2034	203	242	184	219
2035	209	252	189	227

Source: Own elaboration

Table 2.12. Belize Power Increase, %

DNV BASE	ME BASE	DNV LOW	ME LOW
83%	118%	65%	96%

Source: Own elaboration

Annual costs of generation result from the IPP contracts conditions, or from BEL calculations in the case of own generation. The structure of costs is different for each plant. The following tables show prices structure by plant, with the three oil and gas prices projected in Chapter 3 – Oil and Natural Gas price projections.

Table 2.13. Belize Prices Structure by Plant Power (US$/MW- month) - Energy (US$/MWh)

COSTS POWER + ENERGY	dic-17	dic-20	dic-23	dic-26	dic-29	dic-32	dic-35
OIL&GAS BASE							
Existing Supplies + IPP							
GT							
Power (USD/MW-month)	12,918.8	6,459.4	6,459.4	6,459.4	6,459.4	6,459.4	6,459.4
Energy (USD/MWh)	200.0	299.8	329.7	354.8	368.9	398.8	409.3
BAL/BAPCOL							
Power (USD/MW-month)	23,817.6	23,817.6	23,817.6	23,817.6	23,817.6	23,817.6	23,817.6
Energy (USD/MWh)	115.0	181.5	210.2	238.3	260.9	286.9	299.6
CFE							
Power (USD/MW-month)	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Firm Energy (USD/MWh)	89.5	112.6	108.6	110.4	112.7	113.4	111.6
BECOL (Chalillo)							
Power (USD/MW-month)	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Energy (USD/MWh) first 100 GWh/year	117.0	122.3	127.9	133.7	139.9	146.2	152.9
Energy (USD/MWh) over 100 GWh/year	52.5	52.5	52.5	52.5	52.5	52.5	52.5
BECOL (Mollejon)							
Power (USD/MW-month)	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Energy (USD/MWh) first 100 GWh/year	117.0	122.3	127.9	133.7	139.9	146.2	152.9
Energy (USD/MWh) over 100 GWh/year	52.5	52.5	52.5	52.5	52.5	52.5	52.5
BECOL (Vaca)							
Power (USD/MW-month)	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Energy (USD/MWh)	85.1	88.9	93.0	97.2	101.7	106.3	111.2
O&M (USD/month).	225,298.5	235,589.8	246,351.1	257,604.0	269,371.0	281,675.4	294,541.9
Hydro Maya							
Power (USD/MW-month)	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Energy (USD/MWh)	67.5	67.5	67.5	67.5	67.5	67.5	67.5
Belcogen							

Power (USD/MW-month)	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Energy (USD/MWh) bagasse	105.5	110.8	116.5	122.3	128.5	135.1	141.9
Energy (USD/MWh) fuel	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SSE							
Power (USD/MW-month)	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Energy (USD/MWh)	82.0	82.0	82.0	82.0	82.0	82.0	82.0
SREL New Macal (Chalillo 2)							
Power (USD/MW-month)	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Energy (USD/MWh)	83.2	83.2	83.2	83.2	83.2	83.2	83.2
SREL Suasey							
Power (USD/MW-month)	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Energy (USD/MWh)	83.2	83.2	83.2	83.2	83.2	83.2	83.2
GSR Energy							
Power (USD/MW-month)							
Energy (USD/MWh)							
Solar South							
Power (USD/MW-month)	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Energy (USD/MWh)	75.5	75.5	75.5	75.5	75.5	75.5	75.5
New Supplies							
CFE 2 (Equal to CFE 1)							
Power (USD/MW-month)	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Firm Energy (USD/MWh)	89.5	112.6	108.6	110.4	112.7	113.4	111.6
Economy Energy (USD/MWh)	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Wind							
Power (USD/MW-month)	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Energy (USD/MWh)	54.0	54.0	54.0	54.0	54.0	54.0	54.0
Solar PV							
Power (USD/MW-month)	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Energy (USD/MWh)	60.4	60.4	60.4	60.4	60.4	60.4	60.4
GT + Motors							
Power (USD/MW-month)	18,368.2	15.138.5	15,138.5	15,138.5	15,138.5	15,138.5	15138.5
Energy (USD/MWh)	157.5	240.6	269.9	296.5	314.9	342.9	354.5

COSTS POWER + ENERGY	dic-17	dic-20	dic-23	dic-26	dic-29	dic-32	dic-35
OIL&GAS HIGH							
Existing Supplies + IPP							
GT							
Power (USD/MW-month)	12,918.8	6,459.4	6,459.4	6,459.4	6,459.4	6,459.4	6,459.4
Energy (USD/MWh)	392.7	611.8	713.6	770.9	798.4	832.1	854.6
BAL/BAPCOL							
Power (USD/MW-month)	23,817.6	23,817.6	23,817.6	23,817.6	23,817.6	23,817.6	23,817.6
Energy (USD/MWh)	225.8	370.4	455.0	517.7	564.6	598.7	625.6

CFE							
Power (USD/MW-month)	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Firm Energy (USD/MWh)	113.5	134.8	139.4	140.2	144.2	145.5	143.5
BECOL (Chalillo)							
Power (USD/MW-month)	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Energy (USD/MWh) first 100 GWh/year	117.0	122.3	127.9	133.7	139.9	146.2	152.9
Energy (USD/MWh) over 100 GWh/year	52.5	52.5	52.5	52.5	52.5	52.5	52.5
BECOL (Mollejon)							
Power (USD/MW-month)	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Energy (USD/MWh) first 100 GWh/year	117.0	122.3	127.9	133.7	139.9	146.2	152.9
Energy (USD/MWh) over 100 GWh/year	52.5	52.5	52.5	52.5	52.5	52.5	52.5
BECOL (Vaca)							
Power (USD/MW-month)	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Energy (USD/MWh)	85.1	88.9	93.0	97.2	101.7	106.3	111.2
O&M (USD/month).	225,298.5	235,589.8	246,351.1	257,604.0	269,371.0	281,675.4	294,541.9
Hydro Maya							
Power (USD/MW-month)	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Energy (USD/MWh)	67.5	67.5	67.5	67.5	67.5	67.5	67.5
Belcogen							
Power (USD/MW-month)	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Energy (USD/MWh) bagasse	105.5	110.8	116.5	122.3	128.5	135.1	141.9
Energy (USD/MWh) fuel	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SSE							
Power (USD/MW-month)	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Energy (USD/MWh)	82.0	82.0	82.0	82.0	82.0	82.0	82.0
SREL New Macal (Chalillo 2)							
Power (USD/MW-month)	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Energy (USD/MWh)	83.2	83.2	83.2	83.2	83.2	83.2	83.2
SREL Suasey							
Power (USD/MW-month)	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Energy (USD/MWh)	83.2	83.2	83.2	83.2	83.2	83.2	83.2
GSR Energy							
Power (USD/MW-month)							
Energy (USD/MWh)							
Solar South							
Power (USD/MW-month)	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Energy (USD/MWh)	75.5	75.5	75.5	75.5	75.5	75.5	75.5
New Supplies							
CFE 2 (Equal to CFE 1)							
Power (USD/MW-month)	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Firm Energy (USD/MWh)	113.5	134.8	139.4	140.2	144.2	145.5	143.5

Economy Energy (USD/MWh)	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Wind							
Power (USD/MW-month)	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Energy (USD/MWh)	54.0	54.0	54.0	54.0	54.0	54.0	54.0
Solar PV							
Power (USD/MW-month)	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Energy (USD/MWh)	60.4	60.4	60.4	60.4	60.4	60.4	60.4
GT + Motors							
Power (USD/MW-month)	18,368.2	15,138.5	15,138.5	15,138.5	15,138.5	15,138.5	15,138.5
Energy (USD/MWh)	309.3	491.1	584.3	644.3	681.5	715.4	740.1

COSTS POWER + ENERGY	dic-17	dic-20	dic-23	dic-26	dic-29	dic-32	dic-35
OIL&GAS LOW							
Existing Supplies + IPP							
GT							
Power (USD/MW-month)	12,918.8	6,459.4	6,459.4	6,459.4	6,459.4	6,459.4	6,459.4
Energy (USD/MWh)	98.3	117.8	120.1	126.8	139.7	153.0	165.0
BAL/BAPCOL							
Power (USD/MW-month)	23,817.6	23,817.6	23,817.6	23,817.6	23,817.6	23,817.6	23,817.6
Energy (USD/MWh)	56.5	71.3	76.6	85.1	98.8	110.1	120.8
CFE							
Power (USD/MW-month)	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Firm Energy (USD/MWh)	73.5	88.5	88.2	92.0	97.4	101.3	100.3
BECOL (Chalillo)							
Power (USD/MW-month)	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Energy (USD/MWh) first 100 GWh/year	117.0	122.3	127.9	133.7	139.9	146.2	152.9
Energy (USD/MWh) over 100 GWh/year	52.5	52.5	52.5	52.5	52.5	52.5	52.5
BECOL (Mollejon)							
Power (USD/MW-month)	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Energy (USD/MWh) first 100 GWh/year	117.0	122.3	127.9	133.7	139.9	146.2	152.9
Energy (USD/MWh) over 100 GWh/year	52.5	52.5	52.5	52.5	52.5	52.5	52.5
BECOL (Vaca)							
Power (USD/MW-month)	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Energy (USD/MWh)	85.1	88.9	93.0	97.2	101.7	106.3	111.2
O&M (USD/month).	225,298.5	235,589.8	246,351.1	257,604.0	269,371.0	281,675.4	294,541.9
Hydro Maya							
Power (USD/MW-month)	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Energy (USD/MWh)	67.5	67.5	67.5	67.5	67.5	67.5	67.5
Belcogen							
Power (USD/MW-month)	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Energy (USD/MWh) bagasse	105.5	110.8	116.5	122.3	128.5	135.1	141.9
Energy (USD/MWh) fuel	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SSE							
Power (USD/MW-month)	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Energy (USD/MWh)	82.0	82.0	82.0	82.0	82.0	82.0	82.0
SREL New Macal (Chalillo 2)							
Power (USD/MW-month)	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Energy (USD/MWh)	83.2	83.2	83.2	83.2	83.2	83.2	83.2
SREL Suasey							
Power (USD/MW-month)	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Energy (USD/MWh)	83.2	83.2	83.2	83.2	83.2	83.2	83.2
GSR Energy							
Power (USD/MW-month)							
Energy (USD/MWh)							
Solar South							
Power (USD/MW-month)	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Energy (USD/MWh)	75.5	75.5	75.5	75.5	75.5	75.5	75.5
New Supplies							
CFE 2 (Equal to CFE 1)							
Power (USD/MW-month)	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Firm Energy (USD/MWh)	73.5	88.5	88.2	92.0	97.4	101.3	100.3
Economy Energy (USD/MWh)	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Wind							
Power (USD/MW-month)	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Energy (USD/MWh)	54.0	54.0	54.0	54.0	54.0	54.0	54.0
Solar PV							
Power (USD/MW-month)	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Energy (USD/MWh)	60.4	60.4	60.4	60.4	60.4	60.4	60.4
GT + Motors							
Power (USD/MW-month)	18,368.2	15,138.5	15,138.5	15,138.5	15,138.5	15,138.5	15,138.5
Energy (USD/MWh)	77.4	94.5	98.3	106.0	119.3	131.6	142.9

Sources of the information:

- *For SSE, New Macal, Suasey, GSR, Solar South*
  - *New information sent by BEL in January 2018.*
- *For Chalillo, Mollejon, Vaca, HydroMaya.*
  - *"BEL_Least_Cost_Generation_Planning_Study_Final_Report_V0_SIEMENS.pdf"*
- *For GT, BAL, CFE, Belcogen.*
  - *New information sent by BEL in January 2018.*
- *For new generation after 2023, they are assumed the follow hypothesis.*
  - *GT + Motors – Average between current GT and Bapcol.*
  - *Wind Power – International prices increased in 20%.*
  - *Solar PV – 80% of Solar South, that is close to international references plus 20%.*
  - *For imports from the CFE, the price distortions caused by restrictions on electricity transmission, transportation and gas supply that are presumed to occur in the next two years are not modeled.*
- *It was estimated that these restrictions are being solved in this two-year period.*

For the composition of the generation in Mexico, the Report "Prospectiva 2017 - 2031 of SENER" is used. It presents a matrix of the participation of each technology to supply the demand. In this prospective report, the generation with conventional fuel oil decreases, extinguishing in eight years; and the participation of non-conventional renewables and combined cycles with natural gas grows.

- NG Combined Cycle: constant increase accompanying the demand, but its relative participation decreases slightly.
- Wind (the heaviest in this group), solar, geothermal, nuclear, cogeneration, register a growth that is greater than demand.
- Conventional hydraulics remain but decrease relative weight with the growth of demand.
- Others remain constant, decreasing their relative weight in the total.

The participation of natural gas introduces into the price projections, the high, reference and low scenarios of NG, which are combined with the respective oil price scenarios, as already mentioned in the section on oil and natural gas.
For the generation from the CFE, international reference prices were taken in the case of combined cycles, gas turbines, hydraulic, wind, photovoltaic, geothermal and nuclear turbines.

Specific information on the composition of each price structure is detailed in the Annexes “BEL Generation Plan CLERK……...xlsx”. Nine files, four demand scenarios each, three base cases, three with more renewables, variation with oil and gas prices.

2.6 Cases

In total, 36 cases were simulated. These combine the four scenarios of expected evolution of demand, the three oil price scenarios, and the three supply portfolios described above. Two cases were simulated in SimSEE, in order to verify the results obtained with the spreadsheet model (Case 1.6 and Case 2.6).

Table 2.14. Belize SimSEE Simulaltion

Case	Demand Growth	%	Oil Price	Portfolio Supply
1.1	DNV Low	2,85	Low	1
1.2	DNV Average	3,40	Low	1
1.3	ME Low	3,84	Low	1
1.4	ME BAU	4,42	Low	1
1.5	DNV Low	2,85	Base Case	1
1.6	DNV Average	3,40	Base Case	1
1.7	ME Low	3,84	Base Case	1
1.8	ME BAU	4,42	Base Case	1
1.9	DNV Low	2,85	High	1
1.10	DNV Average	3,40	High	1
1.11	ME Low	3,84	High	1
1.12	ME BAU	4,42	High	1
2.1	DNV Low	2,85	Low	2
2.2	DNV Average	3,40	Low	2
2.3	ME Low	3,84	Low	2
2.4	ME BAU	4,42	Low	2
2.5	DNV Low	2,85	Base Case	2
2.6	DNV Average	3,40	Base Case	2
2.7	ME Low	3,84	Base Case	2
2.8	ME BAU	4,42	Base Case	2
2.9	DNV Low	2,85	High	2
2.10	DNV Average	3,40	High	2
2.11	ME Low	3,84	High	2
2.12	ME BAU	4,42	High	2
3.1	DNV Low	2,85	Low	3
3.2	DNV Average	3,40	Low	3
3.3	ME Low	3,84	Low	3
3.4	ME BAU	4,42	Low	3
3.5	DNV Low	2,85	Base Case	3
3.6	DNV Average	3,40	Base Case	3
3.7	ME Low	3,84	Base Case	3
3.8	ME BAU	4,42	Base Case	3
3.9	DNV Low	2,85	High	3
3.10	DNV Average	3,40	High	3
3.11	ME Low	3,84	High	3
3.12	ME BAU	4,42	High	3

Source: Own elaboration

2.7 Results

In the Belize energy system, current generation and IPPs that will be going into service up to 2022 determine the gross supply of energy in the period, together with imports from CFE. The dispatch criteria, and the contracts with IPPs, determine that all the local energy produced must be dispatched, administrated to assure energy for all the year.

When projecting expansion, sources as hydro and bagasse must be discarded, as they won´t have possibilities of a more expressive expansion after 2022.

To supply extra demand growth through the period, renewables can fill the rest of the requirements. In these perspectives, two packages or portfolios were tested for the introduction of new generation, varying the participation of renewables. Renewables substitute energy importation when they are increased.

In all the scenarios, the introduction of a second interconnection with Mexico is considered, but energy imports vary depending on local generation decisions.

Both portfolios are analyzed for the four demand growth scenarios, and the total supply costs are calculated for the three oil and gas price projections.

Regarding new IPP´s already committed, the following dates to be put into service were considered:

- New Macal: 2020
- Solar South: 2018
- Suasey: 2022

The third case considers these three dates delayed as it was commented.

2.7.1 Portfolio 1

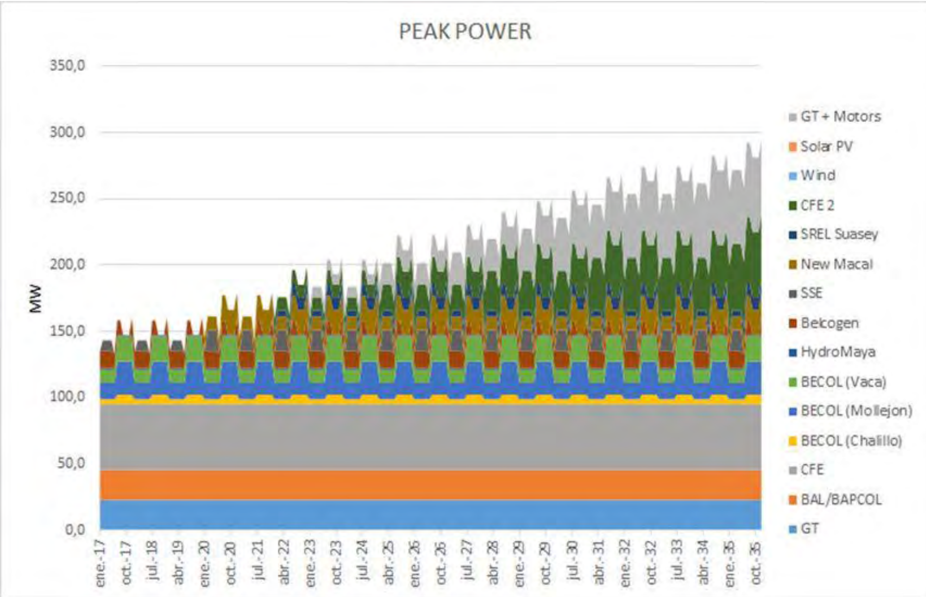
This portfolio uses the energy of the interconnection below 40% of the total demand, incorporating energy in steps according to the needs. Also, the power from the CFE is incorporated in steps, according to the system's power needs (this is not a contractual need, as the payments are energy based). In any case, as an energy security criterion it was verified that at all times the capacity of the local installed power always allowed supplying 90% of the demand.

2.7.1.1 Projections of Power Peak and Energy Supply

In what follows, the power peak and energy supply is shown for each demand projected scenario. See indicated above each power and energy table the dates of accumulated incorporation of new generation post 2022.
DEMAND DNV BASE

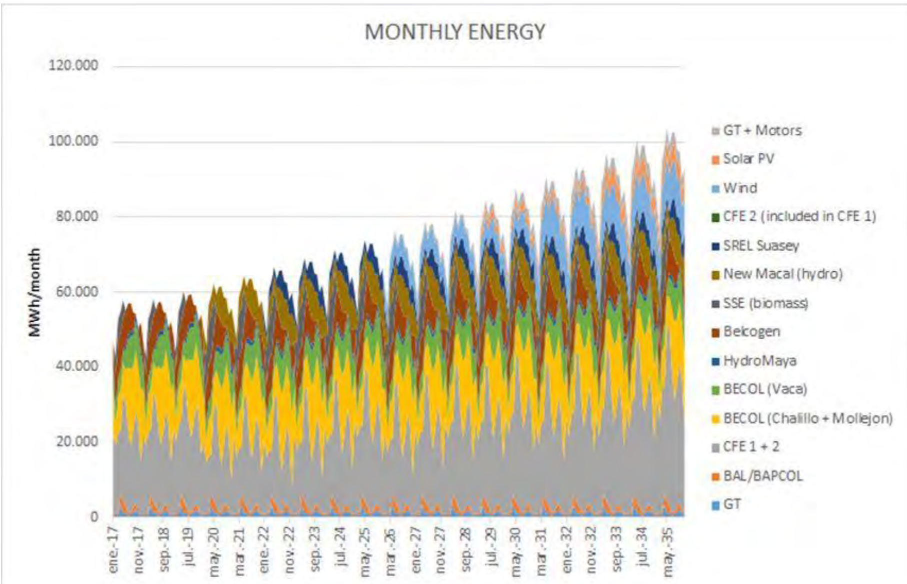
CFE2 (MW/Year): 10/2022, 20/2025, 30/2028, 40/2031, 50/2035.
Wind Power (MW/Year): 20/2026, 40/2031.
Solar PV (MW/Year): 20/2029, 40/2033.
GT+Motors (MW/Year): 8/2023, 16/2025, 24/2027, 32/2029, 40/2030, 48/2032, 56/2034.

Graph 2.2. Belize´s Plants Power Peak, DEMAND DNV BASE-MW



Source: Own elaboration

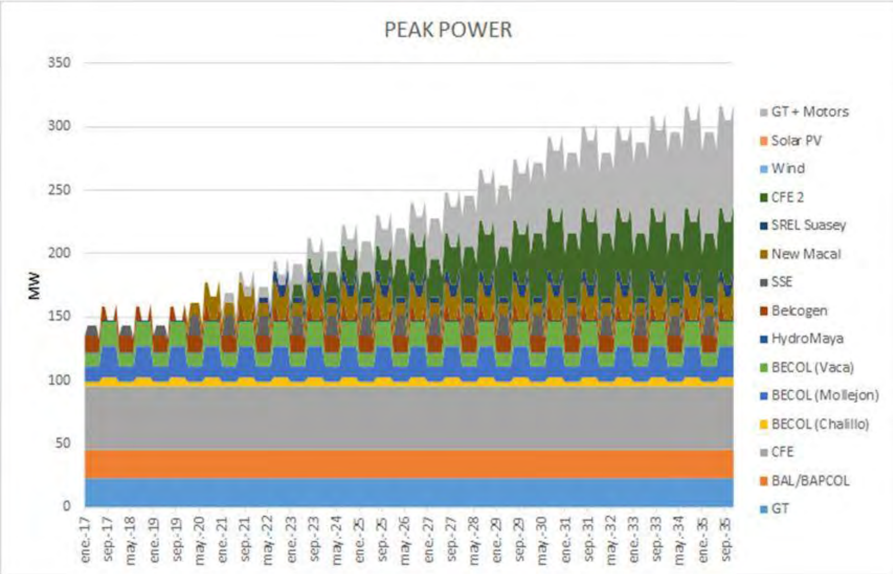
Graph 2.3. Belize´s Monthly Energy Production, DEMAND DNV BASE-MWh/month



Source: Own elaboration

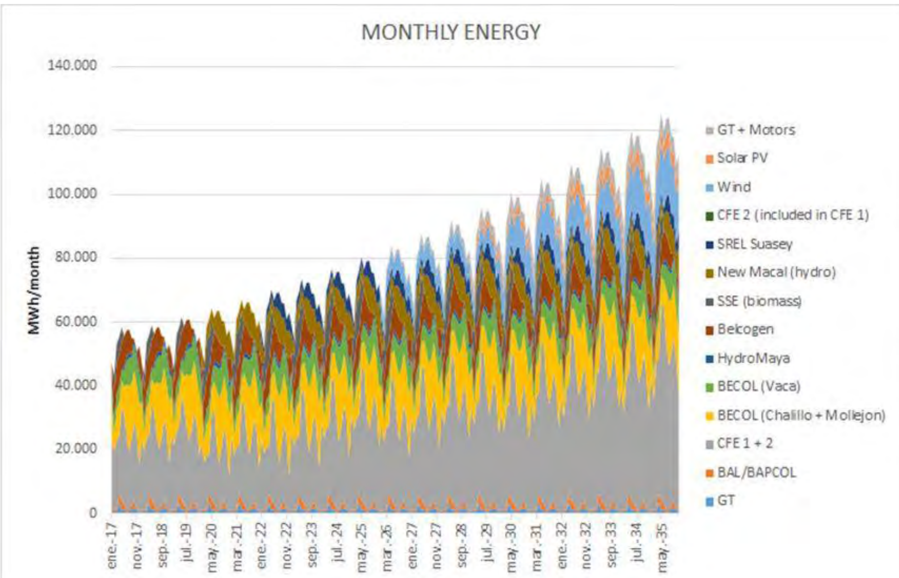
DEMAND ME BASE
CFE2 (MW/Year): 10/2023, 20/2024, 30/2026, 40/2028, 50/2030.
Wind Power (MW/Year): 20/2026, 40/2031.
Solar PV (MW/Year): 20/2029, 40/2033.
GT+Motors (MW/Year): 8/2021, 16/2023, 24/2025, 32/2027, 40/2028, 48/2029, 56/2030, 64/2031, 72/2033, 80/2034.

Graph 2.4. Belize´s Plants Power Peak, DEMAND ME BASE-MW



Source: Own elaboration

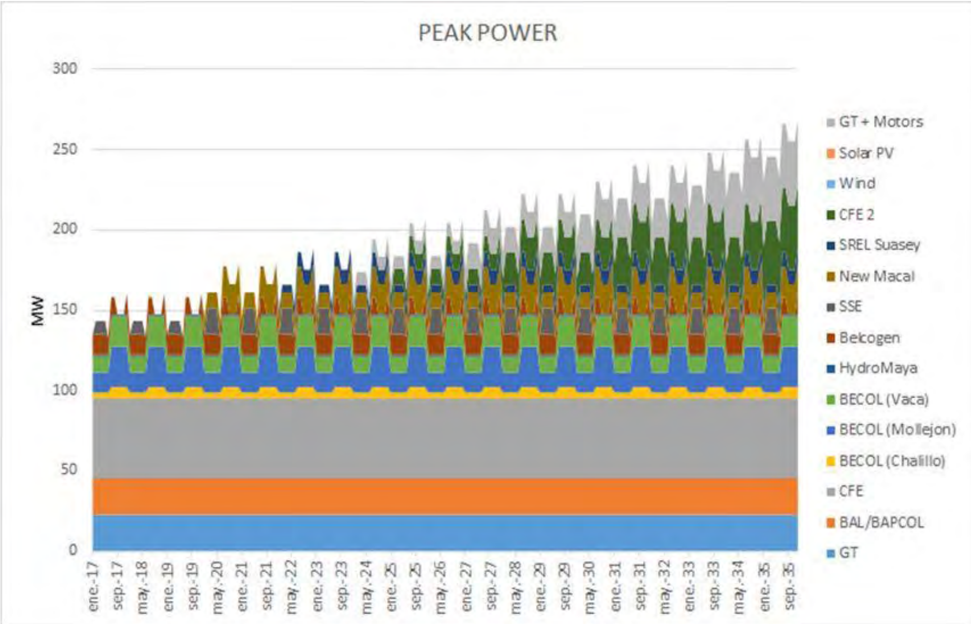
Graph 2.5. Belize´s Monthly Energy Production, DEMAND ME BASE - MWh/month



Source: Own elaboration

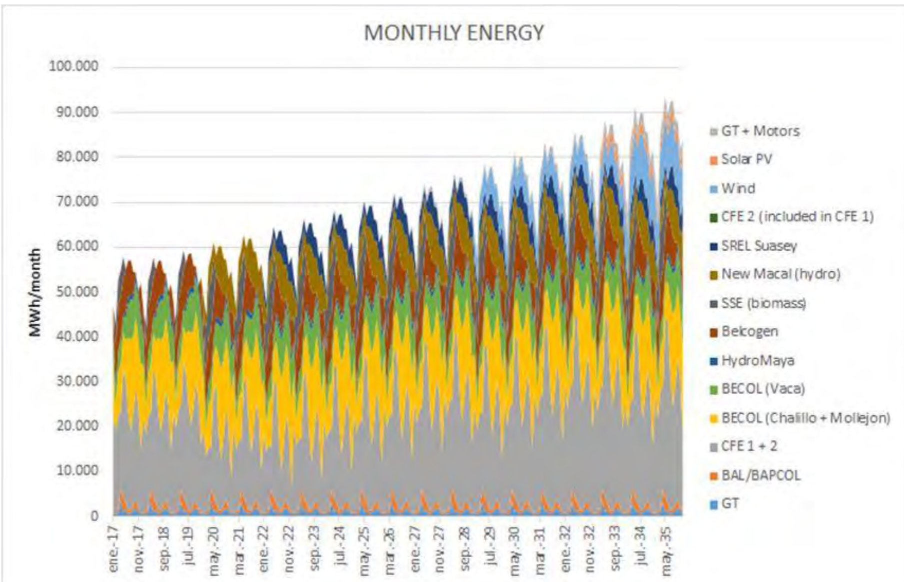
DEMAND DNV LOW
CFE2 (MW/Year): 10/2025, 20/2028, 30/2031, 40/2035.
Wind Power (MW/Year): 20/2029, 40/2034.
Solar PV (MW/Year): 20/2033.
GT+Motors (MW/Year): 8/2024, 16/2027, 24/2030, 32/2033, 40/2034.

Graph 2.6. Belize´s Plants Power Peak, DEMAND DNV LOW -MW



Source: Own elaboration

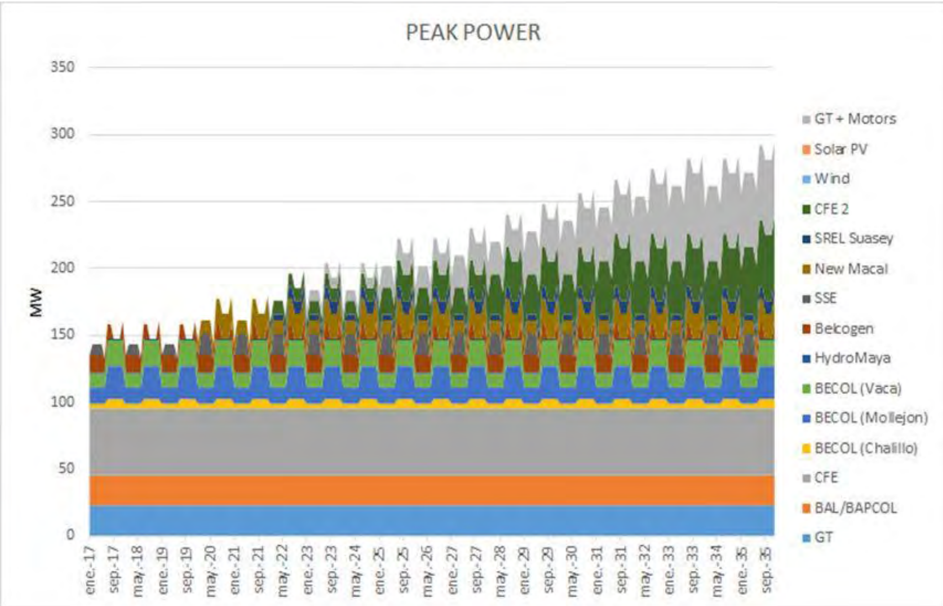
Graph 2.7. Belize´s Monthly Energy Production, DEMAND ME BASE - MWh/month



Source: Own elaboration

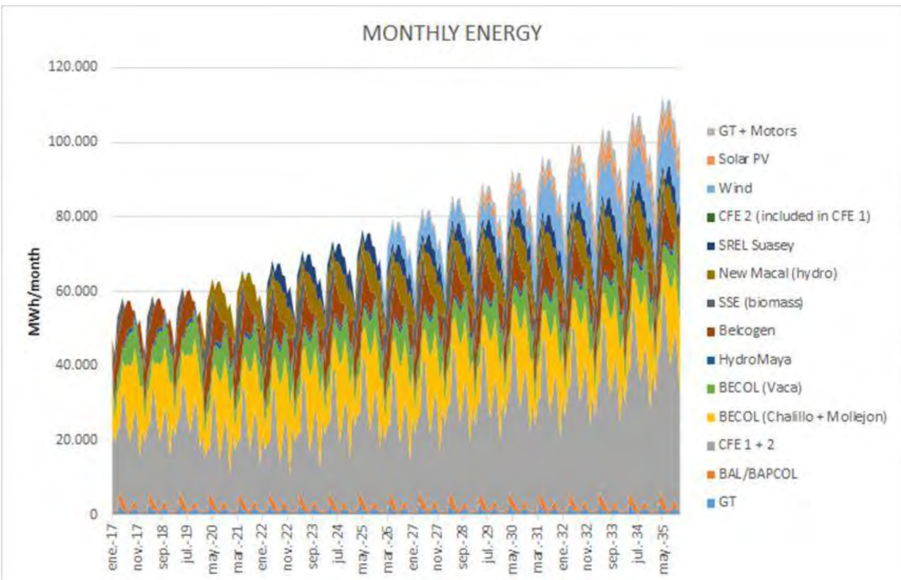
DEMAND ME LOW
CFE2 (MW/Year): 10/2022, 20/2025, 30/2028, 40/2031, 50/2035.
Wind Power (MW/Year): 20/2026, 40/2031.
Solar PV (MW/Year): 20/2029, 40/2033.
GT+Motors (MW/Year): 8/2024, 16/2025, 24/2027, 32/2029, 40/2030, 48/2032, 56/2033.

Graph 2.8. Belize´s Plants Power Peak, DEMAND ME LOW -MW



Source: Own elaboration

Graph 2.9. Belize´s Monthly Energy Production, DEMAND ME BASE - MWh/month



Source: Own elaboration

2.7.1.2 Costs of Supply

The following tables show the total annual demand and the annual average cost per MWh for Portfolio 1 of "BASE". Each table shows these values for the four demand growth scenarios. There are three tables, corresponding to the different oil price projections ("BASE", "HIGH", "LOW").

Table 2.15. Portfolio 1 - Scenarios: DNV BASE, ME BASE, DNV LOW, ME LOW (US$/Year and US$/MWh)

PORTFOLIO 1	DNV BASE		ME BASE		DNV LOW		ME LOW	
OIL&GAS PRICE BASE	USD/YEAR	USD/ MWh	USD/YEAR	USD/ MWh	USD/YEAR	USD/ MWh	USD/YEAR	USD/ MWh
2017	76,459,886	120	76,955,054	120	76,459,886	120	76,955,054	120
2018	82,426,609	125	83,448,292	125	82,024,735	126	83,231,499	125
2019	86,278,927	127	87,982,987	127	85,361,965	127	87,398,452	127
2020	88,620,760	126	91,097,620	126	87,119,012	126	90,087,962	126
2021	91,936,257	127	96,547,486	128	89,892,067	127	93,695,507	126
2022	93,948,100	125	99,524,136	126	91,354,848	126	96,007,602	125
2023	98,788,847	127	105,415,828	128	94,090,297	126	101,096,757	127
2024	102,455,443	128	110,242,183	128	98,657,936	128	105,248,035	127
2025	107,831,711	130	116,875,653	130	102,023,008	129	111,147,192	129
2026	111,077,586	129	122,663,696	130	106,932,807	132	115,003,519	129
2027	118,034,301	133	131,196,825	133	113,220,483	135	122,596,266	132
2028	122,469,424	133	139,861,419	136	116,951,706	136	127,705,211	132
2029	128,410,974	135	147,637,612	137	117,331,888	133	134,365,666	134
2030	136,105,340	139	153,747,429	137	124,116,581	136	142,821,758	137
2031	137,594,486	136	163,619,691	140	128,288,931	137	145,125,496	134
2032	145,411,394	139	169,494,767	138	132,374,225	137	153,753,590	137
2033	148,304,575	137	178,464,673	139	137,110,538	138	160,175,803	137
2034	156,114,919	139	185,113,648	138	140,451,009	138	166,081,886	137
2035	161,561,877	139	193,152,302	138	144,834,867	138	172,532,281	137

Source: Own elaboration

PORTFOLIO 1	DNV BASE		ME BASE		DNV LOW		ME LOW	
OIL&GAS PRICE BASE	USD/YEAR	USD/ MWh	USD/YEAR	USD/ MWh	USD/YEAR	USD/ MW h	USD/YEAR	USD/ MWh
2017	76,459,886	120	76,955,054	120	76,459,886	120	76,955,054	120
2018	82,426,609	125	83,448,292	125	82,024,735	126	83,231,499	125
2019	86,278,927	127	87,982,987	127	85,361,965	127	87,398,452	127
2020	88,620,760	126	91,097,620	126	87,119,012	126	90,087,962	126
2021	91,936,257	127	96,547,486	128	89,892,067	127	93,695,507	126
2022	93,948,100	125	99,524,136	126	91,354,848	126	96,007,602	125
2023	98,788,847	127	105,415,828	128	94,090,297	126	101,096,757	127
2024	102,455,443	128	110,242,183	128	98,657,936	128	105,248,035	127
2025	107,831,711	130	116,875,653	130	102,023,008	129	111,147,192	129

2026	111,077,586	129	122,663,696	130	106,932,807	132	115,003,519	129
2027	118,034,301	133	131,196,825	133	113,220,483	135	122,596,266	132
2028	122,469,424	133	139,861,419	136	116,951,706	136	127,705,211	132
2029	128,410,974	135	147,637,612	137	117,331,888	133	134,365,666	134
2030	136,105,340	139	153,747,429	137	124,116,581	136	142,821,758	137
2031	137,594,486	136	163,619,691	140	128,288,931	137	145,125,496	134
2032	145,411,394	139	169,494,767	138	132,374,225	137	153,753,590	137
2033	148,304,575	137	178,464,673	139	137,110,538	138	160,175,803	137
2034	156,114,919	139	185,113,648	138	140,451,009	138	166,081,886	137
2035	161,561,877	139	193,152,302	138	144,834,867	138	172,532,281	137

Source: Own elaboration

PORTFOLIO 1	**DNV BASE**		**ME BASE**		**DNV LOW**		**ME LOW**	
OIL&GAS PRICE LOW	USD/YEAR	USD/ MWh	USD/YEAR	USD/ MWh	USD/YEAR	USD/ MWh	USD/YEAR	USD/ MWh
2017	70,026,467	110	70,433,235	110	70,026,467	110	70,433,235	110
2018	73,841,585	112	74,652,736	112	73,522,523	113	74,480,617	112
2019	75,950,723	112	77,289,487	111	75,230,328	112	76,830,257	111
2020	79,324,646	113	81,272,193	112	78,143,827	113	80,478,302	112
2021	82,031,390	113	85,991,033	114	80,406,807	114	83,429,522	112
2022	84,464,665	112	89,215,202	113	82,388,606	113	86,113,424	112
2023	88,898,572	114	94,548,903	115	84,813,787	114	90,772,187	114
2024	92,235,409	115	98,908,485	115	89,103,928	116	94,538,223	114
2025	97,179,343	117	104,961,540	117	92,095,771	117	99,944,899	116
2026	98,729,846	115	107,807,878	115	95,304,067	117	101,999,794	114
2027	104,198,141	117	114,652,146	117	100,237,477	120	108,031,360	116
2028	108,426,554	118	121,954,153	119	103,879,202	121	112,880,871	117
2029	113,569,990	120	128,815,012	120	105,153,620	119	118,716,173	118
2030	119,959,127	122	134,350,048	120	110,743,108	122	125,862,786	121
2031	121,821,539	120	142,500,500	122	114,628,862	122	128,503,757	119
2032	127,964,585	122	147,947,906	121	118,362,881	123	135,421,165	121
2033	131,415,580	121	156,081,919	122	122,572,615	124	141,282,108	121
2034	137,519,373	123	161,399,513	121	124,971,307	123	146,519,633	121
2035	142,246,139	123	168,375,828	120	128,784,017	123	152,109,529	121

Source: Own elaboration

With the values of the tables above, the following summary of NPV and LCOE for this portfolio was calculated:

Table 2.16. Portfolio 1-Summary NPV, US$

NPV USD		Demand Growth			
		DNV Low	DNV Average	ME Low	ME BAU
Portfolio 1		2,85%	3,40%	3,84%	4,42%
Oil Price	Low	740,480,580	769,027,325	791,856,218	829,283,435
Oil Price	Base Case	826,328,901	861,996,363	888,930,784	935,798,799
Oil Price	High	969,979,247	1,018,002,366	1,052,373,186	1,116,387,804

WACC 10%

Source: Own elaboration

Table 2.17. Portfolio1-Summary LCOE, US$/MWh

LCOE USD/MWh		Demand Growth			
		DNV Low	DNV Average	ME Low	ME BAU
Portfolio 1		2,85%	3,40%	3,84%	4,42%
Oil Price	Low	116.04	115.51	114.83	115.44
Oil Price	Base Case	129.49	129.48	128.90	130.26
Oil Price	High	152.01	152.91	152.60	155.40

Source: Own elaboration

The more expressive difference of NPV and LCOE, is originated by oil and gas price. CFE is the principal source of this variation, consequence of the parametric formula used for adjusting the price that is indexed to oil prices.

2.7.2 Portfolio 2

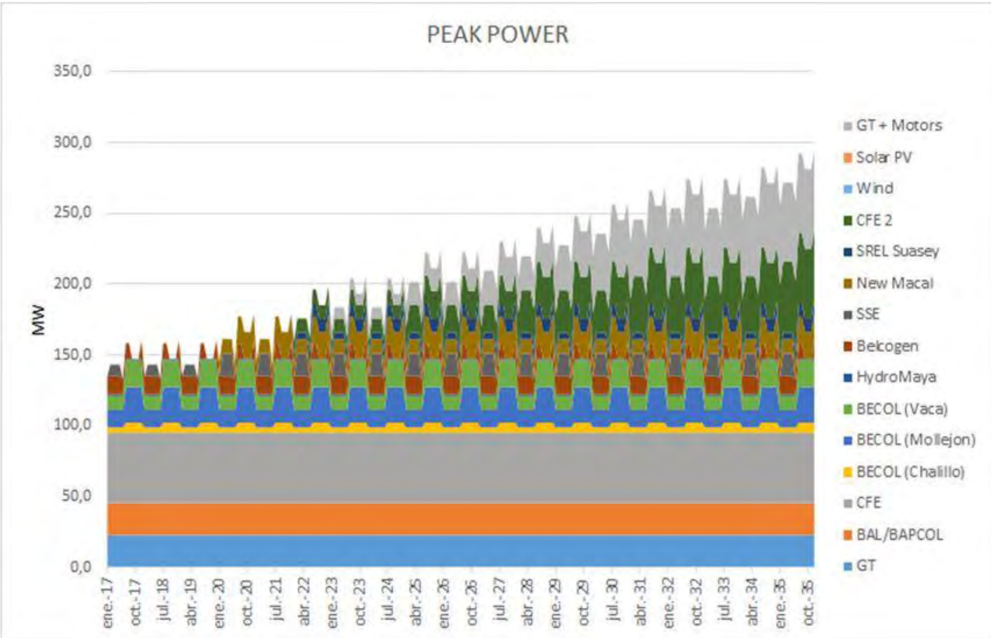
This Portfolio incorporates earlier the new renewables compared with Portfolio 1, with the objective of assessing the variation of the total cost of demand supply. As it can be seen, the different demand growth scenarios do not produce an important variation of the NPV or LCOE.

2.7.2.1 Projections of Power Peak and Energy Supply

In what follows, the power peak and energy supply is shown for each demand projected scenario, for portfolio 2. See indicated above each power and energy table the dates of accumulated incorporation of new generation post 2022.

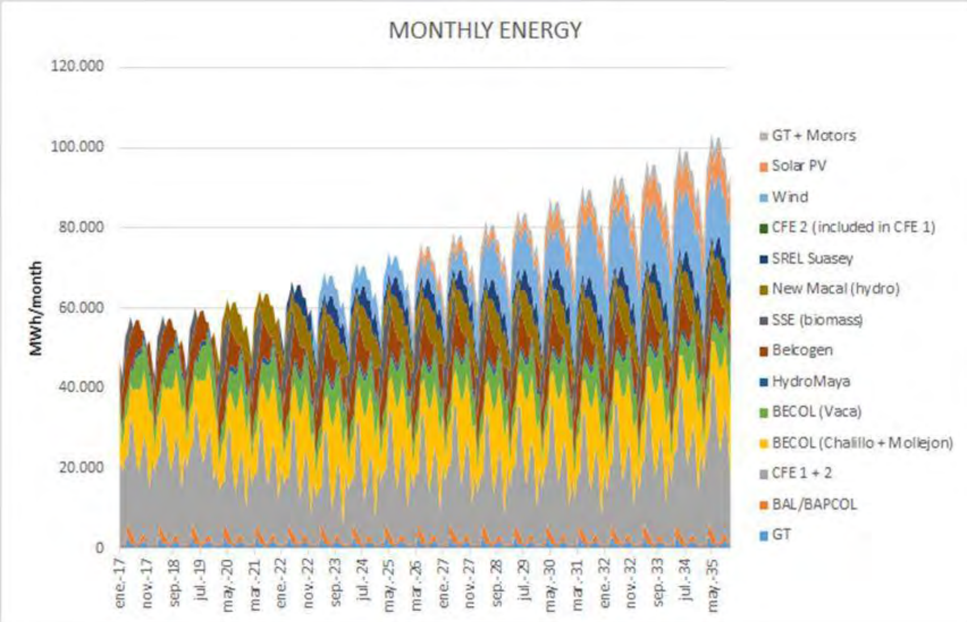
DEMAND DNV BASE
CFE2 (MW/Year): 10/2022, 20/2025, 30/2028, 40/2031, 50/2035.
Wind Power (MW/Year): 20/2023, 40/2028, 60/2031.
Solar PV (MW/Year): 20/2026, 40/2030, 60/2033.
GT+Motors (MW/Year): 8/2023, 16/2025, 24/2027, 32/2029, 40/2030, 48/2032, 56/2034.

Graph 2.10. Belize´s Plants Power Peak, DEMAND DNV BASE -MW



Source: Own elaboration

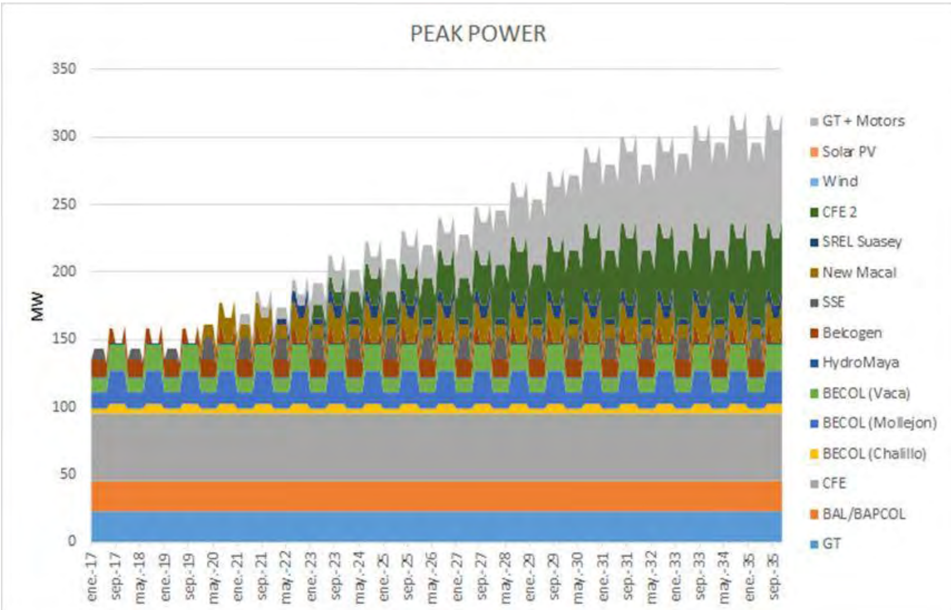
Graph 2.11. Belize´s Monthly Energy Production, DEMAND DNV BASE - MWh/month



Source: Own elaboration

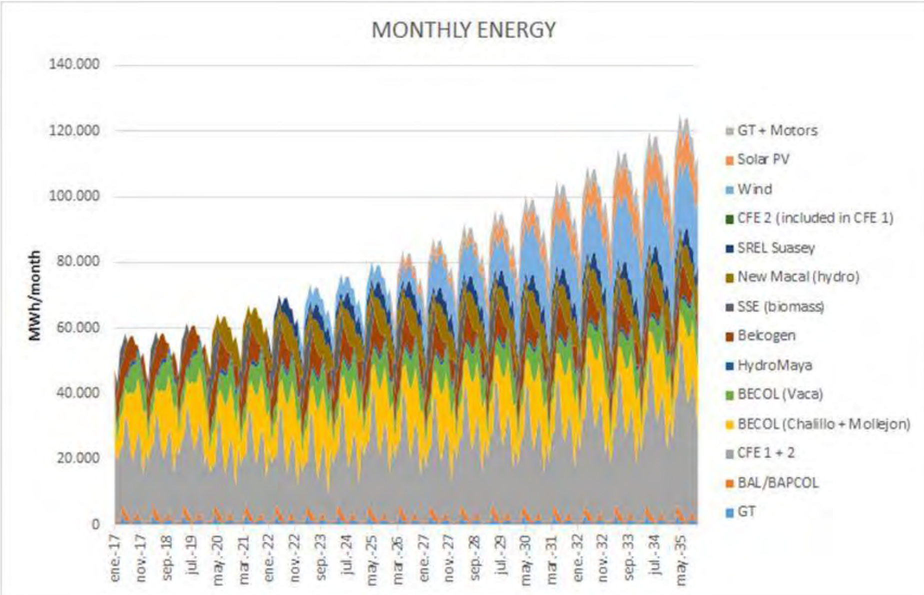
DEMAND ME BASE
CFE2 (MW/Year): 10/2023, 20/2024, 30/2026, 40/2028, 50/2030.
Wind Power (MW/Year): 20/2023, 40/2027, 60/2030, 80/2033.
Solar PV (MW/Year): 20/2026, 40/2029, 60/2031, 80/2033.
GT+Motors (MW/Year): 8/2021, 16/2023, 24/2025, 32/2027, 40/2028, 48/2029, 56/2030, 64/2031, 72/2033, 80/2034.

Graph 2.12. Belize´s Plants Power Peak, DEMAND ME BASE -MW



Source: Own elaboration

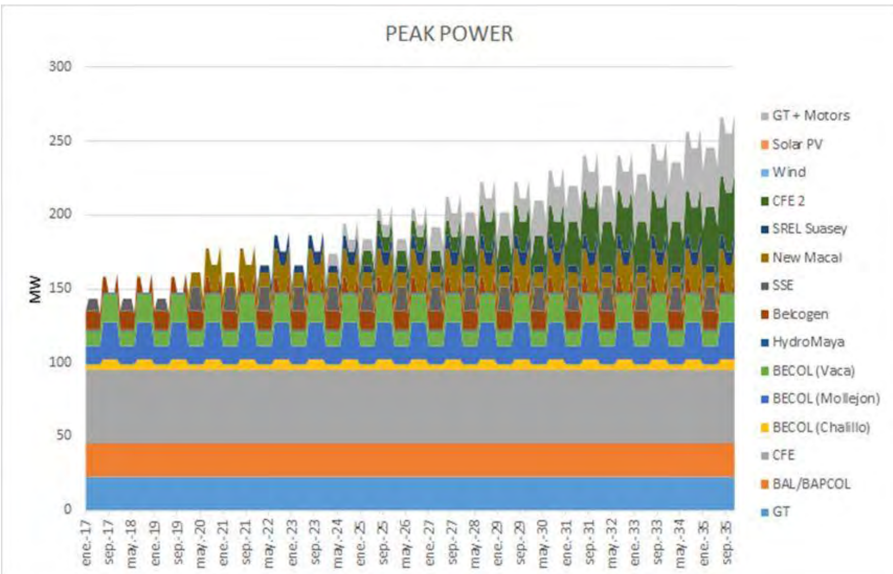
Graph 2.13. Belize´s Monthly Energy Production, DEMAND ME BASE - MWh/month



Source: Own elaboration

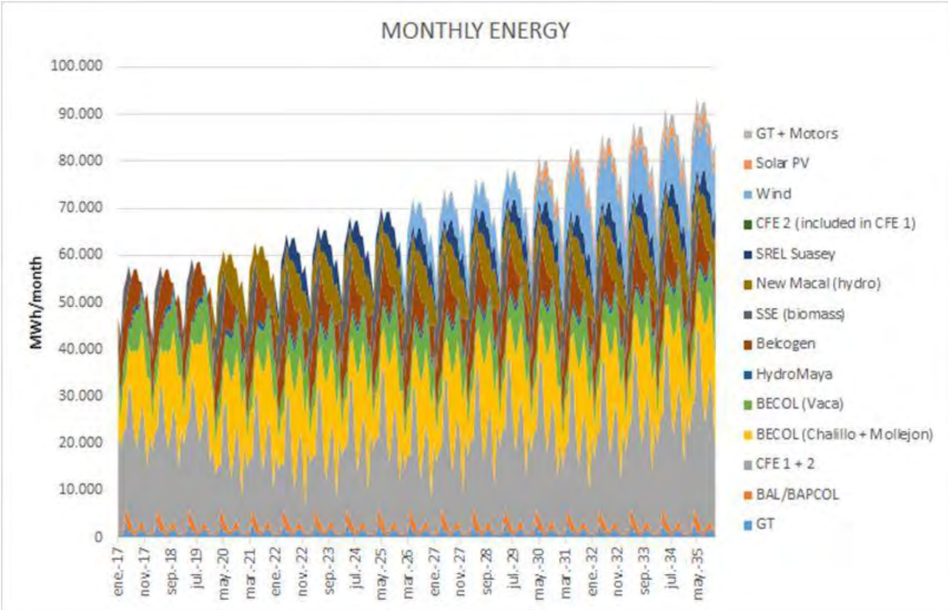
DEMAND DNV LOW
CFE2 (MW/Year): 10/2022, 20/2028, 30/2031, 40/2035.
Wind Power (MW/Year): 20/2026, 40/2031.
Solar PV (MW/Year): 20/2030, 40/2030.
GT+Motors (MW/Year): 8/2024, 16/2027, 24/2030, 32/2033, 40/2034.

Graph 2.14. Belize´s Plants Power Peak, DEMAND DNV LOW -MW



Source: Own elaboration

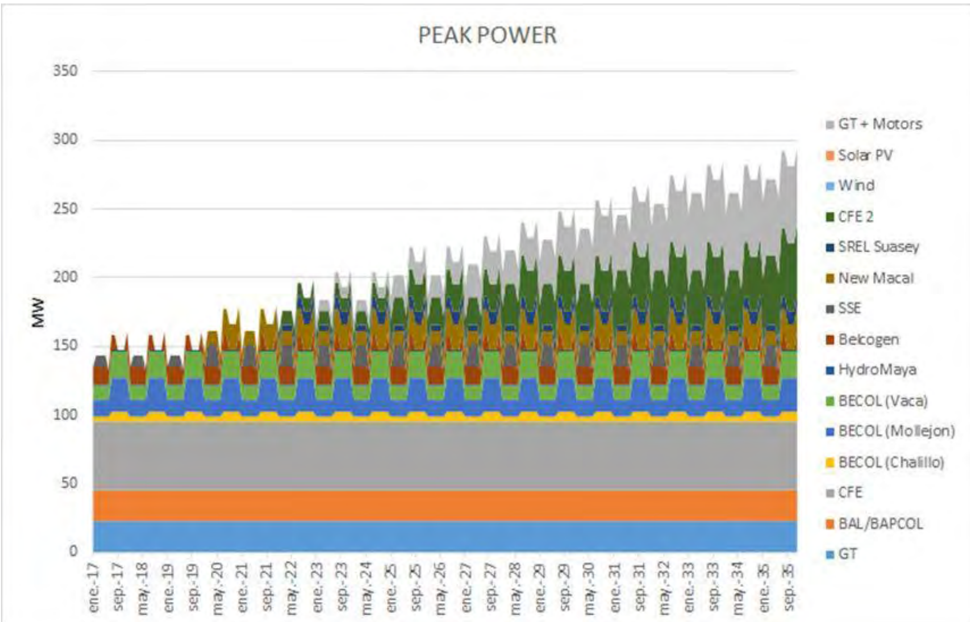
Graph 2.15. Belize´s Monthly Energy Production, DEMAND DNV LOW - MWh/month



Source: Own elaboration

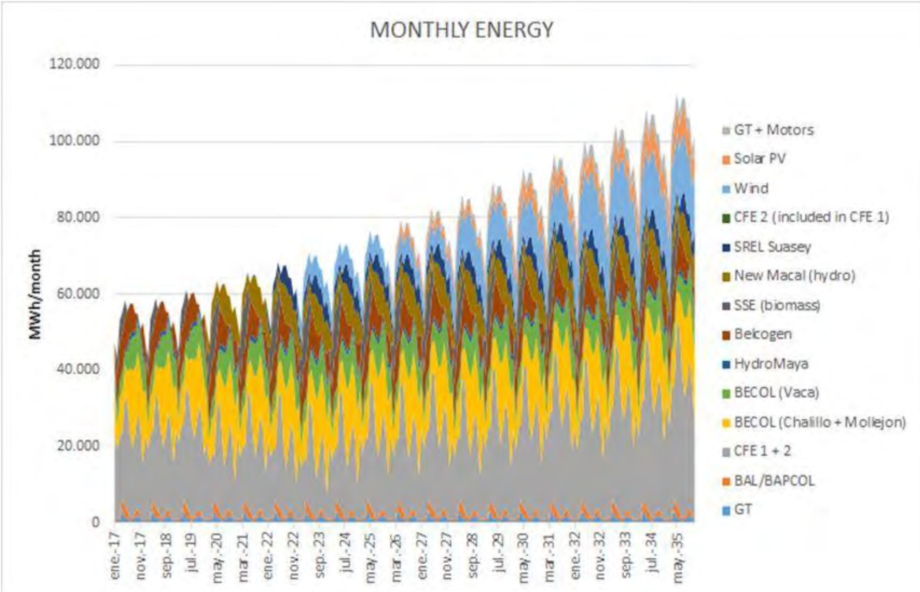
DEMAND ME LOW
CFE2 (MW/Year): 10/2022, 20/2025, 30/2028, 40/2031, 50/2035.
Wind Power (MW/Year): 20/2023, 40/2028, 60/2032.
Solar PV (MW/Year): 20/2026, 40/2030, 60/2034.
GT+Motors (MW/Year): 8/2023, 16/2025, 24/2027, 32/2029, 40/2030, 48/2032, 56/2034.

Graph 2.16. Belize´s Plants Power Peak, DEMAND ME LOW -MW



Source: Own elaboration

Graph 2.17. Belize´s Monthly Energy Production, DEMAND ME LOW - MWh/month



Source: Own elaboration

2.7.2.2 Costs of Supply

The following tables show the total annual demand and the annual average cost per MWh for Portfolio 2. Each table shows these values for the four demand growth scenarios. There are three tables, corresponding to the different oil price projections ("BASE", "HIGH", "LOW").

Table 2.18. Portfolio 2 - Scenarios: DNV BASE, ME BASE, DNV LOW, ME LOW (US$/Year and US$/MWh)

PORTFOLIO 2	DNV BASE		ME BASE		DNV LOW		ME LOW	
OIL&GAS PRICE BASE	USD/YEAR	USD/ MWh	USD/YEAR	USD/ MWh	USD/YEAR	USD/ MWh	USD/YEAR	USD/ MWh
2017	76,459,886	120	76,955,054	120	76,459,886	120	76,955,054	120
2018	82,426,609	125	83,448,292	125	82,024,735	126	83,231,499	125
2019	86,278,927	127	87,982,987	127	85,361,965	127	87,398,452	127
2020	88,620,760	126	91,097,620	126	87,119,012	126	90,087,962	126
2021	91,936,257	127	96,547,486	128	89,892,067	127	93,695,507	126
2022	93,948,100	125	99,524,136	126	91,354,848	126	96,007,602	125
2023	95,485,270	123	102,112,252	124	94,090,297	126	97,793,180	123
2024	99,153,771	123	106,940,511	124	98,657,936	128	101,946,363	123
2025	104,519,544	126	113,563,486	126	102,023,008	129	107,835,025	125
2026	109,782,309	128	121,368,418	129	103,521,969	127	113,708,241	127
2027	116,714,364	131	126,408,511	129	109,752,106	131	121,276,329	131
2028	117,619,987	128	135,011,983	131	113,440,544	132	122,855,775	127
2029	124,861,781	132	142,733,846	133	117,331,888	133	130,816,473	131
2030	131,159,348	134	148,801,437	133	122,749,340	135	137,875,766	132
2031	132,605,374	131	157,250,402	134	123,299,820	132	143,745,320	133
2032	140,448,089	134	164,531,461	134	127,410,919	132	148,790,285	132
2033	143,471,144	132	168,797,812	132	133,610,580	135	156,675,845	134
2034	151,336,114	135	179,017,759	134	140,451,009	138	161,303,081	133
2035	156,755,238	135	187,020,229	134	144,834,867	138	167,725,642	133

Source: Own elaboration

PORTFOLIO 2	DNV BASE		ME BASE		DNV LOW		ME LOW	
OIL&GAS PRICE HIGH	USD/YEAR	USD/ MWh	USD/YEAR	USD/ MWh	USD/YEAR	USD/ MWh	USD/YEAR	USD/ MWh
2017	87,042,958	137	87,670,885	137	87,042,958	137	87,670,885	137
2018	94,330,289	144	95,614,095	143	93,825,311	144	95,341,682	143
2019	100,044,684	147	102,163,921	147	98,904,313	147	101,436,969	147
2020	100,568,097	143	103,532,591	143	98,770,690	143	102,324,156	143
2021	106,122,349	146	111,483,129	148	103,595,465	146	108,297,010	146
2022	109,246,262	145	115,992,558	147	105,919,816	146	111,888,050	145
2023	110,154,640	142	118,253,470	143	109,697,740	147	113,117,049	142
2024	114,388,090	142	123,806,499	144	114,604,064	149	117,898,274	142
2025	120,760,262	145	131,712,080	146	118,817,075	150	124,907,280	145
2026	130,579,628	152	146,446,143	156	121,898,248	150	135,564,729	152
2027	140,557,674	158	153,164,663	156	130,961,501	157	146,352,446	158
2028	140,798,381	153	165,228,723	161	135,532,552	158	147,396,669	153
2029	151,633,427	160	176,474,571	164	140,945,997	159	159,255,991	159
2030	160,209,269	163	184,268,445	164	148,408,662	163	168,808,133	162
2031	160,165,349	158	194,447,382	166	147,154,391	157	174,895,083	162
2032	172,026,410	164	204,844,732	167	153,126,009	159	182,730,321	163

2033	175,225,927	161	209,883,462	164	162,026,064	163	193,783,447	166
2034	186,555,056	166	224,298,780	168	171,998,267	169	199,338,212	165
2035	193,858,190	167	235,073,799	168	177,905,801	170	207,964,694	165

Source: Own elaboration

PORTFOLIO 2	**DNV BASE**		**ME BASE**		**DNV LOW**		**ME LOW**	
OIL&GAS PRICE LOW	USD/YEAR	USD/ MWh	USD/YEAR	USD/ MWh	USD/YEAR	USD/ MWh	USD/YEAR	USD/ MWh
2017	70,026,467	110	70,433,235	110	70,026,467	110	70,433,235	110
2018	73,841,585	112	74,652,736	112	73,522,523	113	74,480,617	112
2019	75,950,723	112	77,289,487	111	75,230,328	112	76,830,257	111
2020	79,324,646	113	81,272,193	112	78,143,827	113	80,478,302	112
2021	82,031,390	113	85,991,033	114	80,406,807	114	83,429,522	112
2022	84,464,665	112	89,215,202	113	82,388,606	113	86,113,424	112
2023	86,831,223	112	92,481,553	112	84,813,787	114	88,704,838	111
2024	90,085,594	112	96,758,670	112	89,103,928	116	92,388,408	111
2025	94,958,255	114	102,740,451	114	92,095,771	117	97,723,811	114
2026	97,912,692	114	106,990,724	114	93,008,850	114	101,182,639	113
2027	103,339,245	116	111,400,635	113	97,844,863	117	107,172,464	115
2028	105,022,142	114	118,549,741	115	101,379,557	118	109,476,459	113
2029	110,946,130	117	125,233,150	117	105,153,620	119	116,092,313	116
2030	116,196,391	118	130,587,312	116	109,730,844	121	122,100,050	117
2031	117,939,341	116	137,570,200	117	110,746,664	118	127,455,655	118
2032	124,041,170	118	144,024,491	118	114,439,466	119	131,497,750	117
2033	127,504,370	117	148,259,498	116	119,718,211	121	138,427,703	119
2034	133,672,741	119	156,515,449	117	124,971,307	123	142,673,001	118
2035	138,412,139	119	163,508,185	117	128,784,017	123	148,275,528	118

Source: Own elaboration

With the values of the tables above, the following summary of NPV and LCOE for this portfolio was calculated:

Table 2.19. Portfolio 2-Summary NPV, US$

NPV USD		**Demand Growth**			
		DNV Low	**DNV Average**	**ME Low**	**ME BAU**
Portfolio 2		2,85%	3,40%	3,84%	4,42%
Oil Price	**Low**	735,34,107	758,694,094	782,410,530	816,453,789
	Base Case	819,352,467	847,642,248	875,704,440	918,096,388
	High	959,324,565	995,888,400	1,031,959,144	1,089,053,140

WACC **10%**

Source: Own elaboration

Table 2.20. Portfolio 2-Summary LCOE, US$/MWh

LCOE USD/MWh		Demand Growth			
		DNV Low	DNV Average	ME Low	ME BAU
Portfolio 2		2,85%	3,40%	3,84%	4,42%
Oil Price	Low	115.24	113.96	113.46	113.65
Oil Price	Base Case	128.40	127.32	126.98	127.80
Oil Price	High	150.34	149.59	149.64	151.60

Source: Own elaboration

The more expressive difference of NPV and LCOE, is originated by oil price. CFE is the principal source of this variation, consequence of the parametric formula used for adjusting the price that is indexed to oil and gas prices.

2.7.3 Portfolio 3

Portfolio 3 is based on Portfolio 2, delaying the entry into service of three plants (IPPs currently under negotiation) 2, 3, and 4 years respectively, and changing the backup criteria, lowering the requirement of local power from 90% to 80%.

Also, from 2022 forward, this portfolio includes biomass generation, in a fixed percentage of installed capacity

Regarding the delayed plants, in order, these are:

- Solar South, it goes from 2018 to 2020.
- New Macal passes from 2020 to 2023 (Chalillo II)
- SREL Suasey goes from 2022 to 2026.

The objective of this Portfolio is to evaluate the risk of delaying current PPA´s negotiations.

Conceptually, this portfolio implies, in the short term, increasing dependence on imports from Mexico, since the possibility to advance the incorporation of unconventional renewables beyond Portfolio 2 does not seem reasonable.

This implies eliminating the 40% import restriction that was used in portfolios 1 and 2.

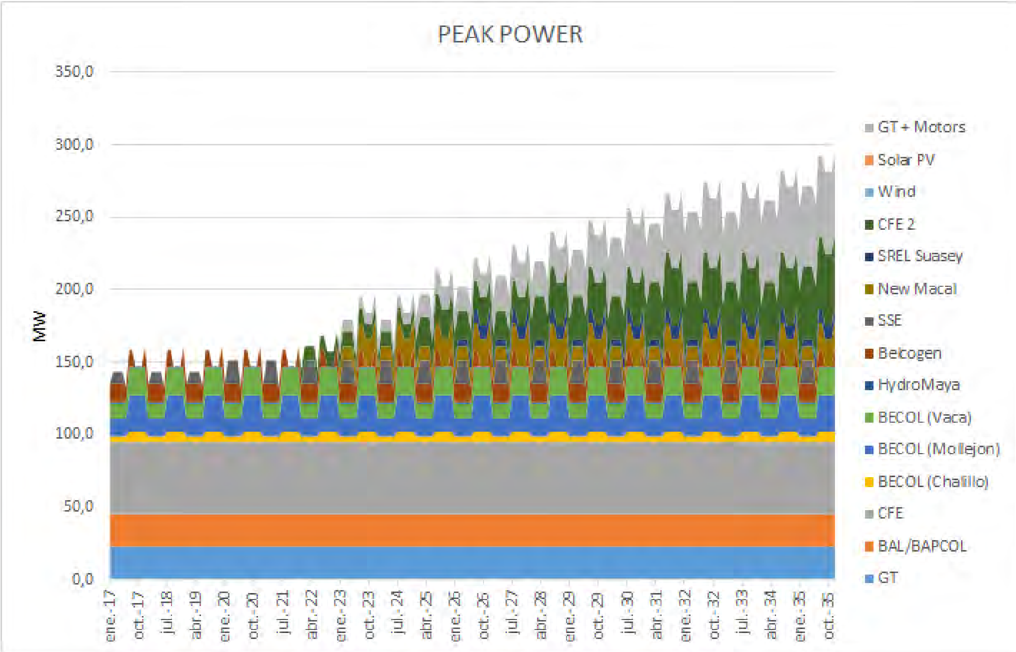
In other hand, power backup is lower than portfolios 1 and 2 up to 2025, as the delay in incorporating new power generation is not substituted by other sources.

The times that are required for the tender and the works, make this last solution unfeasible. After 2022, the participation of renewable power could be increased but not before this date.

2.7.3.1 Projections of Power Peak and Energy Supply

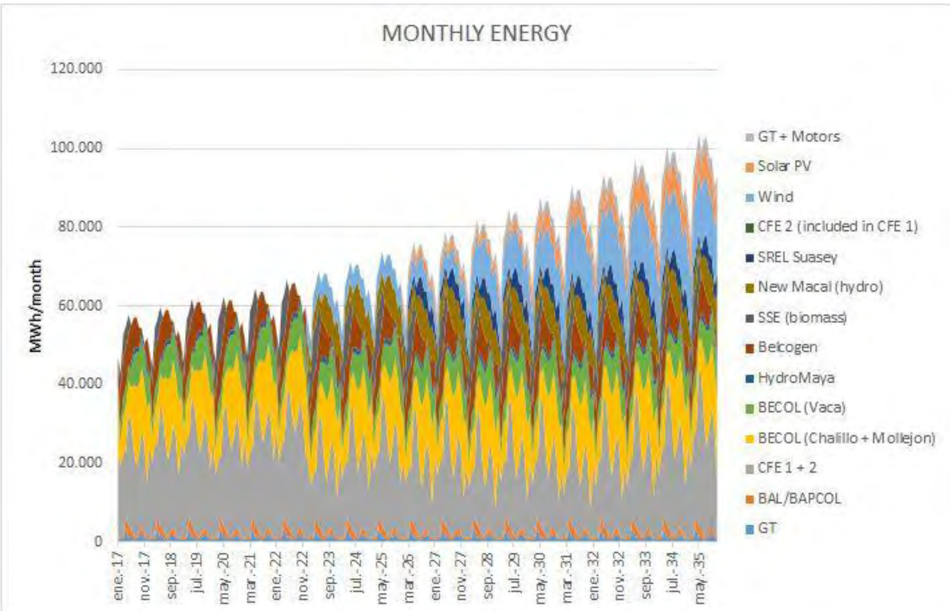
DEMAND DNV BASE

Graph 2.18. Belize´s Plants Power Peak, DEMAND DNV BASE-MW



Source: Own elaboration

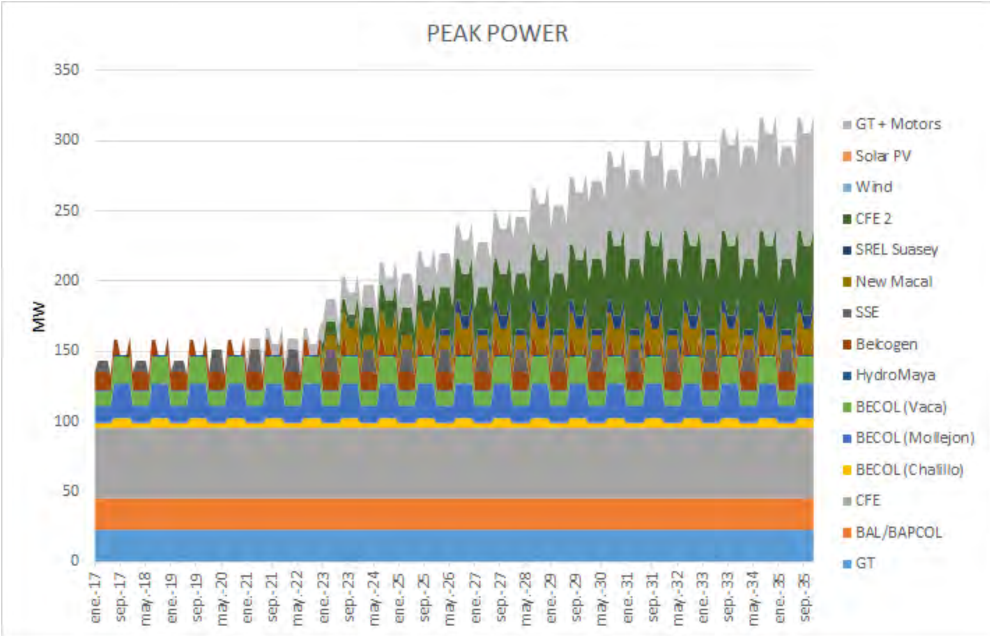
Graph 2.19. Belize´s Monthly Energy Production, DEMAND DNV BASE - MWh/month



Source: Own elaboration

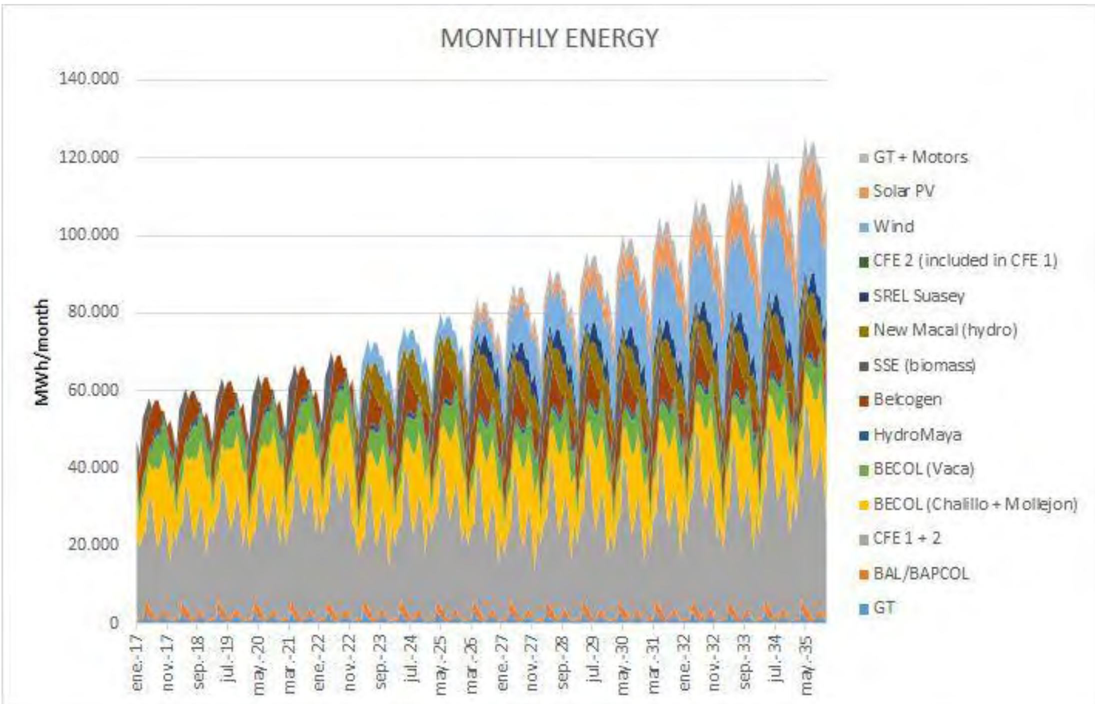
DEMAND ME BASE

Graph 2.20. Belize´s Plants Power Peak, DEMAND ME BASE-MW



Source: Own elaboration

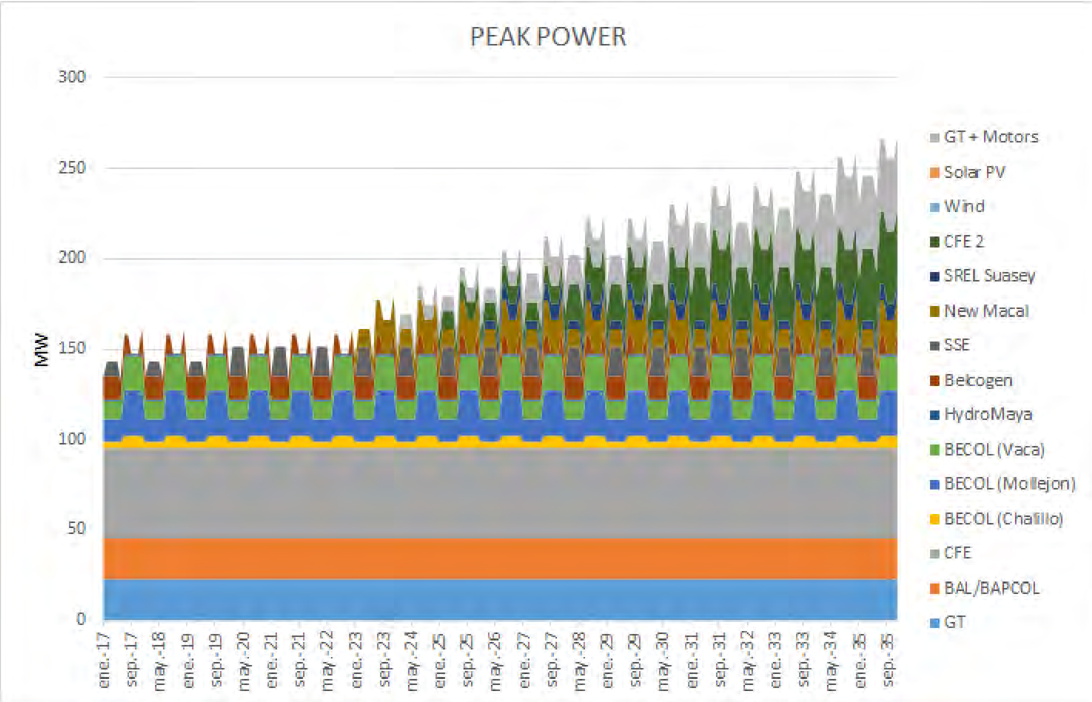
Graph 2.21. Belize´s Monthly Energy Production, DEMAND ME BASE - MWh/month



Source: Own elaboration

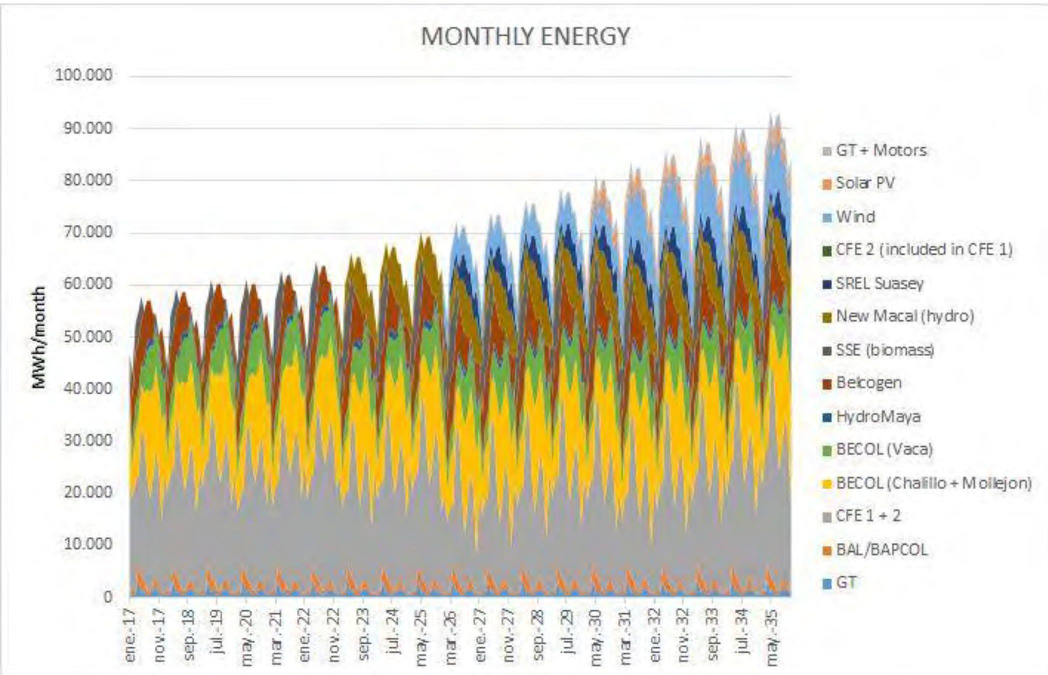
DEMAND DNV LOW

Graph 2.22. Belize´s Plants Power Peak, DEMAND DNV LOW-MW



Source: Own elaboration

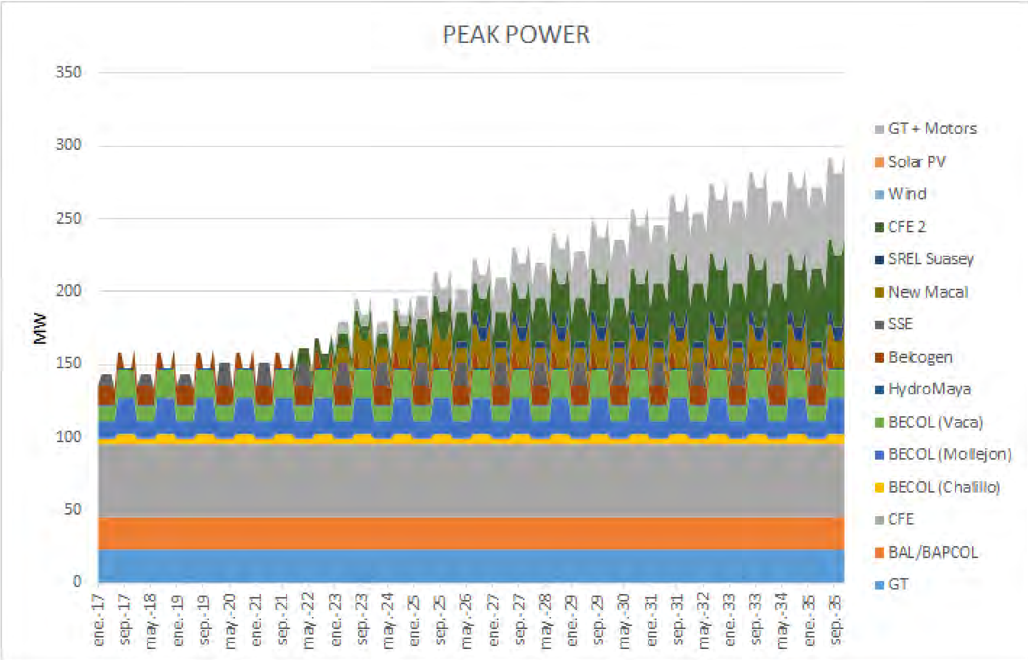
Graph 2.23. Belize´s Monthly Energy Production, DEMAND DNV LOW - MWh/month



Source: Own elaboration

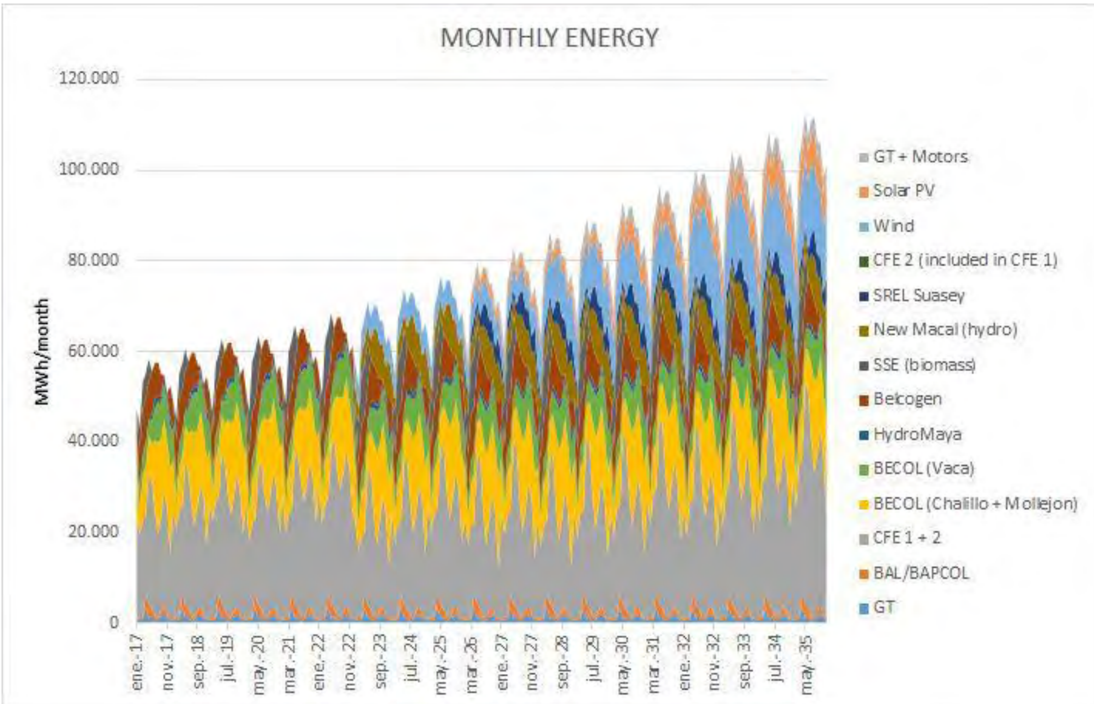
DEMAND ME LOW

Graph 2.24. Belize´s Plants Power Peak, DEMAND ME LOW-MW



Source: Own elaboration

Graph 2.25. Belize´s Monthly Energy Production, DEMAND ME LOW - MWh/month



Source: Own elaboration

2.7.3.2 Costs of Supply

Following tables show the total and average cost of supply per year.

Table 2.21. Portfolio 3 - Scenarios: DNV BASE, ME BASE, DNV LOW, ME LOW (US$/Year and US$/MWh)

PORTFOLIO 3	DNV BASE		ME BASE		DNV LOW		ME LOW	
OIL&GAS PRICE BASE	USD/YEAR	USD/ MWh	USD/YEAR	USD/ MWh	USD/YEAR	USD/ MWh	USD/YEAR	USD/ MWh
2017	76,459,886	120	76,955,054	120	76,459,886	120	76,955,054	120
2018	82,910,782	126	83,932,465	126	82,508,908	126	83,715,672	126
2019	86,903,563	128	88,607,623	127	85,986,601	128	88,023,088	128
2020	90,796,638	129	93,273,498	129	89,294,890	130	92,263,840	129
2021	94,009,788	129	98,621,017	131	91,965,597	130	95,769,038	129
2022	97,060,000	129	102,636,036	130	94,466,748	130	99,119,502	129
2023	96,617,376	124	103,244,358	125	95,222,403	128	98,925,287	124
2024	100,284,475	125	108,071,215	125	99,788,640	130	103,077,067	124
2025	105,657,975	127	114,701,917	127	103,161,440	131	108,973,456	127
2026	109,782,309	128	121,368,418	129	103,521,969	127	113,708,241	127
2027	116,714,364	131	126,408,511	129	109,752,106	131	121,276,329	131
2028	117,619,987	128	135,011,983	131	113,440,544	132	122,855,775	127
2029	124,861,781	132	142,733,846	133	117,331,888	133	130,816,473	131
2030	131,159,348	134	148,801,437	133	122,749,340	135	137,875,766	132
2031	132,605,374	131	157,250,402	134	123,299,820	132	143,745,320	133
2032	140,448,089	134	164,531,461	134	127,410,919	132	148,790,285	132
2033	143,471,144	132	168,797,812	132	133,610,580	135	156,675,845	134
2034	151,336,114	135	179,017,759	134	140,451,009	138	161,303,081	133
2035	156,755,238	135	187,020,229	134	144,834,867	138	167,725,642	133

Source: Own elaboration

PORTFOLIO 3	DNV BASE		ME BASE		DNV LOW		ME LOW	
OIL&GAS PRICE HIGH	USD/YEAR	USD/ MWh	USD/YEAR	USD/ MWh	USD/YEAR	USD/ MWh	USD/YEAR	USD/ MWh
2017	87,042,958	137	87,670,885	137	87,042,958	137	87,670,885	137
2018	95,320,621	145	96,604,427	145	94,815,643	145	96,332,015	145
2019	101,184,212	149	103,303,449	149	100,043,841	149	102,576,497	149
2020	104,384,482	149	107,348,977	148	102,587,076	149	106,140,542	148
2021	110,139,304	152	115,500,083	153	107,612,419	152	112,313,965	151
2022	116,026,236	154	122,772,532	156	112,699,791	155	118,668,024	154
2023	112,658,502	145	125,923,947	153	112,201,601	150	115,620,911	145
2024	116,761,393	145	131,169,101	152	116,977,367	152	120,271,577	145
2025	123,113,451	148	139,027,250	154	121,170,264	153	127,260,469	148
2026	130,579,628	152	148,513,410	158	121,898,248	150	135,564,729	152
2027	140,557,674	158	160,552,762	163	130,961,501	157	146,352,446	158
2028	140,798,381	153	172,597,573	168	135,532,552	158	147,396,669	153

2029	151,633,427	160	184,105,295	171	140,945,997	159	159,255,991	159
2030	160,209,269	163	191,954,997	171	148,408,662	163	168,808,133	162
2031	160,165,349	158	203,998,218	174	147,154,391	157	174,895,083	162
2032	172,026,410	164	212,581,167	173	153,126,009	159	182,730,321	163
2033	175,225,927	161	225,010,519	176	162,026,064	163	193,783,447	166
2034	186,555,056	166	233,924,930	175	171,998,267	169	199,338,212	165
2035	193,858,190	167	244,787,918	175	177,905,801	170	207,964,694	165

Source: Own elaboration

PORTFOLIO 3	**DNV BASE**		**ME BASE**		**DNV LOW**		**ME LOW**	
OIL&GAS PRICE LOW	USD/YEAR	USD/ MWh	USD/YEAR	USD/ MWh	USD/YEAR	USD/ MWh	USD/YEAR	USD/ MWh
2017	70,026,467	110	70,433,235	110	70,026,467	110	70,433,235	110
2018	73,919,221	112	74,730,372	112	73,600,159	113	74,558,253	112
2019	76,122,328	112	77,461,092	111	75,401,933	112	77,001,862	112
2020	79,719,804	113	81,667,350	113	78,538,984	114	80,873,460	113
2021	82,415,496	113	86,375,139	114	80,790,913	114	83,813,628	113
2022	84,989,113	113	89,739,650	114	82,913,054	114	86,637,872	113
2023	87,053,095	112	92,703,425	112	85,035,659	114	88,926,710	111
2024	90,368,186	113	97,041,262	113	89,386,520	116	92,670,999	112
2025	95,293,324	115	103,075,521	114	92,430,840	117	98,058,881	114
2026	97,912,692	114	106,990,724	114	93,008,850	114	101,182,639	113
2027	103,339,245	116	111,400,635	113	97,844,863	117	107,172,464	115
2028	105,022,142	114	118,549,741	115	101,379,557	118	109,476,459	113
2029	110,946,130	117	125,233,150	117	105,153,620	119	116,092,313	116
2030	116,196,391	118	130,587,312	116	109,730,844	121	122,100,050	117
2031	117,939,341	116	137,570,200	117	110,746,664	118	127,455,655	118
2032	124,041,170	118	144,024,491	118	114,439,466	119	131,497,750	117
2033	127,504,370	117	148,259,498	116	119,718,211	121	138,427,703	119
2034	133,672,741	119	156,515,449	117	124,971,307	123	142,673,001	118
2035	138,412,139	119	163,508,185	117	128,784,017	123	148,275,528	118

Source: Own elaboration

With the values of the tables above, the following summary of NPV and LCOE for this portfolio was calculated:

Table 2.22. Portfolio 3-Summary NPV, US$

NPV USD		Demand Growth			
		DNV Low	DNV Average	ME Low	ME BAU
Portfolio 3		2,85%	3,40%	3,84%	4,42%
Oil Price	Low	736,731,423	760,079,409	783,795,845	817,839,104
	Base Case	826,343,385	854,633,167	882,695,359	925,087,307
	High	973,317,163	1,009,880,998	1,045,951,742	1,130,380,402

WACC **10%**

Source: Own elaboration

Table 2.23. Portfolio 3-Summary LCOE, US$/MWh

LCOE USD/MWh		Demand Growth			
		DNV Low	DNV Average	ME Low	ME BAU
Portfolio 3		2,85%	3,40%	3,84%	4,42%
Oil Price	Low	115.45	114.17	113.66	113.84
	Base Case	129.50	128.37	128.00	128.77
	High	152.53	151.69	151.67	157.35

Source: Own elaboration

2.7.4 Portfolio Comparison

Table 2.24. NPV Comparison, US$

NPV USD Comparison

Case	Demand Growth	Oil Price	Portfolio 1	Portfolio 2	Portfolio 3
1.1 -2.1 - 3.1	2,85	Low	740,480,580	735,34,107	736,731,423
1.2 -2.2 - 3.2	3,40	Low	769,027,325	758,694,094	760,079,409
1.3 -2.3 - 3.3	3,84	Low	791,856,218	782,410,530	783,795,845
1.4 -2.4 - 3.4	4,42	Low	829,283,435	816,453,789	817,839,104
1.5 -2.5 -3.5	2,85	Base	826,328,901	819,352,467	826,343,385
1.6 -2.6 -3.6	3,40	Base	861,996,363	847,642,248	854,633,167
1.7 -2.7 - 3.7	3,84	Base	888,930,784	875,704,440	882,695,359
1.8 -2.8 - 3.8	4,42	Base	935,798,799	918,096,388	925,087,307
1.9 -2.9 - 3.9	2,85	High	969,979,247	959,324,565	973,317,163
1.10 -2.10 - 3.10	3,40	High	1,018,002,366	995,888,400	1,009,880,998
1.11 -2.11 - 3.11	3,84	High	1,052,373,186	1,031,959,144	1,045,951,742
1.12 -2.12 -3.12	4,42	High	1,116,387,804	1,089,053,140	1,130,380,402

Source: Own elaboration

Table 2.25. LCOE Comparison, US$/MWh

LCOE (USD/MWh) Comaparison

Case	Demand Growth	Oil Price	Portfolio 1	Portfolio 2	Portfolio 3
1.1 -2.1 - 3.1	2,85	Low	116.04	115.24	115.45
1.2 -2.2 - 3.2	3,40	Low	115.51	113.96	114.17
1.3 -2.3 - 3.3	3,84	Low	114.83	113.46	113.66
1.4 -2.4 - 3.4	4,42	Low	115.44	113.65	113.84
1.5 -2.5 -3.5	2,85	Base	129.49	128.40	129.50
1.6 -2.6 -3.6	3,40	Base	129.48	127.32	128.37
1.7 -2.7 - 3.7	3,84	Base	128.90	126.98	128.00
1.8 -2.8 - 3.8	4,42	Base	130.26	127.80	128.77
1.9 -2.9 - 3.9	2,85	High	152.01	150.34	152.53
1.10 -2.10 - 3.10	3,40	High	152.91	149.59	151.69
1.11 -2.11 - 3.11	3,84	High	152.60	149.64	151.67
1.12 -2.12 -3.12	4,42	High	155.40	151.60	157.35

Source: Own elaboration

The results of the three portfolios are similar, regarding the behavior of total NPV and LCOE. However, the performance of Portfolio 2 is better in all demand and oil & natural gas scenarios.

A relevant conclusion of the simulation of the portfolio 3, is that the presence of the interconnection with CFE allows that any delays in the expansion plan have a very low impact on the total costs of the system. In fact, it functions as a relevant coverage regarding the increase in costs.

2.7.5 SimSEE Simulations

In order to use an alternative method to verify the results obtained with the spreadsheet model, SimSEE software was used. It was not the aim of this work to develop a complete and detailed parameterization of Belize electrical system in SimSEE, because, in particular, not all the required information was available.

However, the results found at this stage were consistent with the spreadsheet model.

In addition, SimSEE allows producing some other results, such as system failure, which cannot be obtained from the spreadsheet model. To model the hydroelectric generation units, historical information of generation and rains from the years 2014, 2015 and 2016 was used.

The two portfolios of generation expansion (Portfolio 1 and Portfolio 2) were evaluated. For both of them, the cases considering reference oil price and base demand expansion were evaluated. In the following section, the main results are shown.

2.7.5.1 SimSEE Simulations – Results for Portfolios #1 and #2

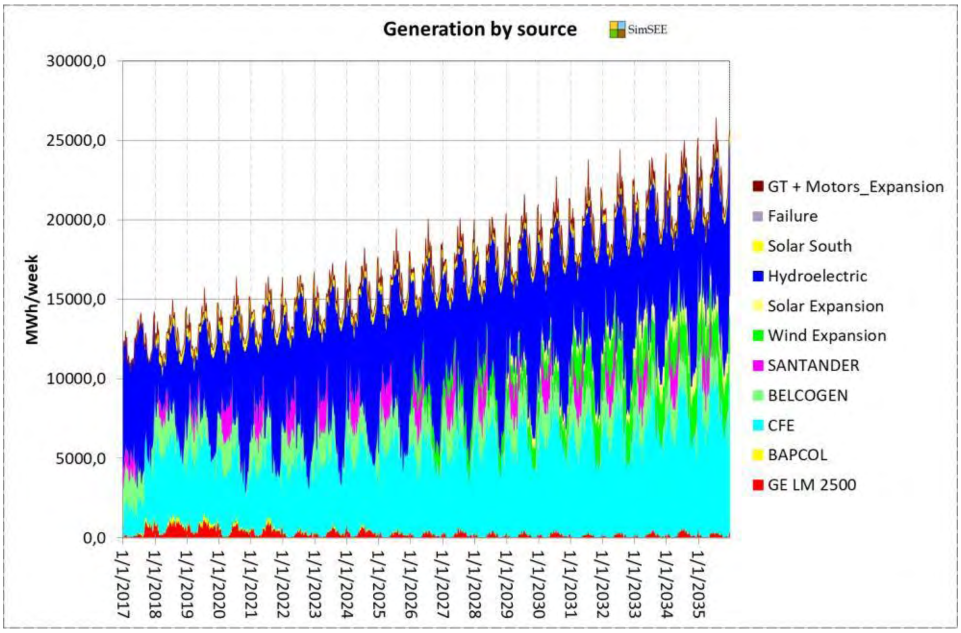
The SimSEE simulator optimizes the energy dispatch, based on the marginal cost of each generation unit. It also considers the price of energy and firm power defined in the PPA contract, which does not affect the energy dispatch but is used to calculate the total cost of generation.

In the simulation, the generation units listed below were considered with zero marginal cost, which means that if available, they are always dispatched. This does not mean that the cost is zero, as the energy and power prices indicated in the corresponding contracts were considered for the calculation of total costs.

- Hydroelectric generation (Chalillo, Mollejon, Vaca, HydroMaya and future expansions)
- Solar power (South Solar and future expansions)
- Wind power (Future expansions)
- Biomass generation (Belcogen, Santander)

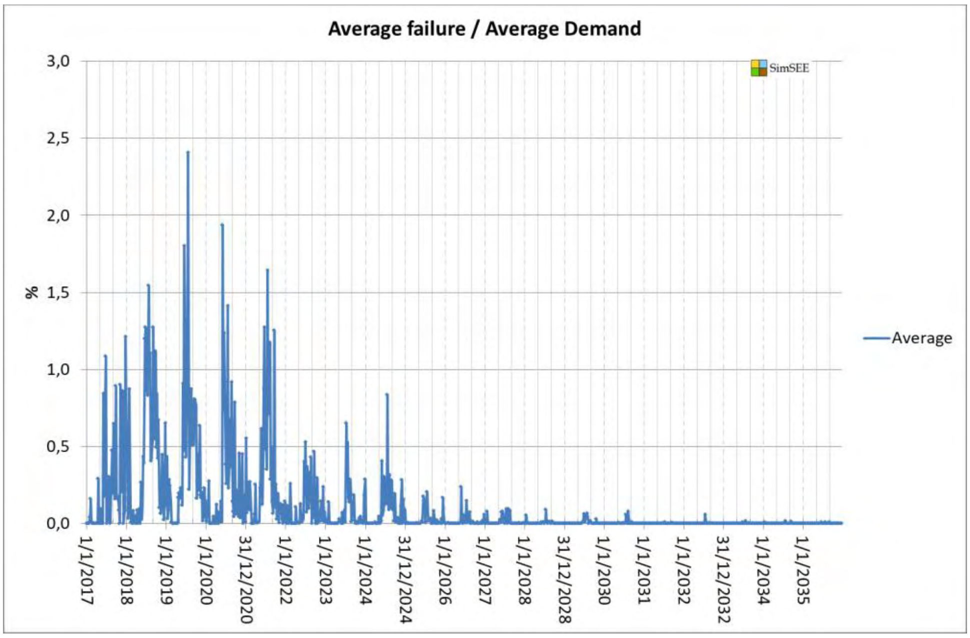
In the graphs below, the long term economic dispatch, as well as the percentage of expected average system failure and the total cost of supply, are presented both for Portfolio #1 and #2.

Graph 2.26. PORTFOLIO 1 - Generation by source, MWh/WEEK



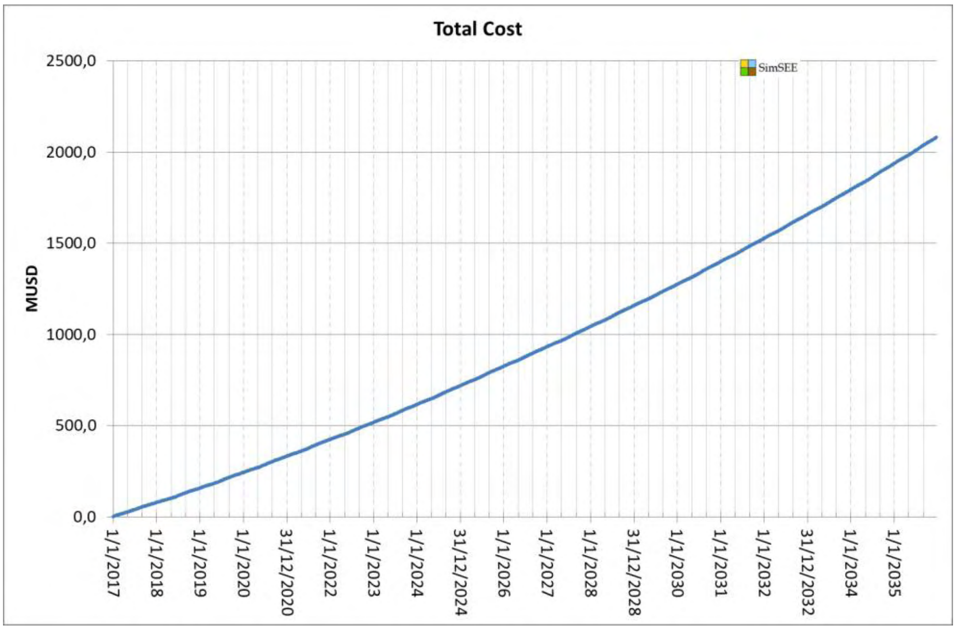
Source: Own elaboration

Graph 2.27. PORTFOLIO 1 - Average Failure/Average Demand, %



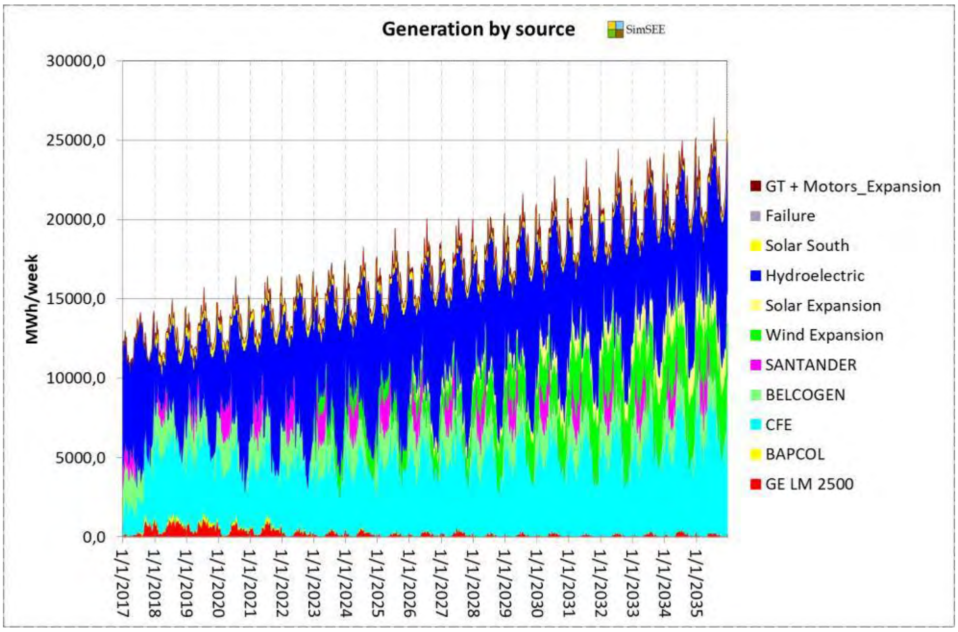
Source: Own elaboration

Graph 2.28. PORTFOLIO 1 - Total Cost, MUSD



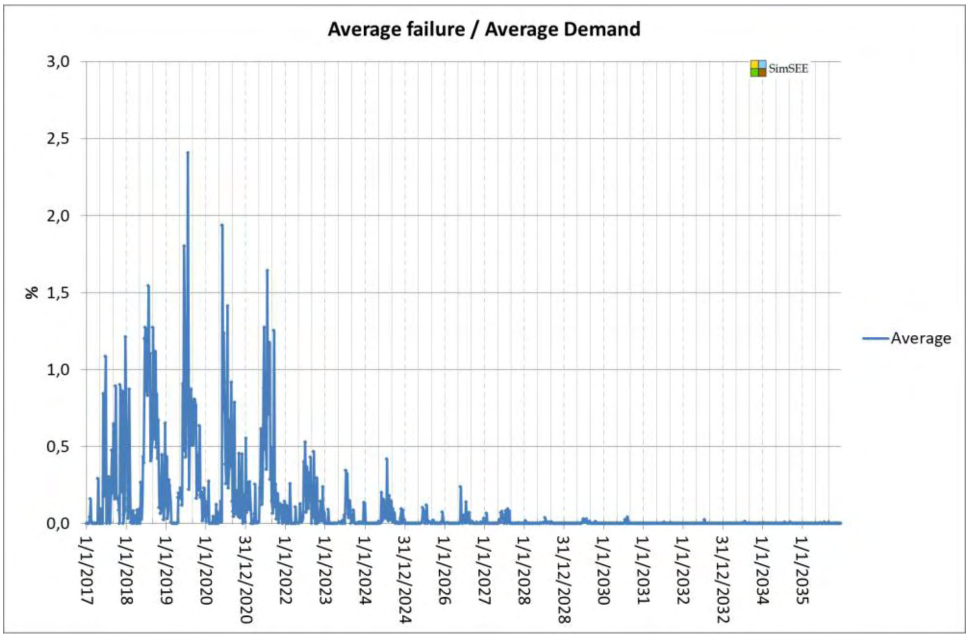
Source: Own elaboration

Graph 2.29. PORTFOLIO 2 - Generation by source, MWh/WEEK



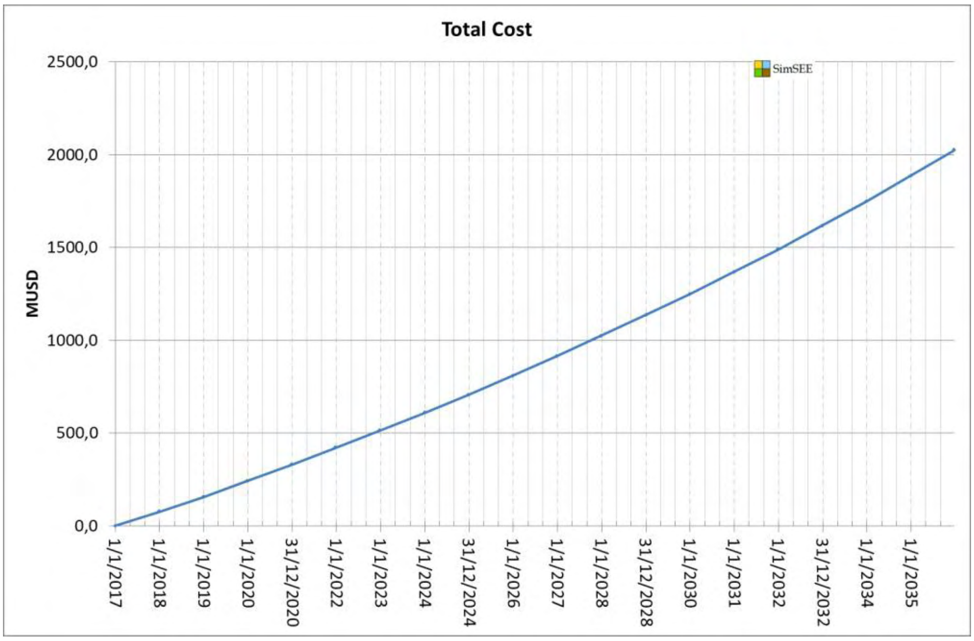
Source: Own elaboration

Graph 2.30. PORTFOLIO 2 - Average Failure/Average Demand, %



Source: Own elaboration

Graph 2.31. PORTFOLIO 2 - Total Cost, MUSD



Source: Own elaboration

As it can be seen, Portfolio #2 dispatches more wind and solar, while CFE imports are less than for Portfolio #1. On the other hand, the other resources dispatch (e.g. hydro, biomass, etc.), remain very similar for both portfolios.

In terms of system failure, Portfolio #2 shows better performance than Portfolio #1, particularly after 2023, when wind and solar generation is introduced. It must be noted that Portfolio #2 develops more wind and solar than Portfolio #1.

Finally, in relation to total costs for this case of oil price, Portfolio #2 results slightly cheaper than Portfolio #1.

Comparing the results of the SimSEE model with the spreadsheet model, it can be seen that the backup thermal units are less dispatched using the SimSEE model, as they have a relatively high marginal cost. The SimSEE model prioritizes CFE imports over local thermal generation, as CFE has a lower marginal cost. Therefore, the total cost results lower in the SimSEE model than in the spreadsheet model.

2.8 Network Expansion Plans

The expansion plan for generation must consider the effects on the transmission system. The localization, respectively, of the generation and demands is important, and the consequent flows on the transmission network. In this study, the generation expansion is analyzed in detail to ensure demand supply, some hypotheses were assumed to minimize network expansion.

First, it was assumed that the second 115 kV line to CFE interconnection will be put in service in the next five years, to ensure the growth of the import capacity. No more lines are assumed up to 2035. With this second line, the maximum power capacity from imports is 100 MW approximately. This line must be connected to La Democracia, West Lake or other point in this region, to contribute to supply the demand of the central region and consequently serve for voltage regulation.

Secondly, the localization of power backup, that will generate mainly in peak hours, and new renewable power facilities, which will not supply firm energy, and must be localized close to the major demand points. Considering that the import income is in the extreme north, that hydro generation facilities are localized on the extreme west, the major part of new backup and renewable generation must be localized close Belize City, considering possible connection points to the 115 kV network.

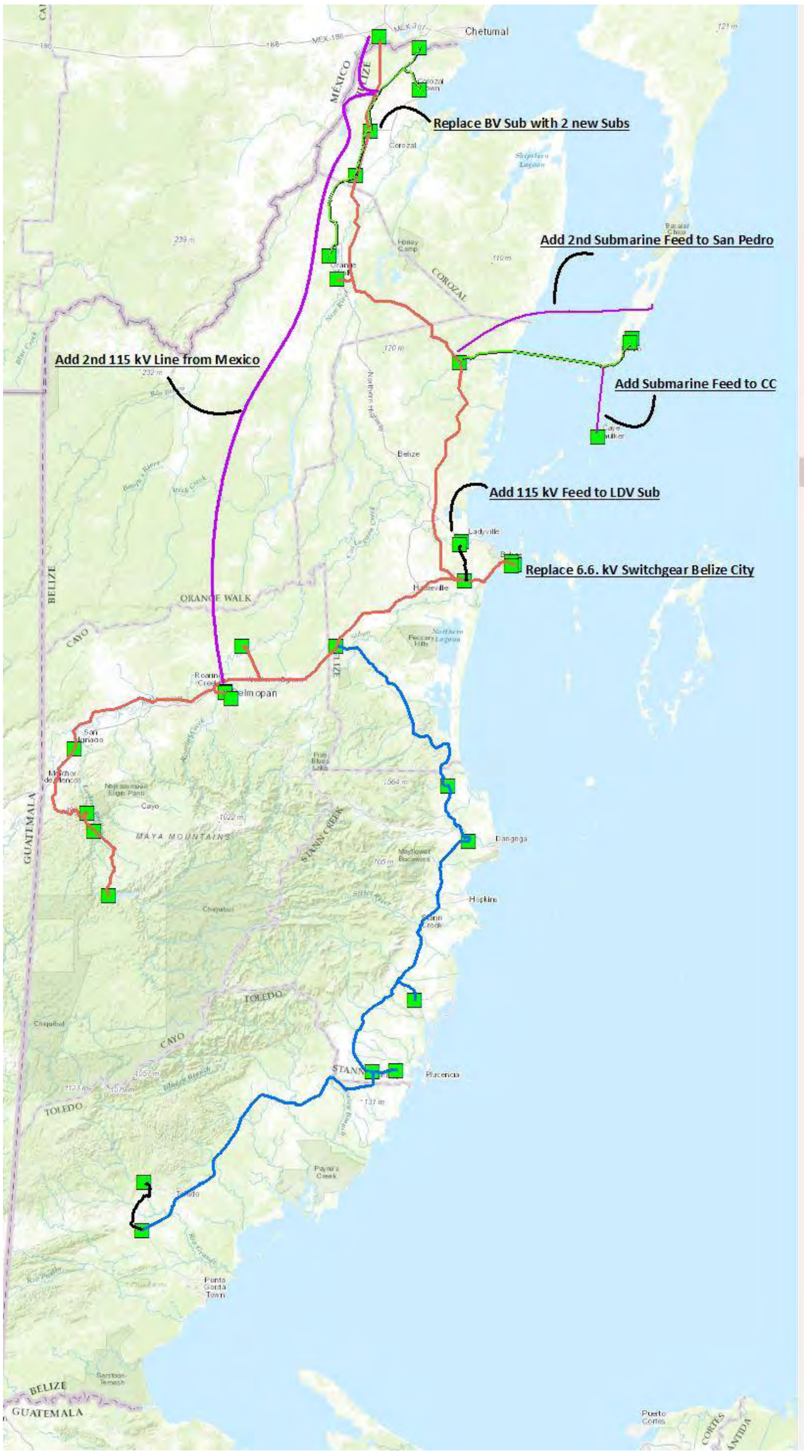
Third, possible over charge on lines should be analyzed, in particular in the south 69 kV line, with the planned demand growth.

In big numbers, the 2035 peak demand of the system will go from 190 MW to 250 MW, depending on the scenario. The peak firm power available goes from 260 MW to 310 MW. Only in the ME Base scenario, the total 100 MW of the planned interconnections are used, and in that scenario local power backup must be increased over the interconnection capacity from 2030. In the other three scenarios, local back up capacity growth should go along with the interconnection capacity contracted. This results from imposing on the simulation that the 90% backup must be local.

In the high growth demand scenario, some new interconnection can be eventually considered, but the decision can be made after 2025, knowing the real performance of the demand growth. It is probable that in 2025 the SIEPAC will be more developed and it will then be the right moment to decide if more regional integration is convenient.

The preliminary conclusion of these considerations is that these issues must be studied with more detail, including power flows and demand expansion by bus. To analyze the network expansion, the Transmission System is divided in regions, as shown in the following map. Also, the map shows the new 115 kV line to reinforce CFE interconnection and new power lines to feed San Pedro and Caye Caulker.

Map 2.1. Belize Transmission Network



Source: BEL

Additionally, a possible new line La Democracia – Dandriga is shown, a solution that is commented below. This division is done to see the balance of generation vs. demand in each region.
The Table 2.26 shows the monthly peak demand by bus, calculated from metering energy supplied to distribution, divided by 0.7 demand factor and by 720 hours/month.

Table 2.26. Belize monthly peak demand by bus, MW

		BELIZE	LADYVILLE/ WESTLAKE	BELMOPAN	SAN IGNACIO	DANDRIGA	MULLINS RIVER	SAN PEDRO	COROZAL	ORANGE WALK	PUNTA GORDA	CAYE CAULKER	INDEPENDENCIA	Total Net Supply
		MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	**MW**
15	JAN	15.7	12.3	7.4	6.3	6.2	0.4	8.3	6.7	6.6	1.9	1.2	6.2	**83.6**
15	FEB	14.4	11.2	6.9	5.7	6.1	0.3	7.8	5.6	6.0	1.8	1.1	5.8	**76.8**
15	MAR	17.5	13.5	8.5	6.9	7.6	0.3	9.5	7.1	7.4	2.2	1.3	6.9	**93.5**
15	APR	17.6	13.9	9.1	7.5	7.6	0.4	10.1	7.3	7.6	2.3	1.3	7.5	**97.3**
15	MAY	18.8	14.8	9.3	7.7	7.5	0.4	9.9	7.3	8.1	2.3	1.4	7.3	**100.1**
15	JUN	18.3	14.4	9.1	7.3	6.3	0.3	9.7	7.3	8.0	2.2	1.3	5.7	**95.3**
15	JUL	19.8	15.2	9.2	7.7	6.4	0.3	11.0	7.5	8.6	2.3	1.5	5.6	**100.9**
15	AUG	20.3	15.4	9.7	7.9	6.3	0.3	11.0	8.0	8.8	2.3	1.5	5.9	**103.0**
15	SEP	19.0	15.3	9.3	7.7	5.7	0.2	8.9	7.6	8.3	2.3	1.2	5.2	**96.5**
15	OCT	18.8	15.5	9.5	7.9	5.9	0.2	9.8	7.8	8.4	2.3	1.2	5.4	**97.7**
15	NOV	17.8	14.7	8.9	7.4	6.0	0.2	10.2	7.2	8.0	2.1	1.4	5.3	**93.5**
15	DEC	17.7	14.7	8.6	7.6	5.9	0.2	10.5	7.2	8.1	2.3	1.4	6.0	**94.0**
16	JAN	15.5	12.9	8.0	6.9	6.8	0.2	9.3	6.5	7.1	2.0	1.3	5.6	**83.8**
16	FEB	14.2	12.3	7.3	6.3	6.6	0.1	8.4	5.9	6.5	1.8	1.2	5.2	**77.4**
16	MAR	17.5	14.9	9.0	7.9	6.9	0.2	11.1	7.3	8.0	2.3	1.5	6.5	**94.1**
16	APR	18.5	15.5	9.4	8.1	7.2	0.2	10.8	7.5	8.5	2.4	1.5	6.4	**97.5**
16	MAY	19.7	16.6	10.5	9.0	8.2	0.2	12.0	8.2	9.4	2.6	1.6	4.2	**103.9**
16	JUN	19.2	16.6	9.5	8.6	7.1	0.2	11.7	7.8	9.3	2.5	1.6	8.5	**104.8**
16	JUL	20.0	16.8	10.7	8.6	6.8	0.2	12.3	8.4	9.4	2.3	1.8	6.5	**106.7**
16	AUG	18.8	15.4	10.0	8.3	6.3	0.2	11.1	7.9	9.5	2.4	1.4	6.3	**101.5**
16	SEP	19.5	16.1	10.8	8.3	5.8	0.2	10.1	7.4	9.0	2.4	1.4	6.3	**101.6**
16	OCT	18.5	15.4	8.6	8.2	5.7	0.2	9.8	7.7	8.6	2.3	1.3	6.5	**97.4**
16	NOV	16.4	13.9	8.6	7.3	5.3	0.2	9.0	7.0	7.8	2.3	1.3	6.1	**88.9**
16	DEC	17.9	14.2	8.8	7.9	5.8	0.2	10.7	7.2	8.3	2.3	1.9	6.3	**93.5**

Source of energy metering per buses: "Losses Trend_2013 to 2016.xlsx"

Maximum demands occur in summer, and July 2016 is taken as a reference base for following calculations.

In the different demand growth scenarios, the peak power results as following:

Table 2.27. Peak Power by Demand Growth Scenarios, MW, 2016-2025-2035

PEAK POWER (July)	2016	2025	2035	Growth Ratio	Growth Ratio
SCENARIOS	MW	MW	MW	2016-2025	2016-2035
DNV BASE	106	150	209	1,42	1,97
ME BASE	106	163	252	1,54	2,38
DNV LOW	106	143	189	1,35	1,78
ME LOW	106	154	227	1,45	2,14

Source: "BEL Generation Plan CLERK"

As a first approximation, the same growth ratio is used for all the buses, with the results shown in the following table:

Table 2.28. Peak Power by bus (same growth ratio), MW

	CENTER	CENTER	WEST	WEST	SOUTH	SOUTH	NORTH	NORTH	NORTH	SOUTH	NORTH	SOUTH	
PEAK POWER	**BELIZE**	**LADY VILLE / WEST LAKE**	**BELMOPAN**	**SAN IGNACIO**	**DANDRIGA**	**MULLINS RIVER**	**SAN PEDRO**	**COLOZAL**	**ORANGE WALK**	**PUNTA GORDA**	**CAYE CAULKER**	**INDEPENDENCE**	**Total Net Supply**
	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW
July 2016	20.0	16.8	10.7	8.6	6.8	0.2	12.3	8.4	9.4	2.3	1.8	6.5	106.7
DNV BASE													
July 2025	28.2	23.8	15.1	12.2	9.6	0.3	17.4	11.9	13.4	3.3	2.5	9.2	151.1
July 2035	39.4	33.2	21.1	17.0	13.3	0.4	24.3	16.6	18.6	4.6	3.5	12.8	210.5
ME BASE													
July 2025	30.7	25.9	16.4	13.3	10.4	0.3	18.9	12.9	14.5	3.6	2.8	10.0	164.2
July 2035	47.5	40.0	25.4	20.5	16.1	0.5	29.3	20.0	22.5	5.5	4.3	15.5	253.8
DNV LOW													
July 2025	26.9	22.7	14.4	11.6	9.1	0.3	16.6	11.3	12.7	3.1	2.4	8.8	144.0
July 2035	35.6	30.0	19.0	15.4	12.0	0.4	21.9	15.0	16.8	4.1	3.2	11.6	190.3
ME LOW													
July 2025	29.0	24.5	15.5	12.5	9.8	0.3	17.9	12.2	13.7	3.4	2.6	9.5	155.1
July 2035	42.7	36.1	22.9	18.5	14.5	0.5	26.4	18.0	20.2	5.0	3.8	13.9	228.6

Source: Own elaboration

When grouped by region, the demand peak power results as follows:

Table 2.29. Demand Peak Power by Region, MW

PEAK POWER	CENTER	WEST	SOUTH	NORTH
DEMAND	**MW**	**MW**	**MW**	**MW**
	36.8	19.3	15.8	31.9
DNV BASE				
jul-25	52.1	27.3	22.4	45.2
jul-35	72.6	38.1	31.2	63.0
ME BASE				
jul-25	56.6	29.7	24.3	49.1
jul-35	87.5	45.9	37.6	75.9
DNV LOW				
jul-25	49.6	26.1	21.3	43.1
jul-35	65.6	34.4	28.2	57.0
ME LOW				
jul-25	53.5	28.1	23.0	46.4
jul-35	78.8	41.4	33.9	68.4

Source: Own elaboration

Seeing the values of the table above, it can be concluded as first highlights:

- The highest demands are in the Central Region.
- Following in importance comes the North Region, but it is close to the CFE Interconnection and Belcogen, with 115 kV lines, so consequently it should not be a problem for power transmission.
- The West Region has a considerable demand, but it is close to the hydro generation facilities, existing and future.
- The South Region, fed in 69 kV, will have demands over 20 MW in 2025 in all scenarios of demand growth, so it could need some solution, as one new line in 115 kV to Dandriga, where the major demand in the region is located.

INTERCONNECTION CFE

In the ME Report (Chapter 6.3.1) says:

a) Analyzed Configurations with Mexico
For the alternative with reinforcement of the interconnection with Mexico, two options were studied in detail: MX1 (Xulha to West Lake) and MX4 (Xulha to Camalote through La Democracia).

The other two alternatives MX2 (Xulha to La Democracia) and MX3 (Xulha to Camalote) are variations of MX1 and MX4 respectively. The network expansions required for the alternatives MX2 and MX3 are thus assumed to be the same as for their respective "root" alternative. Simulations of the MX2 and MX3 alternatives confirmed that no operation problems were identified.

Both solutions for the second 115 kV line are feasible and meet the main objectives:

- To allow importation up to 100 MW peak.
- Contribute to voltage regulation in the Central Zone, where the major demand of Belize City region is located.
- Reinforce Short Circuit Power of Central Zone which is good for stability of the system and voltage regulation.
- Ensure the supply of the Central Zone with the corresponding demand growth for the period analyzed.

CENTRAL 115 kV

It is recommended that the new GT + Motors for backup be placed close to the Belize City region, in order to connect to the 115 kV grid. Complementary, new wind generation, and part of new solar generation, must be placed in the same region, to ensure energy supply close to Belize City region. The wind resource map shows good wind performance in this region on the coast, where new wind farms could be placed.

SOUTH 69 KV

Some measures are needed to avoid forced generation and to ensure voltage regulation. Some complementary solutions for this problem:

- Partial localization of GT+Motors in the South (Independence, Dandriga) for backup peaks and voltage regulation.
- Eventually localization of some MW of Solar PV to mitigate forced generation during the day.
- Convert La Democracia – Dandriga 69 kV line to 115 kV (60 km approx.) and new Substation 115/69 kV in Dandriga. This solution is suggested as the principal or main measure to be considered.
- Possible interconnection with Guatemala in 115 kV, with transformation 115/69 kV in Punta Gorda. Rio Dulce – Punta Gorda. 79 km. This interconnection might be the first step for Guatemala Interconnection, and it should be completed with La Democracia – Dandriga and Dandriga – Punta Gorda in the long term.

WEST REGION

This region does not have problems, considering existing and new hydro generation. The peak power available is greater than the peak demand.

To approximate the power peak balance and energy balance, the ME Low scenario was considered, comparing generation and demand by region.

2.8.1 Generation by Region:

- CENTRAL – Existing GT, new GT+Motors, all new Wind Farm + Solar PV.
- WEST – Chalillo, Mollejon, Vaca, New Macal (Challilo 2), Suasey, SSE.
- SOUTH – BAL Motors, Hydro Maya, Solar South.
- NORTH – CFE 1+2, Belcogen.

Table 2.30 shows these comparisons.

Table 2.30. Comparison Demand and Generation by Region, MW, 2025-2035

PEAK POWER DEMAND (MW)	CENTER	WEST	SOUTH	NORTH
jul-25	53.5	28.1	23.0	46.4
jul-35	78.8	41.4	33.9	68.4
PEAK POWER GENERATION (MW)	CENTER	WEST	SOUTH	NORTH
jul-25	36.0	79.0	16.0	81.0
jul-35	76.0	79.0	16.0	111.0
PEAK GEN/PEAK DEM	CENTER	WEST	SOUTH	NORTH
jul-25	67%	282%	70%	175%
jul-35	96%	191%	47%	162%
AVERAGE POWER DEMAND (MW)				
jul-25	37.4	19.6	16.1	32.5
jul-35	55.2	29.0	23.7	47.9
AVERAGE POWER GENERATION (MW)	CENTER	WEST	SOUTH	NORTH
jul-25	0.5	50.0	6.0	50.8
jul-35	25.2	50.0	6.0	66.6
AVERGAE GEN/AVERAGE DEMAND	CENTER	WEST	SOUTH	NORTH
jul-25	1%	254%	37%	156%
jul-35	46%	173%	25%	139%

Source: Own elaboration

Peak Power Generation considers only firm power. Average Power Generation considers all sources of energy, calculated as monthly energy divided by 720 hours. From the point of view of peak power, each region shows the following characteristics:

- CENTRAL: power peak is covered mainly by local generation, but it requires complementary power from the system.
- WEST: power peak generation exceeds greatly the power peak demand. The surplus is supplied to CENTRAL and SOUTH regions.
- SOUTH: demand is the lowest, but needs to be covered by the system, plus local generation.
- NORTH: similar situation of the west, generation power peak exceeds demand peaks.

From the point of view of average power, that sees mainly energy flows, the relative situation is similar to peak power, but the unbalances are greater.

The Central Region is on the 115 kV network, so it can receive power directly from the hydros (West) and from CFE (North).

The South Region depends on injection from La Democracia in 69 kV, consequently it would be necessary to displace part of the new renewables to the south, but it seems unavoidable to build a new line 115 kV La Democracia – Dandriga and a substation 115/69 kV in Dandriga. In this way forced generation in this region could be avoided.

As a conclusion, expansion generation plans are applicable with some additional reinforcement, in addition of the already planned. After the reinforcements, no additional changes would be necessary if the localization of the new generation is done considering geographical demands requirements.

HV/MV TRANSFORMATION CAPACITY

ME Report analyzes the power flows in detail, includes HV/MV transformation capacity, chapter “6.3.4. Network Expansions for Alternatives with Mexico - MX1 and MX4 – BAU Demand”, that’s match with ME Base scenario, the highest demand growth. For these scenarios, over charges will happen only in transformers HV/MV, in each case it recommended to install more transformers from 2016 to 2030 in different buses.
Planning of transformer expansion capacity must be done in midterm. Particular evolution of region demands, big size specific projects, new generation projects, it must be considered to plan transformer capacity expansion. The current practice is examining annually the real evolution of HV bus demands; evaluate new big demand projects and new generation by region, for the next 2-5 years.

ME Report gives a base to transformer capacity expansion, that’s right for 2016-2020, but in the future this recommendation must be reviewed, as it is suggested. The second thing that is necessary to pay attention is the age and the status of all the existing transformers, mainly the old machines. A complementary plan to replace transformers with several isolation problems, that it could not be solved with maintenance, should be added and combined with the expansion plan.

As a summary, for transformers HV/MV, a midterm plan that combines replacement and expansion, seeing local develop of demands and generation is recommended. This plan must be reviewed annually.

TRANSMISION INVESTMENTS

For the evaluation of the interconnections, ME Report uses regulatory costs taken form regulatory agencies, naturally low. In the second stage of this evaluation, it makes a revision of these costs, showing in Table 2.31.

Table 2.31. Transmission Investments by alternative, USD

Alternative	MX3.1 Xul-Ha to Camalote 2 115 kV	MX3.2 Xul-Ha to Camalote 2 230 kV	GU1 Buena Vista to Camalote 2 230 kV
CAPEX	**17,298,842.28 USD**	**20,475,247.38 USD**	**38,357,382.32 USD**
Preliminary and permitting Phase	1,255,996.49 USD	1,412,443.78 USD	2,629,569.82 USD
Permitting Cost	305,598.60 USD	368,177.51 USD	670,627.93 USD
Engineering Cost	458,397.89 USD	552,266.27 USD	1,005,941.89 USD
Field Studies & ESIAs	492,000.00 USD	492,000.00 USD	953,000.00 USD
Construction Phase	16,042,845.79 USD	19,062,803.60 USD	35,727,812.50 USD
Environmental Monitoring Plan	673,876.00 USD	577,608.00 USD	1,992,896.00 USD
SocioEconomic Monitoring Plan	89,040.00 USD	76,320.00 USD	203,520.00 USD
Construction Cost	15,279,929.79 USD	18,408,875.60 USD	33,531,396.50 USD
OPEX	**297,643.75 USD**	**330,184.79 USD**	**683,101.78 USD**
Operational Phase (/year)	297,643.75 USD	330,184.79 USD	683,101.78 USD
Environmental & Surveillance Plan (/year)	111,444.00 USD	111,444.00 USD	268,888.00 USD
O&M Cost (/year)	186,199.75 USD	218,740.79 USD	414,213.78 USD

Source: IADB SIEPAC Study.docx

Total cost corresponds to approximately 150 km of 115 kV line, and 7 bays of 115 kV in Xulha, Buena Vista and Camalote 2. This total value suggests the following costs for lines and bays in 115 kV:

- Line 115 kV: 100.000 USD/km, it includes all costs, such as project, permissions, materials, construction and commissioning. It is assumed the same kind of existing line in 115 kV.
- Bay 115 kV: 350.000 USD/bay, it includes all costs, such as project, materials and equipment, civil works, control and communications. It is assumed the same kind of existing bays in substations of 115 kV.

These costs are reasonable, if they are compared, for example, with costs of 150 kV in Uruguay. The line has cost of 170.000 USD/km, using metallic towers. The bay has cost over 500.000 USD/bay, with more complex technical projects that it is used in BEL. AO&M costs is 1.72% of the CAPEX annuity, considering 30 years of duty life and 10% of ROR.

Using these unitary values, the total investments in 115 kV lines and substations, except transformers, results in Table 2.32.

Table 2.32. CFE Interconnection Costs, USD

INTERCONNECTION CFE		Units	USD/unit	USD Total
Lina Xulha-La Democracia	km	140	100,000	14,000,000
Bays (Xulha, Buena Vista, La Democracia)	bay	5	350,000	1,750,000
Total Interconnection CFE				**15,750,000**

Source: Own elaboration

It is assumed the conversion of La Democracia in a O-Ring substation, with four-line outputs in 115 kV. For this arrangement, 2 additional bays are needed. The rest of bays correspond to Xulha and Buena Vista substations.

Considering 30 years of duty life, 10% of ROR, and the O&M cost as 1.72% of CAPEX, results annual costs showing in Table 2.33.

Table 2.33. CFE Interconnection Annual Costs, USD

INTERCONNECTION CFE	USD Total
CAPEX ANNUITY	1,670,748
AO&M	280,994
Total	**1,941,742**

Source: Own elaboration

The most probable expansion to the SOUTH region, would have costs as in Table 2.34.

Table 2.34. South Region Costs, USD

La Democracia - Dandriga		units	USD/unit	USD Total
Lina Xulha-La Democracia	km	60	100,000	6,000,000
Bays (Dandriga)	bay	1	350,000	350,000
Total				**6,350,000**

Source: Own elaboration

With similar hypothesis, the total annuity results as follow.

Table 2.35. Interconnection total annuity cost, USD

INTERCONNECTION CFE	USD Total
CAPEX ANNUITY	673,603
AO&M	109,258
Total	**782,861**

Source: Own elaboration

TRANSFORMATION HV/MV INVESTMENTS

ME Report analyzes over charges up to 2030, and the ones detected are all in transformers. As an example, for the BAU scenario shows the follow increase of transformer capacity.

Table 2.36. Increase of Transformation Capacity/substation, %

Year	Overload	Substation	Expansion
2016	133.0%	Ladyville	Second Transformer 14 MVA, 115/22 kV, three windings
2016	106.0%	San Pedro	Second Transformer 10 MVA, 115/34 kV, two windings
2019	103.0%	Buena Vista - Corozal	Second Transformer 10 MVA, 115/34 kV, two windings
2026	103.8%	Buena Vista - Orange Walk	Second Transformer 10 MVA, 115/34 kV, two windings
2026	100.9%	Belize City	Second Transformer 10 MVA, 115/6,6 kV, three windings
2030	109.0%	Belmopan	Second Transformer 15 MVA, 115/22 kV, two windings
2030	109.0%	Lady Ville	Third transformer 14 MVA, 115/22 kV, three windings

Source: Own elaboration

This means an increase of 83 MVA of HV/MV transformer capacity up to 2030. This capacity increase corresponds approximately to the total demand increase in the same period.

Following a general criterion where transformation capacity growth is directly correlated with peak demand growth, in the scenario considered the increase will be of 109 MW peak. With an average cost of investment 70.000 USD/MVA, this means USD 7.630.000 of CAPEX, an average of USD 401.579 per year. This annual amount must be assigned punctually where over charges that are detected, this is only the first approximation for solve the problem. Total cost of substitution of old transformers is not included.

CABLE BUENA VISTA – SAN PEDRO – GAY CAULKER
These investments must be done to avoid expensive generation and to put out of service old machines. It is considered a distribution investment in this report.

230 kV FUTURE INTERCONNECTIONS
All the expansion plans are solved with expansion of transmission in 115 kV. A possible 230 future interconnection with Mexico, Guatemala or Honduras, might be analyzed seeing the development of the 230 kV network in these countries up to 2025-2030.

All the existing development plans that interconnect SIEPAC with Mexico include lines close to the Pacific Coast. Some new scenarios could appear, for example, future 230 kV lines in North Guatemala, which may add a new possible alternative of interconnection with West Region. The other side of this analysis that must be treated is the degree of market integration. For example, SIEPAC has as objective the market integration; consequently, BEL must be continually analyzing if it is convenient to interconnect with the SIEPAC System, and under which conditions.

2.9 Conclusions and Recommendations

As a first and important conclusion, it must be pointed out that the Belize's electrical system presents many strengths:

- Demand is covered, and the developments already committed will support its growth for several years, even under a relatively strong growth forecast.
- The interconnection is an important asset, minimizing risk and supplying competitive energy and power.
- There is reasonable time for decision making on new power capabilities, and new interconnections.
- The transmission and distribution network operate well, with comparatively low losses.

However, there are some issues that should be attended. Maybe the main issue is that the cost of total demand supply in Belize is high in comparison with other markets. This derives from specific causes that can be analyzed. This issue should be taken into account in order to make a general revision of existing contracts. Some of them could be renegotiated considering the new conditions of the market and that the equipment may be completely depreciated.

Because of this previously mentioned characteristic, the Belize system has a very important exposure to the variation of oil and gas prices. In the portfolios that were evaluated, the Net Present Value of the annual cost grows with the price of oil. Although the scenarios of low and high oil prices are quite extreme, they allow the verification of a significant potential risk. However, this risk is very mitigated by the increase of gas and renewables participation in Mexico´s energy matrix. Further in this chapter, other recommendations will be included to deal with this issue.

There are some other issues to be considered. Energy efficiency, new sources of demand, losses and voltage regulation, renewable sources, regional interconnection and the energy policy to support productive projects are some of these issues. Also, the stability, situation and development of the transmission network are important issues. Some ideas related to these issues are presented in the report. Here are some of the highlights:

- Energy efficiency is and will be an important trend, driven both by technology and by public policy. However, Clerk is not as optimistic about its progress as some of the reports that BEL and government officials have shared with us.
- New demand will, without doubt, come from electric vehicles. However, the penetration will be gradual, and the greater part of its impact goes beyond the span of this study.
- Renewable sources (mainly wind and photovoltaic) are already mature technologies that constitute competitive alternatives. Therefore, in a country with little or no oil and gas resources, and considering also environmental constraints, these renewable sources should be the option for future expansion, complementing already committed IPP's and the expansion of interconnection facilities.
- Technical losses are under control and related to the network topology and some minor infrastructural issues. There are also some voltage regulation issues, related to the network topology, and backup generators are being put in operation to mitigate this. An important opportunity to optimize this comes from a new interconnection line at 115 kV.

- Regional interconnection has been an interesting asset, as said, and part of the future expansion should without doubt come from a new second line from Mexico. The supply from this line can be scheduled to grow gradually, depending on how aggressive the local generation effort will be. The new line will also be valuable to stabilize voltage in the system and should arrive in 115 kV near Belmopan. The decision of a third line, with Guatemala or with Honduras, or even with Mexico and from there to SIEPAC, falls, in Clerk's opinion, outside the period of this study (only viable after 2035) and will profit from the regional progress that will be made in these years.
- The development of productive projects is always an issue that relates directly with the electrical system, being it because new demands are put in place, or because the productive projects can also be generating electricity and sending it to the network. That is the situation with the Bagasse projects, for example. However, in the period of the study, Clerk does not consider new projects other than the ones already under development. As a general criterion, Clerk recommends both the pricing and the dispatch conditions in new contracts to be aligned with actual market practices.

Finally, considering the transmission network, generation expansion plans are applicable with some additional reinforcement of the network, in addition of the already planned, mainly a new 115 kV line La Democracia – Dandriga, and reinforcement of the HV/MV transformer park. After the reinforcements, no additional changes would be necessary if the localization of the new generation is done considering geographical demands requirements.

2.9.2 Main results

The main results of the study considered four different demand scenarios, built from previous independent studies (ME and DNV), and evaluated critically by Clerk's team. The study applied these four demand scenarios to three different supply portfolios, subject to some previously agreed upon restrictions, mainly that:

- Imports from CFE did not go over 40% of total energy (except in Portfolio 3)
- 90% of peak power was available through local power plants (except in Portfolio 3).

Each portfolio takes care of the needs to supply energy and power peak to the demand, evolving in each of the scenarios. As a highlight, in every portfolio a second 115 kV line from CFE is built, starting operations after 2022, though the inclusion of its different power blocks is done gradually and is different in each case. Also, in every portfolio, the rest of the demand is supplied by new wind power and solar power IPPs, and the peak power is assured with backup fossil fuel plants, installed when needed (for the peak power supply the renewables are not considered).

The difference between portfolios is that in the second more local renewable power plants were installed, so that fewer imports are needed. The third one has been introduced to show the sensibility of delaying the PPAs under negotiation.

As mentioned, a relevant conclusion of the simulation of the portfolio 3, is that the presence of the interconnection with CFE allows any delays in the expansion plan to have a very low impact on the total costs of the system. The interconnection operates as a very valuable hedge against the increase in total system costs.

Each supply-demand combination then was used to calculate the total cost of demand supply, under three different oil and natural gas price scenarios (extreme scenarios from EIA report). They were then compared using NPV and LCOE.

The conclusion is that the main issue, regarding cost, is the high dependency on oil prices, and therefore one of the strategic concerns should be the mitigation of this risk.

2.9.1 Mitigation of oil and natural gas prices risk

Regarding the risk of oil and natural gas prices dependency, Clerks considers that this risk can be covered in the financial market but in relatively short terms. The risks could also be covered by increasing the participation of sources not indexed with oil or NG (wind and photovoltaic solar) and / or creating a stabilization fund.

The diversification of the supply portfolio from Mexico improves the situation. However, it is necessary to emphasize that the supply from the interconnection will be basically thermal generation. The increasing participation of natural gas in this mix, collaborates to maintain this risk more limited/controlled.

A stabilization fund, managed through a trust fund, would allow accumulating resources during the periods of low prices of oil and natural gas; and use the fund when oil prices are high. This would allow the finances of BEL in a particular year not to be heavily affected, and at the same time it would give a stability signal for the electric tariffs in the medium term.

Countries such as Chile, Peru or Uruguay, have trust funds to reduce the volatility of prices of wholesale electricity or liquid fuels.

Annexes

Technologies' Analysis

A.1 Technologies' Analysis

A.1.1 Solar Systems

Two main technologies are presently being used in the world for converting solar energy into electric power: photovoltaic (PV) systems and concentrated solar power (CSP) plants.

PV systems directly convert the energy of solar light into DC electric power by means of panels made up of solar cells that operate under the principles of the photovoltaic effect. Given that the output of a PV panel is DC power, if a PV system is to be integrated into an AC electric system, a power inverter must be fitted.

CSP, on the other hand, are basically thermal power plants that capture and concentrate the thermal energy of the sunlight and convert it into electric power by means of thermodynamic cycles similar, in principle, to those employed in conventional fossil fueled or nuclear plants, that is, mainly Rankine cycles and sometimes Stirling cycles. As these systems generate AC electric power just as any other conventional thermal plant, they can be directly connected to an AC power grid without the need of a power inverter.

In terms of investment costs, PV systems have benefitted from intense R&D processes in power conversion and manufacturing technologies that have resulted in important cost reductions, and due to their modular nature, they are not particularly affected by economies of scale, what makes them easily scalable and thus especially well-suited for small systems, such as Belize's. On the other end, CSP are strongly affected by economies of scale, and due to their higher conversion efficiency, they are more suitable for larger systems.

Regardless of the technology, solar power is in all cases heavily dependent on solar radiation (basically day hours and cloudless skies). However, after recent developments, both PV and CSP technologies can be provided with some energy storage capability to mitigate that dependence and allow for some energy to be accumulated during the day and be later released into the grid when the demand is higher. For PV systems the storage solution is based on batteries, while the energy storage in CSP is usually implemented by means of thermal energy storage, using, for instance, molten salts.

A.1.1.1 Solar Technology applicable for the Belize case

As stated above, PV systems are better suited for small sized systems (some MW´s) than CSP and will thus be used in our study as the reference technology for the use of solar energy in the Belize expansion plan.

Regarding investment cost, a reference value in the range of 1.5 - 2 USD/Wp (Wp = W of peak installed capacity), with an average of 1.8 USD/Wp (or 1800 USD/kWp) for utility-scale PV systems without storage capability can be considered reasonable[16] .

Solar PV is recommended in combination with wind generation. PV has a lower capacity factor, but it has a considerable simultaneousness with HVAC consumptions.

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16 "Technology Roadmap: Solar Photovoltaic Energy". International Energy Agency (IEA). 7th Oct 2014. http://www.iea.org/publications/freepublications/publication/TechnologyRoadmapSolarPhotovoltaicEnergy_2014edition.pdf

As mentioned in our first report, considering the studies provided (Site selection ranking matrix provided by BEL) and the renewable resources maps (http://globalsolaratlas.info/ ; DNV GL maps provided by BEL), the characteristics of the solar resource are:

- Average Global Horizontal Irradiation: 1600 – 2000 kWh/m2/year
- Photovoltaic power potential: 1300 – 1700 kWh/kWp

Which lead to a capacity factor of approximately 17 - 19%.

As a result, utility scale PV systems are recommended for the case of Belize, which may be installed in power steps taking advantage of the modular nature of the technology.

In addition, solar microgeneration connected at low voltage may be used, but the investment cost increases and could reach values of 3.5 USD/Wp, depending on the installation conditions and additional steel or aluminum structures for solar panels support on roofs.

A.1.2 Wind Energy

Constant and intense R&D in aerodynamics, materials, power conversion and manufacturing technologies performed for more than a decade by major players in the power generation equipment market like Siemens, GE, Enercon, Vestas, Nordex, just to mention a few. It has given way to important investment cost reduction and a significant increase in energy conversion efficiency and capacity factors of windmills, accompanied by a constant increase in the power generation capacity of the basic individual module what provides the additional benefits of economies of scale.

The state of the art technology in windmills currently comprises 2 to 3.5 MW machines with three blades, horizontal axis and rotor diameters of 100-120 meters, utilizing as a rule doubly fed asynchronous or synchronous generators that allow for a limited kinetic energy storage capability that improves the capacity factor.

For this upper end range of windmills, which we will center in the ~3 MW size, we can identify, as a reference, the following commercially available models:

- Siemens-Gamesa: G114-2.5 MW[17] – G132-3.3 MW[18]
- GE: 3.2-3.8 MW Wind Turbine Platform19
- Vestas: V112-3.45 MW[20]

Regarding investment cost, a specific investment value of 1800 USD/kW installed capacity can be considered acceptable for the purposes of the present analysis[21].

17 Gamesa 2.5 MW
http://www.siemensgamesa.com/es/productos-servicios/aerogeneradores-gamesa/gamesa-25-mw.html
18Gamesa 3.3 MW
http://www.siemensgamesa.com/es/productos-servicios/aerogeneradores-gamesa/gamesa-33-mw.html
19 https://www.gerenewableenergy.com/wind-energy/turbines/3mw-platform
20 https://www.vestas.com/en/products/turbines/v112-3_45_mw
21 Lazard's Levelized Cost of Energy Analysis – Version 11.0 – November 2017
https://www.lazard.com/media/450337/lazard-levelized-cost-of-energy-version-110.pdf

For wind speed registered in the best zones on shore, it could be used Class III wind generators, but with special care in hurricane resistance.

Annual energy supplied by wind generation has minor annual variations, it produces a guaranty of package that substitutes fuel generation or energy imports.

As mentioned in our first report, considering the information provided (Site selection ranking matrix provided by BEL) and the renewable resources maps (http://globalsolaratlas.info/ ; DNV GL maps provided by BEL), the characteristics of the wind resource are:

- Average onshore wind speed, at 80m above ground level: 4.5 – 7 m/s
- Average offshore wind speed, at 80m above ground level: 5.5 – 7 m/s

Considering the values mentioned, an onshore wind generation projects would have a capacity factor of approximately 33 - 35%, which are reasonable values for these projects to be developed, and thus recommended for the case of Belize.

A.1.3 Feasibility of Energy Storage Systems

Background

Traditionally, demand supply in electrical systems has been constrained by the economical unfeasibility of large-scale energy storage, which consequently required that the supply followed exactly the load demand at every instant. The emergence of power generation technologies affected by strong economies of scale and/or by the lack of flexibility to follow the demand, as was the case of nuclear or large fossil thermal plants, led to the necessity to implement energy storage systems, usually consisting of pumped storage hydro plants associated with large generating stations, dedicated to storing the surplus energy produced by these station in times of lower demand, later to release it into the system when the demand surpassed the generation. These pumped storage systems were also subject to significant economies of scale just like the generating plants with which they were associated. Later, in the 80's, special cases of small, isolated electrical systems saw certain electrical grid needs such as spinning reserve or peak shaving services being implemented by means of small-sized energy storage systems utilizing front end technologies like cryogenically cooled superconducting coils, known as Superconducting Magnetic Energy Storage (SMES)[22], or the first examples of banks of batteries coupled with power inverters.

In more recent times, the massive incorporation of inherently variable renewable resources, such as wind and solar energies, introduced stronger requirements for large-sized electric energy storage systems to match the random variability of the supply with the partially predictable variability of the demand. Significant R&D carried out in the recent decades in the fields of electric batteries and power electronics allowed for a sharp decrease in investment and operational costs of large-scale battery storage and power inverters stations and thus to an explosive increase in the commercial application of these energy storage systems. Finally, the most recent developments in this area include the combined

22 Alaska SMES: Form and Function for the World's Largest Magnet. https://link.springer.com/chapter/10.1007/978-1-4757-9047-4_133

use of both energy storage and power generation systems through the so-called "Battery-Gas Turbine Hybrid Systems" consisting of the joint installation of battery storage and gas turbines[23] ,[24],[25].

A.1.3.1. Considerations on the Economics of Battery Storage

A significant amount of R&D is currently being carried out on the economics of energy storage systems –particularly of the electric battery type– focusing on the positive effects of this capability at different levels of the supply chain, namely at utility, transmission, distribution and "behind-the-meter" levels.

The fact that these systems are just starting to be utilized is indicative that their profitability is still not yet fully realized, while being strongly dependent on the specific characteristics of the system to which it is applied, such as the variability of the wholesale energy price and the share of total generation from non-dispatchable renewables, among others. However, the services that energy storage can provide to the different agents in the market are well known, such as energy arbitrage, frequency regulation, voltage regulation, black start, transmission congestion relief, just to name a few, being only a matter of time until cost reductions resulting from technological advances and improvements in regulatory conditions allow for their full-scale application[26],[27].

For the specific case of Belize, a gradual addition of wind and solar generation to the system would create increasing requirements for firm backup power or alternative means of providing the same capability, for which energy storage is specially indicated –particularly in combination with PV solar generation, in which the power inverters are a necessary feature that is shared by both batteries and PV cells–, while presenting other advantages over conventional backup generation. It seems reasonable then to expect that energy storage will have the opportunity to play an important role in the future expansion of the Belize system, especially by means of one-day capacity battery storage associated with solar generation, though not in the near future.

A recent Lazard's Levelized Cost of Storage Analysis issued in November 2017[28], (henceforth LCOS 3.0), provides an interesting insight into the main issues encountered when studying the economics of the different energy storage systems. Though its key assumptions are all based in the American electric markets conditions[29], some of the

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23 SCE, GE Debut Battery-Gas Turbine Hybrid System
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29 Ibidem, "Levelized Cost of Storage—Key Assumptions", pages 30-31
https://www.lazard.com/media/450338/lazard-levelized-cost-of-storage-version-30.pdf#page=39

conclusions it derives can be extrapolated to other systems, particularly for the Belize case[30], reinforcing the statement of the previous paragraph:

"…

- Importantly, incremental sources of revenue may only become available as costs (or elements of levelized cost) decrease below a certain value
- In many cases, local market/regulatory rules are not available to reward the owner of an energy storage project to provide all (or the optimal combination) of potential revenue streams…"

As to the applicable technology, LCOS 3.0 states:

"Among commercially deployed technologies, lithium-ion continues to provide most economical solution across all use cases; …"[31], for which case it estimates a capital cost of 335 USD/kWh of energy storage capacity within a range between 291 to 425 USD/kWh, and 1338 USD/kW of power capacity, in the range between 1166 and 1700 USD/kW (pages 14 and 15=, with a steady downward trend in the cost of battery storage being expected (page 16).

A.1.4. Geothermal

Geothermal Energy is a naturally occurring thermal energy, generated and accumulated under the surface of the Earth, which results from the original formation of the planet as well as from radioactive decay of materials under the Earth's crust. The use of this resource by means of specific facilities, either for direct heating purposes or as an energy source for power generation, is generically referred to as "Enhanced Geothermal Systems" (EGS).

Certain geographic areas present more favourable conditions for the economic exploitation of this kind of energy, particularly associated with a local reduction in the thickness of the Earth's crust or the proximity of tectonic plate boundaries and are more clearly identifiable in areas with volcanic activity or in the presence of hot springs.

Regarding Belize, its 2011 National Energy Policy Framework, under the chapter "Geothermal Energy", reads as follows:

Resource Availability and Utility-scale Supply Potential

There is no record of any comprehensive study of Belize's potential for geothermal energy development being done in the recent past. A part of the reason for this may be that Belize, unlike most of its Central American neighbors, does not fall within any of the major young and active volcanic belts and has been deemed not to possess any viable geothermal resources. However, there is evidence that volcanic activity occurred in the South-West region of Belize in the past and it is likely that low-temperature geothermal resources (that can be exploited using Binary Cycle Power Generation technology) may be found in that area. A 2007 Energy Sector Review commissioned by the IDB briefly noted that a RE expert hired by the GOB had mentioned that there was a "promising"

30 Ibidem, "The Energy Storage Value Proposition—Balancing Costs and Revenues", page 4 https://www.lazard.com/media/450338/lazard-levelized-cost-of-storage-version-30.pdf#page=8

31 Ibidem, "Summary of LCOS 3.0 Findings", page 2 https://www.lazard.com/media/450338/lazard-levelized-cost-of-storage-version-30.pdf#page=5

geothermal resource in the South of Belize, but that it was not possible to confirm the claim (Arbeláez, 2007). Given high oil prices, EGS - once commercially rolled out - should therefore be considered an option worthy of further investigation in Belize[32]."

Given the above, no specific analysis will be performed on this topic in the present study. However, if any future developments were to be considered on this area, it seems reasonable to assume that they would be implement them by means of small sized Binary Cycles based on the Organic Rankine Cycle (ORC) concept. These ORCs are, in essence, small Rankine Cycles similar in concept to the conventional steam power plants, though using organic fluids as the working fluid (such as some specific hydrocarbons) instead of water, which are particularly well suited for their use with low-temperature heat sources[33].

For their specific investment cost, a range of 4000 - 6400 USD/kW can be estimated, with an average of 5200 USD/kW[34].

A.1.5. Backup Thermal

Available technologies – Equipment and Fuels
Equipment: Gas turbines and/or piston engines

Two different and competing technologies are currently being put forward in the world as "environmentally friendly" conventional thermal power to backup renewable energy sources: gas turbines (GT) –both in open cycle (OCGT) and combined cycle configurations (CCGT), the latter being the preferred choice in large sized systems– on one side, and piston engines, also referred to as reciprocating internal combustion engines (RICE), on the other[35].

In the case of small sized systems, it is commonly found that both OCGT and RICE are almost interchangeably used to backup renewable sources. Quite a significant amount of research has been and still is being carried out on which of the two technologies is more suitable for this purpose, with different and usually opposite conclusions, some favouring GTs over RICE[36], some others claiming the contrary[37], some remaining neutral[38]. In the end, minor differences between the two technologies, combined with special features of the specific electric system in which they are employed, give way to either of the two being selected, many times even coexisting within the same system. The jury is still out on this matter, no distinctive trend being envisaged for the moment on either of the two prevailing over the other. For the initial stages of this study both technologies will be considered as

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32 National Energy Policy Framework – "Energy By the People … For the People" – 2011, page 49 https://www.iea.org/media/pams/belize/EnergyPolicyFramework.pdf
33 Aqylon ORC Geothermal: ATM-1000H, 1MWe – ATM-5000H, 5MWe http://www.aqylon.com/applications/renewable-energies/geothermal/
34 Lazard's Levelized Cost of Energy Analysis – Version 11.0 – November 2017 https://www.lazard.com/media/450337/lazard-levelized-cost-of-energy-version-110.pdf
35 http://www.eurelectric.org/media/61388/flexibility_report_final-2011-102-0003-01-e.pdf
36 "Comparing Aeroderivatives and Reciprocating Engines for Fluctuating Power Demand" – R. Lengel, C. Mieckowski & B. Marini – Power Engineering, November 14th, 2017. http://www.power-eng.com/articles/print/volume-121/issue-11/features/comparing-aeroderivatives-and-reciprocating-engines-for-fluctuating-power-demand.html
37 Combustion Engine vs Gas Turbine: Fuel Flexibility - Wärtsilä Energy. https://www.wartsila.com/energy/learning-center/technical-comparisons/combustion-engine-vs-gas-turbine-fuel-flexibility
38 Power Engineering, January 2018, "Mid-Sized New Generation: Reciprocating Internal Combustion Engines or Combustion Turbine?", by Melanie J. Schmeida. http://digital.power-eng.com/power-eng/201801?sub_id=5ntmAt30XbVS&folio=24&pg=27#pg27

indifferent alternatives for backing up renewable sources in Belize, until, and if, relevant characteristics that allow to favor one over the other can be identified.
In general terms, however, it can be summarized that the main advantages of GTs over RICE are the significantly lower variable O&M costs, as well as lower contaminating emissions, specially NOx and PM, while on the other hand the advantages of RICE over GTs are their higher efficiencies (lower heat rates) and fuel flexibility which in combination result in lower fuel costs. Regarding specific investment cost, there is not a significant difference between GTs and large sized RICE in the smaller range of capacities, though a slight advantage in favor of GTs can normally be observed[39].

Fuels

When available, natural gas is the fuel of choice for both GTs and RICE, due to its clean burning nature –which provides the lowest emissions and minimum equipment wear in comparison with other fuels– and the fact that it is usually the lowest cost fuel within the low contaminant range in the different regional fuel markets. However, when natural gas is not available, diesel oil (DO) and heavy fuel oil (HFO) are the substitute fuels for these applications, the former being used both in GTs and RICE, while the latter is, as a rule, only used in RICE, due to GTs being particularly sensitive to contaminants present in residual fuels.

A.1.5 Relevant drivers in the selection of proposed technologies for the Belize Generation Expansion Plan

- Fuels, Infrastructure and Logistics: Petroleum-derived liquid fuels currently used in the country: Diesel (DO) and Heavy Fuel Oil (HFO)
- Cost – In this respect, the size of the individual piece of equipment becomes significant in the determination of both investment and operational costs:
  - Investment costs: usually affected by economies of scale.
  - Fuel costs: result from the thermodynamic efficiency of the equipment and the fuel price; should account for exhaust gas treatment variable costs when these mitigation measures are required.

O&M costs:
  - Variable: includes lubricants, other consumables, spares;
  - Fixed: personnel, security, "balance of plant" power (controls, communications, lighting, etc.)
  - Electric system operation costs: related to ancillary services that can be provided by the power plant, such as frequency and voltage regulation, short term reserve, system stability support, etc.

39 Power Engineering, January 2018, "Mid-Sized New Generation: Reciprocating Internal Combustion Engines or Combustion Turbine?", Figure 1.
http://digital.power-eng.com/power-eng/201801?sub_id=5ntmAt30XbVS&folio=24&pg=27#pg27

Environmental Requirements:

Local regulations are to be observed, unless funding from international development institutions is sought, in which case more stringent specific requirements from these institutions may have to be followed. Such is the case with the International Finance Corporation (IFC) of the World Bank Group (WB.

A.1.5.1 Fuel Handling Infrastructure and Logistics

No additional infrastructure projects are being considered in the present study to incorporate new fuels, particularly natural gas, to the ones already in use in Belize. Consequently, all backup thermal generation in this reference expansion plan will be based on the liquid fuels currently employed in the country for power generation purposes, namely HFO and DO, for which a reasonably developed logistics –import, storage and transportation– infrastructure is already in place[40].

Fuels are delivered to power plants via road tank trucks. This situation does not seem to pose any significant issue that might require any different hypothesis for the purposes of the present study.

A.1.5.2 Cost

The specific features of the electric system, together with the available infrastructure and the environmental requirements, set the constraints for the cost optimization that is the basis for the elaboration of the expansion plan.

In this respect, the size of the individual piece of equipment plays a significant role in the determination of both investment and operational costs:

- Investment costs. Usually affected by economies of scale. Should include costs of additional exhaust gas treatment equipment when required.
- Fuel costs: once the fuel is given, the fuel cost depends exclusively on efficiency of the equipment, with larger equipment usually being more efficient than smaller of the same type. Fuel cost should include exhaust gas treatment variable costs when required.
- O&M costs:
- Variable: includes lubricants, other consumables, spares;
- Fixed: personnel, security, "balance of plant" power (controls, communications, lighting, etc.) and other basic services costs.
- Electric system operation costs: flexibility and reliability of the individual equipment help reduce system operation costs, contributing with important ancillary services such as frequency and voltage regulation, short term reserve, system stability support, etc. In this point, smaller units provide higher flexibility and reliability to the system than larger ones. Additionally, in small systems that may experience significant expansion rates, the mobility of generation equipment can become a very valuable feature.

40 Siemens - Least Cost Generation Planning Study, Final Report (Feb 28th, 2009) item 3.3.1 "Fuel Availability":
"… Fuels available for power generation in Belize are diesel (residual N° 2) and HFO (residual No 6).
Fuels are imported mainly from Mexico and their prices fluctuate with US Gulf Coast FOB prices indicators".
(file: "BEL_Least_Cost_Generation_Planning_Study_Final_Report_V0_SIEMENS.pdf")

A.1.6 Environmental Requirements

Three main contaminants are generally considered when dealing with systems that do not present an already degraded environment as a bottom line, and whose expansion is not expected to involve especially problematic fuels from the environmental point of view, such as coal. These three contaminants are sulphur (S) oxides (normally expressed in terms of SO2), nitrogen oxides (usually referred to as NOx, and normally expressed in terms of NO2) and Particulate Matter or PM.

SO2 emissions depend exclusively on the sulphur (S) content of fuel being burned in the prime mover. To this respect, no particular changes are considered for the S content of the fuels that are being used in Belize.

NOx emissions depend on the characteristics of the equipment and on the nitrogen (N) content of the fuel. They are higher in RICE than in GTs, the larger cylinder bore RICE emitting higher quantities than the smaller. That is why exhaust gas treatment systems like selective catalytic reduction (SCR) are usually fitted in larger RICE to reduce emissions down to acceptable levels. As to the N content of fuel –usually referred to as “fuel bound nitrogen”– manufacturers, as a rule, base their guaranteed NOx emissions figures on the absence of fuel bound N.

Projects funded by the International Finance Corporation (IFC) of the World Bank Group (WB), should comply with a set of guidelines for the funds to be awarded. These guidelines are known as the Environmental, Health, and Safety Guidelines for Thermal Power Plants , henceforth “WB’s EHS Guidelines”, which will be used as a reference.

It should be noted that it is particularly difficult to find in the internet reliable, up to date information on emissions of different RICE models, even from the manufacturers’ sources, what seems to strengthen the idea that standard models usually do not comply with stringent emissions regulations, hence additional measures such as exhaust gas treatment are normally needed for these purposes.

A summary of emissions requirements as per WB’s EHS Guidelines, 2017 draft (values for Non-degraded airshed, or NDA, 15% Dry Gas O2 content) are presented as follows:

For RICE:

Table 6 (A) – "Emission Guidelines (in mg/Nm3 or as indicated) for Reciprocating Engine": Liquid Fuels (Plant ≥50MWth to <300MWth)

- PM (NDA): 50
- SO_2 (NDA): 1,170 or use of 2% or less S fuel
- NOx (NDA):
  - 1,460 (Compression Ignition, bore size diameter [mm] < 400)
  - 1,850 (Compression Ignition, bore size diameter [mm] ≥ 400)

According to manufacturers' sources, these NOx emissions figures normally cannot be obtained unless some form of exhaust gas treatment is fitted, normally SCR .

For GTs:

Table 6 (B) – "Emission Guidelines (in mg/Nm3 or as indicated) for Combustion Turbine": Distillate/Light Fuel Oil (Unit ≥ 50MWth)

- PM (NDA): 50
- SO_2 (NDA): Use of 1% or less S fuel
- NOx (NDA): 150 (~74ppm)

A.1.7 Proposed Technologies for the Belize Generation Expansion Plan

A.1.7.1 HFO/DO Fired Reciprocating Internal Combustion Engines (RICE)

RICE models presently in use in Belize:

- BAPCOL: 3 x 7.8 MW HFO fired Wärtsilä 18V32 engines (largest individual size currently operational in Belize).
- Caye Caulker: 3 x Caterpillar 3516 (~1÷1.5 MW ea.) + 1 x Caterpillar 3512 (~0.75÷1 MW ea.), DO fired.
- BelCoGen: 2 x 2 MW medium speed HFO engines (brand/model information not available)

Two different models will be considered for the present study:

- A larger model, of ~ 8 MW capacity, similar to the Wärtsilä 18V32 engine, running on HFO, with DO as startup and backup fuel, and a heat rate of 7700 MJ/MWh referred to the low heat value (LHV) of the fuel, equivalent to a LHV efficiency of 46.7%.
- A smaller model, of ~2 MW capacity, similar to the Caterpillar 3516B, running on DO only, and a LHV heat rate of 9200 MJ/MWh (equivalent to a LHV efficiency of 39%).

Mobility

An additional feature that can turn useful for the Belize system is the possibility of quickly relocating the generator from one place to another. Mobile diesel generators are available in the market, an example being the Caterpillar XQ2000[41], based on the CAT 3516B engine (which comes with fuel day tank and step-up transformer to standard voltage levels), and the Cummins C1250 D6[42], based on the KTA50-G3.

Investment Cost

Siemens' study "Least Cost Generation Planning Study", Final Report (Feb 28th, 2009)[43], provides data which are fairly consistent with values encountered in actual quotations. It should be noted, however, that in the case of smaller models, a significantly wide spread of prices can be expected, depending on occasional circumstances and strategic behavior of suppliers; while in some cases values as low as 400 ÷ 500 USD/kW could be found, quotations of more than USD 1300 USD/kW could also be observed. For the present study it was preferred to adopt a conservative approach, choosing the higher values.

- Larger model (~ 8 MW capacity): 1100 USD/kW
- Smaller model (~2 MW capacity): 1200 USD/kW
- Small, mobile model (~2 MW capacity): 1300 USD/kW

Variable Cost

- Fuel Cost

Fuel Cost (USD/MWh) = Heat Rate (MJ/MWh) * Energy Cost of Fuel (USD/MJ)
Heat Rate (MJ/MWh) = 3600/net efficiency

Calculation example:

- Heat Rate, LHV (MJ/MWh) = 7700 MJ/MWh (net efficiency = 46.7%)
- Energy Cost of Fuel (HFO) = (400 USD/tonne) / (21000 MJ/tonne) = 0.01905 USD/MJ
- Fuel Cost = (7700 MJ/MWh) * (0.01905 USD/MJ) = 146.68 USD/MWh

- O&M Variable Cost: 10 - 12 USD/MWh

Economies of scale are expected, hence the lower value for the larger model will be taken, and conversely the opposite for the smaller model, adding 1 USD/MWh for the mobile modules, taking into account additional maintenance for the mobility equipment. Thus, the following values will be used:

- Larger model: 10 USD/MWh
- Smaller model, fixed: 12 USD/MWh
- Smaller model, mobile: 13 USD/MWh

Fixed O&M Cost

As stated above, fixed O&M costs result from personnel, security, "balance of plant" power (controls, communications, lighting, etc.) and basic services costs. For that reason, they will not strictly depend on the generation capacity of the plant but on the size of the

41 https://www.cat.com/en_AU/products/new/power-systems/electric-power-generation/mobile-generator-sets/18596477.html
42https://power.cummins.com/sites/default/files/literature/brochures/Containerized%20Series%20Generator%20Set.pdf
43 Siemens - Least Cost Generation Planning Study, Final Report (Feb 28th, 2009) item 3.4.1 "Fossil Fuel Generation", table 3.13, Potential Fossil Fuel Generation Economic Data.
(file: "BEL_Least_Cost_Generation_Planning_Study_Final_Report_V0_SIEMENS.pdf")

staff dedicated to operating and maintaining the plant, as well as on the size and complexity of the plant site. Naturally, both staff size and plant site characteristics are related with the plant capacity, but there are certain ranges of plant capacity within which fixed O&M costs remain unchanged.

In this respect, the above-mentioned Siemens study proposes a figure of some 400000 USD/year for both GT and RICE plants in the range of 5 to 30 MW capacity, and of about 170000 USD/year for small sized RICE plants[44], values that will be used in the present study.

A7.1.2 DO Fired Gas Turbines in Open Cycle Configuration (OCGT)

There is one operational OCGT power plant in the country, the Westlake Power Plant, which is equipped with one 22.8 MW, DO fired GE LM2500 aeroderivative GT. Consequently, 25 - 35 MW aeroderivative gas turbines operating in open cycle configuration will be considered, taking into account the existing experience with the Westlake plant.
A LHV heat rate of 10000 MJ/MWh (equivalent to a net efficiency of 36%) will be assumed.

Investment Cost

Based on Siemens' study[45], as well as on other reliable sources[46],[47] a specific investment cost of 1000 USD/kW can be considered reasonable for this type of equipment.

Variable Cost
- Fuel Cost

Calculation example:
- Heat Rate, LHV (MJ/MWh) = 10000 MJ/MWh (net efficiency = 36%)
- Energy Cost of Fuel (DO) = (500 USD/tonne) / (21000 MJ/tonne) = 0.02381 USD/MJ
- Fuel Cost = (10000 MJ/MWh) * (0.02381 USD/MJ) = 238.10 USD/MWh

O&M Variable Cost: 5 USD/MWh[48].

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44 Siemens - Least Cost Generation Planning Study, Final Report (Feb 28th, 2009) item 3.4.1 "Fossil Fuel Generation", table 3.13, Potential Fossil Fuel Generation Economic Data.
(file: "BEL_Least_Cost_Generation_Planning_Study_Final_Report_V0_SIEMENS.pdf")
45Siemens - Least Cost Generation Planning Study, Final Report (Feb 28th, 2009) item 3.4.1 "Fossil Fuel Generation", table 3.13, Potential Fossil Fuel Generation Economic Data.
(file: "BEL_Least_Cost_Generation_Planning_Study_Final_Report_V0_SIEMENS.pdf")
46 Power Engineering, January 2018, "Mid-Sized New Generation: Reciprocating Internal Combustion Engines or Combustion Turbine?", Figure 1.
http://digital.power-eng.com/power-eng/201801?sub_id=5ntmAt30XbVS&folio=24&pg=27#pg27
47 "Cost Estimates for Thermal Peaking Plant", Parsons Brinckerhoff New Zealand Ltd. – June 2008
http://large.stanford.edu/publications/coal/references/docs/thermal-peaking.pdf
48 Power Engineering, January 2018, "Mid-Sized New Generation: Reciprocating Internal Combustion Engines or Combustion Turbine?", Figure 2.
http://digital.power-eng.com/power-eng/201801?sub_id=5ntmAt30XbVS&folio=24&pg=27#pg27

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