

**INTER-AMERICAN DEVELOPMENT BANK**

**Economic Evaluation of the**

**Energy Matrix Diversification and Institutional Strengthening of the Department of Energy (EMISDE)**

**Final Revised Report**

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**Economic Evaluation of the Energy Matrix Diversification and Institutional**

**Strengthening of the Department of Energy (EMISDE)**

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**Economic Evaluation of the Energy Matrix Diversification and Institutional**

**Strengthening of the Department of Energy (EMISDE)**

### I. Introduction

Guyana has an important opportunity to convert its abundant natural resources into sustainable energy. During the past decade, the energy sector has been strategic, and the country has invested in infrastructure and studies that have contributed to its development. The current Green State Development Strategy (GSDS), presents an energy sector that is transitioning to cleaner and greener solutions, a more diversified electricity generation mix and an optimal utilization of indigenous natural resources.

To support those objectives, the Inter-American Development Bank (IDB) is developing a Program with the Government of Guyana (GoG) that will have, among others, the following two components to be financed with IDB resources: *Component 1* - Installation of three photo voltaic (PV) power plants tied to the mini-grid systems in the townships of Bartica, Lethem and Mahdia as Renewable Energy (RE) Solutions for the Hinterland; and *Component 2* - Reinforcement of the transmission infrastructure of the Demerara Berbice Interconnected System (DBIS), including the reinforcement of the transmission link Kinston – Sophia and the upgrade of the New Sophia substation. These investments will develop RE energy power capacity to supply electricity demand in the Hinterland and strengthen the reliability of the DBIS transmission system, increasing demand, reducing technical electricity transmission losses and facilitating the development of future generation (operated with indigenous Natural Gas or RE).

This report contains the results obtained in a Cost-Benefit Analysis (CBA) of the three solar projects included in Component 1: i) Bartica (1.5 MWp), ii) Lethem (1.0 MWp), and iii) Mahdia (0.65 MWp), including 1.575 MWh storage capacity, and the two transmission reinforcement projects included in Component 2: i) Rehabilitation of the existing L5 line (Kingston – Sophia, 69 kV) and installation of the new 69 kV redundant Kingston – Sophia line, and ii) Upgrade of the New Sophia substation, including the installation of a 10 MVAR Static Synchronous Compensator (STATCOM)[[1]](#footnote-1).

In addition, a global CBA for both components is included.

Main benefits that were monetized and incorporated in the analysis of these projects were estimated as follows[[2]](#footnote-2):

1. additional electricity supply provided with solar energy valued at costs savings related to lower Light Fuel Oil (LFO) usage and lower Operation and Maintenance (O&M) costs in the future operations of the existing power plants, associated to Component 1;
2. economic value of carbon dioxide (CO2) emissions reductions, associated to both Components;
3. reliability improvements in DBIS associated to transmission reinforcements valued at the economic value of the expected reductions of non-served electricity demand, associated to Component 2;
4. electricity transmission losses reductions in DBIS associated to transmission reinforcements and reactive compensations valued at marginal costs of electricity, associated to Component 2;
5. additional electricity consumption associated to voltage normalization with new reactive compensation, valued at the consumers’ willingness to pay (total surplus beneath the electricity demand curve less supply costs), associated to Component 2.

Costs were estimated with the investment and O&M costs of the projects.

DBIS fuel and O&M cost reductions associated to the proposed transmission projects were determined through electricity dispatch simulations during 2019-2030 with and without the projects using: a) the SDDP[[3]](#footnote-3) simulation electricity dispatch model with simplified DC load flow representation (for the evaluation of the reinforcement of the Kingston – Sophia 69 kV transmission link), and b) results provided by GPL obtained from traditional load flow analysis including reactive power flows (for the evaluation of the STATCOM reactive compensation).

The purpose of this report is to present the Assumptions, the Methodology applied and the Results obtained in the Cost-Benefit analysis for the proposed projects to support the Program of the Energy Matrix Diversification and Institutional Strengthening of the Department of Energy (EMISDE) in Guyana.

### II. Assumptions and methodology

### II.1 Component 1: Solar generation projects

### II.1.1 Problem

Guyana has remained 99% dependent on imports of fossil fuel for its energy needs. High fuel costs have historically constrained the pace of the country’s development while creating balance of payments challenges. It has also affected the country’s competitiveness on the local and international markets, limiting the opportunities for expansion of the productive sectors. Particularly in the hinterland regions, though there exists an abundance of fertile land, minerals, water and sunlight, many opportunities for large-scale agricultural and industrial development have been lost due to the extremely high cost of electricity supply.

In the Hinterland communities, LFO based electricity supply is provided by the respective Government owned utilities at costs significantly higher compared to the provision of supply on the coastal areas. Fuel use accounts for between 60 – 80% of the total operational cost of the power utilities. The Guyana Hinterland Electrification Programme aims to promote socioeconomic development through the supply of reliable and affordable electricity to several Hinterland communities and reduce CO2 emissions from the power sector by utilizing an indigenous renewable energy source. This component includes the development of three solar generation projects in the following three communities: Bartica, Lethem, and Mahdia.

### II.1.2 Project solution

As partial solution of the Guyana dependence on imported liquid fuels for power generation in the Hinderlands, the Component 1 of the Program includes the installation of three solar projects in the following townships: i) Bartica (1.5 MWp), ii) Lethem (1.0 MWp), and iii) Mahdia (0.65 MWp), including 1.575 MWh storage capacity. They will provide photovoltaic power generation tied to the mini-grid systems in those townships as Renewable Energy (RE) Solutions for the Hinterland implying reduction of liquid fuels usage and reductions of CO2 emissions.

Main considerations identified for the installation of those projects are presented next.

*Bartica:*

Bartica, located in administrative Region 7 (Cuyuni - Mazaruni), is considered the gateway to the interior locations and has been designated to be Guyana’s first Green Town. The ‘Green Bartica Plan’ is a Government of Guyana initiative that involves a holistic approach to sustainable economic growth in the township. The main objectives of the plan are to create a climate resilient economy and to establish a green pathway for the foundation of a new Guyana, which will result in reducing the overall carbon footprint in electricity, agriculture, fisheries, water, forestry, waste, manufacturing, transport, construction, tourism and other sectors. The town has a population of about 15,000 whose main economic activities stem from the extractive industries such as logging and mining as well as commerce. The town has 4 nursery schools, 5 primary schools and 2 secondary schools. Several government entities including the Town Council and the Regional Democratic Council are located in Bartica. The town also has a regional hospital, a community center, police and fire stations, and several commercial banks and hotels. Electricity is provided on a 24-hour basis from an island grid with an installed capacity of 4.4 MW that is operated by the Guyana Power and Light Inc. (GPL). Consumers currently pay an average rate of US$0.19-0.28 per kWh. Fuel accounts for about 70% of operational costs and the current peak load is 2 MW. However, the peak demand grew up to over 3 MW during the period of high gold price in 2009-2010. The population in Bartica is expected to grow in the future and the energy demand will therefore increase constantly.

*Lethem:*

Lethem, a small town on the Guyana-Brazil border and contiguous to Bom Fim, and its neighboring villages of St. Ignatius, Culvert City, Tabatinga and Moco Moco (Lethem Area), have an estimated population of 5,000 residents, largely comprising the indigenous Amerindians. The community, which is located in administrative Region 9 (Upper Takutu-Upper Essequibo) is rapidly developing with its economic activity based largely on commerce between Brazil and Guyana. A large number of warehouses and retail businesses have recently been constructed and large areas for expansion are already earmarked which will buttress the income earning capacity of residents. Electricity supply in the Lethem area is provided by the Lethem Power Company Inc. (LMPC) on a 24-hour basis, generated from the company’s six diesel units with a total installed capacity of 3.825 MVA. Fuel, which accounts for between 60-65% of operational costs, is transported by bulk transportation carriers from the 450-km distant capitol Georgetown to Lethem, on unpaved roads that becomes very challenging during the rainy seasons, resulting in delays in delivery. Though generation cost is about US$0.49 per kWh, consumers currently pay an average rate of US$0.33-0.40 per kWh, thus requiring Government subsidies in the range of US$500,000 per annum. With income at subsistence level, the high cost of electricity supply continues to remain a major burden on the households and businesses, which can only be expected to intensify considering the expansion of businesses and Government’s housing programme in the area. Thus, while the area’s peak demand is 800 kW, this is expected to increase in the short to medium term, particularly since Government of Guyana has recently completed infrastructure works for an industrial estate in the community which will add to the demand for more affordable electricity supply.

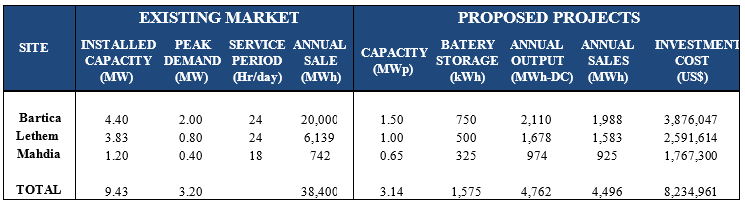
*Mahdia*:

Mahdia is a community located in Region 8 (Potaro - Siparuni) and this hinterland community consists of a vast majority of the migrant residents from other regions of Guyana, ‘Coast Landers’ or international locations ‘Islanders’. The area is dominated by commercial activities in the areas of gold and diamond mining which contributed to a population boom in the community. Mahdia has a population of 4,200 residents and is supplied with electricity by Mahdia Power and Light Inc. (MPL) for 18 hours on a daily basis. Fuel, which accounts for about 65-69% of the company’s total operational costs, is also transported overland to Mahdia, some 200 km away from the capital, on unpaved roads which becomes very difficult during the rainy seasons, resulting in delays in deliveries, lack of continuous supply of fuel and interruption of electricity service to the overall community. MPL’s installed capacity is 1.2 MW, with a peak demand of 0.40 MW. Electricity is generated at a cost of US$0.55 per kWh but sold to residents at a subsidized price of US$0.50 per kWh, requiring subventions from the Government of about US$125,000 annually.

*Summary and basic considerations*

The following table summarizes the existing electricity markets, the basic characteristics and the investment costs related to the three proposed solar projects.

**Existing electricity markets and proposed Solar Projects**



Source: GEA

Bartica and Lethem solar projects intend to produce 10% and 22% of total current electricity sales in their respective markets while Mahdia project would cover total current sales[[4]](#footnote-4).

The information used for the economic evaluation was provided by GEA to IDB. It was obtained from the System Advisor Model (SAM) software, which requires manual input of the parameters. For the azimuth, south facing ordination was used and for estimated tilt 10 degree was used. The following table shows solar irradiation per project and location (latitude, longitude).



Source: GEA (SolarprojectsResponse.doc dated July 9 2018)

The generation has been estimated from software SAM using satellite data and there is some risk that an on-site solar study obtain different solar yield estimates. Annex 4 shows the parameters used to estimate energy per project from solar irradiation. Such Annex explains the different variables used to convert energy produced in each Solar PV Farm to energy sold to the grid. The PV modules degradation considered by GEA was 0.5% annually. The resulting average load factor (during the 20-year evaluation horizon) was 14.4% in Bartica, 17.3% in Lethem and 15.6% in Mahdia.

**II.1. 3 Assumptions and methodologies for benefit estimations**

Benefits estimated for the three solar projects consist in: i) benefits originated by cost reductions associated to liquid fuel substitutions due to lower Light Fuel Oil (LFO) usage in the existing power plants currently used to supply power demand in the three locations, ii) benefits consisting in costs reductions associated to the same substitution of power generation in the existing power plants, and iii) benefits associated to the Carbon Dioxide (CO2) emission reductions in the existing power plants.

The following table shows the basic operational variables assumed per each project.



Source: GEA and consultant estimates

The following table shows the Average fuel Consumption (LFO liters / kWh) estimate made by the consultant using GEA information of LFO consumption and electricity generation in all three sites.



Source: consultant using information provided by GEA

Benefits were estimated as follows:

1. **Benefits due to LFO substitution**

Financial revenues for each project were estimated with Power Purchase Agreement (PPA) prices (USD/MWh) provided by GEA, applied to the new PV generation. Economic benefits were estimated assuming that the new PV generation would substitute the same power generation in the existing reciprocating engines in each site, quantities of LFO substitutions were estimated with the average fuel consumptions (Liters/kWh) in each site, including storage savings due to evaporation[[5]](#footnote-5), and economic benefits were estimated with fuel prices – duty free and transportation costs.

LFO prices were indexed in real terms according to the following price forecasts.

**Fuel Price Forecasts[[6]](#footnote-6)**



Source: EIA for WTI and consultant for LFO

1. **Benefits due to O&M cost reductions**

The non-fuel operation and maintenance(O&M) costs of the existing plants (Reciprocating Internal Combustion Engines – RICE), used in this evaluation to estimate benefits associated to cost savings, includes maintenance labor, engine parts and materials such as oil filters, etc. For this purpose, an indicator of US$ 10/MWh was applied as variable O&M cost for the existing diesel RICE power plants[[7]](#footnote-7). Economic benefits were estimated assuming that the new PV generation would substitute the same power generation in the existing reciprocating engines in each site and applying this indicator.

1. **Benefits due to CO2 emission reductions**

It was assumed that the economic environmental benefits associated with the increase in clean photovoltaic generation in the three projects (which its consequent reduction in LFO generation in the existing power plants) could be estimated with an economic shadow price of US $ 30 per ton of CO2 applied to the reduction of CO2 emissions in the existing power plants, not constituting a financial revenue to the project developers[[8]](#footnote-8). CO2 emissions of the existing RICE power plants were estimated using 706 kg-CO2/MWh of generated electricity supplied to the grid as emission factor[[9]](#footnote-9).

### II.2 Component 2: DBIS transmission reinforcements

This component includes two projects consisting in transmission reinforcements in DBIS: i) reinforcement of the L5 link Kingston – Sophia, and ii) installation of 10 MVAR STATCOM reactive compensation in New Sophia. These projects have different electricity service implications in all DBIS grid. Consequently, its economic evaluation required the examinations of the DBIS grid operations with and without such projects. This section includes the assumptions and methodology applied to forecast DBIS operations and to estimate benefits of these two projects.

### II.2.1 Problem

1. **Reinforcement of Kingston – Sophia link**

Vreed en Hoop, Edimburg and Kingston substations are linked to Sophia substation through the existing Kingston – Sophia 69 kV transmission line (L5). This line is rated at 50 MVA but only transmits a maximum of 42 MVA of power given the capacity of its conductor (394.5 kcmil AAAC, Canton). Total demand in those three substations is around 20-35 MW (off peak – peak) and its installed generating capacity is 84.5 MW implying transmission requirements of more than 60 MW through L5. Sophia functions as the distribution hub of the power system supplying power to the following substations: New Georgetown, Good Hope, Columbia and Onverwagt. In recent times, it has been experienced that a failure of L5 results in a complete system failure since there is no transmission redundancy. In addition, due to the importance of this single line maintenance activities are curtailed and this in turn increases the probability of failure. In the future, new high capacity power plant (natural gas or renewable energy) is expected to be connected to New Sophia substation or New Sophia – Berbice 69 kV transmission line, reversing the power flow in L5 under economic dispatch. DBIS operation under this situation would be also with low reliability due to the constraints imposed by the existing Kingston – Sophia link.

1. **Installation of reactive compensation in New Sophia substation[[10]](#footnote-10)**

In the period between the mid 1970’s and 2016, GPL’s interconnected system operated at both 11 kV, 50 Hz and 13.8 kV, 60 Hz and frequency converters at Sophia substation were operated to balance the supply of generation and loads at the two frequencies. An important function of the converters was their ability to provide voltage support at both the 50Hz and 60 Hz bus - bars. When the DBIS system was standardized at 60 Hz in 2016, the frequency converters operated as synchronous condensers to provide reactive compensation to the system. However, when the frequency converter station was decommissioned in 2017, this voltage support to the DBIS system was no longer available. With no voltage support at Sophia substation, the Kingston power station is expected to provide the required reactive power, however it is unable to do this and supply the necessary real power and this has meant that the voltage levels at Sophia are now low. Recent data recorded by the SCADA system have been used to produce the following graphs. Next figure shows typical levels of voltage at Kingston and Sophia 69 kV bus - bars, indicating voltage levels in Sophia lower than acceptable standards.

**Typical Voltage levels at Kingston and Sophia**

Source: Klass, 2018

Voltage levels for power received at Sophia are on average 5% below the sending end Kingston voltage level and many consumers are receiving voltages below 6% of the standard voltage supply of 120/240 V, with low quality of service and implying reductions of electricity consumption. In addition, these low voltage levels accounts for high transmission losses in the transfer of active (MW) and reactive (MVAR) power between Kingston and Sophia[[11]](#footnote-11).

### II.2.2 Project solution

1. **Reinforcement of Kingston – Sophia link**

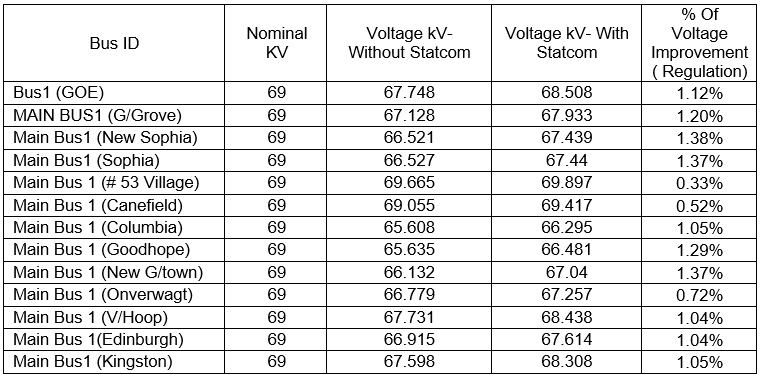
This project will encompass the following: a) Construction and commissioning of a single circuit overhead 69 kV transmission line between the Kingston and Sophia substations (conductor 927 kcmil AAAC Greely), b) Extension of the Kingston and Sophia substations to accommodate the new transmission line, and c) conductor upgrade in the existing L5 line to allow for parallel operation and maximum power transfer (also with conductor 927 kcmil AAAC Greely). This project will provide two main benefits: i) reducing non-served energy in the market due to failures of exiting L5 line, ii) reducing electricity transmission losses due to lower impedance to be crossed by Kingston – Sophia power interchanges[[12]](#footnote-12), and iii) reducing loss of revenue as a result of load shedding during maintenance activities.

1. **Installation of reactive compensation in New Sophia substation**

The proposed solution is the installation of a ±10MVAr STATCOM at the New Sophia 69kV bus - bar that requires the installation of a 69 kV bay to accommodate the connection of the STATCOM. This device is a static synchronous compensator that continuously provides variable reactive power in response to voltage variations while supporting the stability of the grid[[13]](#footnote-13).

Load flow simulations of the DBIS at peak and off peak loads provided by GPL have shown that with this project, the voltages of all bus - bars on the DBIS system will increase. Next table shows the comparison of voltages with and without the installation of STATCOM. Increases vary between 1.38%, at New Sophia substation, the site of installation of the STATCOM, to 0.33% at the furthest location, the #53 Village substation, representing 1.06% average for all DBIS load.

**Voltage Levels at DBS 69 kV bus - bars with and without STATCOM**



Source: Klass, 2018

### II.2. 3 Assumptions and methodologies for benefit estimations

1. **Reinforcement of Kingston – Sophia link**

Main economic benefits associated to the reinforcement of the Kingston – Sophia link are: i) reliability improvements in DBIS associated to transmission reinforcements valued at the economic value of the expected reductions of non-served electricity demand, ii) electricity transmission losses reductions in DBIS associated to transmission reinforcements valued at DBIS marginal costs of electricity, and iii) economic value of CO2 emission reductions associated to electricity losses reductions.

1. **Benefits due to reduced non-supplied energy**

The new transmission line will be constructed to transmit as much as 100 MVA and will connected substations of Kingston and Sophia, both of which will be expanded. The conductors on the existing L5 Kingston – Sophia will also be upgraded to satisfy the requirement of being able to transmit 100 MVA via an alternative route. These initiatives will ensure the safe and uninterrupted transfer of all available power between Kingston and Sophia and better able to serve the growing demands within this area (Georgetown), and the area served by the substations linked to Sophia.

In the short term (2021-2023) this project will reduce the risk of electricity shortages in the markets supplied by New Sophia (New Georgetown), Good Hope, Columbia and Berbice area substations and after 2023 (with the installation of the new natural gas and new renewable energy generation connected to New Sophia, or to New Sophia – Berbice transmission line) it would support reliable supply to Kingstown, Edinburg and Vreed en Hoop substations, also permitting a reliable operation of Vreed en Hoop and Kingston power plants when required to be operated as backup capacity.

Benefits have been estimated considering that this project will reduce the historical risk of electricity shortage events occurred during 2015-2017 when 19 forced outages of the L5 line produced 5.8 Hours/Year of average annual service interruptions and 437 MWh of annual average of non-supplied energy. Valued at USD 1,500/MWh as economic cost of non-programmed electricity outages[[14]](#footnote-14) this will represent USD 0.656 million / year.

1. **Benefits due to reduced transmission losses**

SDDP model was applied to represent DBIS load flows with and without the upgrade of the existing L5 line and the installation of the redundant new circuit Kingston – Sophia. Annex 1 includes the representation of DBIS generation and 69 kV transmission systems considered for SDDP simulations, including DBIS demand forecast and fuel prices of fuels used for power generation. The difference of total DBIS Fuel and O&M annual costs obtained from the simulations with and without this project constitutes an estimation of its benefits related to electricity transmission losses reductions. Results obtained are presented in next table, under the assumption that this project is commissioned at the end of 2020.

**BENEFITS ASSOCIATED TO REDUCTION OF TRANSMISSION LOSSES**

**DBIS FUEL AND O&M COSTS (USD K)**



Source: SDDP simulations

1. **Benefits due to CO2 emission reductions**

It was assumed that the economic environmental benefits associated electricity losses reductions (with its consequent reduction in HFO/Natural Gas generation in DBIS power plants) could be estimated with an economic shadow price of US $ 30 per ton of CO2 applied to the reduction of CO2 emissions in the existing power plants, not constituting a financial revenue to the project developers[[15]](#footnote-15). CO2 emissions of the existing RICE power plants using HFO were estimated using 700 kg-CO2/MWh and using Natural Gas 451 kg-CO2/MWh of generated electricity supplied to the grid as emission factor[[16]](#footnote-16).

1. **Installation of reactive compensation in New Sophia substation**

Voltage improvements in DBIS grid introduced by the STATCOM will imply benefits due to: i) reduction of transmission losses, ii) increase of electricity consumption by final consumers, and iii) economic value of CO2 emission reductions associated to electricity losses reductions.

1. **Benefits due to reduction of transmission losses**

Reduction of transmission losses were obtained from load flows simulations provided by GPL of DBIS grid with and without the STATCOM project for peak and off peak hours conditions in 2020, 2022 and 2024. Next table contains results obtained for DBIS grid load flow simulations indicating how transmission losses will decrease with this reactive compensation.



Source: Results provided by GPL for Load Flows and consultant processing

Benefits associated to transmission losses reduction were estimated using the annual average of marginal electricity costs estimated for DBIS with the SDDP model. These estimates are presented below.

**Benefits associated to transmission losses reductions**

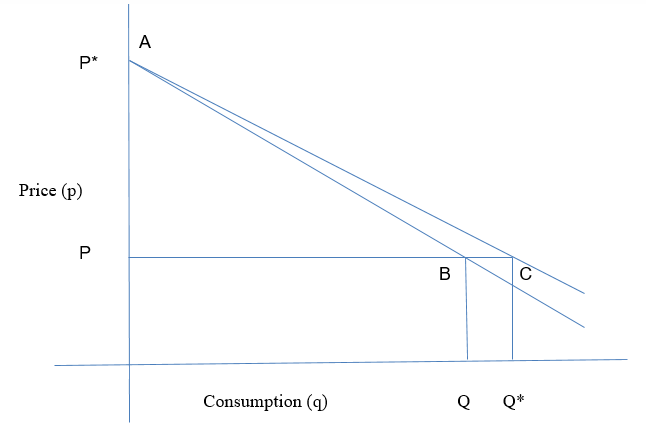


Source: consultant estimates from GPL load flows (losses) and SDDP simulations (Marginal Costs)

1. **Benefits due to increase of electricity consumption**

For the economic evaluation, it was assumed that consumers in DBIS affected by low voltages are mainly residential consumers that in 2017 represented 38% of total DBIS market. Those consumers are supplied at 120/240 v level and through the tap´s operations of the distribution transformers part of the voltage regulation is obtained. According to GPL load flows simulations in DBIS grid, with STATCOM operating voltage at 66 kV level will increase around 1.06% average in all DBIS market. In this order of ideas for the economic evaluation it was assumed that 50% of DBIS residential market would increase 2.1% its electricity consumption due to voltage increase (according to Kirchhoff law, electricity demand would increase with the square of voltage increase).

Benefits associated to the increase of electricity consumption due to voltage increase were estimated as the value of the willingness to pay for it less total supply costs[[17]](#footnote-17). Next graph illustrates how this benefit correspond to the area covered by the triangle ABC[[18]](#footnote-18).



From the definition of Price – Elasticity (*Ε* ) it follows that the derivative of Price p with respect to the quantity q at the point P and quantity Q is given by:  *dp/dq = P/Q x 1/Ε*

The price P\* could be estimated as: *P\* = P – dp/dq x Q = P – P/Ε,* and

Increase of consumer’s surplus is estimated as: (*P\** – *P*) x *Q\* / 2 – (P\*- P) x Q / 2 = -P/E x (Q\* - Q) / 2*

In the equation Q\*- Q is the increase of electricity consumption associated to the project (MWh/year), P is the average tariff (USD 227/MWh) and *Ε* thePrice-Elasticity (-0.5, according typical estimations of similar electricity markets in Latin America[[19]](#footnote-19)). The following table includes the estimation of this benefit considering these parameters and DBIS demand forecasts.

**Benefits associated to electricity consumption increase**



Source: consultant estimates

1. **Benefits due to CO2 emission reductions**

These benefits were estimated with the same assumptions and methodology than similar benefits estimated for the other project of Component 1. It was assumed that the economic environmental benefits associated electricity losses reductions (with its consequent reduction in HFO/Natural Gas generation in DBIS power plants) could be estimated with an economic shadow price of US $ 30 per ton of CO2 applied to the reduction of CO2 emissions in the existing power plants, not constituting a financial revenue to the project developers[[20]](#footnote-20). CO2 emissions of the existing RICE power plants using HFO were estimated using 700 kg-CO2/MWh and using Natural Gas 451 kg-CO2/MWh of generated electricity supplied to the grid as emission factor[[21]](#footnote-21).

### III. Cost and benefit analysis

The Energy Matrix Diversification and Institutional Strengthening of the Department of Energy (EMISDE) includes three projects consisting in the installation of solar power plants and two projects related to DBIS transmission reinforcements. For its economic evaluation, cost and benefits were expressed in market prices and in constant USD dollars of mid 2018[[22]](#footnote-22).

### III.1 Investment costs

Total investment costs associated to this program amounts USD 17.95 million. The investment program was estimated assuming that the construction period required for each project is one year and considering that Bartica, L5 Reinforcement and STATCOM projects will be operative in 2021 and Lethem and Mahdia in 2022. Next table summarizes this program.

**INVESTMENT PROGRAM (USD thousands)**



Source: GPL and GEA

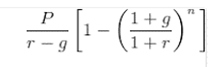
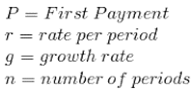
Annex 2 includes the detailed investment costs of each of the five projects. All five projects were evaluated without financial debt, therefore 100% of investment was considered provided with equity in the financial evaluation and total investment costs were included in the economical evaluation.

### III.2 Operation and Maintenance costs

Operation and Maintenance costs of the solar plants were assumed as the 1% per year of its investment costs and 2.0% per year for the transmission reinforcements.

### III.3 Useful lives

The economic life for the STATCOM was assumed in 25 years and the for the L5 Link reinforcement in 30 years. The financial and economic evaluation of Solar PV farms was made using a useful life of 20 years. Benefits for additional 5 years were estimated by the consultant since GEA provided 20 years of energy revenues[[23]](#footnote-23). Such benefits were estimated per each project using the present value of an annuity of periodic payments that decrease on a proportionate rate, according to the following formula:

The payment P was the 20 year economic benefit of each project once the project reaches a steady state (or financial cash flow in the financial evaluation), the growth rate per period (g) was -0.5% per year due to PV deterioration, rate per period (r) was 12% in the economic evaluation and 7% in the financial evaluation and the number of periods (n) was 5.

### III.4 Benefits

Benefits estimated for the solar generation projects consisted in liquid fuel, CO2 emissions and variable O&M cost savings associated to the substitution of power generated in the existing diesel power plants. L5 reinforcement benefits include costs reductions associated to lower transmission losses and lower non-served electricity demand. STATCOM benefits includes cost reductions due to reduced transmission losses and consumers benefits due to additional consumption associated to voltage increases.

Next tables summarizes benefits forecasted for each project.











### Economic and financial returns

The economic evaluation of each project was prepared considering first a financial evaluation of each one and then the forecasts of its economic benefits and costs[[24]](#footnote-24). For the Solar Projects the financial evaluations were done for the potential investors that could develop such projects, selling the produced electricity to the local distribution companies at prices estimated by GEA. For the DBIS Transmission Reinforcement Projects the financial evaluations were done from the point of view of GPL as project developer.

Annex 3 contains the detailed forecasts of Profits and Losses and Cash Flows estimated for the financial evaluations of the Solar Projects and the financial GPL´s incremental revenues and disbursements associated to the Transmission Reinforcement Projects. Financial indicators included in this section considers a referential weighted average capital cost of 7%. Annex 3 also includes the forecasts of Benefits, Costs estimated for the five projects, and the economic indicators included in this section considering a referential discount rate of 12%. Next table summarizes the results obtained.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **PROJECT** | **Financial Net Present Value (7%)** | **Financial Internal Rate of Return** | **Economic Net Present Value (12%)** | **Economic Internal Rate of Return** |
| **Bartica** | 581 | 8.9% | 21 | 12.1% |
| **Lethem** | 912 | 11.4% | 480 | 14.9% |
| **Mahdia** | 328 | 9.4% | 651 | 17.7% |
| **Link L5** | 621 | 9.0% | 2941 | 25.4% |
| **STATCOM** | 13 | 7.0% | 575 | 13.1% |
| **Total** | 2455 | 8.4% | 4548 | 15.7% |

The results obtained indicates that all projects included in the Program would provide financial returns higher that 7% and economic returns higher than 12%. The financial evaluation of all the Program indicates an 8.4% of financial IRR and 2455 USD thousands of net revenues at 7% discount rate. The economic impact of the total Program will provide 15.7% of economic internal rate of return and USD 4548 thousands of economical NPV at 12% referential discount rate.

### Sensitivity analysis

Next table summarizes the results obtained for the economic evaluation of the Program in sensitivity cases of for which it has been considered a +20% and -20% variations in main variables used in the economic evaluation.



Source: consultant

The results obtained in the sensitivity analysis indicate a positive result in the economic evaluation of the program, with positive economic net present values, estimated at 12% referential discount rate and economic internal rates of returns larger than 12% when considering adverse marginal variations up to 20% in all main variables used in the evaluation.

### Conclusions

This report contains the results obtained in a Cost-Benefit Analysis (CBA) of the investment projects included in the Energy Matrix Diversification and Institutional Strengthening of the Department of Energy (EMISDE). Component 1 of this Program includes three solar projects: i) Bartica (1.5 MWp), ii) Lethem (1.0 MWp), and iii) Mahdia (0.65 MWp), including 1.575 MWh storage capacity. Component 2 includes two transmission reinforcement projects of DBIS grid: i) Rehabilitation of the existing L5 line (Kingston – Sophia, 69 kV) and installation of the new 69 kV redundant Kingston – Sophia line, and ii) Upgrade of the New Sophia substation, including the installation of a 10 MVAR Static Synchronous Compensator (STATCOM).

The financial evaluation of the Program indicates an 8.4% of financial internal rate of return and 2544 USD thousands of net revenues at 7% discount rate. The economic impact of the total Program will provide 15.7% of economic internal rate of return and USD 4548 thousands of present value of net benefits at 12% referential discount rate.

Bartica, Lethem and Mahdia solar projects contribute with benefits consisting in fuel, O&M and CO2 cost reductions and indicate that they could remunerate its potential project developers with financial returns of around 8.9%, 11.4% and 9.4%, higher than the 7% referential weighted average capital cost and implying financial net present values of 581, 912 and 328 USD thousands, respectively. The economic evaluation of those projects indicate 12.1%, 14.9% and 17.7%, respectively of economic internal rate of returns and implying economic net present values of 21, 912 and 328 USD thousands, respectively, at 12% referential discount rate.

The reinforcement of Link 5, consisting in the upgrade of the existing line and in the installation of a redundant circuit in Kingston – Sophia link, would improve service reliability to final consumers and reduce of transmission losses and CO2 emissions implying 9.0% of financial return to GPL, as well as 621 USD thousands of financial net present value when estimated with 7% of referential weighted average costs of capital. From the economic point of view in will provide 25.4% of economic return and 2941 USD thousands of economic net present value at 12%. The installation of the 10 MVAR STATCOM for the reactive compensation of DBIS grid will also reduce transmission losses and CO2 emissions and improve quality of service to final users increasing current low voltages (and electricity consumption); implying 7.0% of financial return to GPL and 13 USD thousands of present value of financial net revenues when estimated at 7% of referential weighted average cost of capital. From the economic viewpoint, this project provides an economic return of 13.1% and 575 USD thousands of economic present value of net benefits.

**ANNEX 1**

**SDDP SIMULATIONS OF DBIS GENERATION – TRANSMISSION SYSTEM**

1. **DESCRIPTION OF THE MODEL**

SDDP is a hydrothermal dispatch model with representation of the transmission network and used for short, medium and long term operation studies. The model calculates the least-cost stochastic operating policy of a hydrothermal system, taking into account the following aspects:

|  |  |
| --- | --- |
| seta | Operational details of hydro plants (water balance, limits on storage and turbines outflow, spillage, filtration etc.); |
| seta | Detailed thermal plant modeling (unit commitment, generation constraints due to "take or pay" fuel contracts, concave and convex efficiency curves, fuel consumption constraints, bi-fuel plants etc.); |
| seta | Representation of spot markets and supply contracts; |
| seta | Hydrological uncertainty: it is possible to use stochastic inflow models that represent the system hydrological characteristics (seasonality, time and space dependence, severe droughts etc.) and the effect of specific climatic phenomena such as the El Niño; |
| seta | Detailed transmission network: Kirchhoff laws, power flow limit in each circuit, losses, security constraints, export and import limits for each electrical area, etc,; |
| seta | Load variation per load level and per bus, with monthly or weekly stages (medium or long term studies) or hourly stages (short term studies). |

In addition to the least-cost operating policy, the model calculates several economical indexes such as the spot price (per submarket and per bus), wheeling rates and transmission congestion costs, water values for each hydro plant, marginal costs of fuel supply constraints and others.

All the detailed results of the model SDDP are written to \*. csv format files. These files are managed by a graphic interface (the GRAF program) which produces Excel files with the desired results. The main SDDP results are:

|  |  |
| --- | --- |
| seta | operative statistics: hydro and thermal generation, thermal operation costs, energy interchange, fuel consumption, deficit risks and energy not supplied; |
| seta | short run marginal costs (spot prices) for each submarket and for each bus; |
| seta | marginal capacity benefits: measure of the operational benefit of reinforcing the installed capacity of a thermal plant, the turbine limit of a hydro plant or the storage capacity of a reservoir. These indices are used to determine cost-effective system reinforcements. |

1. **DBIS REPRESENTATION**

SDDP simulations for the estimation of benefits related to transmission losses reductions associated to the reinforcement of Kingston – Sophia link required the representation of the DBIS existing infrastructure (power plants and transmission system), electricity demand forecasts, system expansion and fuel prices as presented in this section.

1. **Existing DBIS infrastructure**

Next graph illustrates the topology of DBIS existing grid considered in the load flow analysis included in SDDP simulations. It also indicates the location of New Sophia substation that will be upgraded with the 10 MVAR reactive compensation.

**Simplified one-line diagram of DBIS grid**



Source: Update of the Study on system Expansion of the Generation System, 2019

The following table includes the existing power plants in DBIS.

Technical characteristics of existing power plants



Source: Update of the Study on system Expansion of the Generation System, 2018

The following table includes the basic parameters of the existing 69 kV transmission lines.

**Technical characteristics of existing transmission lines**



Source: Arco Norte study

1. **Electricity demand forecasts**

Electricity demand forecast for DBIS was updated in the 2018 Generation Expansion Study by analyzing demand growth under different Gross Domestic Product (GDP) growth projections. Commercial oil production in Guyana is planned to commence by mid-2020, with an output of 100,000 barrels/day, implying a high GDP temporary growth with its correspondent impact in electricity demand.

**DBIS demand forecasts**



Source: Update of the Study on system Expansion of the Generation System, 2018

Power demand distribution by DBIS substations was obtained with the following peak demand statistics provided by GPL.

**DBIS: Load distribution (Oct 21, 2016)**



Source: Consultant based on GPL historical information

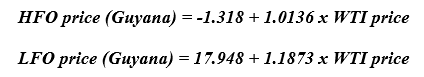
An annual average load factor of 0.755 was applied to forecasted electricity energy demand (GWh) to estimate peak demand (MW) for all forecasted years (such factor was obtained from DBIS energy demand of 762.2 GWh and peak demand of 115.3 MW in 2017).

1. **System expansion**

It was considered the optimal referential generation expansion presented in the 2018 Generation Expansion Update, which was associated to the availability of 50 mmscfd of natural gas for power generation after 2023. It would start with the commissioning during 2019-2021of 8.7 MW in reciprocating engines, 24 MW solar, 40 MW wind, the recuperation 24 MW in biomass power plants. In 2021 it would be also required the commissioning of 34 MW in dual fuel reciprocating engines (2x17 MW) located in the new landing site of the Natural Gas but operated initially with liquid fuels until 2023. After this year this plant would be operated with Natural gas and its capacity would be progressively increased with 17 MW units up to 272 MW in 2032 (according demand increase).

1. **Fuel prices**

This study applies the West Texas Intermediate (WTI) Reference Case price forecast published in March 2018 by the Energy Information Administration of USA (EIA) in the 2018 Annual Energy Outlook. The forecasts for 2018 and 2019 were adjusted using the Short Term Energy Outlook also published by EIA in July 2018 and expressed in price levels of July 2018. HFO and LFO import prices for fuels dedicated to power generation in DBIS were forecasted applying its relationship with WTI price.



Source: 2018 Update of DBIS Generation Program

Next table contains the liquid fuel price forecasts.

**LIQUID FUEL PRICES**



Source: Consultant based on EIA (2018 AEO and July 2018 STEO)

For the supply of Natural Gas at the site of the new power plant the 2018 Update of the Generation Expansion study considers referential price of USD 4.7/MBTU based on typical wellhead prices and offshore transportation costs estimated in other studies (Energy Narrative, 2017) and a take or pay natural gas supply contract with payment obligation of 70% of total contracted gas. These price conditions were also applied in this study.

1. **Connection to DBIS of the new mid capacity power plants**

The connection of the new high capacity gas fired power plants was assumed through a 230 kV transmission connection system to the New Sophia substation. In addition, the new renewable energy power plants were assumed to be connected to this new substation or to the New Sophia – Berbice 69 kV transmission line.

**ANNEX 2**

**INVESTMENT COSTS (US$)**

**Project 1: Solar plant in Bartica**



**Project 2: Solar plant in Lethem**



**Project 3: Solar plant in Mahdia**



**Project 4: Transmission link L5 reinforcement**



**Project 5: STATCOM 10 MVAR reactive compensation**



**ANNEX 3**

**FINANCIAL AND ECONOMIC EVALUATIONS**

**BARTICA**





**LETHEM**





**MAHDIA**





**L5 REINFORCEMENT**

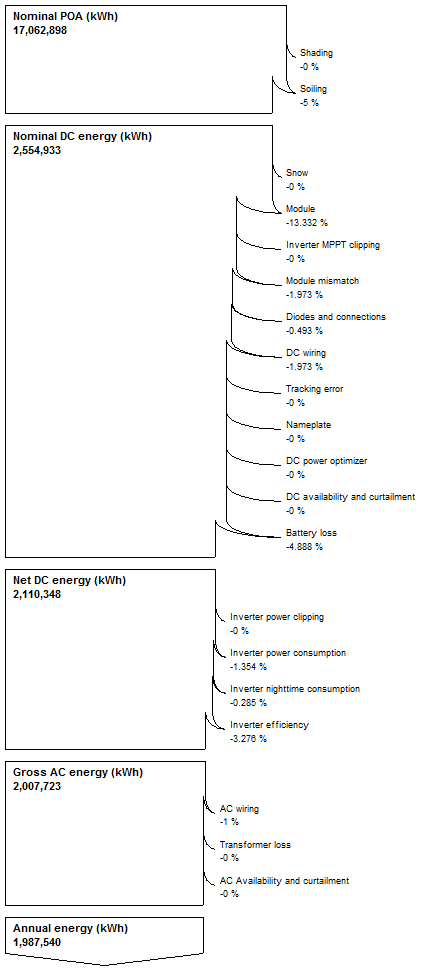


**STATCOM**

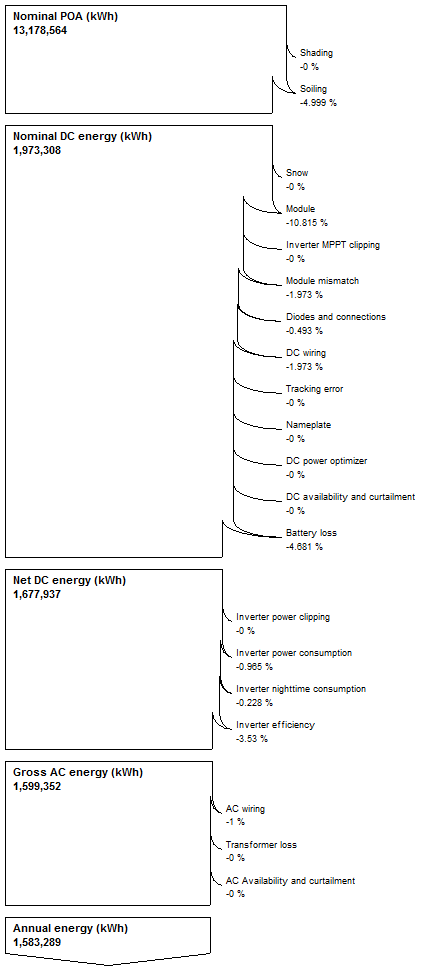


**ANNEX 4**

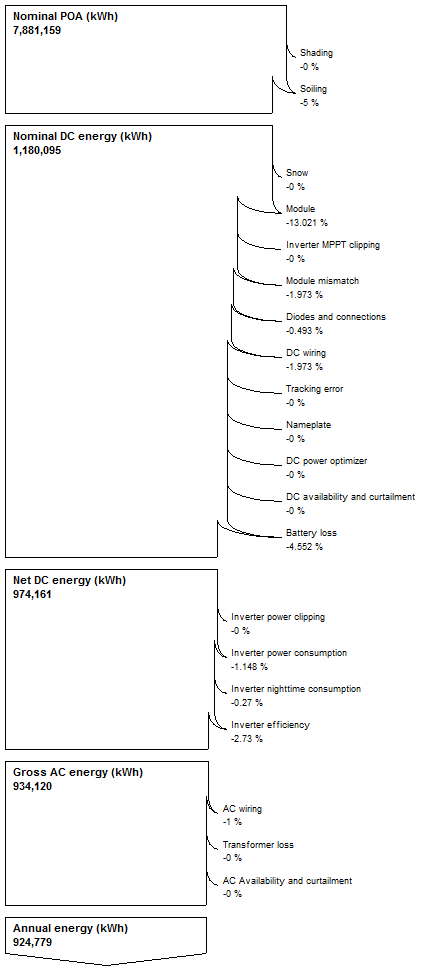
*Bartica*



*Lethem*



*Mahdia*



1. The Static Synchronous Compensator (STATCOM) is a shunt device of the Flexible AC Transmission Systems (FACTS) family using power electronics to control power flow and improve transient stability on power grids. [↑](#footnote-ref-1)
2. The CBA does not includes quantifications of other benefits of the projects that are difficult to evaluate in monetary terms, as impacts of the projects in additional employment generation, reduction in the use of foreign exchange for liquid fuel imports, increase of DBIS operative efficiency, improvement of GPL technical and administrative capacity, contribution of the Program to additional environmental benefits associated to the GSDS and others. [↑](#footnote-ref-2)
3. Stochastic Dual Dynamic Programming optimization – simulation model of hydrothermal (& renewable) systems developed by Power Systems Research Inc. from Brazil. [↑](#footnote-ref-3)
4. This situation requires the verification of future electricity demand growth in this market, including the development of new economic activities expected in this region in order to verify the capacity proposed for this project compared to Mahdia needs [↑](#footnote-ref-4)
5. The economic evaluation uses a 5.7% factor of LFO storage losses. Such factor was obtained from Shelton (Shelton, David. Bashford, Leonard. “Fuel Storage”. Farm Energy Tips. 2014. Available at: <http://digitalcommons.unl.edu/cgi/> viewcontent.cgi? article=4118&context=extensionhist), which provides data from gasoline losses for a variety of a 1140-liters tank situations, ranging from 38 liters per month (equivalent to 36% fuel storage loss factor) in a red tank exposed to sun light until 3 liters per month (equivalent to 3% fuel storage loss factor) in an underground tank. Assuming that average LFO storage in Bartica, Lethem and Mahdia is 100 days per year, and that storage tanks are not underground, the average LFO losses are about 5.7%. Therefore, LFO purchases provided by GEA (in liters) was increased in such factor for all three projects to obtain Fuel Savings Benefits. [↑](#footnote-ref-5)
6. LFO price refers to the imported LFO in Guyana (exclusive of transportation costs to the Hinterlands). It was estimated by the consultant with the following relationship obtained from the recent study of the update of DBIS Generation Expansion: *LFO price (Guyana) = 17.948 + 1.1873 x WTI price.* [↑](#footnote-ref-6)
7. Source: LAZARD’S LEVELIZED COST OF ENERGY ANALYSIS—VERSION 11.0, see page 20. [↑](#footnote-ref-7)
8. This parameter was obtained from “Projected Costs of Generating Electricity”, International Energy Agency, 2015 (p. 33). [↑](#footnote-ref-8)
9. Source: GEA estimations for Bartica, Lethem and Mahdia. [↑](#footnote-ref-9)
10. Part of this section was extracted from “Reactive power compensation”. Draft Report. Klass, 2018 [↑](#footnote-ref-10)
11. Power in an electric circuit is the rate of flow of energy past a given point of the circuit. In [alternating current](https://en.wikipedia.org/wiki/Alternating_current) (AC) circuits, as DBIS grid, energy storage elements such as [inductors](https://en.wikipedia.org/wiki/Inductor) and [capacitors](https://en.wikipedia.org/wiki/Capacitor) may result in periodic reversals of the direction of energy flow. The portion of power that averaged over a complete cycle of the [AC waveform](https://en.wikipedia.org/wiki/AC_waveform), results in net transfer of energy in one direction is known as active power (more commonly called real power). The portion of power due to stored energy, which returns to the source in each cycle, is known as reactive power. The flows of both active and reactive power originate transmission electricity losses, which also originates voltages reductions. [↑](#footnote-ref-11)
12. The use of this conductor Greely instead of Canton in the two parallel lines will reduce the resistance in the existing one line L5 from 0.0610 to 0.0263 Ohms/1000 ft. Considering the two parallel lines total link resistance will be reduced from 0.0610 to 0.0132 Ohms/1000 ft representing total reduction of around 78% and the resistive transmission losses would be reduced in similar percentage under normal operations. [↑](#footnote-ref-12)
13. STATCOM operates according to voltage source converter (VSC) principles, combining unique PWM (pulse width modulation) with millisecond switching, and functions with a very limited need for harmonic filters and only contributing to a small physical footprint.  STATCOM increases power transfer capability by enhancing voltage stability and maintaining a smooth voltage profile under different network conditions. It is also able to perform active filtering which is also very useful for improvements in power quality. STATCOM controls can be integrated with the overall SCADA system control. [↑](#footnote-ref-13)
14. The cost of energy rationing, also called "cost of failure", is the cost per kilowatt-hour paid (or lost economic benefit), on average, by users when energy is not available and has to be generated with emergency units or not consumed, which represents economic costs for end users. For the reduction of electricity consumption, an alternative definition is the price at which users would be willing to pay for energy not available. The reference values ​​of this cost vary greatly in Latin America, mainly due to the market and the methodological and regulatory differences. Its calculation varies according to the region if it is associated with the supply of a certain level of demand. For this reason, some countries have different rationing costs for each segment of the demand (residential, commercial, industrial), and others depending on the percentage of the demand affected by the shortage (for example, 5%, 10%, above 20%), other countries use individual values ​​(such as Brazil, calculated using the costs of generating a hydraulic emergency unit and the valuation of water in reservoirs). This study uses US $ 1,500 / MWh as the cost of failure, similar as the value used in the indicative generation transmission expansion planning in Central America (see: “Plan Indicativo Regional de Expansion de la Generacion”, GTPIR) which is compared with the average range evaluated and applied in several Latin American countries. For example, in Chile the cost of failure is approximately US $ 552 / MWh for rationing of more than 20% of demand, while for the same percentage of demand, Uruguay uses US $ 2000 / MWh; Colombia uses US $ 455 / MWh for the residential segment and up to US $ 1877 / MWh for the medium industrial and commercial segment. Peru uses US $ 746 / MWh, the Dominican Republic uses US $$ 167.8 / MWh and Brazil US $ 270 / MWh. However, the last two values ​​are related to the cost of high capacity temporary backup power sources, a situation that would not be the case in the Project area. [↑](#footnote-ref-14)
15. This parameter was obtained from “Projected Costs of Generating Electricity”, International Energy Agency, 2015 (p. 33). [↑](#footnote-ref-15)
16. Source: Update of DBIS generation expansion program. (HFO emission factor from CEAC, Plan Indicativo Regional de Expansión de la Generación in Central America and NG from EIA). [↑](#footnote-ref-16)
17. The economic literature includes several descriptions of this methodology. See for example: “El ABC de los proyectos de Transmission”. L. Gutierrez. Revista de Economía y Estadística. Vol 26. 1985; and others. [↑](#footnote-ref-17)
18. The demand curves assumes that at current price P with voltage increase consumption would increase from Q to Q\* (being Q\* = 1.021 x Q\*) and that at price P\* consumption would be 0 with or without voltage increase. [↑](#footnote-ref-18)
19. Price elasticity of electricity demand is a measure used in economics to show the responsiveness, or [elasticity](http://en.wikipedia.org/wiki/Elasticity_(economics)), of the quantity demanded of electricity to a change in its price. More precisely, it gives the percentage change in quantity demanded in response to a one percent change in price (holding constant all the other determinants of demand, such as income). Another indicator is Income elasticity of demand that relates percentage change of demand related to percent income variation. Both indicators permit the modeling of the behavior of the consumers to price and income variations permitting the estimation of the economic value of the consumed electricity. This situation has been empirically and theoretical supported in several Latin American countries. Guyana does not count with specific studies at this respect, for this reason in this study it was applied the experience in other Latin American countries. In Chile, recent studies indicate that the price elasticity of residential demand is -0.27 for one year and -0.39 for longer terms. Westley estimated it in -0.5 for Paraguay (1984) and in -0.45 for Costa Rica (1989) and Berndt & Samaniego in -0.47 for México (1984). In summary, available studies indicate that long-term price elasticity of residential demand is in the order of -0.4 to -0.5. Based on such experiences, for the study it was adopted -0.5 as a conservative average price elasticity of electricity demand in Guyana. [↑](#footnote-ref-19)
20. This parameter was obtained from “Projected Costs of Generating Electricity”, International Energy Agency, 2015 (p. 33). [↑](#footnote-ref-20)
21. Source: Update of DBIS generation expansion program. [↑](#footnote-ref-21)
22. Efficiency prices were not applied given the lack of studies of economic shadow prices in Guyana. [↑](#footnote-ref-22)
23. The useful life applied in the analysis was 20 years, according GEA forecasts. However, it was included a terminal correction at the end of such period in order to reflect an expected additional life of 5 years (total economic life of 25 years, shorter than a facility life of 30 years for a solar plant as published in traditional sources: see LAZARD’S LEVELIZED COST OF ENERGY ANALYSIS—VERSION 11.0, see page 20). [↑](#footnote-ref-23)
24. The financial evaluation of a project considers revenues and disbursements for its developer, which are associated to the installation, operation and commercialization the production of the project and estimates its financial Internal Rate of Return (IRR), which measures the rate of return of a cash flow built from the Operation Cash Flow of the Project (EBITDA-taxes-investment). It measures the return that the assets of each project offers. Please note that this is not the investor’s IRR (over dividends - capitalizations). Economic evaluation considers direct and indirect benefits and costs of the project for the national economy of a given country, which are usually expressed in terms of efficiency prices. However, in the case of this evaluation it were expressed in term of market prices due to the lack of studies related to economic shadow prices in Guyana. Based on its evaluation it was possible to obtain estimates of its economic IRR, which measures the rate of return of a stream of net benefits built from the benefits of the project to the overall economy (not to the project nor its investors) less its investment and O&M costs. [↑](#footnote-ref-24)