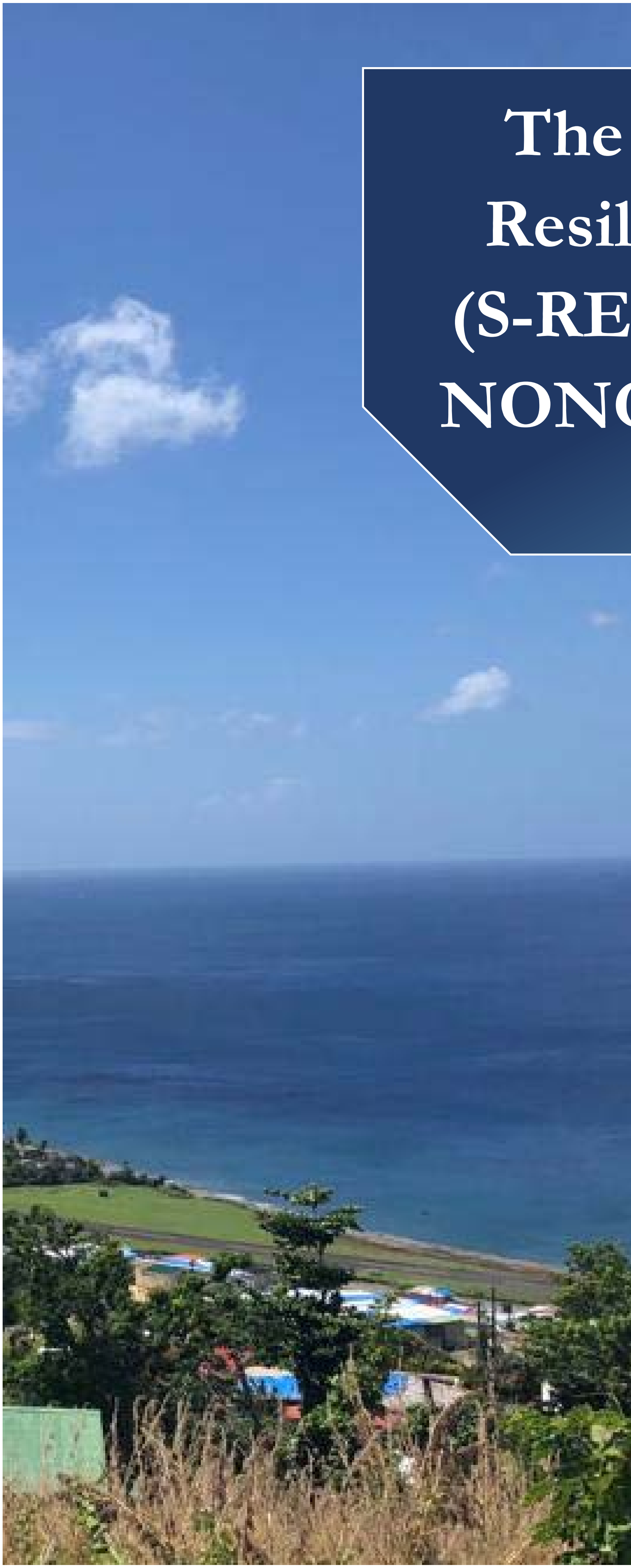

The Sustainable and Resilient Energy Plan (S-REP) for Dominica – NONCONFIDENTIAL REPORT

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Executive Summary

Hurricane Maria revealed the extent to which Dominica's electricity system infrastructure is vulnerable to extreme weather events. The electricity sector also faces challenges that are common to Caribbean Small Island Developing States (SIDS), such as a high dependence on imported, polluting, and volatile fossil fuels. This context has coalesced the GOCD, DOMLEC, and IRC around four mutual priorities for Dominica's energy future:

1. Determine the least-cost energy generation mix.
2. Increase renewable energy penetration.
3. Improve/maintain grid stability.
4. Improve resiliency of electricity-vulnerable communities.

After a meeting between President Bill Clinton and Prime Minister Roosevelt Skerrit in February 2018, CCI and its technical partners were requested by Prime Minister Skerrit and the GOCD to conduct an energy planning process. The goal of the S-REP is to **assess multiple stakeholder-proposed options, and combinations of those options, to determine the most cost-effective, reliable and climate resilient electricity system.**

The scope of the S-REP was divided into four phases:

- Phase 1: Load forecast, developing generation mix scenarios, Portsmouth Feeder constraint modeling, and least-cost generation modeling.
- Sub-Phase 1.5: Determine sensitivity to diesel fuel prices for select generation mix scenarios.
- Phase 2: Transmission and distribution (T&D) steady state stability studies; solar photovoltaics (PV) and onshore wind land assessment.
- Phase 3: Geospatial analysis assessing what Dominica partners deem critical infrastructure to determine the highest needs for serving load
- Phase 4: Building potential investment options for the generation mix scenarios and modeling the total Net Present Cost (NPC) of the scenarios.

To develop the **least-cost energy generation mix**, the S-REP team recommends:

- Dominica partners continue to develop Phase 1 Geothermal (7 megawatt [MW]).
- Dominica partners continue to progress the installation of the United Arab Emirates (UAE)/Masdar battery project near Fond Cole.
- Dominica partners conduct a feasibility-level analysis to pursue installing utility-scale solar and/or battery near Portsmouth or at Tarreau.
- Dominica pursues either the generation capacities outlined in Scenario 4 or 5, depending on the future geothermal expansion plan.

If the above least-cost recommendations are implemented, then Dominica has the potential to **increase renewable energy penetration** to 86% by pursuing Scenario 4 or 97% if Scenario 5 is actualized.

Grid stability improvements would need to be completed to safely integrate and/or take full advantage of the least-cost generation and increased levels of renewable energy. The S-REP team recommends:

- Dominica partners pursue 33 kilovolt (kV) upgrades from the geothermal plant to Fond Cole and from Trafalgar to Fond Cole, as well as a new 33 kV line connecting Fond Cole to Ti Baie.
- Dominica partners pursue five capacitor banks for the low voltage nodes along the Portsmouth Feeder, if a new 33 kV line is built.
- Analysis of the most economical way to provide voltage support in the North, such as through battery storage, solar, or further T&D upgrades.
- Dominica partners pursue a substation and a 33/11 kV transformer at a mid-point along the Portsmouth Feeder, if a new 33 kV line is built.
- Parallel operation of the Portsmouth Feeder and Sugar Loaf West Feeders.

Lastly, **to improve the resilience of electricity vulnerable communities**, the S-REP team recommends Dominica partners conduct resilience feasibility studies in the six vulnerable communities along the Portsmouth Feeder, undergo additional studies of the ten most energy vulnerable communities (to make these communities less vulnerable) based on their resilience rankings, as well as conduct feasibility studies for resilience interventions in the Roseau Valley.

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1. Introduction

1.1 Background & Context

On September 18, 2017, Hurricane Maria hit Dominica as a Category 5 storm, battering the island with torrential rains and recorded wind gusts of up to 160 mph, causing extensive and severe damage to the country's private and public infrastructure, including the electricity system. Total damage and losses are estimated at over US$1.3 billion, which is 226% of Gross Domestic Product.

According to the UNDP Post Disaster Needs Assessment, at least 75% of the electricity network was down and 80-90% of transformers were damaged beyond repair. The total need for rebuilding the electricity sector was estimated at US$81 million. In parallel to the immediate recovery efforts, a rapid assessment and energy plan can identify the optimal investments for medium- to long-term rebuilding of clean and resilient energy infrastructure in Dominica.

1.2 Dominica's Pre-Hurricane Maria Electricity System

DOMLEC is the sole, private concessionaire for distributing electricity in Dominica. The utility serves approximately 36,200 customers, accounting for 98% of the island's population. DOMLEC is the sole system planner and operator, as well as is responsible for dealing with all electricity generation in a consistent and non-discriminatory manner. Independent Power Producers (IPPs) are permitted, but DOMLEC is responsible for system performance and reliability. In 2016, operating costs were US$70.89 million and had a debt-to-equity ratio of 1:3.92. DOMLEC received an 81% customer service satisfaction rating in 2016.

DOMLEC's electricity generation is primarily from two diesel power plants located at Fond Cole, in the southwest outside Roseau, and Sugar Loaf, in the northwest outside Portsmouth. The installed capacity of the diesel generators is 17.5 MW. The utility also owns and operates three, cascading run-of-river hydro plants in the Roseau Valley: Laudat, Trafalgar and Padu. The total installed capacity of hydro is 6.6 MW.

Peak load in 2016 was approximately 17.7 MW and baseload is provided by both the diesel and hydro plants. There is an estimated 15 MW of diesel self-generation.

DOMLEC's T&D system comprises over 400 km of 11 kV overhead lines and 900 km of 230/400 V overhead distribution lines, with approximately 18,000 poles and 1,500 pole-mounted transformers. An 11 kV ring interconnects the diesel and hydro plants. Fond Cole and Sugar Load are connected through the Portsmouth Feeder. The distribution system has nine feeders with Roseau and Portsmouth as the primary load centers.

Approximately 25% of electricity demand is located in the North (around Portsmouth) and 75% is located in the South (around Roseau). Customer categories consists of domestic, commercial, industrial and hotel customers, where the domestic and commercial customers represent the largest segment.

1.3 Integrated Resource Planning

As economies grow, so does the electrical demand. Proactive planning for future energy generation investments is key to ensure that assets are in place to meet the electrical demand.

An Integrated Resource Plan (IRP) is a comprehensive decision support tool and long-term energy roadmap utilized by utilities and regulators to determine how to meet forecasted annual peak and energy demand over a ~20-year period, to best provide reliable and least-cost electric service to all customers. Such plans look at multiple combinations of supply-side and demand-side resources over the study period, require detailed technical and economic modeling of scenarios, include extensive stakeholder and public feedback, and provide a final action plan approved by the regulatory authority.

1.3.1 2014-2033 Dominica Integrated Resource Plan

The 2014-2033 Dominica IRP, recommended generation expansion with a strong preference towards renewable energy technologies – including 14 MW of geothermal, 1.5 MW of solar, and 1.8 MW of diesel. This represented the least-cost plan and led to a significant decrease in fuel costs. This plan was also consistent with the GOCD's Energy Policy, which gives priority to renewable energy.

To accommodate the recommended generation expansion, the 2014-2033 IRP recommended the installation of a 33 kV substation in the Roseau Valley for the geothermal and hydro plants. Furthermore, it advised the installation of 33 kV interconnectors from Fond Cole to Sugar Loaf, as well as from Fond Cole to the new geothermal station, would facilitate future generation expansion of the system and address voltage constraints that would negatively impact optimal generation dispatch.

1.3.2 Dominica IRP Formal Process

Dominica has a formal process through which IRPs are undertaken and reviewed. The S-REP is intended to be used by Dominica partners to complement the existing 2014 IRP or inform a future IRP.

1.4 Post-Hurricane Maria Electricity System Challenges and Priorities

After Hurricane Maria, Dominica partners concluded the 2014-2033 IRP needed to be updated to reflect the changed situation in Dominica.

As revealed by Hurricane Maria, Dominica's electricity system infrastructure is vulnerable to extreme weather events. Also, the electricity sector faces challenges that are common to SIDS, such as a high dependence on imported and volatile fossil fuels, as well as their associated greenhouse gases.

This context has coalesced the GOCD, DOMLEC, and IRC around four mutual priorities:

1. **Determine the least-cost energy generation mix.**
2. **Increase renewable energy penetration.**
3. **Improve/Maintain grid stability.**
4. **Improve resiliency of electricity-vulnerable communities.**

These questions and Dominica's options for long-term post-Hurricane Maria rebuilding can be explored through a techno-economic analysis similar to an IRP process.

Fortunately, Dominica partners have already initiated a couple sustainable and resilient energy options.

In 2016, the GOCD established the Dominica Geothermal Development Company (DGDC) as a special purpose vehicle lead all activities relating to geothermal exploration in Dominica. As recommended by the 2014-2033 IRP, the DGDC has begun to develop the 7 MW (6.4 MW net) Phase 1 geothermal project in the Roseau Valley and it is expected to be completed by 2020.

The UAE and Masdar are in the process of donating a battery storage system, as part of the UAE Caribbean Renewable Energy Fund (UAE-CREF) to help reduce reliance on fossil fuel imports, stimulate economic activity and enhance climate change resilience. The energy storage project is expected to be complete by 2020. The exact battery size is to be confirmed.

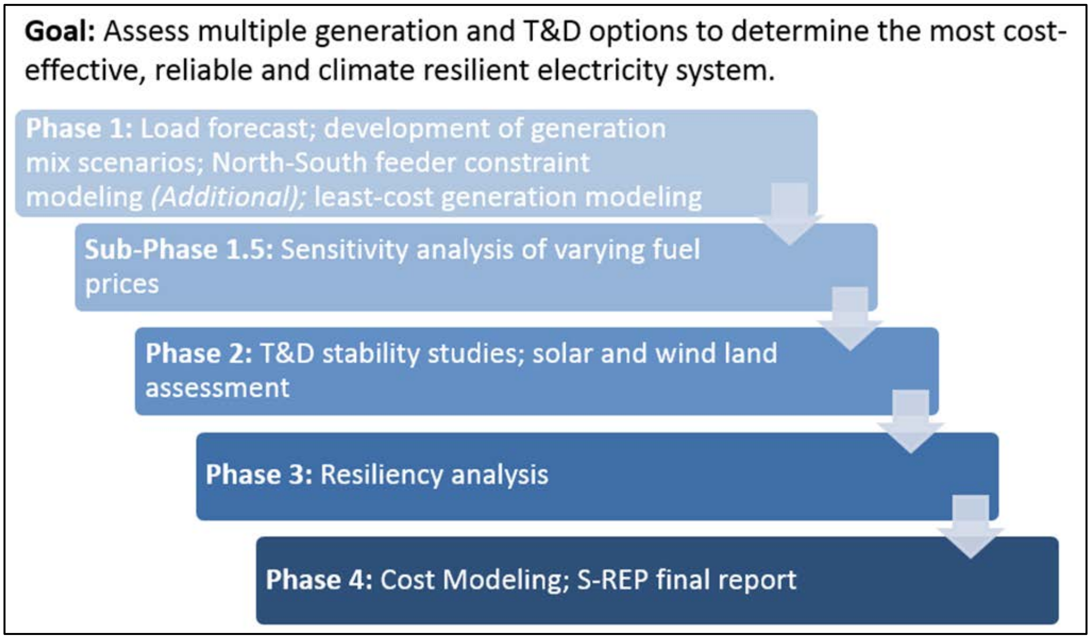
1.5 Overview of the S-REP Process

After a meeting between President Bill Clinton and Prime Minister Roosevelt Skerrit in February 2018, CCI and its technical partners were requested by Prime Minister Skerrit and the GOCD to conduct an energy planning process for the post-Hurricane Maria Dominica to assess optimal renewable energy resources and how to integrate them into the future electric grid, with an emphasis on climate resilience.

The goal of the S-REP was to **assess multiple stakeholder-proposed options, and combinations of those options, to determine the most cost-effective, reliable and climate resilient electricity system.** The S-REP is intended to complement the existing 2014 IRP or a future IRP for Dominica's electricity sector, with a focus on answering the most pertinent questions held by partners regarding Dominica's energy rebuild.

The process outlined below is based on the Islands Playbook, developed by CCI in partnership with the Rocky Mountain Institute (RMI), which provides guidance, support, and tools for islands to develop and execute their transition to high levels of renewable energy (see Figure 1).

Figure 1: Overview of the S-REP Process



The scope of the S-REP was divided into four phases:

- Phase 1: Load forecast, development of generation mix scenarios, Portsmouth Feeder constraint modeling, and least-cost generation modeling which provides generation capital investment and renewable energy fraction.
- Sub-Phase 1.5: Determine sensitivity to diesel fuel prices for select generation mix scenarios.
- Phase 2: T&D system static and dynamic stability studies for the generation mix scenarios; solar PV and onshore wind pre-feasibility land assessment to determine where new renewable energy technologies would theoretically be put onto the grid for the purpose of the T&D study.
- Phase 3: Geospatial analysis assessing what Dominica partners deem critical infrastructure to determine the highest needs for serving load after a disaster.
- Phase 4: Building potential investment options for the generation mix scenarios, modeling the total net present cost of the scenarios, and producing the S-REP Final Report which incorporates results of all phases.

1.5.1 Phase 1 of S-REP

Rapid Baseline Assessment. The S-REP team conducted site visits to Dominica to meet the high-level stakeholders, to assess the current status, to gather data from partners, to compile other information from in-person discussions and interviews, and to keep partners updated on the team's progress.

The rapid baseline assessment formed a full understanding of the current state, including people's immediate need for power, as well as existing plans for rebuilding/reinforcing electricity infrastructure in generation, transmission, and distribution in the short- and longer-term. The assessment also initiated a review of any existing utility expansion plans or integrated resource plans performed by DOMLEC. The S-REP team assessed critically but objectively and provide comments regarding the methodology, approach, and findings as well as the inclusion or exclusion of certain recommendations based on our assessment of the current realities.

Estimate Electrical Load. With input from Dominica partners, the expected electrical load upon completion of the grid rebuilding efforts was assessed. In other words, a forecast was done which encompasses the electrical load during early post-recovery period and after full economic stability. The load assessment incorporated large, planned development projects into its analysis. The load forecast feeds into the modeling and determination of potential options to meet the anticipated demand.

High-level Resource Screening. With input from Dominica partners and on-island organizations, existing resource assessments, and key technology providers, the S-REP team screened and assessed the supply-side, demand-side, and energy storage options to potentially create a largely renewable system.

The initial screening reviewed existing and potential forthcoming conventional diesel assets, hydropower, geothermal, energy efficiency, solar PV, and onshore wind, among other potential sources. This screening considered available resources, their costs, and their ability to deploy in Dominica to assess for inclusion in the detailed generation analysis. Consideration of existing generation, and their planned retirement dates, was taken into account to prevent stranded assets. Such resource screening was the basis of inputs into the modeling efforts to determine the least- cost generation options. This step was done in collaboration with Dominica partners and focused on key technologies that partners are already looking to pursue.

Analyze Portsmouth Feeder Power Flow Constraint. When conducting the analysis of the electricity grid of Dominica, a number of feasibility studies and DOMLEC notified the S-REP team that power flow is constrained along the 11 kV Portsmouth Feeder, the north-south transmission line between Fond Cole and Sugar Loaf. This constraint requires diesel generators to be run in Sugar Loaf to support the Northern loads and voltage requirements. The S-REP team conducted a techno-economic analysis to estimate the financial impact of this constraint on future energy scenarios.

Analyze the Generation Options. The S-REP team considered combinations of energy generation options based on their installed and operational costs and their contributions to the electricity framework of Dominica and created scenarios of generation mixes based on stakeholder feedback. New generation technology cost assumptions are based on specifications to withstand Category 5 hurricanes. Through least-cost generation modeling, each scenario was analyzed from an electricity generation standpoint and an economic standpoint, identifying the generation capital investment required and resulting renewable energy penetration.

1.5.2. Phase 1.5 of S-REP

Generation Cost Details and Sensitivities. The S-REP team took outputs from Phase 1 and performed a sensitivity analysis to fuel prices. This investigated the sensitivity of the model's outputs to fuel price as well as the volatility of the cost to generate electricity in Dominica based on varying fuel price forecasts.

1.5.3. Phase 2 of S-REP

T&D Grid Studies. The S-REP team, with technical support provided by the electrical engineering firm WSP, investigated the impacts of the assessed generation mix scenarios on T&D system operation, and required investments, to maintain reliability and system stability. The grid integration studies required modeling the existing DOMLEC grid as well as creating models for new generation scenarios in addition to higher voltage network upgrades.

Based on stakeholder feedback, assumed locations for new generation assets were determined, and system stability studies investigated how the future generation scenarios impact the grid. The grid integration studies included static (e.g. load flow) and dynamic (e.g. system stability under sudden loss of load) analyses.

Land Assessment. Due to the mountainous terrain, existing natural hazards, and limited land availability, scenarios including new solar PV and onshore wind identified potential locations for siting. This was a high-level pre-feasibility analysis which does not include a review of environmental and social impact or geotechnical suitability.

1.5.4. Phase 3 of S-REP

Resilience Study. As the first two phases focus around sustainable energy in the planning process, the third phase incorporated resilience into the energy plan. The S-REP team worked with French Development Agency (AFD) and Tractebel, existing partners of the GOCD, who are in parallel assessing grid-hardening techniques, line upgrades, engineering cost assessments for undergrounding, etc. The intent is for the S-REP's resiliency analysis to be incorporated into AFD and Tractebel's Master Plan for Resilient Electrical Systems.

Working with stakeholders, the S-REP team assessed what Dominica partners deem as critical infrastructure to determine the highest needs for serving load after a disaster. To ensure these loads are served, the S-REP team conducted a GIS analysis to identify vulnerable areas as well as critical infrastructure which, once strengthened against natural hazards and severe weather events, will improve the country's ability to rapidly withstand and recover from a natural disaster.

1.5.5. Phase 4 of S-REP

Investment Schedule Options and Cost Modeling. Generation mix scenarios were investigated further in the cost modeling process to determine a selection of investment schedules and the NPC associated with those investment schedules.

Create an Integrated Final Plan. The result of the S-REP is a plan that provides the strategic pathway for energy investments to pursue in Dominica for a more cost-effective, reliable and climate resilient electricity system. Selecting which options will create the most viable plan requires whole-systems analysis and input from Dominica partners across the energy sector. The S-REP team has incorporated Dominica partners where relevant and possible, as guided by its client the GOCD, and strongly encourages additional discussion between all key stakeholders to examine the S-REP results, decide on the pathway forward, and act upon it.

The plan indicates the approach for investing in DOMLEC's electricity grid to meet both immediate and long-term energy needs cost-effectively, incorporating sustainability and resilience. This includes an objective assessment and recommendations of what resources (conventional and renewable) and infrastructure upgrades add the highest value in the future electricity grid of the country, and in what timeframe these projects can and should be implemented.

2. Results Summary

Table 1: Least-Cost Technologies Chosen per Scenario by HOMER

Scenario	1	2	3	4	5	6
Diesel (MW)	Existing Diesel + 9.4 MW New Diesel + 7.6 MW Diesel Replacement	Existing Diesel + 8.8 MW Diesel Replacement	Existing Diesel + 5.3 MW Diesel Replacement	Existing Diesel + 1.4 MW Diesel Replacement	Existing Diesel + 1.2 MW Diesel Replacement	Existing Diesel
Hydro (MW)	6.6	6.6	6.6	6.6	7.2	6.6
Geothermal (MW) Net		6.4	12.8	6.4	12.8	
Solar PV (MW)				6.2		9.0
Onshore Wind (MW)				6.6		18.7
Storage (MWh)		3.7	3.7	7.6	3.7	11.5

2.1 Introduction

Dominica partners have a set of options to invest in renewable energy, which will be significantly more cost-effective, have much higher renewable energy penetrations than the status quo, and increase the effectiveness of the electrical grid to maintain reliability and reduce losses associated with maintaining voltage support in the North.

2.2 Recommendations: Least-Cost Energy Generation Mix

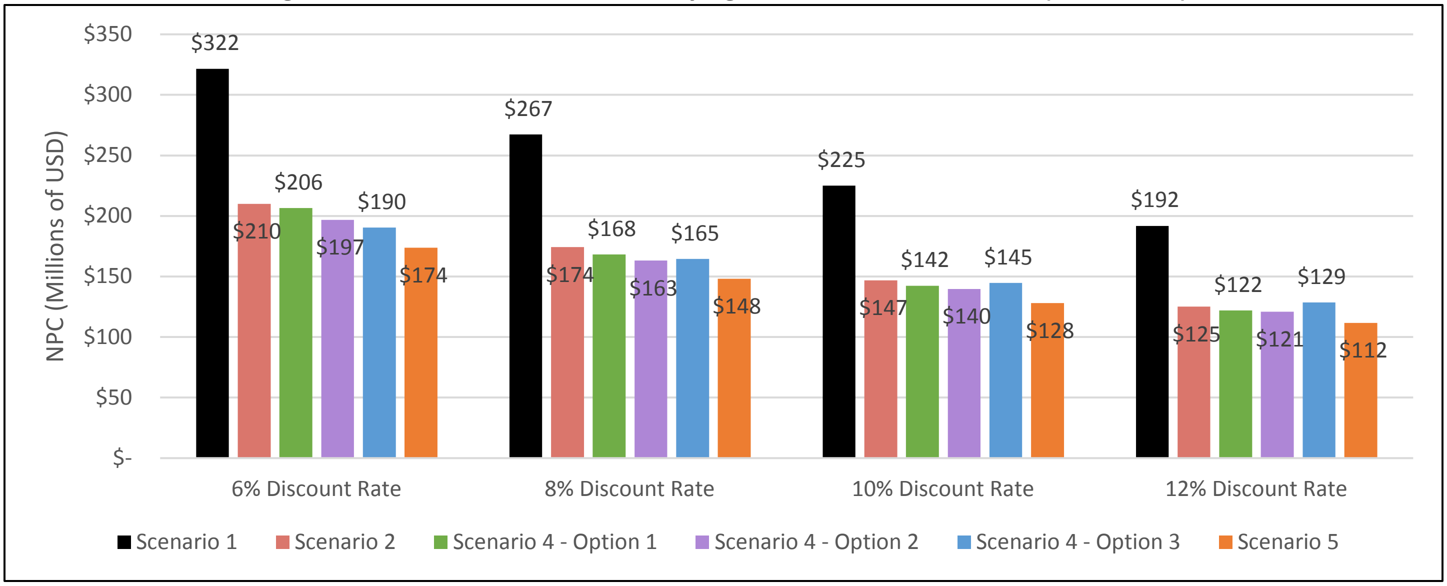
In Phase 1, the S-REP team conducted a techno-economic assessment to determine the least-cost mix of energy generation technologies for each of the six scenarios to meet the forecasted electricity demand. Only Scenario 1 would require expansion beyond the existing diesel generation capacity. Then, in Phase 4, the S-REP team incorporated the diesel generator retirement schedule to determine the amount of diesel that would need to be replaced during the timeframe of this analysis to meet system security and reliability standards.

Table 1 shows the least-cost capacities of complementary technologies, given the constraints defined in each scenario, to meet Dominica's from 2020-2038.

Scenarios 2, 4, and 5 – along with Scenario 1 for comparison – were investigated further in the cost modeling process to determine a selection of investment schedules and the NPC associated with those investment schedules. Figure 2 shows the NPC of each scenario, including 3 investment schedule options for Scenario 4, given varying applied discount rates. The costs taken into consideration included capital expenditures (CAPEX) of new generation technology investments, CAPEX of T&D investments recommended for grid stability, Power Purchase Agreements (PPAs), operational expenditures (OPEX) of all technologies, diesel fuel costs, and the costs associated with stranded assets.

Partners requested additional analysis to determine if it was recommended to bring a utility-scale solar PV plant onto the grid prior to the theoretical Phase 2 geothermal (estimated at 7 MW to come online in 2028), if Dominica were to pursue Scenario 5. Given the results of this study without assessing the auxiliary benefits of a solar plant on the grid, a feasibility level study would be needed to quantify if 2.8 MW of solar at the DOMLEC-owned site at Tarreau would be "no regrets" solar prior to installing Phase 2 geothermal in 2028. If a 7 MW Phase 2 geothermal were not to come online/not in direct competition with the solar plant for various possible reasons, then the diesel costs offset by a 2.8 MW solar plant are high. Separately, voltage support would be needed at various nodes along the Portsmouth Feeder, and having the solar plant located along the Portsmouth Feeder could likely reduce voltage issues in Scenario 4 and 5. In addition, even after the North and South are connected by a 33 kV line and Phase 2 of geothermal would come online, generators in Sugar Loaf would still

Figure 2: Net Present Cost with Varying Nominal Discount Rates (2020-2038)



need to run during peak hours to provide voltage support. Thus, if a solar plant and battery system were located in the North near Portsmouth instead, the benefits from reducing diesel generation in Sugar Loaf to provide voltage could be quantifiably very large and would be realized during the full lifespan of the solar park. Voltage support would be provided by the inverter itself, and further studies into quantifying the benefit of battery solutions, solar solutions, a combination of battery and solar in addition to the voltage support mechanism provided by the inverter, and alternative T&D upgrades, are recommended. A point to note is that peak solar output is coincident with peak demand hours in Dominica. Electricity generation from diesel at peak demand is more expensive than at other times, so the value of shaving the peak through alternative sources (solar and/or battery) can also be quantifiably large.

Based on these results, the S-REP team concludes the following recommendations to achieve the least-cost generation mix:

- Dominican partners continue to **progress the development of the Phase 1 Geothermal (7 MW).**
- Dominican partners continue to **progress the installation of the UAE/Masdar battery project near Fond Cole.**
- Dominica partners **conduct a feasibility-level analysis to pursue installing utility-scale solar and/or battery systems near Portsmouth or at the DOMLEC-owned site at Tarreau.**
- Dominica partners **expand the Padu hydropower** plant, assuming the Roseau Valley line is upgraded.
- Dominica partners pursue either the generation capacities outlined in Scenario 4 or 5, depending on the geothermal resource and future geothermal expansion plans.
- In addition, the grid stability recommendations would need to be completed to safely integrate and/or take full advantage of these generation recommendations.
- Dominica partners conduct a more in-depth analysis to quantify if 2.8 MW or less of solar at the DOMLEC-owned Tarreau site near the city of Layou would be "no regrets" solar prior to installing Phase 2 geothermal in 2028. Partners should consider a rate structure to incentivize this investment if it is net least-cost to generate. This would need to be done quickly to maximize the amount of time the solar PV plant would be online prior to a Phase 2 expansion of geothermal, if the Phase 2 expansion would be 7 MW of domestic-use geothermal. As shown in Scenario 4, at least 6.2 MW (if not more) of solar PV would complement the Phase 1 geothermal

plant, rather than be in competition with it. Dominica partners have expressed interest in exporting electricity generated from a Phase 2 of geothermal, in which case electricity produced and consumed by solar PV within Dominica would not compete with electricity produced by geothermal resources and exported.

- It is important to note that stranded costs associated with retiring diesel generators prematurely to replace them with renewable energy are extremely small compared with the cost of fuel required to run the diesel generators.

2.3 Recommendations: Renewable Energy Penetration

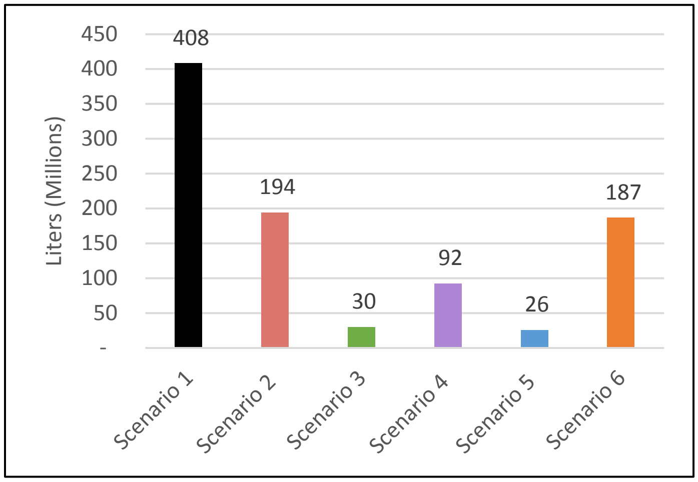
The renewable energy penetration, if all technologies from that scenario are installed and given the forecasted demand in 2029, are shown in Figure 4.

There is a general correlation between scenarios with higher renewable energy penetration and scenarios with lower NPC, showing investing in renewable energy is both beneficial from a cost perspective and in line with Dominica partners' priority to increase renewable energy penetration and be climate-resilient.

Scenario 5, which is the least-cost scenario if all tegeneration technologies are an option and given the estimated future geothermal costs, has the highest renewable energy penetration.

One-hundred percent renewable energy is not shown as an outcome, as the geothermal plants are required to be down two weeks each year for maintenance. During that time, diesel makes up for the geothermal production. These renewable energy penetration levels assume a fully unconstrained grid, meaning the voltage support issues in the North are resolved.

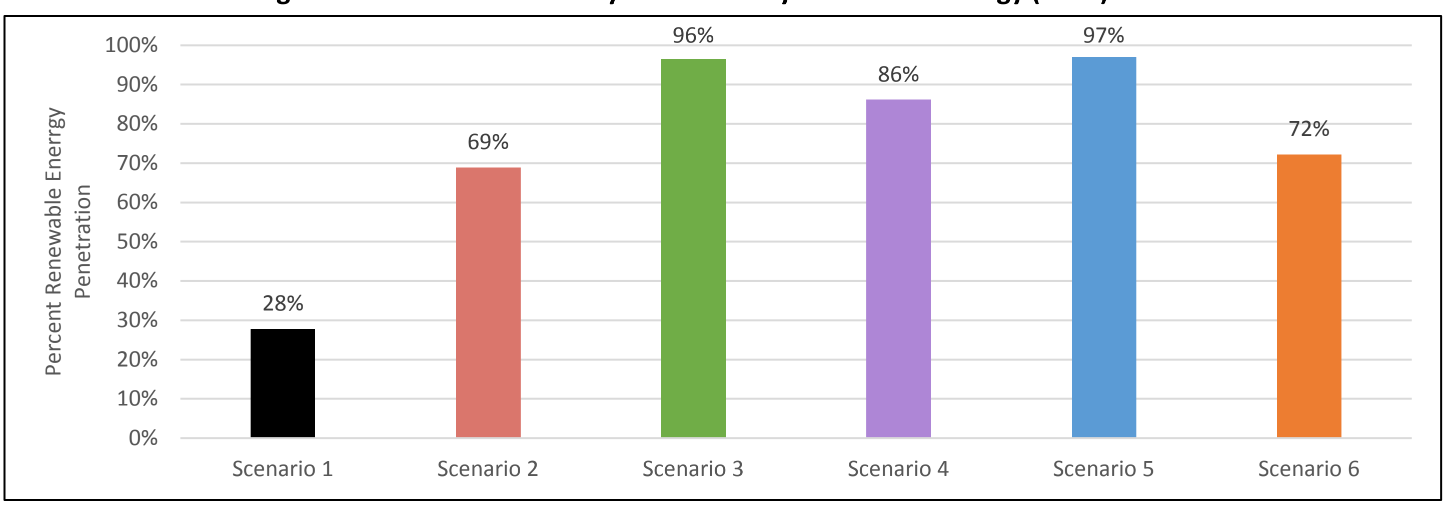
Figure 3: Cumulative Fuel Consumption (2020-2038)



2.4 Recommendations: Grid Stability

The **33 kV system upgrade** outlined in WSP's T&D Power Flow and Grid Integration study enables the geothermal and hydro energy to be evacuated from the valley even if a line went down in the valley. This will also enable the reduction of the Sugar Loaf generation during the off-peak hours (when total load in Dominica is below 15 MW) down to zero levels without any adverse effect on system security.

Figure 4: Percent of Electricity Generated by Renewable Energy (2029)



The 33 kV upgrades outlined include the upgrading of the transmission lines from the Geothermal plant to Fond Cole and from Trafalgar to Fond Cole. Along the west coast, a new line would be built which connects Fond Cole to the Ti Baie connection point.

The 33 kV upgrade allows the geothermal and hydro energy to be evacuated from the Roseau Valley but due to the length of the Portsmouth Feeder, the power flow analysis identified five low voltage nodes. **Capacitor banks** are suggested for these low voltage nodes. Even with 33 kV upgrades and added capacitors, there would be a need for voltage support in the North. This can be provided by diesels at the Sugar Loaf power station, other voltage sources such as a **battery storage and/or solar PV installations in the North,** or possibly further transmission upgrades (such as to a voltage higher than 33 kV).

Adding a **substation and a 33/11 kV transformer at a mid-point along the Portsmouth Feeder** such as at Colihaut or Coulibistrie, adds additional system benefits such as reduced losses, a secure and reliable system in case of a contingency event between Sugar Loaf and Fond Cole and increased operability during maintenance

Figure 8: Cumulative Fuel Consumption (2020-2038)

activities.

Battery storage solutions combined with adequately equipped inverters offer multiple ancillary services to the system, such as spinning reserve support, voltage control, reactive power support, absorbing excess renewable energy, frequency control etc. As such, a more detailed battery study should be undertaken to determine optimal capacities and siting for grid stability.

2.5 Recommendations: Improve Resiliency of Electricity-Vulnerable Communities

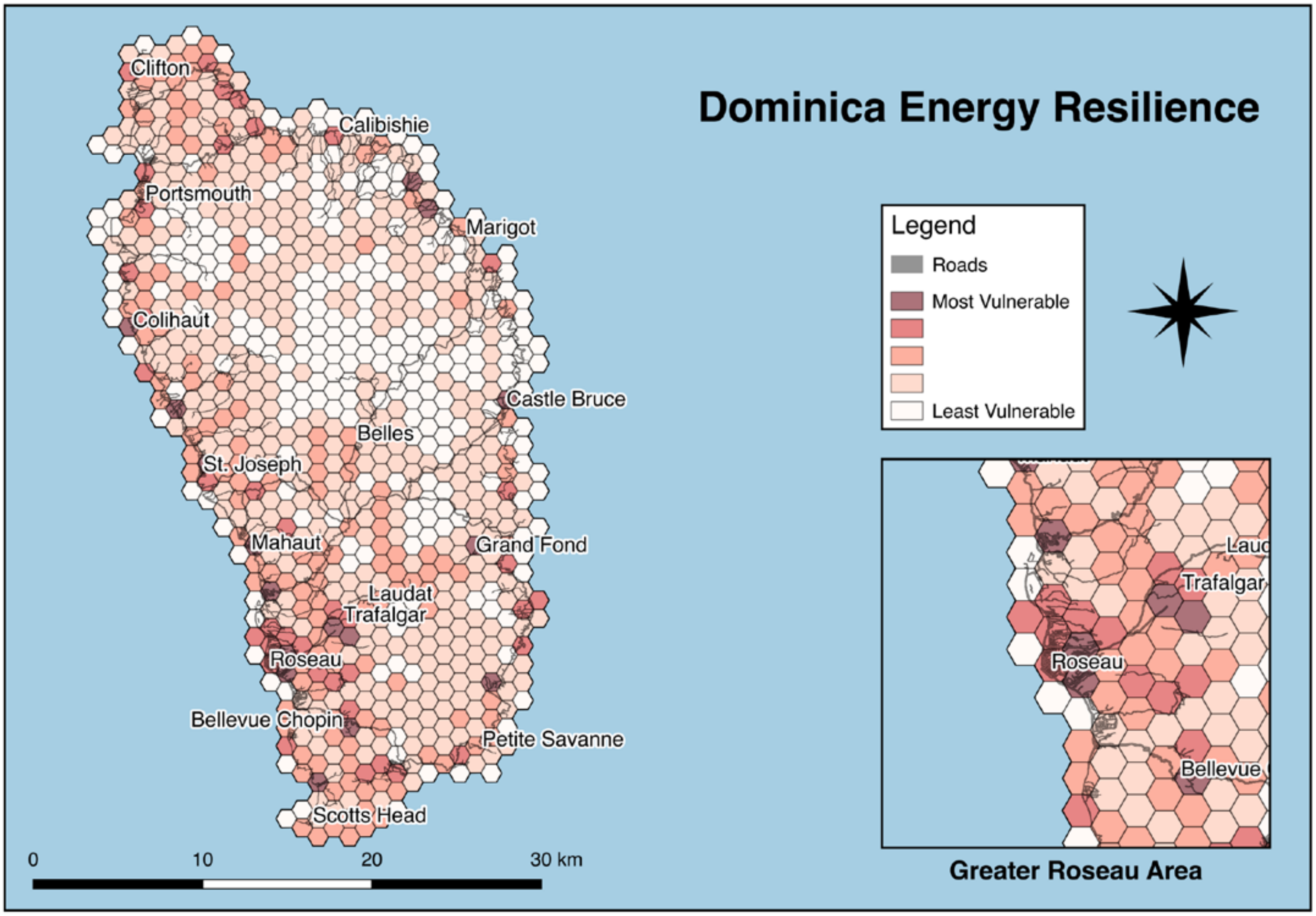
As shown by the impact of Hurricane Maria and other past storms, Dominica is energy vulnerable – the electrical system is subject to conditions which increase its susceptibility to natural disasters which affect the overall system, communities served by the system, electricity assets, and individuals who use electricity. Many areas are considered energy vulnerable because they host a high concentration of critical infrastructure and a disruption in electricity service will interrupt their ability to operate. Once these critical assets are strengthened against natural hazards and severe weather events, Dominica's ability to rapidly withstand and recover will improve, making the country more resilient.

To improve the resilience of electricity vulnerable communities, the S-REP team found and recommends:

- Dominica partners **conduct feasibility studies for resilience interventions in the six vulnerable communities (Roseau, Canefield, Mahaut, St. Joseph, Salisbury, and Colihaut) along the Portsmouth Feeder.** This will help ensure that the electricity from renewable energy sources in the South reach communities in the North.
- Dominica partners should conduct additional studies in the **ten most vulnerable communities (Canefield, Mahaut, Salisbury, Morne Prosper, Bellevue Chopin, Soufriere, St. Joseph, Castle Bruce, Colihaut, and Roseau)**.
- Dominica partners conduct feasibility studies for **resilience interventions in the Roseau Valley** since it is one of the most vulnerable area of the country.
- Communities/Areas identified with high winds, no flooding, and low landslide risks may be considered for **undergrounding**.
- Communities/Areas identified with high winds and moderate landslide risks may be considered for **hardening poles and fast recovery approaches**.
- Western Dominica has the majority of the most vulnerable areas.
- The Northeast and Southeast are vulnerable but have lower risk to natural hazards, in general.

AFD and Tractebel's Master Plan for Resilient Electrical Systems will further refine and recommend locations for cost-effective T&D resilience interventions. This will assist Dominica in overcoming its energy vulnerability and improve its ability to rapidly withstand and recover from disasters.

Figure 5: Map of the Most Energy Vulnerable Communities in Dominica



3. Portsmouth Feeder Power Flow Constraint

While undergoing the high-level resource screening, the S-REP team was notified that Portsmouth Feeder was constrained, which requires diesel generators to be run in Sugar Loaf to support a large majority of the Northern loads. The S-REP team used the Hybrid Optimization of Multiple Energy Resources (HOMER) software to estimate the financial impact of this constraint on future energy scenarios.

In order to simulate the power flow constraint, the electrical grid was modeled as two separate systems and analyzed the impact of the constraint on the cost to generate. Two portfolios of energy generation mixes were defined:

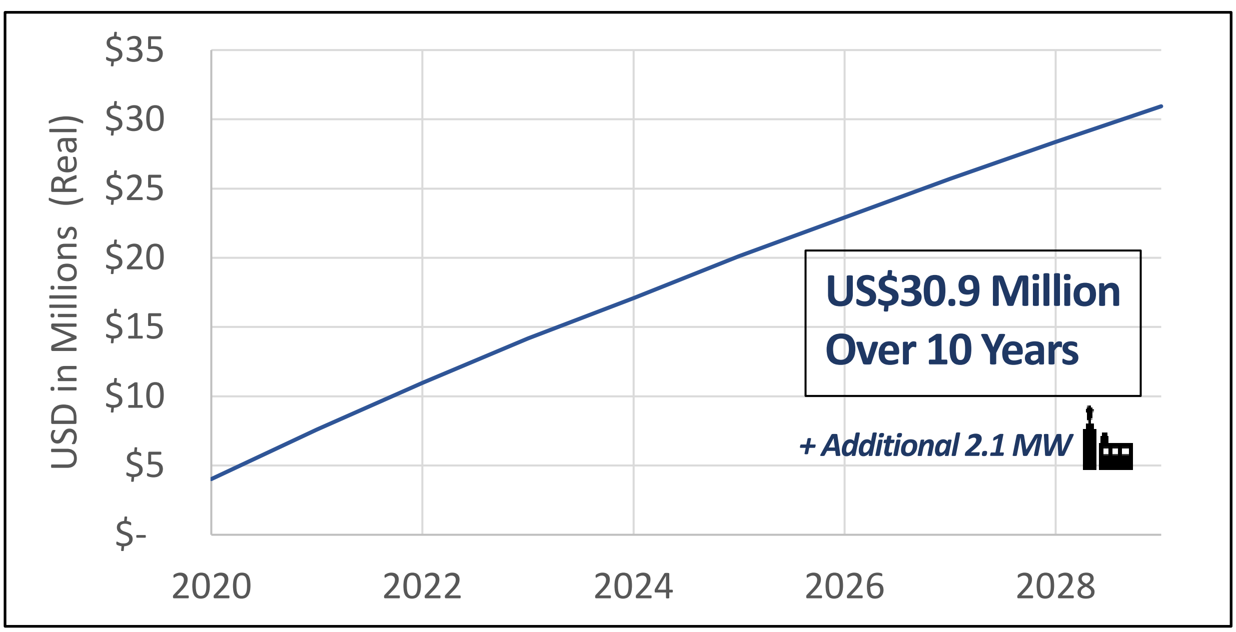
- Simulation 1 which comprises diesel and existing hydropower.
- Simulation 2 which adds the 7 MW Phase 1 geothermal project and the proposed 3.5 MWh battery storage project provided by the UAE and Masdar.

These two energy generation simulations were projected forward over ten years (2020-2029) to incorporate load growth and fuel cost projections. Each simulation considered the constraint on the Portsmouth Feeder and the impact on power flow if the constraint was removed, such as by upgrading the transmission line to a higher voltage and/or making other required upgrades to the T&D network.

The analysis revealed that when generation comes from diesel and hydropower on a constrained grid, the cost to generate is higher because extra diesel needs to be operated in the North of the island for voltage support. With the addition of the Phase 1 geothermal project and battery storage projects, the constrained line restricts electricity to flow to the North. Phase 1 geothermal and/or hydro generation will need to be curtailed while 2.1 MW of extra diesel generation will need to be purchased, operated, and maintained in the North in the next 10 years - in addition to operating as well as replacing existing diesel generators that would be due retire in the next 10 years.

The commissioning of the Phase 1 geothermal plant brings cost to generate down by 39% in the constrained case, and lowers it by 57% in the unconstrained case. As shown in Figure 6, if the constraint is not corrected, the opportunity cost over 10 years is US$30.9 million and would be higher over 15-20 years. This represents the geothermal capacity paid for but not full exploited, as

Figure 6: Cumulative Opportunity Cost (Nominal USD)



well as the extra diesel operations and fuel costs to meet load in the North. Therefore, it is in the financial interest of rate payers, the Government, and DOMLEC to consider T&D upgrades that would reduce this constraint such as building a new 33 kV overhead line along the Portsmouth Feeder, and further explore options that would further eliminate the constraint on the Portsmouth feeder.

In comparison with the US$30.9 million opportunity cost over 10 years, the cost of the 33 kV upgrade (from the geothermal plant to Fond Cole, from Trafalgar to Fond Cole, and building a new 33 kV line from Fond Cole to Ti Baie) was estimated by WSP to be less than half of the opportunity cost. DOMLEC amortizes T&D investments over longer than 10 years, however. While this upgrade would significantly reduce generation requirements in the North, it would not completely eliminate the constraint on the grid. The opportunity cost of a not-completely unconstrained grid should be analyzed with dispatch-level analysis to determine the opportunity cost of that situation.

4. Recommended Further Studies

The S-REP team has put forth generation mixes that can reduce the cost of generation, reduce dependence on imported diesel and contribute to GOCD's goal of becoming the first climate resilient nation. The S-REP team also identified land that can host wind and solar PV, as well as existing grid constraints that can negatively impact the financial metrics of renewable energy, while putting forth T&D recommendations for upgrades that could relieve these bottlenecks.

The overhead line which connects Trafalgar to Fond Cole has been severely damaged by the landslides caused by Hurricane Maria. The first step is to assess the optimal route for rebuilding this line, and assess the value of undergrounding and making this line 33 kV capable.

Even taking into consideration the cost of the grid upgrades that are recommended to take full advantage of the geothermal plant, the S-REP team's analysis indicates significant economic benefits from the 7 MW geothermal plant and UAE/Masdar battery coming online. If the 33 kV upgrade plan is executed, there would still be voltage and dynamic stability issues that would necessitate Sugar Loaf to run during peak hours in all Scenarios. Dominica partners have indicated that taking full advantage of the geothermal project and being able to shut off diesel assets (especially at Sugar Loaf) is a priority. To be able to ascertain the most cost effective and practical way to do this, the S-REP team recommends techno-economic feasibility studies that quantify the benefits of potential pathways or a combination of pathways, such as:

1. A national-level battery study which determines optimal sizing, location and value streams of battery storage solutions
2. Solar feasibility studies (with or without battery) in the North and/or along the Portsmouth Feeder
3. Transmission line upgrades to a voltage higher than 33 kV
4. A dispatch study which quantifies the cost of running Sugar Loaf diesel generators for voltage support and dynamic stability in the North with possible curtailment of geothermal and/or hydro

Battery Storage. The S-REP team recommends an energy storage feasibility study which assesses the optimal sizes and locations of battery systems on multiple nodes on the grid. Battery storage offers a host of services and benefits to DOMLEC's grid. An appropriately sized battery can provide spinning reserve support to the grid, and frequency support. Ancillary services such as voltage support, peak shaving and renewable energy firming can also be unlocked with properly designed and located battery systems. Part of this study may be covered by Masdar's due diligence for the donated battery system.

Solar Feasibility Studies. In scenarios where there is a high penetration of renewables, there is still need for voltage support, even though during low load conditions these sources can often exceed the demand in early years. This can be provided by diesel or battery storage, but can also be provided by solar PV. The S-REP team recommends solar feasibility studies in conjunction with battery studies, to offset diesel requirements and to enhance grid stability and resilience. Solar and storage on critical facilities also offers the benefits of these services being supplied with power during extreme events and providing grid support during normal operation. Additionally, large land parcels would not need to be procured, if these solar/storage systems are located on critical facilities.

Furthermore, in the context of resilience, solar PV and battery storage on critical facilities offers the benefits of these services during extreme events, while providing grid support during normal operation. Project specific assessments for critical facilities as microgrid and grid network support would need to be conducted. Also, recommendations from the Master Plan for Resilient Electrical Systems being completed by AFD and Tractebel should be pursued in parallel.

Transmission line upgrades to a voltage higher than 33 kV. Additional analysis is recommended to explore the possibility of upgrading the Roseau Valley and Portsmouth Feeder to a voltage higher than 33 kV to remove voltage violations that require Sugar Loaf to run during on-peak times.

Dispatch study which quantifies the cost of running Sugar Loaf diesel generators with possible curtailment of geothermal and/or hydro. The S-REP team recommends quantifying the cost of running diesel generation at Sugar Loaf, as well as the possible geothermal or hydro curtailment required for each Scenario, for comparison purposes.

If Dominica partners require further analysis to quantify the effects of upgrading the transmission system to 33 kV and installing the other recommended grid upgrades, the S-REP team recommends a dispatch-level analysis with software such as Plexos, to determine the impact of curtailment of geothermal and/or hydro, by diesel-based generation which is needed for voltage support. This analysis can also yield insights into the value of curtailment versus the value of upgrading the transmission and distribution system.

Project-specific land assessments and due diligence (such as geotechnical studies and interconnection studies) would be needed to progress utility scale solar PV and wind development.

The S-REP team recommends AFD and Tractebel continue with their analysis to conduct feasibility-level cost analyses of various resilient options to connect the west coast from Fond Cole to Portsmouth and Scott's Head. Also, the S-REP team recommends AFD and Tractebel continue conducting feasibility studies for resilient interventions, such as resilient T&D upgrades, connected distribution with planned islanding, or isolated mini-grid or off-grid systems.

Annex A: Documents and Resources Output from the S-REP

Additional Documents or Outputs Provided by the S-REP Team	Who It Was Provided To	Is There Data Known to be Confidential?	Who Else It Should Be Provided To
Sustainable and Resilient Energy Plan (S-REP) Final Report – June 2019	GOCD and DOMLEC	Yes, it contains much data confidential to DOMLEC.	IRC, CREAD, Tractebel
Land Assessment GIS File (without DOMLEC T&D system)	GOCD		
Land Assessment GIS File	DOMLEC	Yes, DOMLEC T&D System.	
Solar PV and Wind Land Assessment: Parcel and Cluster Data (Excel File)	GOCD, DOMLEC		
WSP T&D Power Flow and Grid Integration Report (PDF)	GOCD, DOMLEC	Yes, it contains much data confidential to DOMLEC.	DGDC, Masdar, Tractebel
PSS/E Models of DOMLEC T&D System and Electrical Grid, including 2016 base models and future scenario models (PSS/E Software)	DOMLEC, Masdar (base model)	Yes, all data in the models is confidential to DOMLEC.	Masdar (all models), Tractebel (if relevant)
Resilience Study GIS File (without DOMLEC T&D)	GOCD		Tractebel
Resilience Study GIS File	DOMLEC	Yes, DOMLEC T&D System.	

S-REP Memos	Who Owns the Memo? (Request Memo From)	Is There Data Known to be Confidential in the Memo?
#1: Generation Scenarios	GOCD (Amb. Vince Henderson or Ministry of Energy)	
#2: Summary of Installed Cost Assumptions for Modeling	GOCD (Amb. Vince Henderson or Ministry of Energy)	Please check with GOCD Ministry of Energy regarding geothermal price assumptions.
#3: Fuel Price Forecast	GOCD (Amb. Vince Henderson or Ministry of Energy)	
#4: Load Forecast	GOCD (Amb. Vince Henderson or Ministry of Energy)	
#5: Opportunity Cost of the Constraint on the Portsmouth Feeder	GOCD (Amb. Vince Henderson or Ministry of Energy)	
#6: Solar PV and Wind Pre-Feasibility Land Assessment	GOCD (Amb. Vince Henderson or Ministry of Energy)	
#7: Generation Modeling Results	GOCD (Amb. Vince Henderson or Ministry of Energy)	
#8: Resilience Study	GOCD (Amb. Vince Henderson or Ministry of Energy)	Yes, maps include confidential map of DOMLEC T&D system.